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HIGH SCHOOL MARINE SCIENCE STUDIES

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## MARINE SCIENCE STUDIES

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Francis M. Pottenger is director of the HMSS Project and E. Barbara Klemm is associate director.

## PREFACE

The High School Marine Science Studies Project (HMSS) has developed a program with ten instructional chapters to be taught as a one- or two-semester course. Selected portions can be combined as marine science modules for use in other secondary courses.

HMSS has been developed in Hawaii Dy tne staff of the Curriculum Research and Development Group, University of Hawaii. in consultation with teachers from Hawaii public and private schools, University of Hawaii faculty, and community professionals. The design of the HMSS materials is based on the premise that study of the oceans provides opportunity for students of all abilities to actively engage in multidisciplinary scientific inquiry while learning the basic concepts of science.

The HMSS chapters fall under three themes. Two of the themes, Fluid Earth and Living Ocean together represent the traditional areas of oceanography. The third theme is Technology.

## INTRODUCTION TO THE HMSS STUDENT

Marine Science refers to a wide ranging study of the earth's water environment with emphasis on study of the sea. Marine Science includes content drawn from biology, physics, chemistry, meteorology, geology, cartography, oceanography, aquaculture and marine engineering. You will carry out investigations, design experiments, make instruments, and make interpretations of your findings.

As the program progresses, you will be placed in different roles to get a clearer picture of what science means in modern society. Your chief role will be that of a marine scientist seeking to understand and make predictions about our ocean world, but you will also assume the roles of engineer, technician, and citizen to get insights into how the knowledge of science is used in our society.

## STUDY AIDS

To help you study and rapidly understand procedures, several aids are provided.

1. The first time a new science word is introduced, it is generally underlined.
2. This book is not to be written in. Tables and figures which you write on appear full size in your workbook and are identified in the text with the $w$ sign.
3. Each chapter contains a set of activities. Each activity has six basic parts:

Activity - This statement tells you what the activity is. It is a boxed-in statement.
Background - This is an introduction to the activity.
Materials - The things you need to perform the activity.
Procedure - This is a set of directions to aid in carrying out the activity.
Summary Questions - These questions aid in summarizing and interpreting your knowledge and findings.
Further Investigations - This is a set of additional questions, investigations, and challenges that can extend the meaning of experiments and widen the significance of work completed.

## LABORATORY SAFETY

The following safety precautions apply to all laboratory classes:

1. Wear safety goggles whenever you are working with chemical reagents.
2. Wear a laboratory apron when doing laboratory investigations. If chemicals are spilled, the apron protects both clothing and skin.
3. Stand when doing laboratory work. Standing avoids having chemicals spilled in laps.
4. Always wear shoes with closed tops in the laboratory.
5. If chemicals should be spilled on clothing or skin, wash immediately with large quantities of water. This dilutes, and washes away the chemicals.
6. Never taste any chemical unless instructed to do so.
7. Tie or pin long hair at the back of your head so that it will not accidentally fall into chemicals or flames.
8. Know where the fire extinguisher and fire blanket are and how to use them in case of an emergency.

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## CHAPTER 1

## EARTH AND OCEAN BASINS

Making maps, charts, and globes of the earth gives a better understanding of the earth's geography, size, and time zones. Maps are models that permit us to better visualize parts of the earth's surface.

In this chapter we will make and study a series of maps to get clearer pictures of the geography of earth's oceans.


## 1. How Much Water?

For centuries the only available maps of the world were those drawn by explorers and traders. Studying maps of the world drawn centuries ago reveals much about what was then known or understood about our planet. Today we have photographs from earth satellites and data from space and oceanographic missions. This information has allowed us to develop very detailed and highly accurate maps of the earth.

As we begin our study of the earth and its ocean basins, we will examine two types of maps commonly used to show the surface areas of the oceans and continents. The map in Fig. 1-1 is an equal-area projection. Fig. 1-2 is a Mercator projection. Specifically for this topic, a 0.5 cm grid has been superimposed over both maps. At the equator each grid box represents a surface area of $1,250,000$ square kilometers (or $1.25 \times 10^{6} \mathrm{~km}{ }^{2}$ ).

## Materials

-colored pencils
-atlas, globe, or world maps (optional)
-calculator or slide rule (optional)

## Activity

Identify major continents and oceans.
Determine how much of the earth's surface is covered by water, by land, and by ice.

Compare the effectiveness of an equal-area and a Mercator projection map in depicting the surface area of continents and oceans.

## Procedure

1. Study each map; then select the one which you feel best represents the world's relative surface area of liquid water, land, and ice. You might want to examine a globe before making your choice. Record the reason(s) for your selection.

2. Label oceans and continents on the map using colored pens or pencils. Draw in the boundartes of oceans and continents. Lightly shade in areas covered by ice. You may use an atlas, a globe, or a classrocm world map as a reference if needed.
3. Estimate the surface areas of oceans and continents. Describe the method you use in making the determination.
a. Determine the surface area of each of the continents and oceans. The surface area under the grid marked on the map is $1.25 \times$ $10^{6} \mathrm{~km}^{2}\left(1,250,000 \mathrm{~km}^{2}\right)$. Record data in Tables 1-1 and 1-2.

Table 1-1. Area of the continents.

| Continents | (Munter of | Area | Rank | $\underset{\substack{\text { Aceepted } \\ \text { Area }}}{ }$ |
| :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

b. Rank the continents and oceans in order of size. Rank the largest (1), the next (2), etc. Record data in Tables 1-1 and 1-2.
c. Using an atlas or other reference, look up the accepted area for each of the continents and oceans. Record data in Tables 1-1 and 1-2.

Table 1-2. Area of the oceans.

4. Determine the total surface area of the earth that is covered by (1) liquid water, (2) land, (3) ice. Record data in Table 1-3. Calculate percentages.

Table 1-3. Comparison of area of land, liquid and ice.

| Materal | ibler of Squares | Arat | Percisitug | Accipted Percentage |
| :---: | :---: | :---: | :---: | :---: |
| Land |  |  |  |  |
| Liquit mit |  |  |  |  |
| Ice |  |  |  |  |
| Total surf | aret $\longrightarrow$ |  |  |  |

5. Using the average depth of each ocean given in Table 1-4, calculate the approximate volume of water found in each ocean. The volume will be equal to area tines depth.

> Table 1-4. Depth and volume of the major oceans.

| Ocems | Ares | Gepth | Voluse | Rank | Accepted Yolun |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Arctic |  | 1200 |  |  |  |
| Atlantic |  | 3300 |  |  |  |
| Indien |  | 3600 |  |  |  |
| Pacific |  | 3900 |  |  |  |

6. Rank the oceans according to their volume. The one with the most is ranked (1), the one with the next most (2), etc.
7. Using an atlas or other reference, look up:
a. the accepted area for each of the continents and oceans. Record in Tables 1-1 and 1-2.
b. the accepted percentage of land, liquid, and ice record in Table 1-3.
c. the accepted volume of the oceans. Record in Table 1-4.

## Summary Questions

1. State at least two reasons why you selected the map you used as giving the better representation of the earth's surface area.
2. Calculate the approximate surface area of the earth. The formula for area 1s: Area of sphere $=4 \pi r^{2}$, where " $r$ " is the radius of the earth which is equal to $6.38 \times 10^{3} \mathrm{~km}$ or $6,380 \mathrm{~km}$ and " $\pi$ " is equal to 3.14 . Compare
your calculated area with the sum of the areas measured in Procedure 3. How close are your two measurements? If they differ by more than 10\%, explain why.
3. Compare the surface area of oceans in the northern hemisphere with the surface area of oceans in the southern hemisphere. Which is greater?
4. Refer to Table 1-3 giving your calculated percentage of the total area of the earth that is covered by liquid water, ice or land. How well does your data agree with the fact that 25\% of the globe is covered by continental land masses and $75 \%$ is covered by the ocean or ice? Explain your answer. What are the physical features outlined on the maps?
5. It has been said that the continents are but islands in one great ocean. Explain what might be meant by this statement. Are there exceptions to this statement? Why?
6. Comparing the Mercator projection map and the equal-area map, what are the advantages and disadvantages of each map?
7. Check your understanding of the following terms by defining them in your own words. Give examples where appropriate.
```
a. atlas
b. continent
c. equator
d. ocean basin
e. physical features
f. surface area
g. volume
```


## Further Investigations

1. Compare old maps showing the way the world was thought to be at other times in history, (a) when the Phoenicians traded extensively around Africa, (b) when the Vikings explored the Atlantic, (c) when Columbus discovered America, and (d) when Cook "explored" the Pacific. How are these maps similar? How do they differ? How did the cartographers' view of the world change over this time as represented by the maps?
2. Make a study of place names on maps. Show how some traditional names tell much about what people used to think about themselves and the earth. Begin with "Mediterranean." Find out how the oceans got their names. Give other examples.
3. Locate the seas of the world. How many are there? How are they different from oceans? Make a table comparing features like area, depth, and location.

## 2. Maps and Cartographers

To a person studying the earth, as well as to travelers, maps are an essential tool. There are many different types of miaps. Each has been developed to serve some special purpose, but each map has limitations as to what it can represent to us.

In this topic we will investigate how it is possible for the cartographer, a map maker, to make a flat representation of the spherical and irregular surface of the earth. We will also consider how one locates places on a sphere.

## Activity A

Make a globe marked off with reference lines of latitude and longitude.

## Bgckground

Reference lines. Reference lines are necessary in order to locate a position or place on a spherical surface. Cartographers, people who make maps, use a standard set of imaginary reference lines that we will be learning about in this topic.

Equator and hemispheres. Perhaps the best known of the cartographer's reference lines is the equator, an imaginary reference line drawn around the center of the earth halfway between the north and the south poles. See Fig. 2-1.

The entire surface area of the earth above the equator is the northern hemisphere; below it is the southern hemi sphere. The United States, including Alaska and Hawaii, are in the northern. hemi sphere.


Fig. 2-1. The equator divides the earth into hemispheres.

Parallels of latitude. Latitude is the number of degrees a place is located north or south of the equator. Parallels of latitude are imaginary lines which form complete circles around the earth parallel to the equator and to each other (Fig. 2-2).

The distance from the equator to either of the earth's poles is $90^{\circ}$, or one-quarter of the full circle ( $360^{\circ}$ ) around the earth. By deciding that the equator is $0^{\circ}$, the location of any parallel of latitude can be described by how many degrees it is north or south of the equator. This is shown in Fig. 2-2. A position on the earth then can be located from $0^{\circ}$ to $90^{\circ}$ north (N) or south (S) latitude.

Note that the equator is neither north nor south. Degrees latitude are always labeled as either north or south so that we know whether a location is north or south of the equator. Hawaii, for example, is $21^{\circ} \mathrm{N}$. Sydney, Australia, is $34^{\circ} \mathrm{S}$.


Fig. 2-2. Parallels of latitude form complete circles around the earth.

Meridians of longitude. Longitude is the east or west location of any place on earth. Meridians of longitude are another set of reference lines. Meridians are drawn from pole to pole and are not parallel to each other as shown in Fig. 2-3.

By international agreement the 00 meridian, also called the prime meridian, is drawn through Greenwich, England. Directly opposite the prime meridian (on the other side of the globe) is the $180^{\circ}$ meridian which runs through the Pacific Ocean. Together, the prime meridian ( $0^{\circ}$ ) and the $180^{\circ}$ meridian separate the earth into eastern and western hemispheres. The $0^{\circ}$ meridian and the $180^{\circ}$ meridian, however, are neither east nor west.


Fig. 2-3. Prime meridian and the international
dateline.
The location of all other meridians of longitude can be described as east or west from just beyond $0^{0}$ to just up $180^{\circ}$. Places to the east of the prime meridian (the right half of the globe in Fig. 2-3) have east longitude. An example is Rome, Italy, which is located at 120 E . Places to the west of the prime meridian (the left half of the globe in Fig. 2-3) have west longitude. Washington, D.C., for example, is a 770 W .

The international dateline is about at the $180^{\circ}$ meridian, but it is adjusted so it does not cross through any land areas.

## liteterials

-l orange, thick-skinned
-1 wooden skewer

- 1 protractor
-1 black ballpoint pen
-1 felt-tip pen, fine, waterproof
-] thin cardboard or oaktag, $10 \times 15 \mathrm{~cm}$ approx.
- 1 sharp knife or scissors
-hot water and detergent
-drawing compass and pencil


## Procedure

1. Make a globe of the earth using a skewered orange as shown in Fig. 2-4.


Fig. 2-4. Making a globe from an orange.
a. Obtain a thick-skinned orange. Wash with very hot detergent water to remove the waxy coat. Dry the orange.
b. Insert a skewer down through the center of the orange. Enter at the stem scar and exit on the bottom at a point directly opposite the scar.
c. Attach a small paper flag to one end of the skewer. This represents the north pole. Put your names or initials on the flag.
2. Make cardboard degree templates like those shown in Fig. 2-5.
a. Measure the diameter of the globe (orange). Describe in your notebook how you measured the diameter.
b. On a piece of cardboard, draw a circle large enough for the globe to barely slide through.
c. Using a protractor and felt pen, mark degrees at $30^{\circ}$ intervals around the outer edge of the cardboard circle as shown in Fig. 2-5A, the template for latitude.
d. Using another cardboard piece, make a template for longitude as shown in Fig. 2-5B.
3. Mark the equator on the globe.
a. Place the orange in the longitude template as shown in Fig. 2-6.
b. Using a waterproof marking pen, draw a line around the globe where the template touches the orange.


Fig. 2-5. Using a protractor to mark the templates for latitude and longtitude.


Fig. 2-6. Drawing an equator around the globe.
4. Draw meridians of longitude on the globe
a. Continue holding the globe as you did, as shown in Fig. 2-6.
b. Make small marks at $30^{\circ}$ intervals along the equator as shown in Fig. 2-7A. Use a ball point pen.
c. Draw a line connecting each of the $30^{\circ}$ marks to the north pole. See Fig. 2-7B.
d. Remove the template. Continue drawing each line from the equator to the south pole as shown in Fig. 2-7C.
e. Select one meridian line. Darken it in from pole to pole. Consider this the prime meridian on your globe.

A. Mark equator at $30^{\circ}$ intervals.

B. Connect $30^{\circ}$ mark to north pole.

Fig. 2-7. Drawing meridians of longitude on the globe.

C. Connect meridian lines to poles.
5. Draw the parallels of latitude. Refer to Fig. 2-8.
a. Place the globe in the latitude template as shown in Fig. 2-8A. Align the prime meridian line with the template. The skewer should run from 900 N to 900 S on the template.
b. Make small marks at $30^{\circ}$ intervals along the prime meridian.
c. Hold the pen so that it contacts the globe at $30^{\circ} \mathrm{S}$. Rotate the globe to draw the $30^{\circ} \mathrm{S}$ latitude line.
d. Using the same procedure, draw latitude lines at $60^{\circ} \mathrm{S}$ and at $30^{\circ} \mathrm{N}$ and $60^{\circ} \mathrm{N}$.

A. Mark prime reridian at $30^{\circ}$ intervals.

B. Rotate globe to draw latitude line.

Fig. 2-8. Drawing parallels of latitude on globe.
16. Draw a large imaginary continent and an island on the globe.
a. Locate the continent so that the prime meridian passes through it as shown in Fig. 2-9.
b. Make the continent a simple blocklike drawing. This will be easier to reproduce later in Activity B.
c. Color in the continent and island. Be careful not to color out the latitude and longitude lines.

prime meridiari
Fig. 2-9. Drawing a continent and an island on the surface of the globe.

## Activitv B

Make a equal-area map, an orthographic map, and a
Mercator projection map of a globe.

## Background

A major problem in all mapping of the globe is that of representing a sphere on a flat sheet of paper. Cartographers use many different techniques to solve this problem. Each technique has its advantages and its disadvantages. We will prepare three common types of maps: an orthographic map of the earth, an equal-area projection map, and a Mercator projection map.

## Materiols

-white paper $8 \frac{1}{2} \times 14$ in or larger
-straight-edge ruJer
-pencil
-1 corrugated cardboard, $21.5 \times 28.0 \mathrm{~cm}$ -straight pins
-compass

## Procedure

1. Make orthographic maps of the globe. Orthographic maps are hemisphere projections like those shown in Fig. 2-10.
a. Draw two circles on a sheet of paper with diameters the same as that of the globe. Use the template you made in Activity $A$ to trace the circles.

A. View from the north pole.

B. View from the equator.
b. In one circle, draw a picture of the continent as it looks from the north pole Locate the continent on the drawing, An example is given in Fig. 2-10A
c. In the other circle, draw a picture of the continent as it looks from the equator. Fig. 2-10B gives an example.
d. Label the following on one or both drawings:
1) prime meridian ( 00 )
2) north and south poles
3) meridians of longitude in $30^{\circ}$ intervals
4) parallels of latitude in $30^{\circ}$ intervais
5) north
6) south
7) east
8) west
9) $180^{\circ}$
2. Make a sheet of Mercator projection paper. Refer to Fig. 2-11.
a. Cut a sheet of paper so that it is just long enough to make a cylinder around your globe. The paper should be as long as the circumference of the globe.
b. Remove paper from globe. This is the Mercator projection paper.


Fig. 2-11, Determining length of Mercator projection paper.
3. Mark the prime meridian and the meridians of longitude in $90^{\circ}$ intervals on the Mercator projection paper. Refer to Fig. 2-12.
a. Fold the Mercator projection in quarters. Open. Draw light pencil lines down the fold lines.
b, label the center line as the prime meridian ( 0 longitude).
c. Label the line on the left as $90^{\circ}$ W Igngitude and the line on the right as $90^{\circ} \mathrm{E}$ longitude.


Fig. 2-12. Marking meridians on Mercator projection paper.
4. Draw the equator on the Mercator projection paper.
a. Fold the paper in half lengthwise.
b. Open, then draw a line along the fold line. Label this as the equator ( $0^{\circ}$ latitude).
c. Your Mercator projection paper should now look like Fig. 2-13.


Fig. 2-13. Mercator projection paper with equator.
5. Draw the latitude and longitude lines at $30^{\circ}$ intervals. Refer to Fig. 2-14 as you carry out the steps below.
a. Use the orthographic map you drew of your globe in Procedure 1. (Your map should look something like the one shown in Fig. 2-10.)
b. Line up the equator on the Mercator projection paper with the equator on your orthographic map. The two equators must form a straight line.

Locate the center of the orthographic map $\left(0^{\circ}, 0^{\circ}\right)$. This is the point where the equator and the prime meridian intersect.
d. Draw a straight line connegting the center of the orthographic map ( $0^{\circ}, 0^{\circ}$ ) to the outer edge of the map at $30^{\circ} \mathrm{N}$ latitude ( $30 \mathrm{ON}, 90^{\circ} \mathrm{E}$ ).
$h$. Draw the parallels of latitude in $30^{\circ}$ intervals on the Mercator projection paper. Extend each line from the projected latitude point across the paper. Latitude lines must be parallel to the equator.
e. Extend this line until it touches the left edge of the Mercator prajection paper. You have just projected $30^{\circ} \mathrm{N}$ latitude onto the Mercator projection paper.


Fig. 2-14. Marking latitude on a Mercator projection map.
6. Make a Mercator projection map of the globe.
a. Locate and mark on the Mercator projection map the boundaries of the continent that you drew on the globe. Suggestions for doing this are given below.

1) Hold the globe so that you view it from the equator as in Fig. 2-10B. Locate on the globe where the boundary line of the continent cuts across the equator. Mark the corresponding point on the Mercator projection map.
2) Locate on the globe where the boundary line of the continent cuts across each of the parallels of latitude. Mark these points on the Mercator projection map.
3) Locate where the boundary of the continent cuts across the meridians of longitude. Mark these points on the Mercator projection map.
b. On the Mercator projection map, connect the boundary points of the continent.
c. Color in the continent using the same color as you did on the globe.
d. Draw the island on the Mercator projection map. Follow the steps given above.
e. Complete the labels on the Mercator projection map. Refer to the list given in Procedure ld.
7. Map an equal-area map of the globe.
a. Draw a horizontal line across a sheet of
$8 \frac{8}{2}$ by 11 inch paper. This will represent the equator. Tape the paper to a piece of thick cardboard.
b. Cut the orange into segments along the meridians. Carefully peel skin segments from the orange.
c. Open the segments and staple or pin them flat onto the paper on the cardboard. Make further cuts along the meridian lines if the segments won't lie flat. Be sure that the equator on the segments aligns with the equator on the equal-area map as shown in Fig. 2-15.
d. In pencil, trace the outline of the segments onto the white paper. Remove the orange peel segments. You now have an equal-area map, a map showing the earth as segments.
e. Carefully draw the continent on the equalarea map.
f. Label the equal-area map as you did the orthographic map in Procedure 1d.


Fig. 2-15. Making an equal-area map.

## Summary Questions

1. Explain why both parallels of latitude and meridians of longitude are needed to locate a particular place on the earth.
2. Compare the area of the continent when it is drawn on an orthographic map, on an equal-area map, and on a Mercator projection map. How are they different? How are they similar?
3. What are the problems that must be overcome in making a Mercator projection map of features on a globe? How does your drawing of the continent on the globe compare with its representation in the Mercator projection?
4. What are the problems that must be overcome in making an equal-area map projection of the globe?
5. Compare the advantages and disadvantages of globes, orthographic maps, Mercator projection maps and equal-area maps in doing the following:
a. seeing the total surface area of the earth
b. measuring distance between places
c. determining surface area
d. determining direction
e. ease of reading.
6. Check your mastery of terms. Write a paragraph using at least half of the following terms properly:
a. cartographer
b. dimension (two-dimension, three-dimension)
c. directions (north, south, east, west)
d. distortion
e. equator
globe
g. hemi sphere ( northern hemi sphere, southern hemisphere)
h. latitude (parallel of latitude)
i. longitude (meridian of longitude)
j. map projections
k. parallel
7. pole (north pole, south pole)
$m$. prime meridian
$n$. reference lines

## Further Investigations

1. What other types of projections are used to represent the surface of the earth? How are these projections made? Prepare demonstration(s) for the class.
2. At sea or on land, how is it possible to use the stars or the sun to determine latitude? If you saw a constellation directly overhead, at what position in the sky would someone else $20^{\circ}$ to the north of you view it?
3. Using library reference books, find out how meridians of longitude are used as an aid in establishing standard time on earth. Learn where the international dateline is located. If it were 12:00 noon now where you are, what time would it be (a) in Washington, D. C., and (b) in Greenwich, England?

## 3. The Shape of the Segshore

The shape of the seashore often tells us much about the way in which the land and sea interact. Models of oceanic landform features are used extensively by scientists to explain how the features are formed and how they change over time.

Relief maps are widely used to represent physical features such as hills and valleys on a flat paper. One kind of relief map is the contour map. A contour map uses sets of lines to show the shape of hills or valleys. Each line represents the shape of the land at a fixed elevation. Elevation lines are usually chosen to represent regular intervals, as, for example, 10 , 20 , and 30 meters above or below sea leve] ( 0 meters). An example of a contour map is given in Fig. 3-1A.

Relief maps are sometimes raised to show detailed features of landforms. Raised relief maps are often plastic sheets that have been molded to show hills and valleys. Molded relief maps, however, are hard to store and are easily damaged. In this topic we will construct another type of raised relief map.

## Activity

Interpret contour maps of oceanic landform features.
Construct a raised relief map of a common oceanic feature.

Hypothesize how features were formed and how they will change over time.

A. Contour map.

B. Raised relief map.

Fig. 3-1. Examples of maps.

## Motericls

Contour map
-colored pencils, pens or paint

## Relief map

-carbon paper
-ballpoint pen or pencil
-8 cardboard sheets ( $8 \frac{1}{2}$ by 11 in)
-sharp knife to cut cardboard
-white glue

- paper cutter
-stapler or tape
Landform Model
-newspapers
-1 bucket with lid
-white glue, diluted 1:1
-1 blender
-cotton cloth, about $20 \times 20 \mathrm{~cm}$
$-1,000 \mathrm{ml}$ beaker or $\frac{1}{2} \mathrm{gal}$ milk container
-1 piece cardboard, about $25 \times 35 \mathrm{~cm}$
-1 plastic bag, gallon-sized
$-\frac{1}{4}$ or $\frac{1}{2}$ in brushes
-tempera paints (blue, green, white and black) -containers for paints ( $\frac{1}{2}$ pint milk cartons)
-1 wooden skewer


## Procedure

1. Read the descriptions of features given in the Glossary (Table 3-1) below.
2. Refer to the Glossary as you identify features shown on the contour maps (Figures 3-2 to 3-8).
a. Begin the identification of features in each map by first locating sea level, the zero (0) elevation contour line.
b. Locate the contour lines of features with elevations above sea level. Study the shapes of the contour lines and identify and label features on the maps.
c. Locate the contour lines of features below sea level. Elevations of features below water are shown as negative numbers. Identify and label features that are underwater.
d. Using colored pencils, pens, or paint, color code features on the map. Select appropriate colors for features above and below sea level. Use shading to show changes in elevation.
3. Construct a cardboard relief map from one of the contour maps.
a. Select one of the contour maps. Your teacher will give you an $8 \frac{1}{2} \times 11$ inch enlargement of the map you choose. Label and color code the enlarged map.
b. Place carbon paper under the enlarged contour map. Position the map and carbon paper over a piece of cardboard so that the straight edges of the map are either parallel or vertical with the corrugation in the cardboard.

Table 3-1. Glossary of common landform
features of the ocean and coastilines

Abyssal Plane: a flat region of deep ocean basins.
Alluvial Fan: broad, sloping deposit of material at the foot of a canyon or mouth of a river. The deposits may form alluvial cones.

Banks: a shallow area of the ocean caused either by elevation of the sea floor or by submerging of a land mass.

Bay: an inlet of the sea. An indentation in the shoreline of ten between headlands or capes.
Cape: a large point or extension of land jutting out into a body of water. A cape may be a peninsula or an angular piece of land.
Channel: a deeper part of a river or harbor that is navigable. The term channel is sometimes used to describe a broad strait, as for exampie, the English Channel.

Continental shelf: the shallow ocean bottom extending outward from the edge of a continent. It is seldom deeper than two hundred meters. Continental shelves are submerged parts of continents extending outward to the continental slopes.

Continental Slope: the cliff front of a continental shelf. It is the place where the continent ends. The bottom of the continental slope is the continental rise.

Continental Rise: the area of the ocean bottom between the continental slope and the deep ocean floor.

Guyot: a sea mount with a flat top. Tops are always below the ocean surface.

Headland: a cape or other landform jutting into the ocean. It is usually high above water and prominent when viewed from the sea. It gets its name from the practice of sailors using such features to take their bearings or "headings."

Island: a land mass less than a continent in size and surrounded by water. The smallest continent is Australia. All land masses of lesser size are islands.

Island Chain: a line of islands that have been formed by the sane geological process.

Isthmus: see peninsula.
Lagoon: a shallow body of water almost completely cut off from the sea by land or reef.

Ocean Basin: one of the large depressions in the earth's crust that holds the waters of an ocean.

Ocean Ridge: a long, continuous mountain range on the ocean floor. Ocean ridges are often of volcanic origin and a point of separation of the-earth's crust.

Ocean Trench: a deep cut or trench in the ocean floor, usually found at points close to where continental shelves and ocean floors meet.

Peninsula: a piece of land almost completely surrounded by water. It is usually connected to a larger land body by a narrow land strip called a "neck" or "isthmus."

Point: the tip end of a cape, headland, peninsula, or other land feature jutting into a body of water.

Sea Mount: an isolated undersea hill or mountain. It is usually in the form of a cone.

Sea Stack: an offshore column or pillar formed by wave erosion of the mainland. Many look likeislets.

Sound: a wide waterway connecting two larger bodies of water. It also may be a body of water between the mainland and an offshore island.

Strait: a long, narrow water passage connecting two larger bodies of water.

Submerged Canyon: a deep canyon cut into the continental shelf and slope, often at the mouth of larqe rivers.


Fig. 3-2. Contour map 1.


Fig. 3-3. Contour map 2.



Fig. 3-5. Contour map 4.


Fig. 3-6. Contour map


Fig. 3-7. Contour map 6.


Fig. 3-8. Contour map 7.
c. Prepare a cardboard template for each elevation line. Pressing hard with a ballpoint pen, carefully trace the elevation line onto the cardboard. Trace also the elevation line for the next higher contour so that later you will know exactly where to position the higher contour template. Label the elevation of both contour lines. Include a compass rose showing the directions north, south, east, and west.
d. Cut out the lower elevation line on each of the contour tenplates. To prevent making slash marks in the table, place a blank sheet of cardboard under the template you are cutting. Work slowly and carefully. Try not to bend the cardboard.
e. Stack the cardboard contour templates in order of increasing elevation. Use the elevation lines drawn on each template to position the next higher contour template. See Fig. 3-9.


Fig. 3-9. Stacked cardboard contour templates without risers.
f. Put risers, if needed, between contour templates to provide the proper vertical scale for the model. Risers are scrap pieces of cardboard that are glued together and placed between the contour templates. Determine how many thicknesses of cardboard to include in each riser. To do this you must first decide what elevation interval is to be represented by one thickness of cardboard. Fig. 3-10 shows an example.


Fig. 3-10. Stacked cardboard contour templates with risers.
g. Glue the assembled model together. Glue risers to the bottom side of contour templates. Working from the lowest to the highest elevation, carefully position each contour template and its risers.
h. Allow the glue to dry thoroughly before handling the relief map or continuing with the next procedure.
4. Cover the relief map with papier-mache to make a model of the landform.
a. If you have not already done so, glue a cardboard base to the assembled cardboard relief map.
b. Prepare papier-mache by carrying out the steps below. Your teacher will give you additional information on how best to prepare papier-mache. Here are some tips:

1) Tear newspaper into strips.
2) Soak newspaper strips in water for a few days to soften the paper.
3) Use a kitchen blender to make a slurry of paper and water. Keep blender on low speed.
4) Filter the water from the slurry through a piece of cloth. Wring out the water. Save the pulp.
5) Mix pulp with diluted white glue so that it has a smooth, medium, firm, claylike consistency. Use this firm mixture for the first coat on the model.
6) Make a thinner, more moist papier-mache for the finishing coats. Add a more diluted glue solution to the pulp.
c. Coat the cardboard relief map with firm papier-mache. Fill in all exposed spaces between contour templates and the exposed cut ends of corrugated cardboard. Make a smooth, natural slope between the templates. See Fig. 3-11.
d. Dry the first coat and filling. If possible, place model in $120^{\circ} \mathrm{C}$ oven for an hour. Otherwise, use fans or lights to hasten drying.
e. Apply a second finishing coat of thinner papier-mache over the entire model. Using a wooden skewer or the handle of a fine
brush, stroke wet papier-mache in an upward movement to sculpt valleys and erosion effects.
f. Dry the model thoroughly.
g. Paint the model. Color code features on the map using shades of colors to show changes in elevation. Allow paint to dry.
h. Label the model. Identify landform features. Include a compass rose and a legend showing the different contour heights. Put your name and date on the model.


Fig. 3-11. Coating cardboard relief map.
5. Make accurate drawings of the model. Show all of the following contours:
a. looking straight down from the top,
b. from the north looking south,
c. from south to north,
d. from east to west, and
e. from west to east.
6. Display each model together with its contour map and your drawings from Procedure 5.

## Summary Questions

1. Compare a relief map, a contour map, and a shaded contour map. Make a table showing the relative advantages and disadvantages of each.
2. Discuss the physical feature you have modeled and its relationship to the following:
a. aid or hazard to navigators
b. economic value
c. ecological value
d. aesthetic value
3. Using all models and contour maps, form hypotheses to explain:
a. How were these oceanic features formed?
b. How might the oceanic features change over time? Explain.
4. Make a list of examples of local shoreline features. How well do the terms used in local names agree with the technical terms for geological features? How would you change the local names so they are technically correct?
5. Define the terms listed below in your own words. Give examples where possible:
a. contour line
b. elevation
c. landform
d. model
e. physical feature
f. sea level

## Further Investigations

1. Construct an accurate relief map or model of the local shoreline.
a. Obtain a navigation chart showing your local shoreline.
b. Using tracing paper, construct one or a series of contour maps.
c. Carefully mark contour elevations and latitude and longitude lines.
d. Using lines on your contour map(s), construct and assemble contour templates to form a relief map.
e. Sculpt with papier-mache.
f. Label features and latitude and longitude lines.
(Note: To construct a larger map, prepare a series of relief maps, each carefully marked with latitude and longitude lines. Assemble the series of relief maps in a large box. Sculpt with modeling mixture.)
2. Make profile bathymetric maps from your models.
a. Cover the model with peg-board or hardware cloth covered with aluminum foil.
b. Using skewers as "depth probes," poke skewers into holes in even rows across the model.
c. Record the depth of each probe.
d. Graph the depths recorded for each straight line (called a transect) that you sampled.
e. The graph represents the profile of your model.

## 4. Earth's Moving Plates

Mount Saint Helens erupts with the force of a giant hydrogen bomb (1980). The earth shakes, and 200,000 are buried in China (1976). A tsunami is recorded moving down from Alaska which levels the water front of Hilo, Hawaii (1960). Unconnected events? In time, yes, but these are events that can be traced to common beginnings.

The land masses on which we live are part of a relatively thin, solid crust sealing in the intensely hot matter of the earth's interior. Parts of the interior act as a very slow-moving fluid which constantly moves the crust, sometimes causing it to swell, sometimes to crack, sometimes to rupture and spew out ash and lava. Over the past 20 years, much has been discovered about the structure of the earth and the dynamics of these movements. Many of the recent discoveries have been made by oceanographers, because it is in the deep oceans that we find much of the evidence for regular patterns of crust movements.

## Activity

Read about earth's moving parts and carry out the operations described.

## Procedure

1. On the left side of a separate sheet of paper draw a vertical 1 ine 12.7 centimeters long. Keep your ruler on the line. This line represents the earth's radius.
2. Label and mark the boundaries of each of the following layers:
a. At 1 millimeter from the top of the line, make a mark. This represents the average depth of the lithosphere or the earth's rigid outer shell. The lithosphere is made up of the oceanic crust and continental crust, as well as of a layer of solidified "mantlelike" material.
b. At 1.4 centimeters make a mark. This marks the inner limit of a layer called the asthenosphere. This layer is partially molten and is thought to move like thick tar. The asthenosphere lies between the "mantlelike" rock in the lithosphere above and the true mantle below.
c. At 5.8 centimeters make a mark. This is the inner limit of the mantle, thought to be a rigid layer of rock resting on the outer core.
d. At 9.2 centimeters make a mark. This is the inner limit of the outer core, a region thought to be made of a liquid material rich in iron and nickel. At the heart of the earth is the inner core, thought to be a solid mass composed mostly of iron and nickel.
3. Each millimeter in your diagram represents about 50 km . Record in km the distance of each layer from the top of your diagram.
4. Table 4-1 lists some of the physical characteristics associated with each layer. Record these on your diagram next to the proper layer.

Table 4-1. Density and temperature data on earth.

| Layer | Estimated <br> Average <br> Density | Estimated <br> Average <br> Temperature |
| :--- | :---: | :---: |
| 1. Asthenosphere | $3.5 \mathrm{~g} / \mathrm{cm}^{3}$ | $1400^{\circ} \mathrm{C}$ |
| 2. Lithosphere | $3.0 \mathrm{~g} / \mathrm{cm}^{3}$ | $800^{\circ} \mathrm{C}$ |
| 3. Inner Core | $11.5 \mathrm{~g} / \mathrm{cm}^{3}$ | $4800^{\circ} \mathrm{C}$ |
| 4. Mantle | $4.5 \mathrm{~g} / \mathrm{cm}^{3}$ | $2250^{\circ} \mathrm{C}$ |
| 5. $\quad$ Outer Core | $9.0 \mathrm{~g} / \mathrm{cm}^{3}$ | $4000^{\circ} \mathrm{C}$ |

## Summary Questions

1. What is the radius of the earth? The diameter of the earth?
2. What happens to the density of the material in the earth as depth increases?
3. What happens to the temperature of the material in the earth as depth increases?
4. Fig. 4-1 shows a stylized cross section of the lithosphere.
a. Where is the lithosphere the thickest? Where does it extend the deepest into the earth?
b. How does the density of each layer affect its location in relationsnip to other layers?

5. It is thought that two forces are constantly opposing each other within the earth. One is the tendency of interior material to get hotter, melt, and form currents like water heating in a pan. The second tendency is for matter under pressure to solidify. Internally, the earth is heated by the decomposition of radioactive material. The solid crust of the lithosphere acts as an insulator which allows a build-up of heat within the earth. Periodically, the crust cracks and heat is rapidly released as lava, steam, and ash which is pushed out over the earth's surface and sometimes into the atmosphere.

Over the past 20 years, a great worldwide system of cracks in the oceanic and continental crust has been mapped and interpreted. These cracks break the crust into sets of plates (Fig. 4-2). Inspect the map of crustal plates and answer the following:
a. How many plates are shown?
b. What plate are you now on?
c. Where are the boundaries of plates usually formed-on land or in the ocean?
d. What kinds of structures are found at the boundaries of plates?
e. What plates, if any, carry no continents?
6. At the boundaries of the plates several things may occur. First, one plate may plunge beneath another. Second, the earth may open up, spreading, or pushing, two plates apart. Third, plates may slide past each other (Fig, 4-3).

Subduction is the descending of one plate under another. It produces two primary earth structures: deep ocean trenches where an ocean crust slides under another plate and great mountain chains where continental crusts collide.
a. Locate on Fig. 4-2 the area of subduction. Are there pTaces without trenches? Where, if any, are they?
b. In what direction does the Pacific Plate seem to be moving? Explain.
c. In what direction does the Australian Plate seem to be moving? Explain.


Fig. 4-2. Map of the earth's plate system.
7. We can think of subduction as the earth's way of repossessing dense oceanic crust material. For example, look at the Nazca Plate. This plate plunges under the South American Plate, at a rate of 2.3 cm per year. As the dense oceanic crust enters the asthenosphere, it melts and the less dense molten material within it rises. This molten matter periodically breaks through the surface to form the great volcanoes in the Andes. Fig. 4-4 shows the subduction of the Pacific Plate.
a. What event in the Pacific Plate might account for the eruption of Mt. St. Helens?
b. Look at a map of the Pacific. What processes would you predict formed the

Aleutian Islands, Japan, the Phillipines? Explain.
8. Once the process of subduction starts it seems to continue to pull the sea floor downward like a giant conveyer belt. But when plates carry continents to the point of subduction, they collide and the process stops (Fig. 4-5).
This stoppage has occurred in Europe where the African Plate is colliding with the Eurasian Plate at the Mediterranean, pushing up the Alps.
a. Inspect Figure 4-2 and determine where else continents have collided. What mountain ranges are formed?


Subduction - one plate plunges below another (A \& B)
Spreading - two plates are pushed apart (E \& D) by C
Transverse fracturing - two plates slide past each other (E \& F)

Fig. 4-3. Major movements of the earth's crust
9. One hypothesis which explains why the continents act like a knot in the conveyer belt can be understood by comparing the denser ocean crust and the lighter continental crust. The less dense parts of the ocean crust are melted out and the remaining crust material gets denser and denser as it sinks into the asthenosphere. The continental crusts are already composed of low density material and cannot sink very far once they reach the point of subduction. Therefore, the process stops when a continent starts to be subducted.


Fig. 4-4. Subduction of the Pacific Plate.

Spreading - as one boundary of a plate is being nibbled away by subduction, the opposite boundary is being formed into new plate crust by a process called sea floor spreading. We stated that there are great cracks in the ocean floor where heat carrying molten matter from the asthenosphere rises up and pushes the sea floor apart. This occurs at sites called ridges and rises. See Fig. 4-6.
a. Locate the areas of sea floor spreading at the boundaries of the Pacific Plate on Fig. 4-2. What direction does spreading seem to be driving the plate? Does this agree with Question 6b? Explain.
b. How would the relative density of new ocean crust material formed in spreading compare with the density of continental crust material? Explain.


Fig. 4-5. Progressive subduction of a plate carrying both oceanic and continental crusts.

10. As we might expect, spreading doesn't occur simultaneously along the entire length of a ridge or rise. Instead, it occurs at different sites and times. The plates tend to break two ways--along the ridge during spreading and perpendicular to the ridge. These perpendicular breaks called transform faults allow the plates to slip by each other. See Figure 4-7. The slippage of plates is often a very jerky process. Great tension can build up before slippage occurs so that when it does, earthquakes result. People living near the San Andreas Fault in California regularly experience such quakes.


Fig. 4-7. System of transform faults near a ridge.

Fig. 4-6. Spreading of the sea floor as molten material from the asthenosphere breaks through the crust.
a. On Fig. 4-2, use a colored pencil to mark in areas where great volcanic action could be expected.
b. Use a colored pencil to mark the region where frequent earthquakes could be expected.
c. San Francisco is approximately $10,000 \mathrm{~km}$ from Tokyo. The Japanese Trench is gobbling up crust at the rate of $3 \mathrm{~cm} /$ year. At this rate, how many years would it take before San Francisco might collide with Tokyo.

## CHAPTER 2 FISHES

Fish are cold-blooded animals with backbones, gills, and fins. All aspects of their lives depend on the water they swim in.

The anatomy of fish is sufficiently complex to provide enough of the structure we will find in the study of most other water creatures. Knowing how fish function, we can better understand how less complex organisms function.

We will apply this knowledge of fish in other chapters. For example, in the chapter on invertebrates (animals without backbones) a chart will be filled in for each group of animals we will study. There is a section in this chart labeled "Phylum Chordata." This is the animal group that includes fish and whales, porpoises, and other mammals.

Completion of this chart will draw upon knowledge gained in this chapter.


## 1. Fish as a Food Resource

The oceans once seemed to offer a boundless supply of fish for food, but today we know there are limits to this supply. A few fish species are already overfished because of high consumer demand. In addition, much fish biomass is wasted in preparing food for humans.

To help meet the growing world need for food, we could use the edible parts of popular fish or develop food products attractive to consumers from underused or unpopular fish species.

Fish protein concentrate, or FPC, is an efficient way of using fish and fish waste products. FPC is a dry powder made from ground fish and fish parts, which can be used as a food supplement for animals. For example, it is commonly added to chicken feed. FPC is not yet commonty used as a food additive for humans.

Americans prefer eating fish fillets or formed fish pieces such as fish sticks. In time, we may be attracted to other fish products like fish cakes made from underused or unpopular fish species. Kamaboko (Japanese) and gefilte fish (Jewish) are two types of fish cake products.

Fish cakes are made from chopped fish mixed with sugar, salt, seasoning, and starch or eggs as a thickening agent (binder). They may be shaped into patties or sausages for frying, deep-frying, boiling, broiling, baking or steaming.

[^0]
## Materials

-several fish, 15 cm or larger, to make 3 cups of meat
-ingredients for one assigned recipe
-frying pan and hot plate
-2 tablespoons oil
-1 600 ml beaker

- 1 dinner plate
-l fork, sharp knife, and spatula
-newspaper and paper towels
-measuring spoons and cup


## Procedure

1. Wash fish. Scale them or remove their skins. (If you are using bonefish, cut off the tail and squeeze the flesh out through the cut like toothpaste. Bonefish flesh is not to be filleted, nor should it be washed.)
2. Fillet fish (your teacher will demonstrate how).
3. Chop or dice fish into 1 cm cubes.
4. Place diced fish into a 600 ml beaker. Wash flesh with tap water. Pour the water out of the beaker.
5. Select one of the recipes given in Table 1-1.
6. Add ingredients to diced fish in beaker and mix. For a finer textured product, place diced flesh into a blender and add ingredients. Add cornstarch if needed to thicken.
7. Shape into small patties or sausages. If desired, coat patties with flour or cornstarch.
8. Heat oil in pan. Fry fish patties for 3-5 minutes per side.
9. Give your cooked fish cakes to your teacher so that samples can be distributed to each student.
10. If you modify your recipe in any way, record modifications. Turn these modifications in with your name(s) and comments.

Table 1-1. Recipes for fish cakes.
Add three cups of assorted diced or blended fish to each recipe.

1. ONION
$\frac{1}{2} t$. garlic salt
1 egg, beaten
1 onión, diced
2. PIZZA
$\frac{1}{2} t$. oregano
1 T. onion, diced
1 egg, beaten
1 t. garlic salt
3. TERIYAKI
$\frac{1}{2}$ c. soy sauce
$\frac{1}{2}$ t. sugar
$\frac{1}{2} t$. ginger
$\frac{1}{2} T$. sherry
1 egg, beaten
4. CHIVE

1 egg, beaten
$\frac{1}{4} c$. chopped carrots
$\frac{1}{4}$ c. diced chives
1 clove garlic
$\frac{2}{2} \mathrm{t}$. sugar
5. VEGETABLE

[^1]6. POTATO

1 egg , beaten
$\frac{1}{2}$ t. garlic salt
1 T. diced onions
1 c . mashed potatoes
$\frac{1}{4}$ t. pepper
1 t. chopped parsley
7. MUSHROOM

```
\frac{1}{2}c. onion, diced
\frac{1}{2}c. carrot, diced
\frac{1}{2}c. celery, diced
l large mushroom, diced
\frac{1}{2}}\mathrm{ t. garlic salt
\frac{1}{2}}\textrm{t}
1 T. chives
\frac{1}{2}}\mathbf{t}. suga
```

Note: Salt is added to taste, and often the cooked fish cake is dipped into a prepared sauce such as hot mustard and soy sauce.

## Summary Questions

1. What are the advantages of fish cakes over whole fish?
2. How is fish protein concentrate used?
3. What are some of the reasons for the lack of popularity of kamaboko in the U.S.?
4. What local underused fish species would you suggest using in fish cake?
5. Which fishes should not be used in fish cake? Why?
6. What are some of the uses for unpopular fish?

## Further Investigations

1. Visit a local kamaboko factory and study the process used in making fish cake. Find out what local fish species are used.
2. Do a cultural/historical study on the use of fish (e.g. Chinese, Japanese, Indian, etc.).
3. Have a fish cake sale in your community and discuss the advantages of fish cake with your customers.
4. Look up information on common food fish consumed in the U.S. Obtain information on how many tons of each fish are caught per year. Prepare a chart ranking the fish from largest to smallest catches. Which fish are considered overfished? What, if anything, is being done to protect them?
5. Collect and try new fish recipes.
6. Make a study of the local fish and fish products in your supermarket.
7. Conduct a class survey of how much fish is eaten each year, what kinds of fish and how they are prepared.
8. Compare the nutritional values of fish with other protein sources such as milk, cheese, beef, chicken.

## 2. Fish Prints

Marine biologists need to be able to rapidly obtain and readily store accurate information on organisms. Today they rely heavily on photography. In this topic we will be using gyotaku, fish printing, a method for recording the details of external fish structure. It is older than photography and less expensive. In Japan, gyotaku is a popular art form. Color, spatial arrangement and clarity of details contribute to the quality of gyotaku as art.

## Activity

Experiment with ways of making fish prints.
Prepare a collection of fish prints of common fish species.

Materials - per team of 2 students

```
-1 fresh fish (3-10 cm length)
-corrugated cardboard (8\frac{1}{2}\times11 in, approxi-
mately)
-pencil
-razor blade, single-edged
-plastic modeling clay or pins
-water based ink or paint
-paper for prints (rice paper, newsprint,
    paper toweling or crumpled mimeograph paper)
-brush with \frac{1}{2}}\mathrm{ inch stiff, pointed tip
-news papers
-paper towels
-wax paper ( }10\times10\textrm{cm}\mathrm{ , approximately)
-soap
```


## Procedure

1. Cover the surface of the table or lab bench with newspapers.
2. Gently clean the outside of the fish with soap and water. Pat dry with paper towels.
3. Place the fish on a sheet of corrugated cardboard.
a. Trace the outline of the main body of the fish on the cardboard.
b. Remove fish.
c. Using a razor blade, cut the outline out of the cardboard.
4. Place fish in the "well" formed in the cardboard.
a. Spread fins out.
b. Hold fins in place using clay and pins.
c. If desired, insert a piece of clay into the mouth of the fish to hold it open.
5. Paint fish.
a. Put a small dab of paint onto a piece of waxed paper.
b. Use this paint to brush a thin, even coat on the fish. You may want to dilute the paint.
c. Apply paint gently from tail to head being careful not to damage scales.
d. Clean brusn thoroughly before proceeding to Step 6.
6. Apply paper to fish.
a. Practice the technique with newsprint or inexpensive paper. One partner positions the paper over the fish, holding it in place. The other partner gently uses a paint brush to press the paper onto the fish.
b. Gently stroke paper with brush. Use the top of the brush to reach the curved surfaces and to bring out features of the fins. The harder you press, the less detail you will get.
7. Remove the paper and allow the print to dry. Sign your name on the paper.
8. Repeat procedure and try new techniques to make a collection of fish prints.
a. Try making prints in more than one color.
b. Make a print with more than one fish.
c. Use a smaller brush to add dots of color to the fish.
d. Be prepared to explain your modified procedure to the class.

## Summary Questions

1. Suggest ways that gyotaku can be used.
2. How does gyotaku compare with photography as a means of obtaining and storing information? What are the advantages and disadvantages of each?
3. How did you obtain detail in your prints?

## Further Investigations

1. Prepare a set of fish prints of common fishes or of major fish groups.
2. Use fish prints as an art form for wall hangings, note paper, place mats and other decorations.
3. Experiment with making fish prints on cloth. Make direct prints onto cloth using fabric dyes.
a. Dip brush into water, then mix ink into brush.
b. Apply ink in one direction, either tail to head or in reverse.
c. Use only one color of ink as you learn this procedure. Later, as you become more experienced, you can experiment with mixing colors on the print.
4. Prepare a silk-screen fish print.

## 3. External Fish Anatomy

Anatomy is the study of the different structures of an organism and how they are arranged in relation to each other. The external anatomy of a fish gives clues to where and how it lives. Modification of these body parts permits different fish to live in different types of environments, or parts of the same environment.

In this investigation we will seek to find what anatomical structures are common to most fish. Then, we will get some idea of how the shapes, sizes, and arrangement of anatomical structures are modified in different fish.

## Activity

Identify the common external anatomical structures of several fish.

Compare the relative size, shape, and location of these structures.

Moteriols - per team of 2 to 3
-1 dissecting pan or newspaper
-1 fish
-1 glass slide and coverslip
-1 dissecting microscope
Procedure

1. Obtain a fish. Place it on its side in a dissecting tray or on newspaper.


Fig. 3-1. External anatomy of a soldierfish.
2. Using the soldierfish diagram (Fig. 3-1) as a guide, draw your fish in your notebook. Make your drawings large.
3. Identify and label the structures of your fish that are found on the soldierfish diagram. (Some fish may not have all of the structures found in the diagram.)
4. Identify your fish's family using the key in Topic 9 or obtain the name from your teacher. Write its name on your drawing.
5. Complete Table 3-1.
a. Draw a ray and a spine from your fish. Refer to Fig. 3-2 for an example of a spine and a ray.

Table 3-1. Fish spines, rays, and scales.

b. Remove a few scales from the middle of the body and place them on a slide with a drop of water. Cover and examine them under a dissecting scope. Do not use lateral line scales.
c. Draw and identify the scale type. Compare drawing with typical scales shown in Fig. 3-3.
 ctenoid scale

Fig. 3-3. Two types of fish scales.
6. Compare your fish with the soldierfish (Fig. 3-1), and complete Table 3-2. Draw or describe the relative size, shape, number of parts, and location of each of the structures listed in the table.
7. Follow your teacher's instruction in preparing your fish for preserving.

## Summary Questions

1. Refer to Table 3-2 and other drawings.

List the major distinguishing structures of the two fish, such as shape or size of anatomical parts.
2. How could you use Table 3-2 to distinguish or separate one fish from the other? Explain your answer.

Table 3-2. Structures of two fish.

| Structure | Soldierfish | Your fish |
| :--- | :--- | :--- |
| Dorsal fin (D1/D2) |  |  |
| Pectoral fins (P1) |  |  |
| Pelvic fins (P2) |  |  |
| Anal fin (A) |  |  |
| Caudal fin (C) |  |  |
| Gill cover (G) |  |  |
| Lateral line (LL) |  |  |
| Anus (An) |  |  |
| Eye (E) |  |  |
| Mouth (M) |  |  |
| Nostril (N) | small, two round <br> openings, head |  |

3. How would you know if the two fishes were the same species? By "same species" we mean that organisms are alike except for size and those differences associated with sex and stage of maturity.

## Further Investigations

1. Make a collection of preserved fish or fish photographs for classroom use.
2. Make a key to kinds of fishes based on external anatomy.

## References

Goodson, Gar. 1973. The many-splendored fishes of Hawaii. Marquest color guide books.

Norman, J.R. and P.H. Greenwood. 1963. A history of fishes. 2nd edition. London.

## 4. Fish Counts and Measurements

Researchers from the Department of Fish and Game regularly survey fish populations to find out how many fish and what species are present in an area. They also try to find out whether overfishing or underfishing is occuring and whether diseases or pollutants such as chemicals are affecting fish populations. To do these surveys, researchers must be able to identify fish species by sight.

Scientists classify fish into species by counting and measuring external structures of fish. This is important since males, females and young of a species may be differently colored or patterned.

In these activities you will take some counts and measurements of different fish species and compare them.

## Activity A

Take counts and measurements of fish.

## Materiols

-1 large and 1 small fish of the same species
-1 metric rule
-1 dissecting pan or newspaper
-2 colored pencils

## Procedure

1. Obtain two fish of different sizes but of the same species.

Table 4-1. Fish measurements.

| No. | Measurement | Description |
| :---: | :--- | :--- |
| 1 | Standard length (SL) | The distance between <br> the most anterior part <br> of the head and the end <br> of the vertebral col- <br> umn, (To find the end <br> of vertebral column, <br> bend caudal fin toward <br> head. A crease indi- <br> cates end of column.) |
| 2 | Head length (HL) | From the most anterior <br> tip of head to poste- <br> rior edge of gill <br> cover, |
| 3 | Caudal peduncTe depth | The narrowest part of <br> the caudal peduncle. |
| 4 | Eye width | The distance from the <br> anterior margin to the |
| eye to its posterior |  |  |
| edge. |  |  |


greatest body depth
Fig. 4-1. Fish measurements. (Anterior is toward the head, posterior is toward the tail).
2. Study Fig. 4-1 and Table 4-1.
3. Measure your fish. Record data in Table 4-2.
4. Take a lateral line scale count of the two fishes. On Table 4-2 record information. Refer to the arrows on Fig. 4-2 to start and end your count. Lateral line scales have tubes through them.
5. Determine the fin formula of your specimen after looking at the examples in Fig. 4-3. Spines are indicated by Roman numerals (I; IV, etc.); soft rays are indicated by Arabic numerals ( $1,2,3$, etc.). Count the bases of the rays, not the multiple tips.
a. Record the number of spines in the first dorsal fin. If rays are present, record a comma (,) and the ray count.
b. If there is a second dorsal fin, record a dash (-) followed by fin count (if any), then comma (,) and ray count (if any).

Table 4-2. Fish counts and measurements.

| Measurement | Fish 1 | Fish 2 |
| :--- | :--- | :--- |
| 1. SL |  |  |
| 2. HL |  |  |
| 3. Caudal peduncle <br> depth |  |  |
| 4. Eye width |  |  |
| 5. Pelvic to anal <br> distance |  |  |
| 6. Body depth <br> (Estimate) |  |  |
| 7. Lateral line <br> scale count |  |  |
| 8. Fin formula for <br> dorsal fin |  | W |



Fig. 4-2. How to count scales.

## Single Dorsal



Two Dorsals - Separate


Fig. 4-3. Fin formulas for different fin types.

## Activity B

Make a polygraph of data from Activity $A$ and compare with polygraphs of fish of the same and different species.

## Procedure

1. Put all your counts and measurements on a polygraph (Fig. 4-4). Use a different color for each fish.
a. Put a large mark on each line showing where each fish measurement is located on the line. For example, if your fish's
head length ( HL ) is 9 cm , put a dot on the HL line halfway between 6 and 12 . If HL is greater than 18 cm extend the polygraph line beyond the circle.
b. Using a ruler, connect adjacent marks with a straight line.
2. Compare your fish polygraphs with the polygraphs of other fish species constructed by other teams.


Fig. 4-4. Polygraph for comparing fish.

## Summary Questions

1. Refer to your team's data on different sized fish of the same species.
a. Decide what counts and measurements remained the same as the fish grows.

Why might these counts and measurements remain the same?
b. Decide which counts and measurements differed as the fish grows. Why might these be expected to be different?
2. Refer to work done with different species. Where possible, compare fishes of approximately the same length. Decide which counts and measurements could be used to tell the fishes apart. What are they?
3. How does a polygraph help identify the differences between different but similar sized species?

## Further Investigations

1. Visit local fish markets and make a tally of the popular fish and the number of fish species sold locally. Find out if the average size of any of the fish is becoming smaller each year.
2. Visit the local Fish and Game Department and discuss the reasons for having or not having closed fishing seasons on many local fish.

## References

Goodson, G. 1973. The many-splendored fishes of Hawaij. Marquest color guide books.
Norman, J.R. and P.H. Greenwood. 1963. A history of fishes. 2nd edition. Lonđon.

## 5. Hawai ian Fishes - Form and Function

Fishes have been swimming in the waters of our planet for millions of years. During this time, some body parts of fishes have changed. These adaptations or adjustments to enviroments enable them to survive and live in many different habitats. A habitat is where animals live and may be a coral reef, a sand patch, a bed of algae, etc. This activity is designed to investigate some of the similarities and differences in fish body forms and how they affect the way a fish behaves in its habitat.

## Activity

Compare the external anatomy of different fish.
Predict the kind of environments fishes have adapted to and the behavior of fishes from their external anatomy

## Moterials

-5 different species of fish
-newspaper or dissecting pan

## Procedure

1. Obtain a fish.
2. Identify its family using the fish key in Topic 9.
3. Record the name above the same number on

Fig. 5-1 and Table 5-1.
4. Draw the parts listed on Fig. 5-1.
5. Use the key to fish form and function (Fig. 5-2) as a guide.
Fig. 5-20. Forte and function of some fish parts.

Fic．5－2b．Form and function of sone fish parts．

|  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $y s^{m}$ |  | $=\operatorname{sen}$ 0 |  |  |  | $\eta \square$ |
| 唇 |  |  |  |  |  |  |  |
| 起 |  | $\frac{\stackrel{4}{3}}{3}$ | 咅 | 5 <br> 0 <br> 0 <br> 0 <br> 0 |  |  | $\overline{5}$ |

## b. List their form and predict their function on Table 5-1.

6. Obtain a second tish and repeat Procedures 1-4.

## Summory Questions

1. Make the following predictions about your five fishes on Table 5-2.

Table 5-2. Predicted behavior in habitat.


## Further Investigations

1. Visit the aquartum during feeding time and make the following observations:
a. What are the principle body parts of each fish below used in locomotion:
i. Jack (ulua)
ii. Triggerfish (humu)
iii. Scorpionfish (nohu)
iv. Eel (puhi)
v. Wrasse (hinalea)
vi. Pufferfish (o'opu)
vii. Butterflyfish (kikakapu)
b. Name a fish which usually:
i. rests on its pectoral fins
ii. hangs in the water
iii. swims continuously
iv. lives in holes
y. "hops" along the substrate
c. Determine three different ways in which fishes feed.
2. Determine which fish are nocturnal (in the open at night and in holes during the day).
3. Visit a fishing boat or fish market and report on the kinds of fish you see and what habitat you think they live in.

## 6. Fish Watch

Animal behaviorists often study their subjects with sophisticated equipment such as event recorders which resemble typewrtters. Every time an animal does something a key is pressed down and held there until the animal does something else. The time taken to perform the activity is recorded. The object or behavior which is thought to stimulate the activity is also noted. For example, if two male and two female fish were being observed, the record might look like Table 6-1 .

Table 6-1. \% Time of activity

| Activity | Male | Male 2 | Femate 1 | Female 2 |
| :---: | :---: | :---: | :---: | :---: |
| Courting |  |  |  |  |
| male 1 | -- | -- | 25 | -- |
| male 2 | -- | - | -- | -- |
| female 1 | 25 | --- | -- | -- |
| female 2 | -- | -- | -- | -- |
| Fighting |  |  |  |  |
| male 1 | -- | 25 | -- | -- |
| male 2 | 25 | -- | 10 | -- |
| female 1 | -- | 10 | -- | -- |
| female 2 | -- | -- | -- | -- |
| 0ther | 50 | 65 | 65 | 100 |

The table shows that male 1 and female 1 are involved in courtship behavior. Male 2 does not attempt to court the females but he fights with both male 1 and female 1 . This indicates that the pair have staked out a territory (defended space). When male 2 enters the territory, he is attacked. Female 2 spends all of her time doing other things

Male 1 , male 2 , and female 1 recognize each other. Since female 2 didn't interact with the other fishes, we can't say that she was recognized by them.

In the following activities, we will be observing several different kinds of fish. These fish react not only to other fishes but to the habitat (type of substrate, e.g. rocks, sand, plants) that we give them. Observe changes in both their actions and their coloration.

How an animal behaves is determined by something in its environment that causes the behavior. The cause is called a stimulus and the behavior a response. In the following activities, ask yourself, "what is the fish responding to?" and "how is it responding?"

## Activity

Describe different fish behaviors and determine the stimuli for these behaviors.

## Materials

Listed with each option or design your own using Aquarium Reference.

## Procedure

1. Scan the Aquarium Reference.
2. Become familiar with the following behaviors:
a. Schooling is a behavior of some fish species which orient in the same direction, move at the same speed and keep equal spacing.
b. Aggregating is a behavior of some fish which bunch together but do not orient in the same direction or keep equal spacing.
c. Aggression is threatening or fighting others. To show aggression most fish raise their dorsal fin spines, push out their gill covers, open their mouths and approach other fishes. Some fish may also change color. If fighting takes piace, fish may bite, stab with their spines or blades and chase offenders away.

Aggression arises from territory and peck order. If space is limited, fish may defend smaller areas than they normally do.
d. Courtship occurs during mating activities and differs from species to species. Behaviors include abnormal swimming patterns like wriggling and shuddering, close contact between mating fish and changes in color. The male usually takes the lead during courtship and the female during spawning.
e. Food searching is a behavior that varies from species to species. Among some fish, food searching may look like random hunting and pecking. Other fish may lie in wait to dart out and snatch passing prey. Some fish feed alongside other species and some do not. Some feed in schools and some feed alone.

Topic 5 lists many examples of feeding types.
f. Swimming, hovering, perching, or lying on
the bottom are behaviors which differ from species to species. Note which fins are used, and if the animal swims all the time or stays on the bottom most of the time. Observe what fins a fish uses to move, how they are modified and how the fish is oriented. Some fishes such as shrimpfish spend most of their time in a head down position while others such as sea horses remain in a head up position.
g. Camouflage and mimicry are behaviors some fish use to disguise their presence in the environment. A fish that behaves like seaweed mimics seaweed. A fish that uses changes in bodily appearance to blend in with coral, rocks or sand is camouflaging itself. Fish use both mimicry and camouflage to disguise their appearance.
h. Advertising coloration and other behaviors occur in many fish. A fish with dangerous spines of a different color from the rest of the body is advertising this to others. Poisonous fish may also advertise by their bright coloration.

Cleaning wrasses attract fish to be cleaned by advertising coloration and dances. Fish wanting to be cleaned use advertising behavior to signal that they want to be cleaned.
i. Habitat preference is behavior related to where a fish lives. Some fish require substrates such as sand or rocks. As you
put objects in the tank, which one does your fish respond to? It may avoid or remain near, on, or under the object.
Some fishes are very specific about what they require. Certain butterflyfishes must have a particular coral to eat; otherwise they starve.
j. Learning is a behavior which fishes engage in to recognize objects and other animals in their habitat. Many fishes can easily be trained to come to a specific place to receive food and can learn how to navigate mazes.
k. Fright in fish is a reaction similar to that of humans and involves moving away, color change, and other behaviar.
3. Work in tearis of two to four.
4. Each team should design a behavioral experiment, select, or modify one of the suggestions which follow and submit the design to your teacher.
a. Review the literature on the fish you have chosen to watch.
b. Explain what you want to do, what is to be observed or what hypothesis is to be tested.
c. Explain how you will do it. What are your methods?
d. Estimate the time it will take to do it.
5. Secure aquaria, pumps, filters, substrates, and water as needed.
6. Set up the aquaria as needed.
7. Carry out the experiment or observations. keep records of the results. What happened?
8. Write a report describing your observations, hypothesis, methods used, results, and the literature reviewed. Do the results validate the hypothesis?
9. Give a verbal report to the class.

## References

Breder, C.M. and Rosen, R.E. 1966. Modes of reproduction in fishes. Nat. Hist. Press, New York.

Emmens, C.W. 1971. How to raise and breed tropical fish. T.F.H. Publications.

Goodson, G. 1973. Many splendored fishes of Hawaii. Marquest Colorguide, 2nd Ed.
Marshall, N.B. 1965. The life of fishes. Werdenfeld and Nicholson. London.

## 1. Tilapia in un Aquariun.

## Materials

-1 20 galion established aquarium with 6 $4-6 \mathrm{~cm}$ tilapia.

- 1 bare 20 gallon aquaria with fresh water
-l fish net
-1 needle
-I stop watch


## Directions

1. Observe tilapia in an aquarium and fill in Table 6-2.

Table 6-2. Behavior and coloration of tilapia.

| -- | Established Aquariun | Bare Aguarium |
| :---: | :---: | :---: |
| a. Respiration rate |  |  |
| b. Coloration. |  |  |
| c. Dorsal fin |  |  |
| d. Swimuing - |  |  |
| e. Other behavior |  |  |
| f. Slit.tall |  |  |

a. Use a stop watch to time the respiration rate. This is the number of times the gill covers or mouth moved per minute.
b. What color pattern(s) do your fishes have?
c. Dorsal fin. Is this fin raised or lowered most of the time?
d. Swimming. Time a fish for one minute. How many seconds is it engaged in swimining?
e. List what other behavior you see.

## Questions

1. How does the behavior and coloration of the tilapia in the bare tank differ from the tilapia in the established tank?
2. What stimuli caused the behavioral color change?
3. What stimuli do tilapia react to?

## 2, Guppy Courtsinip Behavior.

## Materials

-1 small aquarium with fresh water and a few - floating plants
-1 male and 4 female guppies
-1 plastic or glass partition

## Directions

1. Put a partition into the aquarium.
2. Put the guppies into the aquarium the day before doing the experiment. Isolate the male from the females. See Fig. 6-1.
3. Observe the male. List four ways in which you can tell the difference between male and female guppies. Outline his color pattern in Fig. 6-1.


Fig. 6-1. Male guppy
4. Raise the partition. Observe the guppies and record your observations in Table 6-3.
a. Color change. Does the male's color pattern change when he is actively courting? How?
b. Fin action. Which of the male's fins moves differently when he is courting and not courting? What is the function of these fins?
c. Body action. How is the body held when the male is courting? Is this different from a normal swimming position?
d. Position with respect to the female. Where is the guppy located when he is courting? Is he anywhere in the tank or does he attempt to be in a specific location with respect to the female?
e. Does the male single out a specific female or does he court them all?
f. What are the responses of the female to the courting male?

Table 6-3. Guppy behavior.

|  |  |
| :---: | :---: |
| 1. Golor chames |  |
| b. Finckion |  |
| C. Bayy artion |  |
| d. Position with respact to fendit |  |
| 1. Pretareste of if:alex |  |
| t. Fenala responses |  |

5. Observe the sequence of events in guppy courtship and spawning. Look for:
a. Who initiates courtship?
b. What is the response of the female to the male?
c. What is the response of the male to the female?

## Question

1. Describe or draw a diagram of the sequence of events in guppy courtship behavior. An example of fish courtship is given in Fig. 6-2.


Fig. 6-2. Courtship behavior stimuli of cichlid fish.
3. Learning to run a maze.

## Materials

```
-1 maze
-2-3 small, easily kept fishes
-food
```


## Directions

1. Design and construct a simple maze for your fishes. A fish maze may consist of a series of partitions with holes placed in the aquarium.
2. Every day, approach one end of the maze and put food there; stand near the end until fishes eat the food.
3. Record in your record book the number of days it takes for your fishes to go directly to the end of the maze at feeding times.
4. Feed the fishes at the same end of the maze for one week. Continue to stand at the end until the fishes have eaten.
5. The following week, put food at the other end of the maze. Record as in Direction 3.
6. Repeat Direction 4.
7. The following week put food at the other end of the maze, but stand at the end where you were the week before.
8. Continue to do this for a week and record the number of days it takes for the fish to go directily to the food with you standing on the other end of the maze.

## Questions

1. Is the learning process faster or slower when you feed the fishes at the one end of the maze than the other end?
2. Does your presence at one end of the maze and the food at the other end result in the fishes' learning speed being different than when food is given in your presence?

## 4. Damselfisin Territoriality

Materials
-1 coral head
-1 aquarium with sand, sea water and one coral head
$-6-12$ similar sized moon damselfishes in a holding tank

## Directions

1. Place one damselfish in an aquarium with coral head. Record its behavior for 5 minutes.
2. On the next day, record its behavior for one minute; then place another damselfish in the aquarium. Record what happens.
3. If the fishes ignore each other, add another fish every 5 minutes until they interact. Record the behavior.
4. Add another coral head to the aquarium, Record what happens. Record where the damselfishes are on the next day.

## Questions

1. How many fish have to be added for an interaction to take place with one coral head?
2. What happened when a second coral head was placed in the tank?

## 5. Other suggestions.

1. Observe spawning fishes like Hawaian gobies or fighting fish (Betta). Describe their behavior and record the stimuli that trigger this behavior.
2. Observe fishes by snorkeling or diving. Are male and female color patterns different? Do they behave differently?
3. Determine the extent of a fish's territory and change the rocks around. Then recalculate the territory size and shape. Remove rocks from or put rocks into the territory and record the changes.
4. Experiment with different damselfishes and cover items like coral or rocks to determine their preferences.
5. Observe damselfishes in the field and determine their preferred habitat and territory boundaries.

## 7. Internal Fish Anatomy

In this topic we will study the internal anatomy of a fish.
Activity
Read the material, fill in the figures and tables,
and answer the Summary Questions.

Like humans, fish are made up of parts called organs arranged in interacting groups of systems. The systems react together to enable a fish to function. We will investigate 10 of these systems. Table 7-1 lists these systems, along with some of their functions and organs.


Fig. 7-1. Diagram of an $x$-ray of a fish skeleton.

Table 7-1. Body systems.

| 5ystin | Dindin | Functiom |
| :---: | :---: | :---: |
| l. Sbatimal syatm | till, Hbs, | $\begin{aligned} & \text { wiver } \\ & \text { proter } \end{aligned}$ |
| 2. Meaular yytto | -utclat. teptow | morment |
| 3. 0iperive sytim |  intutinct this, dipmelve gland | foed erventilit |
| 4. Mantratory tytie |  bladerer |  <br>  |
| 5. Ciralatory mitia |  weint, lymptic ducts, blood | $\begin{aligned} & \text { body riuld } \\ & \text { tremaport } \end{aligned}$ |
| 6. Emarairy mytam |  urthary duct | mate riocis |
| 7. Rarvowi syster |  belaneimg mechanty, meture racpleri, metrils, tistit raciptors and anrs | 56410. notion ath maporit |
| 8. Reprouktive rytum |  | sperivel of the |
| 9. Intofurimicry mitem |  | mextertion |
| 10. Entaiclme systa | harame produciay plands | charchl ravulation |

## Skeletal system

The system that most determines the body shape of a fish is the skeletal system. Some of the hard organs of the skeletal system house and protect softer organs related to other systems.

A diagram of an x-ray of a fish is shown in Fig. 7-7. The fins are supported by bones, and the body cavity is protected by ribs. The skull
houses the eyes and nostrils and protects the brain. Observe that the vertebral column, or backbone, is not a solid rod but a string of small bones or vertebrae. When muscles are attached, the bones act as Tevers to move large parts of the body.

Table 7-2 gives a quick overview of the skeletal system. It lists the organs and their functions.

Table 7-2. Organs and functions of the skeletal system.

| Skeletal system general function | Organs | Organ functions |
| :---: | :---: | :---: |
| Support and protection | Skul1 | Protects brain, eyes. nostrils, supports jaws |
|  | Ribs | Protects body, gives shape |
|  | Yertebrae | Levers for moving musctes, central support bean of body |
|  | Sptres | Protection |
|  | Fin supports | Smifining, body shape |

## Muscular System

Muscles are special organs that have the power to contract, or shorten, and to relax, or extend. Fishes move by contracting and relaxing their muscles. Like humans, fishes have three types of muscles:

1. Skeletal muscle moves the skeleton and the entíre body.
2. Heart ruscle moves blood.
3. Visceral or mooth muscle lines the tubes of the body and moves food and blood in these tubes.

Skeletal muscles are called voluntary because they move only when the thinking part of the brain signals them to move. Animals must learn how to contract and relax their skeletal muscles properly.

Pairs of skeletal muscles are connected to the bones. As a muscle contracts, it pulls the bone it is connected to towards it. As it does so, the other muscle relaxes and the bone moves away from it. For example, a fish wiggles its tail from side to side to move forward by first contracting the muscles on the right side of its tail, then on the left side.


Fig. 7-2. Fish voluntary muscle pattern.

Visceral or smooth muscles are called involuntary because to move they do not need signals from the thinking part of the brain. Smooth muscles contract and relax in waves to push food in the digestive tract from the mouth to the anus.

The heart muscles are also involuntary. By contracting and relaxing, they create a pump-like effect to move blood through the body.

Fill in Table 7-3, using the information from this reading.

Table 7-3. Muscles and their functions.

| Mascular Systain <br> Ganaral Function | Muscles | Organ Functions |
| :--- | :--- | :--- |
|  | Skeletal |  |
|  |  |  |
|  | Heart |  |
|  |  |  |

## Digestive System

The digestive system's function is breaking down food into molecules small enough to pass into the bloodstream. These molecules are distributed to the other organs of the body. Undigested waste products are eliminated through the anus.

There are three main parts to the digestive system: the mouth, the digestive tube, and the digestive organs and glands.

1. Food first enters the body through the mouth. From here food is either swallowed whole, or it is first broken into smaller pieces by the teeth. In swallowing, the tongue helps push food into the digestive tube. Gill rakers (Fig. 7-4) prevent food from escaping through the gill covers.
2. As food passes from the mouth and pharynx into the digestive tube, it first goes to the stomach. Here food is partially digested by
chemicals similar to those in the human stomach. This partially digested food moves into the intestine where other chemicals complete the digestive process. Digested food and water are absorbed into the blood through vessels in the intestinal walls. Undigested solid waste moves along the intestine and is passed out of the body through the anus.


Fig. 7-3. The digestive system of a fish.
3. The chemicals used in the digestive process are produced by digestive organs.

Two such organs are the liver and the pancreas. The liver, a large, red organ, can easily be seen in a fish dissection. The liver's bile breaks fats and oils into smaller particles which are absorbed through the wall of the intestine. The pancreas, arid other small digestive organs lining the intestines, produce digestive juices.

Fill in Table 7-4 using the information from this reading.

Table 7-4. Organs and functions of the digestive system.


## Respiratory System

The main function of the respiratory system is to take oxygen into the body and to pass carbon dioxide $\left(\mathrm{CO}_{2}\right)$ out of the body. The fish's chief organs for doing this are gills. Each gill has many gill filaments which contain a vast network of capillaries (very thin, small blood vessels).

Water is brought into the fish's mouth and forced over the gills. As this occurs, blood in the capillaries of the gill filaments picks up oxygen from the water and passes carbon dioxide into the water. The blood carries the oxygen to the body, the water is flushed out through the gill slits, and the process is ready to be repeated (Fig. 7-4).

Oxygen in the body combines with food molecules to release energy for the body's needs. This chemical process (nutrient oxidation) breaks food
down into water and carbon dioxide, releasing energy in the food molecules. The oxjdation of sugar is an example of this process:

$$
6 \mathrm{O}_{2}+\mathrm{C}_{6} \mathrm{H}_{12} \mathrm{O}_{6} \rightarrow 6 \mathrm{CO}_{2}+6 \mathrm{H}_{2} \mathrm{O}+\underset{\text { Energy }}{\text { Released }}
$$



Fig. 7-4. One gill of a fish.

The gas bladder (if present) is considered another part of the respiratory system. It is a silvery sac which lies below the kidney. The amount of gas in the bladder determines whether the fish can rise, sink, or maintain its level in the water. Blood vessels supply gases used for its inflation and remove them during deflation.

Because of the slow movement of gases into and out of the bladder, fish caught at great depth and suddenly hauled up and into a boat are often bloated because of increased gas pressure in the gas bladder. This normally results in internal injuries to the fish. Therefore, fish collectors bring their fish up in stages to give gases enough time to leave the gas bladder. Most fishes which
sit on the bottom do not have a gas bladder. However, for those fishes that spend most of their time in open water, a gas bladder is extremely important.

Fill in Table 7-5 using the information from this reading.

Table 7-5. Organs and functions of the respiratory system.


## Circulatory System

The circulatory system is a transportation system for body fluids. It is made up of four kinds of organs:

1. The heart is the pump of the system. In the fish it is a muscular organ with two chambers and pumps blood to other body parts.

A fish's heart lies just under its gills (Fig. 7-5). Blood, which is low in $0_{2}$ and high in $\mathrm{CO}_{2}$, flows from the heart to the gill filaments where $\mathrm{CO}_{2}$ is released and $\mathrm{O}_{2}$ is picked up. From the gills, the now oxygen rich blood moves forward towards the brain and backwards towards the digestive system. Food
absorbed from the digestive system is carried in the blood and distributed throughout the body.


Fig. 7-5. Parts of the circulatory system.
2. A network of tubes called arteries, veins, and capillaries connect the pump with all parts of the body. Collectively, these make the organs called the blood vessels.
3. Another organ is a group of tubes called lymph ducts which pick up the liquid that seeps out of the vein-artery system and collects in various parts of the fish's body.
4. The blood may be called an organ. It is made up of plasma and blood cells. Water, $\mathrm{CO}_{2}$, hormones, food, waste materials, and other compounds are part of the plasma. There are two main types of blood cells, red and white. White blood cells are disease fighters. Large concentrations of these white blood cells may be found around infected wounds (e.g., pus is dead white cells). Red blood celis carry $0_{2}$ from the gills to the other cells in the boay.

The circulatory system is much like a canal system. It carries the fuel and building material necessary to maintain and allow the (body) to grow and be repaired; it transports police (white blood cells) to wipe out disease invaders; and it acts as a sewer for the bodily wastes.

Fill in the Table 7-6 using the information from this reading.

Table 7-6. The circulatory system.


## Excretory System

The excretory system is the filter system for the blood. The fish kidney looks like a single, long, dark red organ which lies just under the vertebrae. The blood carries a host of waste products to the kidney (Fig. 7-6). The function of this organ is to filter waste materials from the blood. All reusable materials such as sugars, salts, water, etc., remain in the blood. Only the wastes and other selected materials are removed by the kidney and pass down the urinary tubes to the bladder, if present. Wastes are finally excreted from a hole behind the anus. Eggs or sperm from the ovary or testis leave also from this opening.

The blood also carries waste products to the gill filaments. $\mathrm{CO}_{2}$ is excreted by these organs and also salt if the fish lives in seawater.


Fig. 7-6. Excretory and reproductive systems of

Fill in Table 7-7 using the information from this reading.

Table 7-7. The excretory system of the fish.


## Nervous System

A. Brain, Spinal Cord and Nerves

The nervous system is a complex group of organs that start, stop, and control most processes of the body. It operates and is built like a city telephone system, with a master computer in its central office. This analogy is a good one because both the telephone system and the nervous system are electrical systems. Both communicate through electrical impulses. There are three primary parts to the nervous system:

1. The brain, like a central computer, receives information from sense organs that monitor the environment around the fish and the conditions within the fish. The brain interprets this information and sends response commands to the body.
2. The spinal cord, like a telephone trunk line, connects the brain with the rest of the body. Composed of a long bundle of nerve fibers, the spinal cord receives and transmits nerve impulses between the brain and the body.
3. Peripheral nerves, like branch lines, lead from the spine or from the brain to body organs. The nerves are either sensory or motor nerves. Sensory nerves carry information from the body to the spinal cord or brain. Motor nerves send conmands from the brain or spinal cord to the body.

A third group of nerves, connector nerves, carry nerve impulses between sensory and motor nerves.

The brain of fishes is divided into five parts. Each part has a different function. At the very front of the brain are two bulb-Tike structures sitting side by side. These are called the olfactory lobes, and receive information about chemicals in the water from the nostrils.

Behind the olfactory lobes are two lobes called the cerebrum. The cerebrum controls the voluntary muscles. Fish also have a limited memory because they can learn simple tasks and adapt to new environments. In higher animals, such as man, the cerebrum is the center for thought processes.

The two lobes, just behind the cerebrum, are the optic lobes. Large nerves connect the optic lobes to the eye. Right behind the optic lobes are two bulbs called the cerebellum. Here is centered control of the involuntary muscles.

Finally, the medulia lies underneath the cerebellum and connects the rest of the brain within the spinal cord. One of its functions is to control the flow of hormones in the fish.

Label the parts of the moray eel brain in Fig. 7-7.


Fig. 7-7. Moray eel brain.
Fill in Table 7-8, listing the parts of the nervous system and their functions.

Table 7-8. Parts of the brain, spinal cord and nerves.

B. Sense Organs

Fish have a number of sense organs to monitor changes in their environment and in their bodies. This group includes the eyes, nostrils, ears, and lateral lines. Also every part of each organ has sensory nerve endings.

1. Fish eyes closely resemble those of humans (Fig. $7-8$ ). The eye has a lens which focuses and makes a clear image of the the object on the retina. The retina is a light sensitive surface which is rich in nerves. These nerves are connected to the optic lobe of the brain. Fish have no eyelids, therefore the eye is constantly open.


Fig. 7-8. Fish eye.
2. Fish have two inner ears imbedded in pockets of their skulls. They are used for balance and detecting sound vibrations. Sound vibration detection corresponds to human hearing.

The semicircular canals in the inner ears are shown in Fig. 7-9. They act much like the bubble in a carpenter's level. When the fish rolls right or left, tail up or down, the liquids and otoliths (earstones) push against hair-like nerve endings which line the canal. When these nerve endings are moved, messages pass to the brain.


Fig. 7-9. Fish inner ear.
3. Fish have a row of nerves running along both sides of their bodies which register changes in pressure. These sensing nerve endings are in a system of tubes. When water pressure changes or when the fish enters a current or another fish swims by, water moves faster through the tubes and activates the sensory nerve ending. This system of tubes and pressure sensing nerve endings is called the lateral line. As can be seen in Fig. $7-10$, the lateral line runs laterally down the length of the fish and also appears as pores on the head.
4. Touch and taste receptors are found in many parts of the body. Taste receptors of most fishes are located in the mouth but some fishes have touch-taste bud combinations located on their fins or on other special structures.

Fill in Table 7-9 using the information from this reading.


B

Fig. 7-10. A) Location of the lateral line along the sides and head of a fish.
B) Section of the lateral line.

Table 7-9. The sensory system of the fish.


Reproductive System
Reproduction is the process by which organisms give rise to offspring. Fishes develop when eggs from the ovaries of a female are fertilized by a sperm from the testes of a male. These eggs develop into free-swiming individuals.

Fishes have numerous ways of spawning (shedding eggs and sperm). In the ocean, most males and females simultaneously shed their eggs and sperm into the water. However, some female fish lay eggs on the bottom where the males fertilize them. 0ther fishes, including sharks and guppies, fertilize the eggs internally and the female gives birth to living young.

Several groups of fishes have caught the attention of the public because they are able to change their sex. Some of the most interesting fishes of this group are the Pacific cleaner fishes. A male cleaner fish often has harems, or groups of females which remain with him. If a male disappears from his harem, the dominant female assumes the role of the male and in a week, her ovaries become functional testes. Some of the fish which change sex also change their color patterns and behavior.

Although there are some fish that can change their sex, at any given time, the gonads (ovaries or testes) of these fish contain either eggs or sperm, not both. Therefore they cannot fertilize their own eggs.

The gonads of the fish are connected to a genital duct through which eggs or sperm pass to the outside. For a diagram of the gonads and their ducts, see Fig. 7-6.

Fill in Table $7-10$ using this reading as a guide. List both the testes and ovary.

## Table 7-10. The reproductive system of the fish.

| Reproductive System Gemerel Function | Organs | Organ Functions |
| :---: | :---: | :---: |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

## Integumentary System

The integumentary system includes the skin or epidermis, the scales, and the dermis, out of which the other two grow.

Most fishes have a covering of scales which grow out of the dermis to protect them from mechanical damage when they bump into things or fight with other fishes (Fig. 7-11). A few fish, such as catfish, have no scales.

Fishes also have pigment grains in their epidermis. Pigment grains give the fish color. Expansion or contraction of colored grains in pigment cells are controlled by hommes (see Endocrine System) and nerves.

Mucous cells are found in the epidermis of most fish. Mucus is the sticky material, like unjelled jello. It helps the fish slide through the water.


Fig. 7-11. Fish epidermis.

Fill in Table 7-11 using the information from this reading.

## Endocrine System

In addition to control by the nervous system the fish has a chemical control system called the endocrine system. The chemicals that operate in this system are called hormones. Hormones are produced in ductless glands that are built around great beds of capillaries. Hormones can pass rapidly into the capillaries and bloodstream.

Table 7-11. Parts of the integumentary system and their functions.

| Intequantiry systion General Parts | Parts | Function |
| :---: | :---: | :---: |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

Hormones can speed up body processes, slow them down or start new ones.

Common hormones perform the following kinds of functions:

1. regulate growth rate
2. regulate sex characteristics
3. regulate the capacity to respond to light and stress.

## All Systems

Figure $7-12$ is a drawing showing the internal systems of a fish. Parts of every system, except the endocrine system, are visible. Write the organ and system to which the organs listed below belong and draw an arrow from your label to the picture of that organ on the fish diagram.

| rib | blood vessels |
| :--- | :--- |
| fin support | tongue |
| skull bone | nostrils |
| gills | heart |
| intestine | muscie |

kidney ovary anus stomach backbone

## lateral line liver vertebrae air bladder pharynx



Fig. 7-12. Internal anatomy of a fish.

## References

Marshall, N.B. 1965. The life of fishes. Werdenfeld and Nicholson.

Norman, M.R. and P. Greenwood. 1963. A history of fishes. 2nd Edition London.

## 8. Dissection of a Fish

All living things are made up of one or more
cells. Groups of similar cells form tissues, such $\frac{1}{\text { as muscle and bone. Groups of tissues form organs. }}$ Body organs perform specific functions. For example, the eye is an organ in which all the different tissues operate together to provide sight. Groups of organs form systems.

Systems perform more general functions. For example, the eyes, ears, taste buds on the tongue, the smelling part of the nose, and the feeling part of the skin all make up the system that helps each of us sense the world. Each part of this system is connected by nerves to the brain. The brain is the body's control center.

In this activity, you will examine the internal anatomy of a fish. Refer to Topic 7, Internal Fish Anatomy, for information and drawings you will use as you dissect your fish.

## Activity

Examine a fish internally and identify organs of the different systems.

Compare the organs in a fish with those of a human.

## Materials - per team of 2 or 3

-1 microscope and dissecting microscope

- brepared slides of human and fish blood
-1 fresh fish
-1 probe
-1 slide
- 1 pair scissors and 1 single edged razor blade
-newspaper or dissecting tray
-pins
-1 heat source
-1 model or diagram of a human
-1 pot


## Procedure

1. Open the fish to expose its organs.
a. With razor blade or scissors make a shallow cut (avoid cutting into organs) through the skin of the belly of the fish. Start at the anus and cut toward the throat.
b. Expose the organs in the body cavity (see Fig. 8-1) by cutting the skin upward in front and back of the body cavity. Snip away this skin flap or pin the fish to a dissecting pan or newspaper.


Fig. 8-1. Exposing the internal anatomy of a fish.
2. Draw an $8^{\prime \prime}$ outline of your fish and its body cavity on a piece of $8 \frac{1}{2} \times 11$ in paper.
a. Write the fish's name and your team's names above the drawing.
b. Refer to Topic 7.
c. Draw in and label as many of the organs as you can see of each organ system listed in Topic 7. Be sure to draw the organs that you observe in your own dissected fish, not those shown in the examples in Topic 7. The organs of different fishes vary in shape, size and location.

Compare the fish's organs to those of the human body by looking at a labeled model of a human.
3. Study the digestive system.
a. Draw, label, and describe the functions of the organs listed below on your fish outline:

| stomach | teeth |
| :--- | :--- |
| $l$ liver | tongue |
| intestine | pharynx |

b. Identify and label the three kinds of body openings to the outside.
c. Cut open the stomach and remove some of the food, (if present). Put a small amount on a slide, add a drop of water and observe under the dissecting microscope. Attempt to identify the contents. Another animal, plant, or both?
d. Examine your fish's teeth. If they are small, pull or cut one or two out and view under a dissecting microscope. Draw a tooth in your notebook.
4. Study the reproductive system.
a. If your fish has well developed ovaries or testes, the ovaries will be filled with tiny pinkish or yellowish eggs or the testes will contain white fluid. Draw and label either the male or female organs on your fish outline.
b. Locate the opening through which eggs or sperm pass into the water. Draw and label.
5. Study the excretory system. Draw and label the kidney in your fish outline.
6. Study the respiratory system.
a. Remove a gill arch with its attached filaments and rakers and draw it on your diagram. Label the following:
(1) gill raker
(2) gill filament
(3) gill arch
b. Determine whether or not your fish has a gas bladder. If it is present, draw and label it on your diagram.
7. Study the circulatory system.
a. Draw the heart in your fish outline and label it.
b. Locate and draw in the fish's large blood vessels that (1) lead to the heart and
(2) that lead from the heart to the gills.
c. Obtain slides of fish and human blood from your teacher. Locate and draw a white blood cell. Draw a few red blood cells from fish and from humans in your notebook.
8. Study the muscular system.
a. Tease away some of the skin from the area near the base of the tail. Observe the muscles and silvery tendons.
b. Draw the muscle pattern near the tail on your diagram.
9. Study the skeletal system.
a. Examine the backbone and ribs. Draw in your notebook.
b. Observe the bones which support the fins.
c. Cut off the head and place it in boiling water for about five minutes. Pour off the water and let the head cool.
d. Pull back the skin, remove any muscles and fat tissue and examine the skull. Draw in the detalls on the skeletal diagram. Record which parts are hard and which are flexible.
10. Study the nervous system.
a. Carefully cut away the top of the skull and expose the brain. Locate some of the nerves leading from the brain. Draw and label.
11. Study the sensory system.
a. Remove an eyeball. Carefully cut it in half and draw and label the parts in your notebook.
b. Separate the brain from the skull. Locate and remove the inner ear stones. Draw the largest stones in your notebook.

## Summory Questions

1. What do we mean when we say an organism is made up of different systems?
2. Is your fish an herbivore ( $p$ lant eater) or a carnivore (animal eater)? How did you determine the answer?
3. Was your fish a male or female? How did you make this detemination?
4. How were the red blood cells of fish similar or different from those of humans?
5. Gill rakers belong to what system? Explain your answer.
6. Why don't bottom living fishes need gas bladders?
7. When you eat fish, what system are you eating?
8. What is the function of gill filaments?
9. Are the bones which support the fin attached to the backbone? Why or why not?
10. What sense organs do fish have that humans don't have?
11. Why does a fish, which is supported by water, need a backbone? Why are there so many bones in the backbone?
12. How does a human skeleton differ from a fish's?

## Further Investigations

1. Make mounted fish skeletons.
2. Trace the path of blood through the circulatory system and of food through the digestive system.
3. Make a list of fishes with special kinds of sensory organs.
4. Dissect several types of fishes and find out the differences between them.
5. Make a collection of scale types and otoliths or skulls of local fish species.

## References

Marshall, N.B. 1965. The life of fishes. Wedenfield and Nicholson.

Norman, M.R. and Greenwood, P. 1963. A history of fishes. 2nd Editon, London.

## 9. Fish Classification

Scientists classify and name organisms to make it easier to quickly identify them and to show relationships among them. We know most organisms by their common names.

While common names are useful, confusion may arise when speakers of different languages or even speakers from different regions of the same culture try to talk about the same organism. Here are some reasons why confusion may occur:

1. A language may contain several common names for a single organism, especially if the organism is important in some way. In Hawaiian there are 12 common names for one species of mullet which was an important food fish.
2. A language may have one common name for several similar but different organisms. In Hawaian there are only 2 common names, kikapu and lauhau, for 15 species of butterflyfish.
3. Common names differ from language to language. One species of butterflyfish is called the "racoon butterflyfish" in Hawaii, the "cross butterflyfish" in Polynesia, and the "redstriped butterflyfish" in parts of Melanesia.
4. Common names sometimes contain misleading descriptive words. "Starfish," "silverfish," and "crayfish" are not fish.

To help people all over the world to talk about any given organism, scientists have developed a

2-name, or binomial system, for identifying organisms. Speakers of al7 languages can use this system to talk with each other about organisms.

Scientific names are written in Greek or Latin with latinized endings. A scientific name includes the genus name written first with its initial letter capitalized, and the species name written second and not capitalized. For example, the scientific name of the "racoon butterflyfish" is Chaetodon lunula which may be written as you now see it with both names underlined, or it may be in italics like this without underlines, Chaetodon lunula.

When a new organism is identified, its name is entered in an international registry of organisms used by scientists worldwide. Further, a specimen of the new organism is carefully described and piaced in a museum.

Biological classification is used for placing organisms into an orderly arrangement of easily identifiable groups. The basic unit in biological classification is the species. A species is defined as a group of organisms that can breed and produce fertile offspring. Members of each species share the same features. Two or more species which cannot produce fertile offspring but which have somewhat similar features are grouped together to form a genus. Genera (plural of genus) are grouped together to form a family. Groups of families form an order, groups of orders form a class, groups of classes form a phylum and, finally, groups of phyla form a kingdom. The characteristics of a kingdom are common to all organisms in that kingdom. The organisms making up a species have all the characteristics of their kingdom, phylum, class, order, family, and genus, but they also have features that are unique to the species.

The "racoon butterflyfish" is classified as follows:

| Kingdom. | Animal |
| :---: | :---: |
| Phylum. | . Chordata |
| Class | .Osteichthys |
| Order. | . Perciformes |
| Family. | . Chaetodontidae |
| Genus. | .Chaetodon |
| Species | lunula |

Normally, easily seen external features like hair or scales are used in classification. Sometimes, not easily seen features of internal anatomy need to be used. For example, the presence or absence of a cavity around the gut is a classification feature for worms.

## Activity A

Identify species of butterflyfish using a classification key.

## Background

There are over two million named species of organisms and probably hundreds of thousands of them yet to be named. To distinguish one organism from another, modern biologists place them in a classification system of easily recognizable groupings of similar organisms and make keys so that these organisms may be identified. A key helps us to quickly sort through organism descriptions until we find one that matches the organism we wish to identify.

The following key, Fig. 9-1, in the form of a diagram shows different descriptions to identify vertebrates (backboned animals) that live in the ocean around the Hawaiian Islands.


Fig. 9-1. Key to Hawailan oceanic vertebrates.

Look at the first branch point. If one animal has gills it is a fish or a shark. If it has lungs it is a turtle, seal, porpoise or whale.
Now look at the second branch point above gills. If it has only one gill opening it is a fish. If it has more it is a shark. We would have to make a more refined key if we were to find the scientific names of a particular fish or shark.

## Procedure

1. Use the butterflyfish key (Table 9-1) to identify the butterflyfishes shown in Fig. $9-2$. In the following explanation, one butterflyfish (C) will be keyed out.
a. Find fish (C) in Fig. 9-2.
b. The key is divided into a series of alternative choices. Look at the two statements made describing one characteristic of fish at \#1 and decide which fits the picture of fish. "Pelvic fin dark" is the correct description for fish $\mathcal{C}$.
c. Refer to the number on the right side of the page opposite this statement under cross reference. It is 2 .
d. Go on to description $\# 2$ and decide which statement best describes fish C. The second statement, "Lacks the two large white subdorsal spots" is the correct choice.
e. Follow the directions under cross reference and go to \#3. Again select the proper description. Of the two choices there, "Tail with one dark bar at tip" is the correct choice. With description \#3 we have identified the organism and its name appears. It is Chaetodon kleint.
2. Record the name of your fish below its picture in Fig. 9-2.
3. Pick another fish and follow the same identification procedure. Write its name below its picture in Fig. 9-2. Do the same for all the fish shown.

## Further Investigations

1. Make a key that will allow anyone to quickly identify each person in your lab class.
2. Make a key to the trees around your school.
3. Find a published key to a group of organisms that you are interested in and see if you can identify some species within that group.

## Activity B

Identify fishes to the family level.

Iable 9-1 Key to the butterflyfishes of the genus Chaetndor

1. Pelvic fin dark Pelvic fin light 2
4

2 (1) Jwo large white spots below dorsal fin $\ldots \ldots \ldots \ldots \ldots \ldots .$.
$\qquad$
3 (2) Tafl with two dark bars at tip $\frac{\text { C. }}{\text { Ceticulatus }}$

4 (1) Posterior or dorsal fin has long filament extension $\qquad$ $\begin{array}{ll}\cdots & 5 \\ \cdots & 6\end{array}$
5 (4) Spot on body half body length Spot on body only twice the size of eye C. ephippium

6 (4) No vertical band through eye $\qquad$
7 (6) Incomplete eyeband on face $\qquad$ C. $\frac{\text { multcinctus }}{8}$

8 (7) Mose area with band 9 Nose ared lacks band 10

9(8) Eyeband split $\qquad$ C. oratissimus Eyeband not split C. Erlfasclatus

10 (8) Eyeband split. $\qquad$ C. Inneolatus Eyeband not split $\qquad$ At least $1 / 3$ of side darkly pigmented $\qquad$ 12
13

12(1) No black band on caudal fin Obvious black band at base of caudal fin $\frac{\text { C. }}{\text { citrinellus }}$ Approximately $1 / 3$ of side darkly plgmented ted .. Amost entire side darkly pigmented
$\qquad$ $\frac{C}{C}$. $\frac{\text { unimaculatus }}{\text { tinkeri }}$ Side with a large black teardrop
Side wth a slanting black region $\qquad$ C. Bunuta

$\mathbf{w}$

## Background

There are over 700 fish species in Hawaii. If you had one of these fishes and wanted to know something about it, how would you find out?

One of the easiest ways is to identify the family to which the fish belongs. The pictoral key in Fig. $9-3$ includes the 40 families to which the most common fishes belong.

If you compare your fish with the drawings and descriptions in this key, you can match your fish with a family name. Then you can use a more detailed fish book to find out what species you have and something about it. This saves you from having to look at 700 individual pictures.

Using the sub-keys on the first page of the key further reduces the amount of time you have to spend looking for your fish. The 40 families are divided up into 4 different sub-keys based on what the pelvic and dorsal fins of your fishes look like.

## Materials

```
-tagged fishes (fresh or preserved)
-dissecting pan or newspapers
-simplified key to Hawaiian Fish Families
    (Fig. 9-3)
```


## Procedure

1. Obtain a fish and the key.
2. Find which sub-key applies to your fish and turn to that section of the key.
3. Identify your fish with the key. Put the family name in Table 9-2 with its tag number.

Table 9-2. Family of fishes.

4. Repeat Procedures 1-3 and identify as many fishes as you can.

## Summary Questions

1. Which features should be used when constructing a key for a group of animals or plants?
2. Why is it important to classify organisms?
3. List the rules to be followed when writing scientific names of organisms.
4. If you were to make a dichotomous (two choice or branching) key for another group of organisms, what rules would you follow? Review the present key.
5. Starting with your own description, construct your own key for the 15 butterflyfishes in Fig. 9-2.
6. Using your fish family key, name a fish family:
a. with scutes on the caudal peduncle.
b. without a pectoral fin.
c. with sharp spines over body surface.
d. with a medial caudal filament.
e. with spine(s) on the operculum or cheek.
f. with pelvics fused into a suction cup.
g. with the lower jaw longer than the upper jaw.
h. with a tubular snout.
i. with finlets.
j. with a blade on the caudal peduncle.
7. How many families with more than five pelvic fin rays are included in the key?
8. In the key, how does:
a. a white eel differ from a moray eel?
b. a triggerfish differ from a filefish?
c. a wrasse differ from a parrotfish?
9. How many dorsal fins do the following have?
a. mullet
b. awa awa
c. butterflyfish
d. triggerfish
e. porcupinefish
10. Name 3 fish families with caudal fins that
are:
a. truncate
b. forked

## Further Investigations

1. Write your own key to a group of fishes found in local tide pools, or reef. Use references Gosline and Brock, or Tinker, to identify your fishes to species.
2. Identify the fish sold/found in your local fish markets. Find out about their habits.

## References

Goodson, G. 1972. The many-splendored fishes of Hawaii. Marquest color guide books.

Gosline, W.A. and V.E. Brock. 1960. Handbook of Hawaiian fishes. University of Hawaii Press. Hawaii.

Hobson, E.S. and E.H. Chave. 1972. Hawaiian reef animals. University of Hawaii Press, Hawaii.

Tinker, S. 1979. Hawaiian fishes. Hawaiian Seryice Press.

## Fig. 9-3. Simplified key to Hawaian fish families.

(Hodified from Hawailan Fishes, by W.A. Gosline and V.E. Brocik.)

1. Eyes on either side of head. $\qquad$
Eyes on one side of head. Flatfish. [Paku]. BOTHlOAE.

2. No ture in front of spines on head. (subkeys) Lure in front of spines on head, pared fins hand-like. Anglerfish. ANTEMHARI IDAE.


Sub-Key A
Pelvic fins absent.
Sub-Key B
Pelvic fins with more than 5 soft rays.
Sub-Key C
Pelvic fins with 5 or fewer soft rays. Dorsal fins composed of 2 or more completely separated parts.
Sub-Key D
Pelvic fins with 5 or fewer soft rays. A single dorsal fin which may be somewhat divided, but section one is connected wasally to section two.

## 

1. Caudal fin present

Wo caudal fin
Body eel-like. Pectoral fin present. White eel. [Puht uha]. COHGRIDAE


Pectoral fins absent, Moray eel. [Puhi]. muraemidaE.


2 (1) Single dorsal........................................................................................ 3
Two separated dorsals
First dorsal composed of only one large spine. Filefish. [0'111]. MOHACANTHIDAE.


First dorsal composed of two or more splnes. Triggerfish. [Humu]. galistidae.


3 (2) Body inflatable.
Body enclosed in non-inflatable bony box. Trumkftsh. [Pahu]. OSTRACIONTIDAE

(3) Body not spiny.

Splny body. Porcuptnefish. [0'opu]. DLODONTIBAE.


5 (4) Erect flap on nose. Balloonfish. [0'opu]. tetradomitidae.


Without erect flap on nose. Sharp-back puffer. CAMthigastiridaE.


## SUB-KEY B

## Pelvic fins with mare than 5 soft rays

1. Ho spines in anal fin

One or more spines in front of the anal fin. Squifrelfish. [Ala'ith]. holocemtridat.


2 (1) Without adipose fin
With adipose fin. Lizardfysh [Ulae]. SyHODOMTIDAE.

3 (2) Snout not tubular
Snout tubular, tail with medium filament. Cornetfish. Fistularilidag.


Sneut tubular with a barbel, tall without a median flament. Trumpetfish. [Munu]. AuLOŚroridak.


4 (3) Lateral line obvious
Mo lateral line, snout overhangs lower Jaw. Anchovy. [Mehu] EMGRALIDAE.


5 (4) Mouth does not extend behind eye
Mouth long, extending behind eye. Ladyfish. [Awa "aws]. ELOPloAf.


6 (5) Snout overhands lower jaw. Bonefish. [0'fo]. ARBULIDAE


Snowt and Jaw equal. Nilkfish. [mal]. Chamidaie.


## SuB-KEY C

Dorsal fins composed of 2 or more completely separated parts.

1. Pectoral fins not winglike.

Pectoral fin wing-like; head completely anmored. Flying Gumard. [LOLO]: DACTYLOPTERIDAE.


2 (i) Pelvic fins separate.
Two pelvic fins fused to one another to form a sucking disc. Coby [0'opu]. coblidie.


3 (2) Pectoral fin without threads. ... 4
Base of pettoral fin divided into several thread-like rays. Threadfin, [moi]. Polywenipaz.


4 (3) Mo finlets or separated anal splne.
Two spines separate from the anal fin or fins followed by 1 to several finlets. Anal fin preceded by two spines. Scutes on caudal peduncle of many Jacks. [Akule, Ulua, lae]. caramgidae.


Anal fin not preceded by two spines. Tuna. [Ahf. Aku]. SCOMPRIDAE.


5 (4) Two dorsal fins $\qquad$
Three dorsal fins. False blemy. TRIPTERYgILDAE.


6 (5) Mo barbels on chin
A patr of barbels on chin. Goatfish. [Weke, Kum, etc.]. MULLIDAE.


7 (6) Pelvic fins behind pectoral fin base.
Pelvic fins below or in front of the pectoral base. Cardinalfish. [Upapalu]. APOGOWIOME.


8 (7) Lateral 1 ine absent, teeth small $\qquad$
Lateral line present, teeth large. Barracuda. [Kaku]. Sphyraenidae.


9 (8) Anal fin with about 17 soft rays. Silverside. [fac]. Atherinidae.


Anal fin with aboul 10 soft rays. Multet. [Ama 'ama]. mugilidaf.


## Stho-KEY 0

A single dorsal fin which maybe somevhat divided, but section one is connected basally to section two.

1. Body scales.

Body scaletess. Blenny. [Puo'o]. BLENNIDAE.


2(1) 6111 openings reach under throat
6111 openings not reaching throat (only on sides of head). One or two pairs with blades on the caudal peduncle. Surgeonfish. [Tangs, Kala, Manlini, Patani, etc.]. ACANTHURIDAE.


Blades lacking: first few dorsal spines greatly elongated. Moorish Idol. Blades lacking inirst fer
[Kihikihi]. ZACLIDAE.

$\qquad$
3(2) Spiny ridge not running horizontally across cheek.
Spiny ridge running horizontally across cheek. [Mohy, turkeyfish, ett.]. SCORPAEMIDAE.

4 (3) Branched caudal rave, 14 or more $\qquad$
Two front teeth protruding and separated. Wrasse. [Hinalea]. LABRIDAE.


Teeth fused into beak or with two to several overlapping fused rows Teeth fused into beak or with two to several over
of front teeth. Parrotfish. [Un]. SCARIDME.
......................

5 (4) Anal fin with 3 spines
Anal fin with 2 spines. Damselfish. [Kupipl, Macaco, etc.]. POMACENTRIDAE.

$$
1
$$

6 (5) Sides never platri silvery.
en ex ex Sides plain, silvery. Flagtail. [Amolehole]. RUHLIIDAE.


7 (6) Mouth moderate to large; body depth no more than $1 / 2$ the body length. . 8 Mouth small; body about as deep as long. Dorsal with 12 or more spines. Butterfiyfish. [xikakapa, las tau]. CHAETOOONTIOAE.


Dorsal with 11 spines
Stripey. SCORPIDIDAE.


8 (7) Anal rays 14 or more. Bigeye. [Aweoweo]. PRIACANTH]DAE,


Anal soft rays 12 or less. snapper. [Tape]. LUTJAMIDAE.


## CHAPTER 3

## PHYSICAL PROPERTIES OF WATER

It is the unique properties of water that make life on this planet possible. What would happen to fish in a pond if ice did not float? Few other solid compounds float in their own liquid form. What would happen to fish in the pond if water dissolved only a small amount of gasses?

Think of these and other questions as you do the activities in this chapter. Water is so much a part of the earth's environment that we need to study it specially. In the following series of investigations we will look closely at its special properties.


## 1. Characteristics of Water and Other Liquids

Looking at a picture of earth from space, one is struck by the amount of the total surface that is covered by water. In the oceans and lakes we have liquid water; around the poles, ice; and in the atmosphere, clouds. But what are the characteristics of this substance called water? In a series of laboratory investigations we will attempt to observe and identify some of these properties.

## Activity

Test some of the properties of water.

## Procedure

1. Go to each of your assigned stations and do the following:
a. Perform the operations indicated on the procedure card.
b. Record the observations in your notebook.
2. Put the station back in the same order it was before you used the equipment. When instructed, go to the next station.

## Summary Questions

1. What is meant by the phrase, "properties of water?"
2. What properties of water might account for each of your observations?
3. Which observations, if any, might be explained by the same properties?
4. Which of your observations can't you explain?

## 2. Gases in water

Dissolved gases make it possible for fish and other organisms to live in water. For example, we know that enough oxygen will be dissolved in water that has been stored at room temperature for several days to support aquatic life, at least temporarily.

But what would happen if the temperature of the water were increased or decreased? Is the same amount of dissolved oxygen in cold as in hot water? In salt water as in fresh water? Fresh water is water with such low content of minerals that we cannot taste it. Salt water has sufficient dissolved minerals to taste salty.

## Activity

Determine the effect of temperature on the volume of gas dissolved in water taken from a freshwater aquarium and from a saltwater aquarium.

## Materials

-1 250 ml Erlenmeyer flask with solid stopper
-1 250 ml beaker
-165 mm diameter funnel with 5 cm of clear plastic hose attached

- 1 strong pinch clamp
-1 5 ml syringe
-150 ml syringe
-1 thermometer ( -10 to $110^{\circ} \mathrm{C}$ )
-l system for heating beaker and contents
-fee
- aquarium fresh water (shaken)
-aquarium salt water (shaken)
-narrow strip masking tape (3-4 mm wide)
- 1 container in which to cool beaker (bucket
or a gallon can of water)
-felt pen, fine tipped


## Procedure

1. Assemble and calibrate a funnel gas collection device following the steps shown in Fig. 2-1.


Fig. 2-1. Calibrating a funnel gas collection device.

Step a Slip a piece of plastic hose over the end of the funnel stem.

Apply a strong pinch clamp as close to the end of the funnel stem as possible to tightly seal it off.

Mark the location of the clamp with a fine-tip felt pen so the clamp can be removed and returned to the same place.

Run a narrow strip of masking tape from the point where the clamp is attached to the rim of a funnel.

Step b Using a 5 ml syringe, add water in 0.2 ml increments into the funnel stem.

With the felt pen, mark each increment on the masking tape. Before marking an increment, gently tap funnel to remove any air bubbles in stem.

When the stem is filled, add water in 5 ml increments to fill funnel cone. Mark each 5 ml increment on the masking tape.

Record the volume of funnel in Tables 2-1 and 2-2.

Table 2-1. Volume of gas collected upon heating freshwater.


Table 2-2. Volume of gas collected upon heating seawater.

| Yecsurenents |  | $\begin{aligned} & \text { Aoom Tenp } 125^{\circ} \mathrm{C} \\ & \text { Aerated } \end{aligned}$ |  | $\begin{aligned} & 5^{\prime} r^{\prime} \\ & \text { enteo } \end{aligned}$ | Rocon !emp Non-heratici |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Fotal tolume of ater (in sume) |  |  |  |  |  |
| 2. Starcing Temperature |  |  |  |  |  |
| 3. Hignest |  |  |  |  |  |
| 4. volume of Gas in furne |  |  |  |  |  |
| c. Volume of Gas par rit of brquid n 5unnal -4 : 1 |  |  |  |  |  |

Step $c$ Use a metric rule to divide each 0.2 ml increment on funnel stem into 4 equal intervals of 0.05 ml each. Mark these on masking tape with felt pen.
2. Determine the volume of gas in different samples of aerated, ice cold water. Run one series using fresh water (Table 2-1) and a second using salt water (Table 2-2). Follow the steps below and in Fig. 2-2 to do this experiment. Do not do Step c for this part of the experiment.

NOTE: These steps will also be used in Procedures $3,4,5$, and 6 .

Step a Pour 100 ml of water into a 250 ml Erlenmeyer flask.

Add about 50 g of crushed ice. Use freshwater ice with fresh water and saltwater tce with salt water.

Step b Stopper the flask.
Shake flask vigorously until all ice is melted. Doing this ensures the water has a maximum amount of gas dissolved in it at the start of the experiment.

Step c (This step is only used in Procedures 4 and 5.)

Heat the aerated water to $50^{\circ} \mathrm{C}$; then cool to room temperature, about $25^{\circ} \mathrm{C}$, using an ice bath.

Step d Pour water from flask into 250 ml beaker.

Step e Measure water temperature and record in Table 2-1 or 2-2 as starting temperature.

Step f Place funnel gas collection device upside down into the beaker

Step $g$ Attach a 50 m ] syringe and remove clamp.
Draw enough water to fill funnel and syringe.

Replace clamp and remove syringe.
Step h Place beaker and gas collection system on a heat source.

Heat to $90^{\circ} \mathrm{C}$, or until there is a sudden increase in gas volume.

Using a towel, remove beaker immediately from heat source.
Fig. 2-2. Determining the volume of gas in different water samples.

If gas escapes from under the funnel, repeat this step.

Step i Place beaker and gas collection system into a cooling bath.
Cool liquid and gas to room temperature.

Measure the volume of any gas produced and record the volume to the nearest 0.05 ml on Table 2-1 or 2-2. Before measuring, gently tap funnel until all gas bubbles are collected in the upper part of funnel stem.
3. Determine the volume of gas in an aerated water sample (fresh or salt) with a starting room temperature, or about $25^{\circ} \mathrm{C}$.

Pour 150 ml of room temperature water into a 250 ml Erlenmeyer flask.

Stopper the flask and shake vigorously for 2 minutes. Remove stopper.

Carry out Steps d to $\mathfrak{i}$ in Procedure 2. Record data in Fig. 2-2.
4. Determine the volume of gas in an aerated water sample (fresh or salt) with a starting temperature of $50^{\circ} \mathrm{C}$.

Pour 150 ml of water into a 250 ml Erlenmeyer flask.

Stopper the flask and shake vigorously for 2 minutes. Remove stopper.

Carry out Steps c to i in Procedure 2. Record data in Fig. 2-2.
5. Determine the volume of gas in an aerated water sample (fresh or salt) with a starting temperature of $75^{\circ} \mathrm{C}$.

Poor 150 ml of water into a 250 ml Erlenmeyer flask.

Stopper the flask and shake vigorously for 2 minutes. Remove stopper.

Carry out Steps c to $i$ in Procedure 2 and Fig. 2-2, except heat the water to $75^{\circ} \mathrm{C}$ in Step c instead of $50^{\circ} \mathrm{C}$.

After carrying out these steps, save cooled water sample for Procedure 6.
6. Determine the volume of gas in a nonaerated water water sample (fresh or salt) previously heated to $90^{\circ} \mathrm{C}$. Use the water sample from Procedure 5 after it has been cooled to $25^{\circ} \mathrm{C}$.

Carry out Steps $d$ to $i$ in Procedure 2 and Fig. 2-2.

## Summary Questions

1. Calculate the volume of dissolved gas/ 100 ml of Tiquid in funnel for both fresh water (Table 2-1) and salt water (Table 2-2).
$\frac{\text { Volume of gas }}{100 \mathrm{mT} \text { Tiquid }}=\frac{\text { Volume of gas }}{\text { Volume of } 1 \text { iquid }} \times \frac{100}{100}$
in funnel
2. Graph the aeration data from Table 2-1
(fresh water). Display the starting temp: eratures $\left(0^{\circ} \mathrm{C}, 25^{\circ} \mathrm{C}, 50^{\circ} \mathrm{C}, 75^{\circ} \mathrm{C}\right)$ on the
horizontal axis and gas volume per 100 ml of liquid on the vertical axis. Make a separate graph for the salt water data recorded in Table 2-2.
3. What happens to the amount of gas dissolved in fresh water as the starting temperature increases? In salt water?
4. At what starting temperature is the most gas dissolved in fresh water? In salt water?
5. At what temperature would you expect no gas to be dissolved in fresh water? In salt water?
6. Why was the water heated to $90^{\circ} \mathrm{C}$ or until gas formed rapidly? Why not $100^{\circ} \mathrm{C}$ ?
7. What is the role of aeration (shaking the flask) in the investigation?
8. What gas or gases has this investigation dealt with? Explain your answer.
9. What would be the total volume of gas recovered from one liter of ice cold freshwater? Of ice cold salt water?

## 3. Dissolved Gas and Daphnig

In this activity we will investigate the ability of the fresh water organism called a Daphnia to survive in water samples with varying amounts of dissolved gas. The amount of gas will be controlled by heating.

## Activity

Test whether or not the amount of dissolved gas in water affects the activity of an organism.

## Materials - per team

-1 100 ml beaker
-1 250 ml beaker
-520 ml test tubes

- 1 test tube rack
-1 250 ml Erlenmeyer Flask and stopper
-1 thermometer
- 100 ml graduated cylinder
-1 system for heating beaker and contents
-4 rubber bands (sma11)
-live Daphnia (about 25)
-ice
- tap water
-plastic wrap
-marking pen or labels (4)


## Procedure

Procedures 1 and 2 involve preparing water samples and test tube environments. Using teamwork, these procedures should be done together. Read the procedures before starting.

1. Prepare four water samples with varying amounts of dissolved gas. Follow the steps below (also shown in Fig. 3-1).

stepa

step $b$

stepc
temperature, about 250 C (Fig. 3-1, a-d). Pour sample into test tube \#2. Discard excess water in beaker.
c. $75^{\circ}$ C water sample

Repeat procedure for preparing $50^{\circ} \mathrm{C}$ sample, except heat water to $75^{\circ} \mathrm{C}$ (Fia. 3-1 a-d). Pour cooled water sample into test tube \#3. Discard excess water in beaker.
d. $90^{\circ} \mathrm{C}$ water sample

Repeat procedure for preparing $50^{\circ} \mathrm{C}$ sample, except heat water to $75^{\circ} \mathrm{C}$ (Fig. 3-1, a-d). Pour cooled water sample into test tube \# 4. Discard excess water in beaker.
2. Prepare four experimental test tube environments.
a. While water samples are being prepared, put 5 heal thy Daphnis and about 1 ml of their aquarium water into each of four test tubes labeled \#1, 2, 3, and 4. If a Daphnia is killed in the transfer, do not remove it. Simply add another one to take its place (Fig. 3-2, a).
b. Pour water samples into test tubes (Fig. 3-2, b).
c. After the Daphnia and water samples have been added to each test tube, cover the tubes with plastic wrap. Make sure there are no air bubbles in any of the test tubes. If a bubble appears, add more water from the appropriate sample and cover the test tube again. Secure the plastic wrap with rubber bands (Fig. 3-2, c).


Fig. 3-2. Pouring daphnia into test tubes.
3. Observe the swimming behavior of Daphnia until the end of the class period. Compare with behavior of control Daphnia (room temperature) in test tube \#1. Describe differences in your notebook. Record number of active Daphnia every 5 minutes in Table 3-1.

Table 3-1. Number of active Daphnia in test tube.

| Temperature <br> of water before <br> cooling to $25^{\circ}$ | Time |  |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  | $0^{\prime}$ | $5^{\prime}$ | $10^{\prime}$ | $15^{\prime}$ | $20^{\prime}$ | $25^{\prime}\{24 \mathrm{hrs}$. |
| Room (250) |  |  |  |  |  |  |
| $50^{\circ}$ |  |  |  |  |  | $\{$ |
| $75^{\circ}$ |  |  |  |  |  | $\{$ |
| $90^{\circ}$ |  |  |  |  |  |  |

4. Allow the test tubes to sit overnight ( 24 hrs .) and record number of active Daphnia in Table 3-1.
5. Calculate the percentage of swimaing Daphnia for each time period.
number of swimming Daphnia
\% Swimming $=$ at time of measurement Daphnia $=\frac{\text { number of swimming Daphnia }}{\text { na }}$ at start
6. Make a bar graph of the Daphnia activity as related to the amount of dissolved gas as controlled by temperature. Show the time on the horizontal axis and percent of active Daphnia on the vertical axis. If 5 Daphnia are active, there will be $100 \%$ activity. If 4 Daphnia are active, $80 \%, 3$ Daphnia; $60 \%$, etc. Use a different color to represent each temperature ( $25^{\circ} \mathrm{C}, 50^{\circ} \mathrm{C}, 75^{\circ} \mathrm{C}, 90^{\circ} \mathrm{C}$ ) treatment.

## Summary Questions

1. What happens to the activity of Daphnia in the test tubes where water was subject to different temperatures?
a. During the first class period of observation.
b. After 24 hours.
2. What was the role of heating the water in this investigation?
3. What role did the plastic wrap play in the investigation?
4. Compare data on Daphnia with data collected on gases (Topic 2, Question 2). What relationship, if any, might exist between \% activity and dissolved gas?

## Discussion of Topics 2 and 3

The principal components of air and their percentage composition by volume in sea water are shown in Tables 3-2 and 3-3.

The relative amounts of dissolved oxygen and nitrogen in fresh water and seawater are shown in Figures 3-3 and 3-4.

The principal gases dissolved in seawater and each percentage composition by volume are shown in Table 3-2.

Table 3-2. \% composition of gases and air by volume.

| Nitrogen | $78.1 \%$ |
| :--- | ---: |
| Oxygen | $20.9 \%$ |
| Argon | $.9 \%$ |
| Other | $.1 \%$ |

Table 3-3. \% composition of gases in sea water by volume.

| Witrogen | $55 \%$ |
| :--- | ---: |
| Oxygen | $36 \%$ |
| Carbon Dioxide | $8 \%$ |
| Other | $1 \%$ |



Fig. 3-3. Oxygen and nitrogen dissolved in sea water.


Fig. 3-4. Oxygen and nitrogen dissolved in fresh water.

Based on the these data, answer the following:

1. How does the concentration of gases in air compare with the concentration of the same gases in seawater? In fresh water?
2. How do the concentrations of the gases, nitrogen and oxygen, compare in seawater and fresh water?
3. Estimate the expected nitrogen and oxygen content in seawater in Hawaii (average water temperature $25^{\circ} \mathrm{C}$ ), New York ( $20^{\circ} \mathrm{C}$ ), Los Angeles ( $15^{\circ} \mathrm{C}$ ), Portland, Oregon ( $10^{\circ} \mathrm{C}$ ), and Antarctica ( -10 C ).
4. Would temperature change have a greater effect on fresh- or saltwater organisms? Explain your reasoning.
5. Suggest a reason for aerating aquarium water. Explain your answer using information gathered on the gas content of water that had previously been heated.
6. Suggest circumstances where aquarium water would not have to be aerated.

## 4. Floating and Sinking

To anyone using a boat, it is important to know how much mass the boat will carry before it sinks. In this topic, we will try to find out how to predict the maximum amount of mass a boat will hold before sinking. To do this, we need to review the meaning of several terms.

MATTER is anything that has the properties of mass and volume. Objects are examples of matter.

MASS is a measure of the amount of matter in a body. We measure mass on a balance. The basic unit of mass is the gram. One cubic centimeter of pure water at $4^{\circ} \mathrm{C}$, has a mass of 1 gram .

VOLUME is a measure of the space an object takes up. We measure volume of liquids using a graduated cylinder. We can also calculate the volume of geometric solids. The basic units of volume are the milliliter (ml) and the cubic centimeter ( $\mathrm{cm}^{3}$ ). One cubic centimeter equals one milliliter, $1 \mathrm{~cm}^{3}=1 \mathrm{ml}$.

DENSITY is a measure of the amount of matter (mass) in a given volume of an object. We measure the density of an object as the number of grams of matter in $1 \mathrm{~cm}^{3}$ or 1 ml , of its volume. We use a formula:

$$
\text { Density }=\frac{\text { mass }}{\text { votume }}
$$

Pure water at $4^{\circ} \mathrm{C}$, for example, has a density of $1 \mathrm{~g} / \mathrm{cm}^{3}$ or $1 \mathrm{~g} / \mathrm{ml}$. Seawater has an average density of $1.027 \mathrm{~g} / \mathrm{ml}$. Iron has a density of $7.86 \mathrm{~g} / \mathrm{cm}^{3}$; common woods have densities that vary from $.12 \mathrm{~g} / \mathrm{cm}^{3}$ for balsa wood to $1.07 \mathrm{~g} / \mathrm{cm}^{3}$ for iron wood.

DISPLACED LIQUID is the liquid pushed out of the way when objects are put into that liquid.

FORCE is a push or a pull. Though there are several units of force, we will use the gram force (gf) and the kilogram force (kgf). One gf is the force of gravity acting on one gram of matter measured at sea level, while 1 kgf is the force of gravity acting on one kg or 1000 g at sea level.

MOVEMENT of an object is produced when an unbalanced force acts on an object. The direction of movement is in the direction of the unbalanced force.
STATIONARY OBJECTS on earth have equal and opposite forces (batanced forces) resisting all pushes or pulls on them.

BUOYANCY is an upward force exerted by water which tends to make objects float. Buoyancy opposes the force of gravity, which tends to sink objects.

## Activity

Test the conditions in which an object floats or sinks in fresh water and salt water.

## Materiols

-l plastic cup<br>- 1 large container in which to float cup<br>- 110 ml graduated cylinder<br>-tap water<br>-salt water<br>-unknown object<br>-balance<br>-toweling

## Procedure

1. Take measurements on a cup filled with tap water that just floats in tap water. Record all data in Column $A$, Table 4-1.
a. Fill the large container with enough tap water so that a plastic cup can completely sink in it. See Fig. 4-la.

Place an empty plastic cup into the water in the container and remove all air bubbles beneath the cup.


Fig. 4-1. Cup in container.
b. Use a graduated cylinder and add measured quantities of tap water to the cup until it just barely floats. See Fig. Ib. Record the volume of water used in Table 4-1. Make all volume measurements to read to 0.1 ml .
c. Remove the cup and dry it on the outside. Measure and record the mass of the cup and water in Table 4-1. Keep the balance dry. Mark all mass measurements to read to 0.1 g .
d. Determine the approximate mass and the volume of the water displaced by the cup filled with tap water.
2. Take measurements on a cup filled with salt water when placed in tap water. Record all data in Column B, Table 4-1.
a. Fill the cup to the rim with salt water. Weigh the cup and contents and record in Table 4-1.
b. Predict whether the cup and contents will float or sink in tap water. Circle $F$ for float or $S$ for sink in Table 4-1.
c. Test your prediction. Record whether it floats or sinks in Table 4-1. Be sure there are no gas bubbles beneath the cup.
d. Determine the mass and volume of the water displaced by the cup. Record in Table 4-1.
3. Take measurements on a cup filled with salt water when placed in salt water. Record all data in Column $C$ of Table 4-1.
a. Fill a large container with enough salt water so that a cup will completely sink in it as in Procedure la.
b. Follow procedure 2a-2d and test whether the cup filled with salt water floats in salt water.
4. Take measurements on a cup filled with tap water when placed in salt water. Record all data in Column D, Table 4-1.

Follow procedures $2 a-2 d$ and test whether a cup filled with tap water floats in salt. water.
5. If time allows, get an object from your teacher. Make whatever measurements are necessary to predict whether the cup, when holding the object, will float or sink when placed in salt water. Test your prediction. Record in Column E, Table 4-1.
6. Complete the calculations required in Table 4-1.

Table 4-1. Data on floating and sinking,


## Summary Questions

1. What assumptions are made in determining the mass and volume of tap water and salt water displaced by the cup and its contents?
2. What effect might the mass and volume of the cup have on a more exact measurement of the density of salt water and tap water? How are the mass and volume of the cup dealt with in this investigation?
3. Show the relationship between the force of gravity and the buoyancy force acting on the cup. Use the symbols from Table 4-2 to show the relationship between the forces in Tables 4-3 to 4-5.
4. Show the relationship between the density of the cup and contents and the density of the supporting liquid in Tables 4-6 to 4-8. Use symbols from Table 4-2.
5. Show the relationship between the volume of the cup and its mass, and the volume of the liquid displaced and its mass. Use the symbols given in Table 4-2 in Tables 4-9 to 4-11.

Table 4-2. Mathematic symbols.

| $a=b$ | $a$ equals $b$ |
| :--- | :--- |
| $a>b$ | $a$ greater than $b$ |
| $a<b$ | $a$ less than $b$ |

Table 4-3. Object fleats at surface.


Table 4-4. Object sinks.

| Relationship |  |
| :--- | :--- |
| Gravitationa <br> Force of <br> Object <br> Pushing Down | Buoyancy <br> Force of <br> Pushing <br> Up |

Table 4-5. Object floats above surface.


Table 4-6. Object floats at surface.


Table 4-7. Object sinks.


Table 4-8. Object floats above surface.


Table 4-9. Object floats at surface.

|  | Relationship |
| :--- | :--- |
| Volume of <br> Object | Volume of <br> Displaced <br> Liquid |
| Mass of <br> Object | Mass of <br> Displaced <br> Liquid |



Table 4-10. Object sinks.


Table 4-11. Object floats above surface.

|  | Relationship |  |
| :--- | :--- | :--- |
| Volume of <br> Object | Volume of <br> Displaced <br> Liquid |  |
| Mass of <br> Object | Mass of <br> Displaced <br> Liquid | $w$ |

6. The density of sea water in a certain region is $1.02 \mathrm{~g} / \mathrm{ml}$. From the investigation above, fill in the statements.
a. A water soaked log that just floats so that it is just seen at the surface will have a density that is $\qquad$ ( $=>$ ) $1.02 \mathrm{~g} / \mathrm{ml}$.
b. A boat that sinks so the bottom will have a density $\qquad$ $(=><) 1.02 \mathrm{~g} / \mathrm{ml}$.
c. A boat that floats high above the surface of the liquid has a density $\qquad$ ( $=>\ll 1.32 \mathrm{~g} / \mathrm{ml}$.
d. A $10,000 \mathrm{~kg}$ vessel that floats in the liquid displaces $\qquad$ kg of liquid.
e. A $10,000 \mathrm{~kg}$ object that sinks will displace a mass of liquid $\qquad$ $(=><) 10,000 \mathrm{~kg}$.
f. An object that floats above the surface will have a volume $\qquad$ ( $=><$ ) the volume of the liquid displaced.
g. An object that just floats will have a volume $(=><)$ the volume of the liquid displaced.
h. An object that sinks will have a volume ( $=><$ ) the volume of the liquid displaced.
i. A $10,000 \mathrm{~kg}$ object that floats in the liquid has a gravitational force of
$\qquad$
j. A $10,000 \mathrm{~kg}$ object that floats in the liquid is supported by a buoyant force of
$\qquad$ kgf.
7. A 10 g object sinks to the bottom of a fresh water lake (water density $1.0 \mathrm{~g} / \mathrm{ml}$ ). From the investigation above fill in the statements below. Include all units.
a. The volume of the object is $\qquad$ $(=><) 10 \mathrm{ml}$.
b. The buoyant force is $\qquad$ $(=><)$ 10 gf .
c. The density of the object is $\qquad$ ( $=><$ ) $1.0 \mathrm{~g} / \mathrm{ml}$.
d. If the volume of the object were 5 ml the buoyant force would be $\qquad$ .
e. If the volume of the object were 5 ml the unbalanced gravitational force tending to sink the object would be $\qquad$ .
f. If the volume of the object were 5 ml its density would be $\qquad$ -
g. If the volume of the object were 5 ml it would displace $\qquad$ of 1 iquid.
8. How would you determine the maximum amount of mass a boat can carry before it will sink?
9. Under what conditions will a boat float in fresh water? (Density $1.0 \mathrm{~g} / \mathrm{ml}$ ) Use the density of water in your explanation.
10. Under what conditions will a boat float in salt water? Use the density of seawater, $1.027 \mathrm{~g} / \mathrm{ml}$, in your explanation.

## 5. Making and Standardizing a Hydrometer

A common device for measuring the density of liquids is the hydrometer. In this activity we will make and standardize hydrometers which will be used throughout the remainder of the course. Care should be taken in construction so that the device is durable and accurate.

## Activity

Construct and standardize a hydrometer.

## Moterials

-1 small 3 ml shell vial
-fine grain sand
-cork to fit vial
-1 skewer
-1 metric rule
-1 pencil
-standard solutions stations
-1 nail
-1 razor blade
-white glue

## Procedure

1. Mark the hydrometer scale (Fig. 5-1).
a. Cut a skewer 6.5 cm long and sharpen one end with a knife or razor blade.
b. Start at the unsharpened end, Use a metric rule and pencil to mark a scale with divisions 1 mm apart. Darken every

5th mark to represent 0.5 cm . Number every 10th mark using consecutive numbers of your choice: for example, 1, 2, 3, etc., or 30 , 40, 50, etc.


Fig. 5-1. Measuring and marking skewer.
2. Make the scale-cork assembly following steps shown in Fig. 5-2.


Fig. 5-2. Making the scale-cork assembly.

Step a. Mark the center of the cork.
Step b. Press the cork flat against a table edge. Align a small nail and push it 1 cm into the cork. Remove the nail and insert the skewer.

Step c. Mark the point where the skewer emerges from the cork with a heavy line. (If the skewer is pulled out, it can be reinserted to the same depth.)
3. Seal the scale and cork against water by spraying with a fast-drying clear varnish (See Fig. 5-3).


Fig. 5-3. Varnishing.
4. Weight the vial and complete assembly.
a. Add wet sand to a small shell vial to a depth of approximately 1 cm . Tap down the sand so that it is deposited on the bottom of the vial. Insert the scalecork assembly into the vial.
b. Adjust the hydrometer by pushing down on the cork so that the vial floats with about 7.0 cm of the scale above the water level in tap water (Fig. 5-4).


Fig. 5-4. Vial being weighted.
c. Dry and glue scale-cork assembly in place. Lightly cover with spray varnish.
5. Standardize hydrometer.
a. Record the density of the five standard solutions.
b. Place your hydrometer in solution 1. Twirl it gently to overcome surface tension. Read the stem in cm and record in Table 5-1.
c. Repeat procedure (b) with the remaining standard solutions.

Table 5-1. Standardizing the hydrometer.

| Solution | Šcalé Reading of Hydrometer | Standārd Denșity - |
| :---: | :---: | :---: |
| 1. |  |  |
| 2. |  |  |
| 3. |  |  |
| 4. |  |  |
| 5. |  |  |

$w$

## Summory Questions

1. Construct a graph of the standardization data. Show density on the horizontal axis, your hydrometer's reading on the vertical axis. This graph will be used in later investigations to provide conversion for direct reading of density.
2. What are the highest and lowest readings you can make with your hydrometer?
3. Explain how changes in density of the liquid affect the hydrometer.
4. Explain how the small diameter stem increases the sensitivity of the hydrometer.
5. At what density would the vial part of the hydrometer emerge above the water's surface?
6. Explain what occurs when the hydrometer is not twirled.
7. Explain how you could restandardize your hydrometer.

## 6. Density and Temperature of water

We have seen that fresh water and salt water have different capacities to dissolve oxygen when heated. We have also seen that salt water and fresh water have different densities. In this investigation we will look at the effect of change in temperature on the density of fresh water and salt water.

We will need a new concept, salinity. Salinity refers to the amount of mineral matter dissolved in water. Salinity is measured as the number of grams of minerals per kilogram of water. Its abbreviation is $/ 00$ (parts/thousand).

Salinity $(\% / \infty)=\frac{g \text { of mineral dissolved }}{1000 \mathrm{~g} \text { solution }}$
Thus, if 35 g of mineral are recovered in boiling away the water in a kilogram sample of seawater, the salinity is $35 \mathrm{~g} / \mathrm{kg}$ or $350 / 00$.

| Activity |
| :---: |
| Test the effect of increasing temperature on |
| the density of fresh water and salt water. |

## Materials

-1 250 ml beaker
-1 400 ml beaker for bath
-1 thermometer ( $-10^{\circ}$ to $110^{\circ} \mathrm{C}$ )
-1 hydrometer (from Topic 5)
-1 stirring rod

```
-fresh water (ice-cold)
-salt water (ice-cold)
-system for heating beaker
```


## Procedure

1. Check hydrometer against a standard solution and adjust the scale as needed. Record in Table 6-1.

Table 6-1. Hydrometer data.

| Solution | Standiard <br> Oensity | Hydrometer <br> Reading | Mydrometer <br> Error |
| :---: | :---: | :---: | :---: |
| 11 |  |  |  |
| 42 |  |  |  |
| $\# 3$ |  |  |  |

2. Measure density change on warming of cold fresh water as it is heated to boiling.
a. Put 200 ml of ice water ( $0^{\circ}$ to $1^{\circ} \mathrm{C}$ ) in a 250 m 7 beaker. Record the temperature and density in Table 6-2.
b. Place the 250 ml beaker in a bath of warm $30^{\circ}-40^{\circ}$ water. Stir the cold water beaker contents with a stirring rod. Record the uncorrected density of the water in Table $6-2$ with each $1^{\circ} \mathrm{C}$ increase in temperature until a temperature of $10^{\circ} \mathrm{C}$ is reached.
c. When $10^{\circ} \mathrm{C}$ is reached, place the beaker on a heat source. Continue to stir the contents of the beaker with a stirring rod.

Record the temperature and ungorrected density in Table $6-3$ every $10^{\circ} \mathrm{C}$ until the liquid boils. (When taking hydrometer measurements, remove the heat source. Remove hydrometer after reading and cool it).
Tabie 6-2. Temperature and density ice water $-10^{\circ} \mathrm{C}$.

3. Boil the water for 4 minutes, taking density and temperature readings every minute. Record in Table 6-4. (When taking density measurements, remove the heat source. Remove the hydrometer after reading and cool it).
4. Follow Procedures 1 and 2 using a sample produced from ice-cold salt water.
5. Correct all densities and graph the data from Tables $6-2$ and $6-3$ separately. Display temperature on the vertical axis. Use different colored lines or different kinds of lines. (dots, dashes, circles, ect.) to represent salt water and fresh water.
6. Make 2 graphs from the data found in Table 6-4.

Graph A. Display time on the horizontal axis and temperature on the vertical axis.

Graph B. Disolay temperature on the vertical axis and density on the horizontal axis.

Use different colored lines or different kinds of lines (as in Procedure 5) to represent salt water and fresh water.

Table 6-3. Temperature and density $10^{\circ} \mathrm{C}$ - boiling.

|  | Fresh Water |  |  | Salt Water |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Measurement | Tenp |  | Density | Temp |  | Denstity |
| Start |  | Uncarr. | Conrected |  | Uncorr. | Corrected |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |

Table 6-4. Temperature and density at boiling.

| Time | Frest Water |  |  | Selt Mater |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Temo | Density |  | Temp | - Density |  |
|  |  | Uncorrected | Corrected |  | Uncorrected | Corrected |
| Start |  |  |  |  |  |  |
| 1 min |  |  |  |  |  |  |
| 2 min |  |  |  |  |  |  |
| 3 min |  |  |  |  |  |  |
| 4 min |  |  |  |  |  |  |

## Summary Questions

1. In any saltwater aquarium it is possible to get a reading of salinity from temperature and density data. Fig. 6 -1 shows this information. Inspect Fig. 6-1 and respond to the following in your lab notebook:


Fig. 6-1. Temperature, density and salinity
a. What do the curved lines represent?
b. What do the vertical lines represent?
c. What do the horizontal lines represent?
d. What does the line running diagonally across the bottom of the figure represent?
e. Use Fig. 6-1 to complete Table 6-5.

Table 6-5. Corresponding densities-salinities and temperatures.

| Salinity <br> $(0 / 00)$ | Temperature <br> $\left({ }^{\circ} \mathrm{C}\right)$ | Dersity <br> $(\mathrm{g} / \mathrm{ml})$ |
| :---: | :---: | :---: |
| 20 | 10.0 |  |
| 30 | 20.0 | 1.005 |
| 20 |  | 1.020 |
|  | 27.5 |  |
| 25 | 15.0 | 1.005 |
| 25 |  | 1.015 |
|  | 12.5 |  |
| 28 | 30.0 | 1.0075 |

2. At what temperature is fresh water the most dense? salt water?
3. Compare what happens to the density of fresh water and salt water as temperature increases.
4. Compare what happens to the density of fresh water and salt water as they boil.
5. Compare what happens to the temperature of fresh water and salt water as they boil.
6. From your knowledge of fresh and salt water, suggest an explanation for any differences in Answers 4 and 5.
7. When water is heated and no evaporation occurs, does the mass or volume change? Explain your answer.
8. Under what conditions found in the natural environment might fresh water and salt water boji?

## 7. Evgporation of Water

When water boils in a pan, some water is lost as steam. However, wet clothes, water on a freshly scrubbed floor, and perspiration on our bodies all dry at room teriperature. In these latter cases the loss of water is by a process called evaporation. In this investigation we will study conditions under which evaporation may occur and some of the effects evaporation has on density of seawater and fresh water.

## Activity A

Test the effect, if any, of low heat on the evaporation of fresh and salt water.

## Background

When the sun beams down on a lake or on an ocean the surface water is warmed. In this activity we are going to warm water to study evaporation. We will use a closed system so that any vapor or evaporated water that is formed can be trapped, collected and studied. Such a system is called a stilf.

## Materiols

```
-1 low range hot plate
    -2 1-gallon cans, both ends out
    -2 small tin cans
    -2 250 ma beakers
-4 rubber bands
-2 pieces plastic wrap 30 cm }\times30\textrm{cm
```

-2 aluminum pie pans

- 1 flat metal sheet
-1 hydrometer from Topic 5
-salt water
-tap water
-1 thermometer ( $-10^{\circ}$ to 1100 C )
-1 pair pliers
-sand
-2 ring stands


## Procedure

1. Set up the heating system as shown in Fig. 7-1.


Fig. 7-1. Evaporation device.
a. Center flat metal sheet on hot plate. Support each end of the sheet with a ring stand.
b. Cover the sheet with sand to about 1 cm deep.
c. Place 2 pie pans to hold stills at an equal distance from the center of the hot plate.
d. Measure the density of the fresh water and salt water to be used. Record in Table 7-1.

Table 7-1. Data on contents of systemafter operation.

e. Pour fresh water into one pie pan and salt water into the other pan to about 1 cm deep.
2. Make 2 stills.
a. Place a small tin can in the center of each pie pan. Set a 250 m 1 beaker on each tin can. The top of such beaker should be 3 to 4 cm below the rim of the gallon can, as shown in Fig. 7-2.


Fig. 7-2. Tin can stand for beaker.
b. Cover each gallon can loosely with plastic wrap and seal with a rubber band.
c. Place a gallon can over each beaker.
d. Put a stopper in the center of the plastic wrap so that a conelike depression forms. Make sure that the bottom of the depression is over the beaker and that the plastic wrap is not touching the beaker. Each completed still should look like Fig. 7-3.


Fig. 7-3. Beaker and can in freshwater pan.
3. Turn the heater on low and allow the system to stand from 30 minutes to 24 hours. Make the following measurements on both fresh water and salt water at the end of the investigation. Record in Table 7-1.
a. The temperature of any liquid remaining in the pan and beaker.
b. The density of any liquid remaining in the pan and beaker.
c. The taste of the contents in the beaker and pan.

## Questions

1. Explain how the still works.
2. Must water boil to be converted to the gaseous state? Explain your evidence.
3. In what way, if any, did the results of heating fresh water differ from that of heating salt water? Give your evidence.
4. How might this device be used to get fresh water from ocean water?
5. How might this investigation relate to ways that moisture is provided for cloud formation?

## Activity B

Test the effect, if any, of moving air on the rate of fresh and salt water evaporation.

## Background

A common device to dry our hands after washing is a blast of warm air. Is it the heat, the moving air or both that do the drying? In nature, winds are constantly blowing over lakes and oceans. Can these winds alone produce evaporation? Is there any difference in the way that wind affects fresh and salt water?

## Materials

-1 25 ml graduated cylinder
-4 petri dishes 30 ml or larger
-1 fan
-salt water
-fresh water
-1 hydrometer (Topic 5)
-1 thermometer

## Procedure

1. Set up the experiment.
a. Measure and record the density and temperature of the fresh and salt water samples and record in Table 7-2.

Table 7-2. Data on moving air and evaporation.

b. Pour 25 ml samples of salt water into 2 petri dishes of the same dimensions.

Pour 25 ml samples of freshwater into 2 other petri dishes.
c. Place one sample of fresh water and one of salt water equal distances from a fan.
d. Adjust the fan so that it blows across the surface of the dishes without splashing the liquid.
e. Place the two remaining dishes in a nonbreezy spot. They should receive the same light and heat as the dishes in the path of the fan (Fig. 7-4).


Fig. 7-4. Petri dishes away from and in the path of the fan.
2. After 24 hours measure the volume, temperature, and density of the liquid in each petri dish. Record in Table 7-2 along with your observations.

## Questions

1. Calculate the rate of volume change for each container.

Rate of Volume Change $=\frac{\text { Volume Change }}{\text { Time Exposed }}$
2. What effects, if any, does moving air have on volume of liquids? How did you make that determination?
3. Is there any difference in volume change of fresh water and salt water in moving air?
4. What effects, if any, does moving air have on the density of liquids? Explain any differences.
5. What factors were controlled in this investigation to help ensure that we were studying only effects due to air movement?
6. What effect may winds have on large bodies of water such as lakes? oceans?

What does this investigation suggest about the conditions needed for an aquarium?

| Activity C |
| :---: |
| Test the effects of different sized surface |
| areas on rate of evaporation of fresh and |
| salt water. |

## Background

One might think that more water will evaporate faster from a lake with a large surface area than one with a small surface area because the large lake would receive more heat from the sun. But what about two lakes at the same temperature with different volumes and the same surface areas? What about two shaded tide pools with the same volumes and different surface areas?

## Materials

-2 petri dishes ( 30 ml or larger)
-2 25 ml beakers
-1 25 ml graduated cylinder
-1 metric rule

- fresh water
-salt water
-1 hydrometer (Topic 5)
-1 thermoneter ( $-10^{\circ}$ to $110^{\circ} \mathrm{C}$ )


## Procedure

1. Measure the following and record in Table 7-3:
a. the diameter of the petri dishes and the 25 ml beakers, and
b. the temperature and density of the liquids to be used.

Table 7-3. Data on surface area and evaporation.

|  | Fresh hater |  | Silt hatir |  |
| :---: | :---: | :---: | :---: | :---: |
|  | Petirf Dish | Beaker | Petr 0 䉼 | B60 |
| Dimeter |  |  |  |  |
| Fn Surface Arsa |  |  |  |  |
|  |  |  |  |  |
| F1R1 <br> TE.ETriturt |  |  |  |  |
| 1. 5tart |  |  |  |  |
| \% Final |  |  |  |  |
| changt |  |  |  |  |
| * Start. |  |  |  |  |
| F Final |  |  |  |  |
| Time Expard |  |  |  |  |
| Rate of Examertion |  |  |  |  |

2. Pour 25 mi of salt rater into a petri dish and 25 ml of salt water into a 25 ml beaker. Repeat using fresh (tap) water in the same size containers.
3. Place all 4 samples in the same general location where they will receive the same amount of light, moving air, and heat.
4. Allow the samples to stand for 4 to 5 days. Then take the measurements listed below and record in Table 7-3:
a. the temperature of the liquid,
b. the volume of the liquid, and
c. the density of the liquid.

## Questions

1. Calculate the surface area when $\pi=3.14$. Area $=\pi \times(\text { radius })^{2}$.
2. Calculate the amount of the volume lost per centimeter of surface area for each container.

Volume change $=$ Volume start - Volume final
$\frac{\text { Volume } 1 \text { ost }}{\mathrm{cm}^{2}}=\frac{\text { Volume change }}{\text { Surface area }}$
3. What effect, if any, does surface area have on the total amount of evaporation?
4. How could one predict the yolume of liquid evaporating from a $1000 \mathrm{~cm}^{2}$ dish of freshwater under similar conditions?
5. Is there any difference in volume change of fresh water or salt water?
6. What effect, if any, does surface area have on density of liquids. Explain any differences.
7. What factors were controlled or kept the same in this investigation to ensure that we were studying only the effects of surface area on evaporation?
8. Calculate the rate of evaporation of liquids from each container.

Rate of Evaporation $=\frac{\text { Volume change }}{\text { Time exposed }}$
9. What will happen to the salinity of two tide pools with the same volume of salt water but different surface areas as they are exposed to sunlight?
10. What will happen to the water volume of two pools of freshwater of the same volume but different surface areas as they are exposed to sunlight?

## Activity D

Test the effect, if any, of agitation on the rate of evaporation of fresh and salt water.

## Background

Water in streams tumbles over rocks, swirls around objects producing splash and airy froth. Waves on beaches and in the open waters of lakes and oceans rise and mix with air to form a short lived froth. Does this agitation or violent movement of water, affect the evaporation of water?

## Materials

-4100 ml beakers
-1 aquarium pump

- 1 hydrometer
-1 thermometer
-2 clothes pins
-salt water
-fresh water
-1 25 ml graduated cylinder
-250 cm length plastic tubing
-110 cm length plastic tubing
-1 y valve
-2 screw clamps


## Procedure

1. Measure the temperature and density of the saltwater and freshwater samples. Record in Table 7-4.

Table 7-4. Data on agitation and evaporation.

|  | Frich |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | ITIETH? |  |  |  |
|  |  |  |  |  |
| Finpl |  |  |  |  |
| Puprytri___Start |  |  |  |  |
| Figal |  |  |  |  |
| Yolum: Start |  |  |  |  |
| F\|mi |  |  |  |  |
| Chame |  |  |  |  |
| Tice Exporad |  |  |  |  |
| Rext of Exacoricton |  |  |  |  |


| $w$ |
| :---: |

2. Pour 50 ml samples of salt water into each of two 100 ml beakers. Repeat using fresh water. Record the volume in Table 7-4.
3. Place all four samples where they receive the same amount of light, heat, and movinq air.
4. Aerate one sample of fresh water and one sample of salt water. Secure hoses from the aquarium pump so that air can bubble continuously and at the same rate into the beakers of fresh and salt water. If splashing occurs, replace the liquid and reduce the air flow. Adjust the clamps so that the amount of air flow appears to be the same in each beaker.
5. Allow the system to run for 24 hours.
6. Measure the temperature, volume, and density of the contents of each container and record in Table 7-4.
a. the temperature
b. the volume
c. the density

## Questions

1. What effect, if any, does agitation have on the amount of evaporation?
2. Does it make any difference if the liquid is fresh or salt water?
3. What factors were controlled or kept the same in this investigation to ensure we were studying only the effects of agitation on evaporation?
4. Calculate the rate of evaporation of liquid from each container.

$$
\text { Rate of evaporation }=\frac{\text { Volume change }}{\text { Time exposed }}
$$

5. What aquarium problems are related to agjtation and evaporation?

## Summary Questions

1. Where does evaporation take place? Throughout the entire body of water, at the surface, or elsewhere? Give your evidence.
2. What is the state of the water that evaporates from a sample (solid, liquid, gas)? Give your evidence.
3. How do you account for changes in density during these experiments?
4. If you had a piece of plastic and a bucket, how might you get fresh water from salt water when on a desert island? Use a drawing.
5. What conditions increase the rate of evaporation in an aquarium?
6. In what part of the globe would you expect the greatest amount of evaporation to take place from ocean water? Explain your answer.
7. Using the data collected in these investigations, suggest what ocean conditions would produce maximum evaporation.
8. Suggest an explanation of how wind produces evaporation.

## Further Investigations

Distillation of seawater or the recovery of fresh water in stills, is very important to ships at sea, and many parts of the world where there are deserts. Design a device that gives high recovery rates of fresh water with no addition of electricity or other artificial energy source.

## 8. Freezing of Water

It is a common experience to see ice float on water. In nature, ice forms both on freshwater lakes and on the open ocean. In this investigation we will compare the properties of ice made from fresh water and salt water.

## Activity

Determine the temperatures that melt fresh and salt water ice. See if salt water ice floats in freshwater and find out what happens to the density of ice as it melts.

## Moterlals

-2 one-quart milk cartons (tops removed)
-1 metric rule

- 4400 ml beakers
-1 ice pick
-salt water
-tap water
-1 thermometer
-1 hydrometer
-150 ml (or larger) graduated cylinder
-1 heat source
-newspaper
-1 stirring rod
-knife


## Procedure

1. Prepare containers and samples.
a. Remove lids from 2 one-quart milk cartons. Rinse out insides if necessary.
b. Pour 900 ml of fresh water into one carton and 900 ml of salt water into the other carton.
c. Measure the distance from the bottom to the surface of the water in each carton (see Fig. 8-1). Use a pencil to mark the water surface on the outside of each carton. Record distances in Table 8-1.


Fig. 8-1. Measuring distance to surface.
d. Freeze the water in both cartons.
2. Conduct experiments.
a. Spread newspaper over working surface and cut away the carton from the saltwater ice. Keep the freshwater ice frozen until you start Procedure 3 .
b. Measure ice from bottom to surface and record in Table 8-1.

Table 8-1. Data on freezing liquids.

|  | STl | Praghthar |
| :---: | :---: | :---: |
| Molve of Ltowld start |  |  |
| Voluen of Ltoutd Fimil |  |  |
| yolve of LTewid Change. |  |  |
| O9stunct co surfice start |  |  |
|  |  |  |
| Qaspane to surface chanat |  |  |
| Density at miting Top 1/3. |  |  |
| Density at Malting mad 1/3 |  |  |
| Density at mitime Botery 1/3 |  |  |

c. Carefully using an ice pick, break ice into three blocks of about equal volume (see Fig. 8-2). Remember which blocks are the surface, middle, and bottom.
d. Put a small chunk of ice from the surface, middle, and botton blocks into tap water.

Record in your notebook whether each chunk floats.
e. Put larger chunks of ice from surface, middle, and bottom blocks into 400 ml beakers labeled surface, middle, and bottom.
f. Place the beaker labeled surface, holding ice from the surface block, on a heat source. Gently heat until all but about one-tenth of the ice has melted.

Remove from heat source and stir contents until remaining ice melts.

While stirring contents, take temperature readings every minute until ice is melted and record data in Table 8-2.

Table 8-2. Temperature during melting.

|  | Top $1 / 3$ |  | Hfdale $7 / 3$ |  | Eqtad $7 / 5$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Mriutes | Frioli | 5it wher | Frash | 5it Matr | Frash | Silthetr |
| Start |  |  |  |  |  |  |
| 1 |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |
| 4 |  |  |  |  |  |  |
| 5 |  |  |  |  |  |  |

Fig. 8-2. Using ice pick to break block into thirds.
g. Measure the density just as the last ice melts and record in Tables 8-1 and 8-2.
$h$. Repeat steps $e, f$, and $g$ for the ice in beakers labeled middle and bottom. Record data in Tables 8-1 and 8-2.
i. Compare the taste of the water from the ice melted in the three beakers. Rate each as most salty, least salty, or equal. Record in your notebook.
3. Repeat Procedures $2 a-i$ using the freshwater sample.

## Summory Questions

1. What happens to the volume of water as it freezes? Be as quantitative in your answer as possible. Explain how you made your calculations.
2. What difference, if any, is there between the volume of frozen fresh water and frozen salt water? Explain how you made your calculations.
3. Where does ice form first, at the top or bottom of the water body? What is the evidence to support your answer?
4. What differences are there in the properties (density, melting temperature, saltiness, etc) of the top, middle, and bottom segments of fresh and saltwater ice?
5. What is the effect of melting ice on the temperature of surrounding liquid water? Is there any difference between fresh and salt water?
6. What happens to the minerals in water as salt water freezes? What is the evidence to support your answer?
7. At night, how would the salinity of water beneath an oceanic ice sheet compare with that of open, nonfreezing ocean water. Explain your answer.
8. How do freezing point (temperature) and melting point appear to be related? Explain.
9. From work done to date, what techniques can be used to purify water?

## 9. Moving Liquids

In this series of investigations we will simulate different conditions found in oceanic and fresh water bodies so that we can see how currents are formed.

From work in Topic 4, recall that motion occurs when we have unequal forces meeting. Movement occurs in the direction of the stronger force. Forces in water are gravitational and buoyant forces. In the case of floating objects, the buoyant force of the liquid pushing up is equal to the gravitational force of the object pushing down. An object that sinks exerts a gravitational force greater than the supporting buoyant force.

We were able to predict whether the gravitational force would or would not exceed the buoyant force by conparing the apparent densities of objects put in liquid and the density of the liquid. We found that objects with densities equal to or less than the densities of supporting liquids float and objects with greater densities sink.

| Activity |
| :---: |
| Determine under what conditions currents are formed. |

## Hoterigls

-3400 ml beakers
-1 thermometer
-1 two-hole cup (clear plastic)
-1 one-hole cup (clear plastic)
-1 hydrometer

- 1 heat source
-room temperature tap water (25-270 C)
-chilled tap water (0-40 C)
-hot tap water ( $50-700 \mathrm{C}$ )
-room temperature salt water (25-270 C)
-hot salt water (70-900 C)
-food coloring or other water soluble dye
-2 baby food jars
-1 $3 \times 5$ file card
-1 clean container (shoe box)


## Procedure

1. Test the interactions of eight water combinations shown in Table 9-1.
a. With a hydrometer, determine the relative density of water samples in each combination. Record your results in Table 9-1. Example: "density salt water $>$ density fresh water" means the salt water is denser than the fresh water.
b. Predict the color on top and bottom when the reaction is complete for each combination. Draw diagonal lines ///// in the boxes under predictions in Table 9-1 where you predict color will be at the end of each reaction.
c. Carry out the steps in Fig. 9-1 for each water sample combination. Check Table 9-1 to make sure you have the right sample colored in each combination and that you have the samples correctly on top and bottom to start each reaction.




Table 9-1. Gravitational response of
different water samples.


Step b. Place the card over the mouth of the jar. Turn the jar over.


Step d. Pull out card allowing the two liquids to come in contact with each other.

Step c. Put the two jars together with the card between.
Step a. Fill two jars with two different kinds of liquid.

Fig. 9-1. Steps in manipulating jars.

Note that combination 6 in Table 9-1 is simply combination 5 that has been allowed to cool.

For combination 8, aerate the "top" water by shaking vigorously in a stoppered flask for a few minutes.
d. Draw diagonal lines ///// in boxes under actual results in Table 9-1 to show where color appears at the end of each reaction.
2. Test the interaction of two bodies of water, one deeper than the other as shown in Fig. 9-2. Follow the instructions below.
a. Predict, using the same symbols as in Table 9-1 ( $>,\langle,=$ ), the relative force of the water flowing through holes (A) and (B).
b. Predict the direction of flow using an arrow.
c. Carry out the two experiments shown in Fig. 9-2. At the start of both experiments, the water in the cups is colored. Record actual results in Fig. 9-2.


Fig. 9-2. Movement of water at different w helghts.
3. Test the interaction of water of different densities at their borders as shown in Fig. 9-3. Follow the instructions below.


$$
\begin{aligned}
& \text { Preducted direction } \\
& \text { of flow } \\
& \text { not weter } \frac{1}{T} \text { cold water } \\
& \text { actual firection }
\end{aligned}
$$

$$
\text { hat water } \frac{1}{T} \text { culd water hot water } \frac{1}{T} \text { cold wator }
$$

Fig. 9-3. Movement of water through a single hole when water is at different densities.

a. Predict the direction of flow using arrows.
b. Carry out the procedure using blue colored water for cold and red for hot water. Record the actual results in Fig. 9-3.
4. Test the simulated interaction between arctic and tropical waters as shown in Fig. 9-4. Follow the instructions below.
a. Predict the direction of flow using arrows.
b. Carry out the investigation using blue colored water for cold and red for hot water. Record the actual results in Figure 9-5.


Fig. 9-4. Equipment to study the interaction of hot and cold water.
5. Devise a system that would test the interaction between water of different salinities. Predict what will occur, then test the system.

## Summary Questions

1. What are the interactions of water in each system shown in Procedure 1 in terms of gravitational and buoyant forces?
2. Wind can blow water out to sea creating a"hill" in offshore waters. This process is called is called upwelling. Using the results of Procedure 2, decide which of the diagrams, (a) or (b), in Fig. 9-5, would best describe the expected water movement in response to such winds. Explain your selection.
3. Wind has a tendency to pile water up at the equator forming a measureable hill. Which of the diagrams below would best describe expected water movement? Explain your selection.
4. Use arrows to show the direction of flow in the following systems and explain why the currents move as they do.

b


Fig. 9-5. Effect of wind on water movement.

## 10. Coriolis Effect and Currents

The earth constantly rotates or spins on its axis. Since the earth is a sphere, different parts of the earth travel at different speeds. At the equator, the velocity of rotation is about $0.46 \mathrm{~km} /$ sec , or $1040 \mathrm{miles} / \mathrm{hr}$. At a point 50 km from the pole it travels about $0.0036 \mathrm{~km} / \mathrm{sec}$., or 16.8 miles/hr. In this investigation we will simulate a current of water flowing from the north polar reqion, down across the equator to the south polar region. We want to observe what happens to the direction of the water flow as it moves southward on a spinning globe. This is called the coriolis effect.

## Activity

observe demonstration and determine the effect rotation has on global currents.

## Procedure

1. Predict how the current of liquid will flow on the demonstration flask when the flask is at rest. Draw the predicted path of the flow on Circle a, Fig. 10-1.
2. Predict how the current will flow on the flask when it is rotating. Draw the predicted path on Circle c, Fig. 10-1.
3. After the demonstration, record on Circle b, Fig. 10-1, the actual path of current on the flask at rest.
4. Record on Circle d, Fig. 10-1, the actual path of current on the rotating flask.

a. Predicted path of cur- $b$. Actual path of current rent when flask is at rest.

c. Predicted path of cur- d. Actual path of current rent when flask is rotating. when flask is rotating.


Fig. 10-1. Path of liquid over flask when stationary and rotating.

## Summary Questions

1. Explain why the earth's rotational velocity is greater at the equator than at the poles.
2. How is the NaOH solution driven out of the flask?
3. Compare the total path of the liquid when the flask is stationary and when it is in motion.
4. Predict how the total path of the current would look if the cord were wound the other way. Explain your reasoning.
5. How does the path of the current above the equator relate to the direction of rotation? Suggest an explanation for this movement.
6. What were the forces acting on the liquid as it flowed over the surface of the flask? When it was stationary? When it was rotating?

## 11. Ocean Circulation

A current is a body of fluid moving in one direction. Since fluids are either gases or liquids, both winds and streams are also currents.

In studying oceans we find they are collections of many currents moving in different directions, at different levels and at different seasons. The way these currents move is called ocean circulation.

## Activity

Read the materials and answer the questions

## Current Formation

To move, a body must be under the influence of a force (push or pull). Forces producing ocean currents are provided by winds, tides, gravity, coriolis effect, and density differences.

To produce movement, a force must be greater than forces opposing it. For example, we have seen that when the force of gravity exerted by a boat is opposed by an equal buoyant force of water, a boat floats. Sinking the boat requires the gravitational force to be greater than the buoyant force (Topic 4).

Unbalanced forces also explain movement of water, or current formation in cups (Topic 9).

Winds, Waves and Currents
Winds produce waves, but waves do not move water horizontally. Wind waves occur only at the surface of the ocean, and the water moves up and down as the wave advances. This can be seen when we are in a boat on the open ocean. A wave passing under the boat lifts it and lets it fall. Waves then are not currents.

Winds can produce currents by the same ways that they create waves if they blow from the same direction for long periods of time. The generation of currents requires a prevailing wind such as a trade wind which blows from the same general direction year round.

If there is constant push on the ocean's surface by wind, water begins to move. Since water sticks together, water movement at the surface results in underlying water being dragged along. Ocean currents such as the Gulf Stream are as much as 2 km deep. Because of the great volume of water that must be moved, it takes continued application of force to keep it moving.

## Wind Formation

Wind is produced wherever two bodies of adjacent air have different densities. More dense air has a tendency to sink and push up less dense air (Fig. 11-1). This produces a convection current.

## Changing Air Density

There are two primary ways that the density of air changes. First, the air can be heated and become less dense or it can be cooled and become more dense. Second, when water vapor is added to the
air during evaporation, the mixture in air changes. Water vapor has approximately half the density of the major gas components of air. Therefore, as vapor enters the air, the air becomes less dense.


Fig. 11-1. A convection current showing more dense air sinking and pushing up less dense air.

## Questions

1. How do winds form currents?
2. What are the differences between waves and currents?
3. What is a force? Give four examples.
4. How is a convection current produced?
5. How can air become more dense? Less dense?

## Global Winds

Equatorial regions of the earth are hot, while the poles are cold (Fig. 11-2).


Fig. 11-2. Amount of sunlight at poles as affected by the tilting of the earth.

The amount of warming sunlight that falls on the equator is approximately 60 times that falling on the region of the poles. Sunlight is the earth's principle heat source. As a result water vapor is evaporated in great quantities from oceans and jungles near the equator. Air here is hot, vapor filled, and low in density. Air at the poles is cold and relatively high in density.
The cold air hugs the ground and moves down from the arctic and up from the antarctic to displace the hot air at the equator. As it moves over the earth's surface it warms. The hot rising air from the tropics spreads out toward the poles, being cooled as it goes.

## Earth's Rotation and Effect on Wind

In Topic 10 we have seen that as a fluid flows from the pole to the equator over a rotating globe it moves in a direction opposed to that rotation. (Fig. 11-3).


Fig. 11-3. Coriolis effect showing that direction of flow in the opposite direction of rotation.

We can explain the coriolis effect as follows:
As the earth rotates on its axis, the air column above it rotates at the same relative speed. If this were not so, there would be constant east to west wind at all latitudes. Comparing the rotational speed of the earth and air 50 km from the poles to that at the equator, we find equatorial earth and air moving about 110 times faster in the direction of rotation.

Let's follow a slow rotating body of polar air as it moves toward the equator. As it moves the earth beneath it keeps moving faster and faster in the direction of rotation. When a fast moving equatorial air body moves toward the poles it passes over an ever slower moving surface and tends to move in the direction of rotation.

When a fast moving equatorial air body moves toward the poles, it passes over an ever slower moving surface and tends to move in the direction of rotation.

## Questions

6. Why would more sunlight fall on the equator than on the poles?
7. Draw arrows showing the direction of wind moving in the southern hemisphere (Fig. 11-3).

## Coriolis Effect and Wind Pattern

To get an idea of how winds are affected by the earth's rotation, we will use a model of what really happens on the earth. Assume a surface totally covered with water and air 50 that conditions over its surface are constant.

On this model earth there are three circulation cells in the northern hemisphere. Use Fig. 11-4 to study the following discussion.

Again we will follow a polar air body as it travels toward the equator. Such an air body is cold and travels next to the earth's surface. When it has reached latitude 600 , the bending of the


Fig. 11-4. Prevailing winds on an ideal model of the earth showing major circulation cells.
path by the coriolis effect is sufficient so that it is travelling almost due west. Further, this original cold air from the poles has in its travel southward warmed and it rises. The winds it produced in its travels toward the equator are called polar easterlies. Winds are named for the direction from which they come. A wind moving toward the west comes from out of the east and is called an Easterly wind.

Now let's follow a body of equatorial air moving toward the poles. This is a hot, moist, low density
rising air. As it advances, it cools in the upper atmosphere, losing its moisture as rain and becoming more dense.

At about 300 latitude, it sinks back to the surface. Between latitude $0^{\circ}$ and 300 , colder surface air is coming from the direction of the north and therefore, is moving toward the west. These easterly winds are called trades.

Now look at a body of surface air between latim tude $30^{\circ}$ and $60^{\circ}$. Here, there is a change in direction of surface winds. Most of the body of air comes from the equator. Since it is revolving faster than the earth beneath it, wind movement is from the west and the winds are called westerlies. The real atmospheric circulation only approximates the circulation suggested by the model. However, the model does describe the general year round pattern of air movement.

## Questions

8. Predict what the major circulation pattern would look like in the southern hemisphere. Draw it on the left bottom edge of Fig. 11-4.
9. On Fig. 11-4, label the relative temperature and density condition of the air at $30^{\circ} \mathrm{S}$, $60^{\circ} \mathrm{S}$ and $90^{\circ} \mathrm{S}$.
10. Using Fig. 11-4 as a model, use arrows to show the direction of the surface winds as the air circulates in the southern hemisphere.
11. Compare the major currents of air in the northern and southern hemispheres.

## Major Ocean Surface Currents

In ocean basins, the prevailing winds create surface currents. In the northern hemisphere, the general circulation follows the patterns shown in Fig. 11-5.


Fig. 11-5. Major ocean currents.

## Questions

12. On Fig. 11-5, draw in the current that you would expect generated in the South Pacific. Use arrows to show the direction.
13. Relate Fig. 11-4 to Fig. 11-5. How do the major surface winds compare with the major currents?
a. Look at the major North Pacific currents. Which of the winds drives the northernmost part of the current?
b. What part of the currents do the trades drive?
14. On the map of the world (Fig. 11-6) viewed from the south pole, draw the following:
a. a set of arrows showing the water circulation around Antarctica, and
b. indicate the direction of rotation of the earth in relation to the south pole.
15. What role does the coriolis effect have in producing surface currents?

## Thermohaline Circulation

Vertical movement of water in the ocean may be of wind origin (see Topic 9, Question 2 concerning upwellings) or they may be produced by differences in water density. Ocean water density can be changed by the increase or decrease in salinity. For example, by the evaporation of water (increase) or the addition of fresh water (decrease). Density can also be altered by changing temperature.

A term combining both the idea of salinity and temperature is thermohaline. Haline refers to the halide ions, principaliy chloride ions, which are used to measure the salinity or quantity of dissolved mineral while thermo refers to temperature.) Thermohaline circulation refers to water movement due to differences in density produced by differences in salinity and temperature.

## Thermohaline Cfrculation in the Mediterranean

The Mediterranean Sea is constantly swept by dry winds. As a result, great volumes of water evaporate producing dense surface water which sinks. This dense water pours out of the Mediterranean

through the Strait of Gibraltar and plunges down into the Atlantic. Meanwhile, as dense water leaves, less dense Atlantic water flows in to take its place. See Fig. 11-7.

## Ice Formation and Thermohaline Circulation

Ice formation in salt water increases the salinity of unfrozen water. Recall from Topic 8 that salt-free ice can form in salt water. Removal of water in the form of ice has the same effect as evaporation. Water from the Arctic and Antarctic, for example, are both very cold and very dense. Arctic waters have a temperature of less than $-1^{\circ} \mathrm{C}$ with densities of more than $1.028 \mathrm{~g} / \mathrm{ml}$. This compared with an average surface density of $1.025 \mathrm{~g} / \mathrm{ml}$. These polar waters sink and are replaced by surface water from more temperate regions.

Fig. 11-6. Maps of the world from the poles.


## Questions

16. How is the density of sea water increased? Decreased?
17. List in order the most to least dense bodies of seawater exposed to different conditions.
a. body at surface in a tropical rain storm.
b. body at surface in the antarctic.
c. body at surface in tropical sun.
d. body at surface in tropics at night.
e. body directly beneath a mass of freezing polar ice.
18. During World War II, German submarines passed in and out through the Straits of Gibraltar without using their engines. How could they have done this?
19. In the mid-Atlantic and in various parts of the Pacific and Indlan Oceans, there are hot spots at the margins of continental plates. How might these affect deep water circulation?

## Tidal currents

Tidal currents are produced by the general raising and lowering of the sea surface under the influence of the sun and moon. They are usually the strongest currents in a coastal region. Tidal currents are often visibie at the mouths of rivers, and the narrow inlets of bays and harbors.

## Tide information

Tides result from the gravitational pull of the moon on the water of the earth and the centrifugal force of the earth resisting that gravitational
force. The moon and earth attract each other by gravitation. If there were no resistance to this force, they would crash together. However, they whirl around each other creating a balancing force called centrifugal force which keeps them apart.

Centrifugal force is observed when we put water in a bucket and whirl it rapidly in a circle. The water does not fall out but instead pushes on the bottom of the bucket.

In the case of tides in the region of the earth immediately beneath the moon, water is pulled toward the moon. On the opposite side of the earth, centrifugal forces pull water away from the earth opposing the force of the moon. See Fig. 11-8.


Fig. 11-8. Spring and neap tides.
The sun also exerts a gravitational force on the earth and produces its own tide. Again, opposing the tide is the centrifugal force of the earth as it wheels around the sun. As before, this centrifugal force pushes out a balancing mass of water on the other side of the earth because the earth's gravitational force is shifted towards the sun and moon. When the two tidal forces act together (from moon and sun) we get, over the course of a month, two days of extra high and low tides called spring tides. See figs. 11-8 and 11-9.

gravitational
garce at right
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Fig. 11-9. Neap tide.

## Time and tides

The moon passes overhead once every 24 hours and 50 minutes. If we are on the ocean on a calm day when the moon is overhead the ocean beneath us is at its maximum height or high tide. Six hours and twelve minutes later it is at its low tide.

## Questions

20. What is centrifugal force?
21. Draw on Fig. 11-8 the location of the moon at the second spring tide.
22. Draw on Fig. 11-9 the location of the moon at the second neap tide.
23. On Fig. 11-10 mark the time of the high and low tides for a 25 hour period.


Fig. 11-10. Graph of tides.
24. Complete the following calendar showing when the spring and neap tides would occur. It takes $29 \frac{1}{2}$ days for the moon to orbit the earth (See Table 11-1).

## Coastal tides

Tides along coastlines vary greatly. This is principally due to the shape of the ocean basins. To be sure of the tides one must consult records of past tides for an area.

Tides may be very high. For example, in the Bay of Fundy in Nova Scotia, the difference between high and low tides may be 15 m or almost 50 feet. The most spectacular tidal currents are the tidal bores or walls of water, that rush up some rivers at high tides.

## Questions

In Fig. 1i-11 are charts of tides in Honoluiu and New York.
25. How are they different? similar?
26. When are neap tides, spring tides?


## 

Fig. 11-11. Tide charts for September in New York and Honolulu.

Table 11-1. Calendar showing spring tide on first day of month.


There are several ways of measuring tidal heights. Tide tables are average tidal data obtained at a given location for a 19 year period. Daily tide tables are often printed in the newspaper, usually near the weather report. An example is shown in Table 11-2.

Table 11-1. Newspaper tide table for Honolulu Harbor and elsewhere.

"Tides Elsewhere" gives the figures to be added or subtracted from the Honolulu Harbor data. To determine exactly when a high or a low tide will arrive at a nearby location it may be necessary to add or subtract time from the time shown on the chart. For example, on that day there was a high at Waimanalo at $4: 55 \mathrm{AM}$. This is due to complex island topography and bathymetry.

## Question

27. On Tuesday, when will the tide be high at
a. Haleiwa?
b. Hilo?

## CHAPTER 4

## INVERTEBRATES

More than 95 per cent of all animals are invertebrates. Invertebrates are animals without backbones. They vary greatly in size and form and include animals as diverse as the 12 m long giant squid and the 1 cm long brine shrimp.


## Glossury to Animal Pnylum Comparison Sneet

The Animal Phylum Comparison Sheet (Table 1) asks for information about several invertebrate phyla that will be studied in this chapter. Chapter 2, Topic 9 explains what a phylum is.

Sometimes you may need to use a biology reference book to find answers to the comparison sheet. If you study other phyla, add columns to the sheet.

Several terms in the Animal Phylum Comparison Sheet are defined below:

1. Body Symmetry.
a. radial symmetry - an arrangement of body parts radiating from the center in all directions.

b. bilateral symmetry - an arrangement of body parts so that there is a "top," different from the "bottom" and two sides similar to each other.

c. assymetry - no specially arranged body parts.

2. Body segmentation.
a. segmented - a repetition of body parts, one following the other. These parts (segments) are alike.

b. nonsegmented - no repetition of body parts.

3. Digestive tract.
a. complete - having a mouth, a digestive tube and an anus (like a fish).
b. sac-like - having a digestive tube. The mouth and anus are the same opening (like a balloon).
c. none - having no digestive tract.
4. Nervous system.
a. dorsal nerve cord - runs along the "top" (dorsal side) of the animal.
b. ventral nerve cord - runs along the "bottom" (ventral side) of the animal.
c. nerve net - runs throughout the animal (like a 3 -dimensional spider web).
d. radial nerve cord - runs in a circle around the animal (like a ring).
e. irregular nerve cord - may branch into three parts or may be ladder-like. Each of the main branches are controlled by ganglia.
f. ganglion - a small swelling of the nerve cord which may be located anywhere on the cord.
g. brain - an enlarged anterior part of the nerve cord.
The nervous system of invertebrates is hard to see. Therefore, you may need to refer to biology textbooks or ask your teacher for help in locating it.
5. Method of respiration.
a. lungs remove $\mathrm{O}_{2}$ from the air (e.g.in man).
b. gills remove dissolved $\mathrm{O}_{2}$ from the water (e.g. in fish).
c. skin allows $\mathrm{O}_{2}$ to pass directly into the animal. There is no special organ for respiration.
d. respiratory tree is a special feature of one phylum which removes dissolved $0_{2}$ from the water. It looks somewhat like a tree and is not mentioned in these topics. See if you can find out which phylum has respiratory trees.
6. Unique anatomy.

All unique anatomical terms needed will be described in this Chapter's topics.
7. Economic importance.

In many of the topics we talk about the economic importance of members of each phylum.

Table 1. Common Hawaiian multicellular animal phyla comparison sheet.


## 1. Stinging Cells of Cnidario

Members of the phylum Cnidaria (coelenterates) are simple animals with sac-ike digestive tract. Around the mouth are tentacles with stinging cells containing structures called nematocysts. Food is caught by tentacles, stung by nematocysts, and stuffed into the mouth. Food is digested and expelled through the same opening that it entered. Examples of cnidarians are hydra, jelly fish, sea anemones and corals. Cnidarians may be solitary (live alone) or may live in colonies. The animals in colonies are attached to each other by thin layers of tissue.

There are two principal forms of cnidarians:

1. Polyps usually attach to hard surfaces. Their mouths point upwards (Fig. 1-1). Examples are: hydroids, anemones, and corals.
2. Medusae (jellyfish) swim freely in water. Their mouths usually point downwards (Fig. 1-1).

The cells of cnidarians are arranged in two tissue layers called ectoderm and endodern. Each contains special cells.

The ectoderm, or outer layer, contains stinging cells and secretes mucus. The endoderm, or inner layer, has cells which digest food. The endoderm also contains special cells with flagella (whiplike structures) which stir the food in the digestive cavity. Between these two cell layers is a jelly-like layer. This layer may be thick (as in the bell of the medusa) or thin (as in hydroids).


Many cnidarians (e.g., anemones, reef building corals and soft corals) have zooxanthellae in their tissues. Zooxanthellae are small algae. When exposed to sunlight, these plants produce nutrient molecules used as food by themselves and by the cnidarians in which they live.

Colonial cnidarians which do not have zooxanthellae in their tissues include precious corals, some hydroids, some jellyfish, and the Portuguese man-of-war. The cnidarians lacking zooxanthellae must catch their own food and are able to live in deeper or muddier water where there is less light.

One of the unique characteristics of the cnidarians is that they can protect themselves and catch food organisms with their nematocysts (Fig. 1-2). Most of these thread-1ike structures are located in the tentacles of cnidarians and are discharged at other organisms. Nematocysts often contain toxins (poisons). The nematocyst toxins of the Portuguese man-of-war, some hydroid colonites, many jellyfish and fire coral produce a severe burning sensation and in a few cases, shortness of breath in humans. Some jellyfish called cubomedusae are deadly. One species produces toxin stronger than cobra venom.


Fig. 1-2. Three types of discharged nematocysts stinging a daphnia.

Cnidaria discharge from one to three types of nematocysts: threads that wrap or entangle (lasso); threads that are adhesive (glue-like); threads with barbs that penetrate the prey (barbed).

## Activity

View unfired and fired nematocysts using selective staining techniques.

## Materials

-1 microscope ( 100 x )

- 2 glass slides and cover slips
-2 pairs of tweezers
- 2 stains (safranin " 0 " and methylene blue), each in an eyedropper bottle
-1 cnidarian (Portuguese man-of-war or anemone)
-scissors
-2 toothpicks


## Procedure

1. Snip off a 2 mm piece of a tentacle from the living or frozen cnidarian specimen using scissors. Place the piece on a clean glass slide. Add a drop of water and a coverslip. Fig. 1-3 shows an example of tentacles and nematocysts at different magnifications.
2. Observe your specimen under the microscope at 100X, and find the unfired and fired nematocysts. Draw some of each.

3. Test the nematocysts with a hair root:
a. Remove a hair with a root from your head.
b. While one person inserts the root of the hair under the coverslip and into the tentacle tissue, the partner should watch through the microscope
c. Pull the root slightly away from the tentacle.
d. Observe if there are hair-like nematocysts projecting from the hair root.
e. Save slide for Procedure 5.
4. Test the nematocysts with saliva:
a. Place several drops of saliva on one end of a second glass slide.
b. Get a fresh plece of tentacle and place it close to the saliva.
c. While one person is watching the tentacle through the microscope, the partner should move the saliva onto the tentacle with a toothpick.
d. Describe what happens.
e. Save slide for Procedure 5.
5. Staining the nematocysts:
a. Place one drop of safranin " 0 " on the hairroot slide and add a coverslip. View at 100X. Draw the nematocysts.
D. Add one drop of methylene blue to the saliva slide. View at 100X. Draw the nematocysts.

## Summary Questions

1. In Procedures 3 and 4, which stimulant (hair or saliva) caused the greatest release of nematocysts?
2. Did staining release more nematocysts?
3. Suggest two general categories of stimulants which cause nematocyst firing.
4. If a cnidarian has just finished feeding, will it discharge more nematocysts if the tentacles touch another piece of food? Explain your reasoning.
5. Suggest an explanation of why some people receive severe reactions to Portuguese man-ofwar stings while others are not severely affected.
6. Of the two stains, which brought out the nematocysts most clearly?

## Further Investigotions

1. Find out why some species of small fish can live among the tentacles of certain types of anemones.
2. Study local cnidarians to find out which types of nematocysts each species contains. Make drawings of the different nematocysts in each species.
3. Find out if cnidarians retrieve their nematocysts, whether they grow new nematocysts and how long it takes to "recharge a tentacle."

## References

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Buchsbaum, R. 1974. Antmals without backbones. University Chicago Press.

## 2. Corol Identification

More reef coral species (as many as 300 species) may occur in tropical regions than elsewhere because of higher temperatures and higher intensities of light. For example, at Fanning Atoll, which is in a tropical region, about 70 reef coral species occur. In the main Hawaiian Islands, located in a subtropical region, about 40 reef coral species occur. At Kure Atoll, the northernmost Hawaijan island, there are no reef corals. In general, fewer reef coral species are found in the Central Pacific than in the Western Pacific.

Most reef corals are colonies made up of many polyps. Each cup, or hole, in the surface of the coral contains a polyp. All the polyps are joined to each other by a thin layer of tissue. This tissue secretes the coral skeleton which is made of calcium carbonate, or lime (Fig. 2-1).


Fig. 2-1. Diagram of one kind of coral showing colony structure and the individual cups in which the polyps live.

Fig. 2-2 shows both a coral polyp in its cup and the empty cup. The septa are calcium carbonate partitions radiating inward from the side walls.


Fig. 2-2. Solitary coral cup.
In solitary corals the side walls of the cups may be present or absent (Fig. 2-3).


Fig. 2-3. Solitary corals.

In colonial corals the cups may be separated, unseparated, or missing parts of the side walls (Fig. 2-4).

side parts of walls
absent

cups unseparated
broken 1 ines
indicate where walls would be if present

Fig. 2-4. Colonial corals.

Colonial coral cups can be flat with the coral surface elevated (side wells extending above the surface). In some spectes, the septa join one cup to another. In others the septa do not join cups to one another (Fig, 2-5).


Fig. 2-5. Colontal coral cups.
Septa may be solid, but are often highly porous or reduced in size (Fig. 2-6).

reducad


F1g. 2-6. Septa variations in colonial coral cups.

## Activity

Identify five coral types and record their features.

## Materiols

- 5 different coral types -dissecting microscope with light source -small plastic metric ruler -a coral key


## Procedure

1. Obtain five coral samples.
2. Place each sample on the dissecting microscope stage and adjust lighting. Coral is white and reflects light, so too much light can be as bad as not enough. Experiment to find the optimum light for greatest contrast.
3. Describe coral cup features as indicated in Table 2-1.
4. Identify the coral by their scientific name.

## Summary Questions

1. Do each of the samples (excluding Fungia) have cup features that are different from each other? If they were part of a beach gravel sample, do you think you still could make a positive identification?
2. What coral cup parts are lacking in Fungtat
3. How does a colonial coral grow?
4. Excluding Fungia, which coral's cup features were the most different from the other types?
5. Do you think that any of the coral species studied would break during a storm? Why do you think they would break?
6. Define the following terms:
a. polyp:
b. colonial:
c. elevated cup:
d. septa:

## Further Investigations

1. Make a coral survey of your local offshore area. Record findings on both aerial and profile drawings. Indicate distance from shore, depth of species, and wave/current action.
2. Make a report on coral in terms of its social and economic importance.
3. Find out which species of caral can be maintained in your aquarium. List the reasons why it can live there.
4. Make a report on anfmals that eat coral based on personal observations and a literature survey

Table 2-1. Cup features of five corals.


## References

Maragos, J.E. 1974. Coral transplantation: a method to create, preserve and manage coral reefs, UNIHI Sea Grant Ar-74-03.

Maragos, J.E. 1977. "Order Scleractinia" In: Reef and shore fauna of Hawail. D. Davaney and L. Eldredge. Eds. Bishop Museum Press.

## 3. World Distribution of Coral Reefs

A coral reef is the only marine biological community which resists waves and continually grows and aids in maintaining the shoreline. As the reef builders form reefs, many small environments are formed. All these small environments make up the reef community.

Most tropical and subtropical Pacific islands are volcanic islands fringed by reefs or they are barrier reefs with low limestone islands. Reefs form a hard substrate (bottom) in shallow water which allows plants and living corals to flourish. Currents and waves constantly bring nutrients and food to the organisms living there.

The organisms of a coral reef community can be divided into four main groups:

```
-reef builders.
-crack fillers (sediment producers),
-destructive agents, and
-passive residents who may not greatly
    affect the reef but may eat reef organ-
    isms or be eaten by them.
```

Table 3-1 give examples of each group.
Coral reefs grow very slowly. In Hawaif, the fastest upward growth of a reef measured to date is 4 mm per year. A continuous upward growth rate is possible only if sea level is rising or if the platform on which the reef rests is sinking. Otherwise, the reef would grow above sea level, which is impossible since reef builders cannot live out of water. On Midway, the oldest island of the Hawailian chain, reef rock was found to extend to 380 meters deep in one bore hole. This reef is sitting on volcanic rocks that are $20-25$ million years old. The weight of the Midway volcano has

| Reef Builders | stony corals <br> encrusting coralline algae |
| :---: | :---: |
| Crack Fillars | fragnents of corals <br> forminifera (ono-celled animals with make shells, e.g., paper shelis) red, green and brown non-encrusting calcareous algae mol fusks ech1noderms |
| Destructive <br> Agents (destroy by chewing or by actdic secretions) | ```(waves) boring algae boring sponges speclally adapted fish, such as parrotfish worms seo urchins baring mollusks``` |
| Passive Residents | many fishes crus taceans worns non-calcareous aigae octopus anemones |

caused the island to slowly sink, thus permitting 380 meters of upward reef growth. On the Island of Hawait, the youngest island in the Hawailan chain, the only deep reefs are found at the oldest part of the island, near Kawaihae. The rest of this island's coral communities form thin crusts over lava.

The primary producers of food in the coral reef community are algae, so light is a necessary factor in reef growth. Most coral reef polyps contain within their tissues microscopic alge, zooxanthellae, which aid the growth and metabolism of the coral. The same is true of many foramintfera and some mollusks.

Light in the ocean is regulated by depth and turbidity. Turbidity can be caused either by rivers carrying silt and clay into the ocean or by an overabundance of plankton, a "bloom" caused by natural or human-made nutrient enrichment.

Corals, and probably other members of the reef communtty, are sensitive to both temperature and salinity. Corals with zooxanthellae grow best in water temperatures between $25^{\circ}$ and $31^{\circ} \mathrm{C}$. However, some corals have been known to survive temperatures as low as $18^{\circ} \mathrm{C}$ and as high as $35^{\circ} \mathrm{C}$ or more. Corals do not grow vigorously at these extremes. Coral growth occurs most rapidly in salinities of between 34 and $37 \%$. Most corals die in salinities below $25 \%$ and above $40 \%$.

## Activity

Generate and test a hypothesis on the global distribution of coral reefs.

## Procedure

1. Look at Fig. 3-1, a map of the distribution of coral reefs in the world's oceans.
a. Why do you think coral reefs are where they are?
b. Why are coral reefs absent where you think they "should" be present?
c. Write your hypotheses in your lab book.
2. The following information will enable you to test your hypothesis.
a. Light and depth. The amount of light that algae in corals receive is very important for coral growth. In clear waters of equatorial regions in the open ocean, reef growth does not occur at depths greater than 100 m . For example, see Fig. 3-2.
b. Light and latitude. The amount of light hitting a given area decreases from the equator to the poles (Fig. 3-3).
As a result, the water at the equator is warmer than at higher or lower latitudes (Fig. 3-4). Because the presence or absence of coral reefs is probably most influenced by winter temperatures and solar energy, winter values for the northern and southern hemispheres are shown on Figs. 3-4 and 3-5. The two halves of maps showing these values have been pasted together so that the lines do not always come together at the equator. Winter in the northern hemisphere is January-March; in the southern hemisphere it is July-September.
c. Light and season. During summer months at a given location, more light strikes the earth's surface than in winter because there are more hours of sunshine. Water temperature is higher in the summer than in the winter.
d. Light and cloud cover. In areas of extended periods of cloud cover the amount of light reaching the earth's surface is lower, no matter which season or latitude.

Latitude, season, and cloud cover determine how much 1 ight reaches the earth's surface and is shown in Fig. 3-5.



Fig. 3-2. Distribution of light with depth at Bikini Atoll $11^{0 N} 165^{\circ} \mathrm{E}$.


Fig. 3-3. Amount of sunlight in different parts of the world.

The units of radiation are in kcal (1000 calories) $/ \mathrm{cm}^{2}$ /month. One calorie of radiation will heat lcc of water 10 centigrade.
e. River runoff. All of the world's oceans and marginal seas with the exception of some river mouths have salinities suitable for coral reef growth. River runoff can reduce salinity which can limit coral growth. Major rivers occur in the tropics and subtropics. As you can see from Table 3-2, the Amazon is "King River" for water runoff.

Table 3-2. Water discharge of tropical rivers.

| River | Location | Water <br> Discharge <br> $\left(\mathrm{km}^{3} /\right.$ year $)$ |
| :--- | :--- | :---: |
| Amazon | E. South America | 5680 |
| Congo | W. Africa | 728 |
| Ganges | W. India | 382 |
| Indus | E. India | 683 |
| Mekong | Maylasia | 346 |

River runoff can also reduce light penetration in the ocean by increasing the amount of silt and clay suspended in the water. Further sediment is deposited on the bottom, and forms a soft substrate on which coral reefs cannot grow. Large volumes of water are not always responsible for large amounts of sediment, as seen in Table 3-3.

Northern Hemi sphere Winter

February


August
Southern Hemisphere
Winter
Fig. 3-4. Winter surface water temperature ( ${ }^{\circ} \mathrm{C}$ ).

February


Table 3-3. Sediment transport by tropical rivers.

| River | Location | Millions of <br> tons/year |
| :--- | :--- | :---: |
| Ganges | E. India | 1600 |
| Indus | W. India | 480 |
| Amazon | E. South America | 400 |
| Makong | Malaysia | 190 |
| Congo | W. Africa | 90 |

3. Modify your hypothesis based on the information you have been given.
a. Why do you think coral reefs are where they are?
b. Why are coral reefs absent where you think they should be?

## Summary Questions

1. Coral reefs can grow to approximately what depth? What is the most important factor which limits coral growth below this depth?
2. Why do you think coral reefs are not present off:
a. West Africa
b. Northwest India
c. Northeast India
d. Northeast South America
e. Northwest South America
f. Eastern Central Pacific
g. Northern Mexico and California
3. How is solar radiation related to ocean surface temperature?

## 4. Kaneohe Bay Reefs

In Topic 3 we have seen that solar energy, salinity and turbidity affect the world's coral reefs. A small area, such as Kaneohe Bay, is also affected by these factors and by man's influence there.

## Activity

Generate a hypothesis (after studying and reading the topic's reading and the maps) that explains why Dictyosphaeria and corals have particular distribution patterns in Kaneohe Bay.

## Procedure

1. Study the maps and the reading which follow.

THE KANEOHE BAY REGION 1820-1970
Prior to 1940
Before the arrival of Captain Cook, the Kaneohe Bay region was the center for a large population of Hawaiians and was one of the main areas for taro farming. A system of terraces was constructed throughout the area which trapped stream runoff from the mountains. Taro was grown in these watery terraces.

The bay itself was very important to the early Hawaiians, and no less than 23 fishponds were built on the shallow reefs cTose to the shore.

The first descriptions of the bay waters were made during the Tate 1800 's and early 1900's. Reef corals flourished on the outer slopes of the fringing reef along the entire shoreline of the bay.

During this time several people remarked that although there were swampy areas around mouths of streams, water within the protected areas of the bay was clear, and beaches along the bay were dazzling white. The "coral gardens" were exceptionally beautiful.

In the early 1820's, missionaries, sailors, and adventurers followed earlier explorers to Hawaii, bringing with them their religions, customs, and diseases. As elsewhere in the Islands, the population in the Kaneohe Bay region declined (Fig. 4-1).

fig. 4-1. Kaneohe Bay region population.

From the 1860's onward, workers were imported from other countries to meet labor shortages in the canefields and elsewhere. During this time the Kaneohe Bay area population increased to about 5,500 , and it remained at this level until 1940. During this period, rice replaced taro in some of the terraces.

## 1940-1970

Ranching increased steadily from 700 acres in 1880 to 3,000 acres in 1969. Hills near Heeia were scarred red from erosion. Native vegetation was being gradually replaced by weeds and other introductions. Conversion of the watershed into cattle ranches decreased in the number of rice and taro patches which efficiently trapped stream sediments. Muddy areas around mouths of streams became larger and larger.

In 1938, engineers began construction of the Kaneohe Marine Corps base, and lagoon and channel areas of the bay were dredged extensively. Dredging of the reef by private landowners had also increased, especially during the 1960's, mostiy in the south lagoon.

The Kaneohe Marine Base began dumping untreated sewage into the south lagoon in the 1940's (Fig. $4-2$ ), and in 1963 a Kaneohe municipal sewage treatment plant was constructed which began dumping settled and chlorinated sewage into the south lagoon. As the population climbed, the sewage from the municipa! plant increased from about $2,700 \mathrm{~m}^{3} /$ day to over $11,000 \mathrm{~m}^{3}$ /day in 1970.

Several eplsodes of unusual weather severely damaged coral reefs in the bay. The tsunami of 1946 and high winds in 1947 dislodged many large coral heads from the tops of reefs. In 1965,
torrential rains, coinciding with very low tides, flooded the bay and killed many of the animals and plants on reef tops and upper reef slopes. The damaged areas were resurveyed in 1968 and corals were only beginning to recover at that $t$ ime. The survey also showed that in the south lagoon there were fewer varieties of organisms than in other parts of the bay. In the middle lagoon the most abundant species were those that thrived on nutrients from sewage. In the north lagoon the water contained less nutrients and was clearer than in the other parts of the bay. North lagoon had the most variety of organisms.

The opening of cross-mountain, four-lane highways in the 1960's promoted rapid urbanization of the bay region and the population sharply increased (Fig. 4-1) from about 5,000 people in 1940 to over 47,000 in 1970.

Construction in Hawaji also increased. Between 1915 and $1945,0.04 \mathrm{~km}^{2}$ of land was bult dozed for tract homesites; between 1945 and 1970, over 2.0 $\mathrm{km}^{2}$ was bulldozed. These figures do no include land used for streets and pubitic buildings.

Storm control projects began in Keapuka in 19631965 and have since inciuded several drainage systems in Kaneohe and Kahaluu. Before there were storm-control projects, much of the flood water eventually permeated the porous lava rock and slowly leaked into the bay. Flood water confined to concrete conduits now enters the bay directiy, and during rainstorms sediment discharge into the bay can be tremendous.

Although the depth of the bay remained essentially unchanged between the 1882 and 1927 surveys, the lagoon in 1969 was about 1.6 m shallower than it had been before.
2. Compare the distribution patterns of the number of coral species in Fig. 4-2 and Dictyosphaeria abundance in Fig. 4-3. Draw one continuous line on each of the figures around the areas where they are most numerous or most abundant as indicated by the two largest circles.


Fig. 4-2. Number of species of coral at each station in Kaneohe Bay.
3. Write your hypothesis for the distributions you find.

## Summory Questions

1. Circle or outline the following on Fig. 4-4:
a. The two sewer outlets.
b. Coconut Island (Moku o loe).


Fig. 4-3. Abundance of Dictyosphaeria cavernosa in Kaneohe Bay.

$w$

Fig. 4-4. Kaneohe Bay.
c. Quter margin of the barrier reef.
d. The two sand channels leading into the bay.
e. Chinaman's Hat (Mokolii).
f. 4 fish ponds.
g. The fringing reefs (not all are labeled).
2. How does a fringing reef differ from a barrier reef? What is a patch reef?
3. More silt was added to the bay after the 1920's. What were the reasons for this?
4. Kaneohe Bay has become shallower in recent years. What kinds of sediments do you think have been added to the bay?
5. What do you think happened to the coral gardens in the south lagoon?
6. Name five of man's activities which changed the bay.
7. For what reasons was Dictyosphaeria most abundant in the middle lagoon in 1970?
8. Around what date was the Wilson tunnel completed? What effect did it have on the bay?
9. For what reasons are corals not abundant in south lagoon?

## Further Investigations

1. Present a summary or panel discussion on the developments in Kaneohe Bay from 1970 to 1980.
2. Try to acclimate fish or algae from a "clean" water aquarium to the "polluted" water of a second aquarium. Vary time schedules and species. Determine which organisms are the most tolerant. Report your findings.

## 5. Chemoreception of Sed Anemones

Chemoreception is the ability to detect chemicals by smell or taste. It is important for locating and testing food, discovering harmful substances, selecting mates, and finding suitable places to live. Mechanoreception is the ability to detect pressure or touch stimuli. Generally, animals respond to chemical and mechanical stimuli by moving toward the material (positive response) or away from the material (negative response).

Species' responses to chemicals have evolved over a long period of time. People can change the odor and chemical composition of a river or intertidal area almost overnight by putting new chemicals into the water. If this hanpens, aquatic animals may become unable to locate their mates, suitable living places and food, and thus may die.

Sea anemones are good subjects for testing responses to chemical and mechanical stimuli.


## Materiols

-1 sea anemone

- 10 filter paper disks
-chemicals (see Table 5-1)
- tweezers
- sea water
- paper towels
-marking pens
-culture dish, 8 cm diameter


## Procedure

1. Set up experiment.
a. Obtain a culture dish filled with seawater and containing one anemone.
b. Wait until the anemone is relaxed (erect with tentacles as shown in Fig. 5-1b). Complete Procedures c and d .
c. Soak each of 8 filter paper disks in each of the substances to be tested. Remove with tweezers and place on an appropriately labeled paper towel.
d. Let the disks dry.


Contracted


Relaxed

Fig. 5-1. Contracted and relaxed sea anemones.
2. Test the anemone.
a. Pass the first chemically soaked disk listed in Table 5-1 quickly along the anemone's tentacles with the tweezers. Release the disk and withdraw the tweezers.
b. Observe and time the anemone's response. A positive ( + ) response is indicated when the animal retains the paper disk for longer than two minutes. Anything else is a negative (-) response. Record your observation ( + ) or ( - ) in Table 5-1.

Jable 5-1. Sea anemone response.

| Oisk Material | Positive <br> Response | Negative <br> Response |
| :--- | :--- | :--- |
| clam juice |  |  |
| shrimp juice |  |  |
| saliva |  |  |
| plain disk |  |  |
| fish food <br> solution |  |  |
| hair root |  |  |
| clean tweezers |  |  |
| grease from <br> skin |  |  |
| vinegar |  |  |
| plant juice |  |  |

c. Wash off the tweezers. NOTE: The tweezers must be washed off after each trial, and dried with a paper towel. Occasionally after cleaning off the tweezers, place its tips among the anemone's tentacles. If a positive response is demonstrated, your tweezers are still dirty. Reclean them. Remove any disks that are rejected by the anemone with clean tweezers.
d. Wait until the anemone is relaxed before proceeding.
3. Repeat Procedure 1 using a plain unsoaked disk. Observe. Record response.
4. Repeat Procedure 1 for the remaining chemically soaked disks and the hair root in the order shown in Table 5-1. Periodically test the water for contamination by using a plain unsoaked disk. If anemone responds positively, change water.

## Surmary Questions

1. What was the purpose of using a plain disk?
2. Why should tweezers be cleaned?
3. How does the anemone respond to fish food after being given a vinegar solution?
4. In this experiment, how might it be possible to get a positive response from a plain disk?
5. How might the presence of chemicals in the water result in a starved anemone even when normal foods are available?
6. Fill in the characteristics of cnidarians on your Animal Phylum Comparison Sheet. Use material from Topic 1, your teacher's lectures, and biology books to complete the column.

## Further Investigations

1. Try foods other than those listed in Table 5-1 and observe your anemone's responses.
2. Determine if different species of anemones have the same or different food preferences.
3. Set up an experimental situation to see if sea water from different places affects feeding response of your anemone.
4. Make dilutions of household products (detergents, sewage, etc.). Observe their effects on your anemone.

## References

The following Scientific American reprints apply to chemoreception:

March 1960. "Portuguese Man-of War"
May 1971. "The Chemical Language of Fish"
March 1969. "Thermal Pollution and Aquatic
August 1955. "Homing of Salmon"

## 6. Regeneration in Sea Anemones

Some organisms are capable of regenerating parts that are damaged or destroyed. Starfish, for example, can regenerate (or grow back) one or more missing arms.

## Activity

Determine whether the rate and degree of regeneration in sea anemones depend on the part of the animal cut, or the amount of tissue eliminated, or both.

## Materials

-1 water proof marking pen
-3 sea anemones
-6 small beakers
-8 razor blades
-seawater aquarium
-1 glass slide
-1 net

## Procedure

1. Mark the beakers 1-6.
2. Observe a sea anemone. Without disturbing it, carefully note the size and number of tentacles. Record in your lab book.
3. Gently scrape a sea anemone from the stock aquarium.
4. Place the anemone on a glass slide and cut tissue as shown in Fig. 6 -1A with a razor blade.
5. Place the two parts of the cutting in separate saltwater-filled beakers labeled 1 and 2.
6. Draw a picture of the pieces in your lab book.
7. Carefully place beakers containing your anemone in stock aquarium.
8. Repeat Procedure for the next two anemones.
a. Make the tissue cuts shown in Fig. 6-1B and 6-1C.
b. Place in appropriate beakers labeled 3, 4, 5 , and 6 in the stock aquarium.
9. Observe the anemones for two weeks. Make sketches of regenerating animal every three days. There should be four pictures. Arrange in a table such as table 6-1.

A

B

$c$

Fig. 6-1. Cutting sea anemones to observe regeneration.

Table 6-1. Sea anemone regeneration.

|  | Cut A |  | cut 8 |  | cus 0 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | bewker ! | beater 2 | beuter 3 | benker 4 | beoker 5 | mater 6 |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |

Summary Questions

1. Do the same number of tentacles as originally present regenerate in each anemone piece?
2. Can a severed body column regenerate a new oral disc?
3. Which cut ( $A, B$, or $C$ ) would you use to colonize your salt water aquarium the fastest?
4. Which pieces, if any, do not regenerate?

## Further Investigations

1. Study regeneration in marine animals such as crabs and sea stars. Record, draw and graph your results.
2. Budding (asexual reproduction) from the anemone's basal disc can be observed. (Some species are better for observation than others.) Note things such as number of buds
per unit time, rate of growth, and change of growth rate with changes in the aquarium's temperature and salinity.
3. Cut several anemones at different column levels and see which ones regenerate the fastest.
4. Repeat experiment, but put severed pieces in a dark closet. Do these regenerate as well as those exposed to light? Explain.

## Reference

Buchsbaum, R. 1974. Animals without backbones, University of Chicago Press.

## 7. Sponges and Tunicates

Sponges and tunicates are often found together on pier pilings or under rocks in the water. Members of both phyla have a number of different shapes. Sponges can be simple, having one central chamber; or they can be compound, having more than one chamber. Tunicates can be solitary, meaning they live singly, or colonial, meaning several individuals live together attached to each other. Tunicates and sponges of ten look alike at first glance. However, if they are observed closely and dissected, they can be seen to be different.

## Activity

Observe how a sponge differs in structure from a tunicate.

## Materials

-1 simple sponge and 1 solitary tunicate -dissecting microscope
-2 petri dishes
-probe
-scissors or razor blade
-carmine particles
-pipette
-live sponges and tunicates

## Procedure

1. a. Examine the external covering of a sponge and a tunicate. Gently touch the tunicate. Write a description of how each feels in Table 7-1.
b. Place a sponge under the dissecting microscope and look at its external covering. Do the same with the tunicate. Record your observations on Table 7-1. Note whether the external covering is smooth, rough, or covered with tiny pores.

Table 7-1. Comparison chart for sponges and tunicates.

|  | Sponge | Tunitate |
| :---: | :---: | :---: |
| Touch tent |  |  |
| Extermit cowtring |  |  |
| Internal structuras |  |  |
| mentar of 1arge opshing: |  |  |

c. Describe other characteristics, such as
color.
2. Examine the inside of a sponge.
a. With a sharp razor blade or scissors carefully cut the sponge in half.
b. Observe the sponge under a dissecting microscope and then with the naked eye.
c. Draw the internal structure of the sponge in the space for internal structures on Table 7-1.
3. Examine the inside of a tunicate.
a. If the tunicate is opaque, cut the outer covering or tunic lengthwise.
b. Observe the tunicate under a dissecting microscope and then with the naked eye.
c. Draw the internal structure of a tunicate in the space for internal structures on Table 7-1.
4. Count the number of large external openings possessed by a tunicate, by a sponge. Record in Table 7-1.
5. How does a sponge differ from a tunicate? Write answer in your lab book.
6. Observe the path of water circulation through live tunicates and sponges. Place carmine particles at a large opening and observe. Next place carmine on the surface of both sponge and tunicate. Apply very small quantities using a toothpick. Watch for currents.
7. Read the material below and fill in the summary questions.

## SPONGES

Sponges belong to the phylum Porifera which means "pore-bearing" because sponge surfaces contain many small openings called pores (see Fig. 7-1).

Water containing dissolved oxygen and particles enters these pores. Food particles and oxygen are taken in by the cells lining the sponge's cavity. The water leaves through an osculum, the large hole in the sponge. Since sponges digest food within their cells, they can take in only tiny food parti-

A. Simple


Fig. 7-1. Simple and compound sponges. Arrows indicate path of water.
cles. Even giant three-meter sponges, which are found in the Caribbean and some parts of the Pacific, feed only on microscopic particles. Sponges are abundant in water which contains many small nutrient particles.
Leathery sponges were used by the ancient Greeks for bathing, scrubbing tables and floors, and as padding in helmets and leg armor. Romans used sponges as paint brushes or tied them to wooden poles for use as mops. Occasionally, they used a sponge instead of a cup for drinking. Even today, the sponge fishing industry produces many tons of bath sponges taken from warm, shallow seas.

There are three major types of sponges:

1. Calcareous sponges with spicules of lime (calcium carbonate)
2. Glass sponges with glass spicules (silicon dioxide)
3. Leathery sponges (some may have glass spicules)

Spicules are small, glass or carbonate structures which support the tissues. Glass sponges live in deep water. The fibrous material of leathery sponges, called spongin, also supports the tissues and may contain glass spicules.

The form of simple or compound sponges vary. They can be either radially symmetrical or assymetrical, simple or compound (Fig. 7-1). They may be encrusting (spread flat over a surface), moundlike, or column-like in appearance and the mounds or columns may or may not have finger-like projections (Fig. 7-1).

In Hawaii, most sponges are leathery with glass spicules. They are always attached to hard sub-
strates such as coral reefs or wood pilings and are often brightly colored. Sharp glass spicules prevent most animals from eating them.

## TUNICATES

Tunicates are also found attached to hard substrates in the same habitat as sponges. Solitary tunicates are usually dull in color whereas colonial ones are smaller and may be more colorful. See Fig. 7-2 for typical shapes. Tunicates have no known use to man.
Tunicates belong to the phylum Chordata which also includes vertebrates, such as fish or humans. The features which make choradates different from other phyla are a notochord, gill slits, and a hollow nerve cord dorsal to the notochord. The

notochord is a rod of cartilage which becomes replaced by a calcified, segmented vertebral column in fishes, birds, etc. Tunicates have a notochord only when very young (Fig. 7-3). The young tunicate is a bilaterally-symmetrical, freeswimming animal like a tadpole. Its tail contains both the notochord and most of the dorsal nerve cord. When the larva attaches to the substrate and becomes an adult, it loses its tail, notochord and most of the nerve cord.

The adult tunicate's gill basket is a sac-like structure which under a microscope looks like the material in a gauze bandage. The gill basket can be exposed by cutting the tunic, or outer covering, open. A tunicate takes in water carrying dissolved oxygen and food particles through its mouth and into the gill basket. Water flows through the gill basket where $\mathrm{O}_{2}$ is removed. The food passes into the intestine for digestion, and wastes leave through the anus.

B. Colonial
A. Solitary

Fig. 7-2. Solitary and colonial tunicates.

Along the shoreline, solitary tunicates are easy to identify because they will send up a jet of water when squeezed. This is why they are often called sea squirts.


## Summary Questions

1. What is the function of the basket-like structure in a tunicate?
2. What do sponges and tunicates filter?
3. Use your observation of carmine particles to describe the circulation patterns of water through sponges and tunicates. Where did the carmine particles go?
a. Sponge:
b. Tunicate:
4. From your observations and the reading, how do sponges and tunicates respire?
5. Which of the two organisms, sponges or tunicates, is more like a fish? Explain your answer.
6. How do tunicates differ from sponges? Record your observations on the Animal Phylum Comparison Sheet.

## Further Investigations

1. Report what you find after dissecting and examining compound tunicates found at local sites. For each species, locate the gill basket and other structures. Draw these structures.
2. Using drawings, report on the contents from the gut of a tunicate. Compare the gut contents of different species of tunicates from different intertidal areas.

## References

Buchsbaum, R. 1974. Animals without backbones. University Chicago Press.

Storer, T, and R.L. Usinger. 1965. General zoology. McGraw Hill.

## 8. Sponge Spicules

A sponge contains many microscoplc glass or calcium carbonate spicules along with a fibrous, leathery framework. Sponge species are identified by the types of spicules they contain. Color and texture, although used in sponge identification, may vary greatiy within a species and are not as important as the kinds of spicules. Fig. 8-1 shows some large and small sponge spicules types.


Fig. 8-1. Types of sponges.

## Activity

Prepare spicule slides and draw the types of spicules found in local sponges.

## Materials

-sponge material
-bleach
-4 plain slides and 4 coverslips

- labels
-white giue or mounting medium
-marking pen
-microscope (100X)
-paper towel or filter paper disks
-tweezers


## Procedure

1. Prepare wet mounts to draw spicule types in sponges $\mathrm{A}-\mathrm{D}$.
a. Break off 2 mm pieces of each sponge with tweezers. Place samples on 4 microscope slides.
b. With an eyedropper, add enough bleach to cover samples A - D. Wait about five minutes to give the bleach time to dissolve the flesh from spicules.
c. Meanwhile, complete Procedures 2 and 3.
2. Describe characteristics of the 4 live sponges from which you are preparing spicules. Record the color, texture, and shape of each sponge on Table 8-1.

Table 8-1. Comparison of sponge characteristics.

| 4 | crim | reature | Smpu |
| :---: | :---: | :---: | :---: |
| 4 |  |  |  |
| - |  |  |  |
| c |  |  |  |
| 0 |  |  |  |

3. While the bleach is working, observe how the spicules are arranged in the sponge tissue.
a. Prepare a separate wet mount by placing a 2 mm piece of sponge on a slide.
b. Add a drop of water, then cover with a coverslip.
c. Examine the slide under a microscope.
4. Examine the bleached spicules under a microscope at a power of 100 x .
a. With an eyedropper of tap water carefully wash the bleached spicules. Absorb the water from the spicules with filter paper.
b. Put a coverslip on the slide and draw the spicule types you see in your lab book. Label all four sponges spicule types $A, B$, C , and D .
5. Prepare a slide collection of sponge spicules.
a. On a label, write the color, texture, and shape of the sponge, as well as where it was collected and your name.
b. Attach the label to a clean slide.
c. Put glue on the slide where shown in Fig. 8-2. Place the edge of a coverslip in the glue at a $45^{\circ}$ angle and slowly lower it over the spicules so that air is forced out as the coverslip descends.


Fig. 8-2. Diagram of slide with spicules.
d. At the end of class, put your slides in the class slide collection box. Keep the slides flat until glue dries thoroughly.

## Summary Questions

1. Sponges are often brightly colored. Of what advantage might this be to a sponge?
2. How are sponges useful to humans? Are they useful to any other animals?
3. Why are most Hawaiian sponges unsatisfactory for washing a car?
4. How many types of spicules did you find in each of your sponges?
5. How many spicule types did you see?

## Further Investigations

1. Using the slides you prepared in class, construct a class spicule chart. Draw the spicule type of each specimen on the chart. Then decide how many sponge samples are similar and how many are different. Write a simple key to the sponges examined using spicules and other characteristics.
2. Locate good sponge collecting sites near your school. Indicate where these sites are found on a local map of the area.
3. The Hawaiians used dyes contained in sponges to color cloth before the arrival of Captain Cook and western culture. Try to color some cloth using sponge dyes.

## References

Bergquist, P. 1977. Sponges In: Reef and shore fauna of Hawaii. Devaney, D. and L. Eldredge, Eds. B.P. Bishop Mus. Spec. Publ.

Buchsbaum, R. 1974. Animals without backbones. University of Chicago Press.

## 9. Sponge Symbionts

Symbiosis refers to the ways organisms of different species live together and respond to each other. Large sponges have many small chambers where other organisms can live. Although the sponges do not usually benefit from this arrangement, their symbionts do.

The number of symbionts a sponge may house can vary from a few to many different animals. The symbiont biomass (the volume of the symbionts) will be measured in the following experiment.

## Activity

Determine the biomass by volume of the animals living in a given species of sponge and how many kinds of animals live in the sponge.

## Materials.

```
-1 3 cm}\mp@subsup{}{}{3}\mathrm{ piece of sponge
-1 100 m] graduated cylinder
-1 10 ml graduated cylinder
-1 petri dish
-1 pair of tweezers
-1 probe
-1 dissecting microscope
-1 vial, filled halfway with 6% formalin if the
    sponge is fresh
```


## Procedure

1. Obtain a sponge sample. Record its number in Table 9-1.
2. Determine the total volume of sponge plus symbiont animals.
a. Fill a 100 ml graduated cylinder with 30 ml tap water.
b. Place the sponge sample in the graduated cylinder. Read the volume.
c. Subtract the original reading of 30 ml from this volume. The difference is the volume of the sponge material and water in the sponge plus the volume of the animals living in the sponge. Record the total volume in your lab book.
3. Place the sponge sample in a petri dish and add tap water to it. Using a dissecting microscope, gently tear apart the sponge with tweezers and separate the animals from the sponge tissue. Keep the sponge pieces.
4. Fill the 10 ml graduated cylinder with 5 ml of tap water. Add the animals separated from the sponge tissue to the cylinder. Read the new volume and subtract 5 ml from this figure. The difference is the volume of animals living in the sponge sample. Record the volume of the animal biomass in your lab book.
5. Determine the volume of sponge biomass by squeezing the water out of the sponge. Place the pieces in 30 ml of water. The difference between the total volume and the original 30 ml is the volume of the sponge biomass.
6. Calculate the empty space within the sponge by subtracting the volume of the sponge biomass from the total volume in Procedure 2. c.
7. Make a count of each kind of symbiont. Write this data in Table 9-7.

Table 9-1. Sponge resident chart.

| Anima 1 | Number |
| :---: | :---: |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
| Total |  |

8. Draw the inhabitants of your sponge sample in your lab book.
9. Put all the animals in your vial and give it to your teacher.

## Summory Questions

1. How many types of animals live in the sponge from which you have taken a sample?
2. What is the volume of the total biomass of your sponge sample? What is the volume that the animals housed in your sponge can live in?
3. How do symbionts benefit from living in the sponge?

## Further Investigations

1. Obtain a termite and crush its abdominal region on a glass slide. The released intestinal contents should contain some symbiotic protozoans. Place a drop of methylene blue on the termite viscera and add a coverslip. Look at the slide under a 400 x microscope. Then draw each of the symbionts seen. Identify them by consulting available reference books. What kinds of symbionts are present, and why?
2. Prepare a slide, as in (1), of the intestinal contents of a large fish (e.g., tuna or mahimahi). Repeat the procedure used in (1).
3. Prepare a slide, as in (1), of your mouth's salivary contents. . Good material is found near tooth bases. Repeat the procedure used in (1) using an oil immersion microscope lens.

## 10. Free-living Morine Worms and Worm-like Anlmals

There are many different phyla in the marine worm group. All are bilaterally symmetrical. Marine worms make up a large part of the shallow water shore community and are found at all ocean depths. Most are benthic (bottom dwelling), but others are pelagic (open ocean dwelling) during part or all of their life cycle. Some marine worms are similar to earthworms in behavior and they crawl through the sand or mud. Other worms live on, in or with other animals and plants. Still others live under or are attached to rocks and coral.

Flatworms of phylum Platyhelminthes, Fig. 10-1, are the simplest of the worm groups. They have a head and a tail, although it is sometimes difficult to tell which is which. Occasionally you will see a small, oval-shaped animal which often looks like a frilly colored piece of paper. This is probably a marine flatworm. Most flatworms are carnivores. The slit-like "mouth" and "stomach" are in the middle of the underside of the body, and since a flatworm has no intestine or anus, wastes must leave by the "mouth."


Fig. 10-1. Marine flatworm.

Members of the phylum Sipuculoidea (Fig. 10-2) are called peanut worms. Those of the phylum Echiuroidea are called sausage or spoonworms (Fig. $10-3$ ). Ribbonwarms belong to the phylum Nemertina (Fig. 10-4). Members of these phyla burrow in mud, sand, or rock. If you sort through a shoveiful of sand or crack open a rock taken from below the water line, you will usually find one of them. Ways to tell these phyla apart are: (1) peanut worms have tentacles, which can be retracted (pulled into the body); (2) spoonworms have a long tube (proboscis) which cannot be retracted; and (3) ribbonworms have a simple mouth opening. Members of these three phyla have a mouth, a digestive tract, and an anus. Peanut worms feed by catching food particles with their tentacles. Spoonworms secrete a mucous net and then pump water through their bodies, which draws small animals and plants into the mucous net. This net is then swallowed. Ribbonworms eat animal food they find in mud or sand.


Fig. 10-2. Marine peanut worm.


Fig. 10-3. Marine spoonworm.


Fig. 10-4. Ribbonworm.

The most common member of the phylum Annelida is the terrestrial earthworm. There are also many marine annelids (Fig. 10-5). All annelids are segmented and have a complete digestive tube. They have a well-developed ventral nerve cord, an anterior swelling in the head region. This is the worm's "brain." They also have a complete circulatory system.


Fig 10-5. Marine polychaete.

Economically, annelid worms are important as fishing bait and as a source of food. For example, in parts of the Pacific, the palolo worm is a delicacy. People in the U.S. are even experimenting with ways to fry, bake or make earthworms into bread.

Most marine annelid worms are polychaetes.
Polychaete worms have a pair of arm-like structures called parapodia on their body segments. The parapodia bear stiff bristles called setae.

The many different kinds of polychaetes are found in muddy sand, living coral, sponges, and algae. They are also found in and under rocks. Some are free-moving; others live in leathery, usually sandcovered or calcareous tubes.

Tubeworms feed by extending their feather-like tentacles from the tube and retracting them when food lands on them. Some tubeworms rum the food along grooves to the mouth. Free-moving polychaetes have a proboscis which they can evert (push out) from their mouths to catch prey. Often the proboscis is armed with small teeth or jaws at the tip. Fireworms have many stinging setae on each parapodium. These setae can easily penetrate a person's skin.

In this activity we will study the annelid Nereis, commonly called the clamworm. Nereis is a freemoving marine carnivore living in hotes or clam shells, hence its name clamworm.

## Activity

Draw and locate some of the internal and external parts of a marine worm.

## Materials

-1 clanworm (Nereis)
-1 dissecting pan
-6 pins
-1 razor blade
-1 glass slide with coverslip
-1 microscope (100X)
-1 dissecting microscope

## Procedure

1. Head
a. Look at the diagram of the head of a clamworm. (Fig. 10-6)


Proboscis retracted


Fig. 10-6. Dorsal view of head of a nereis.
b. Draw your worm's head.
c. Locate and label the anatomical structures numbered in Fig. 10-6.
2. Parapodia
a. Cut off a section of worm tissue so that it includes one parapodium with setae.
b. Make a wet mount of this tissue.
c. Observe and draw the tissue under the microscope at low power (40X). Draw the parapodium and setae (Refer to Fig. 10-7).


Fig. 10-7. Generalized parapodia with setae.
3. Internal Organs
a. Cut a cross-sectional slice of a segment of a worm tissue with a razor blade, as illustrated in Fig. 10-8.
b. Make a wet mount of the tissue cross-section and observe it under the microscope.


Fig. 10-8. Cut a segment from the worm.
c. Draw a cross-section of your segment. Locate the parts labeled in Fig. 10-9 on your worm.


## Fig. 10-9. Cross section of a marine worm.

4. Determine whether the dorsal and ventral blood vessels of worms are segmented.

## Summary Questions

1. What appears to be the functions of the proboscis and jaws of the clamworm?
2. In Fig. $10-6$, several structures on the first segment have been numbered. Which ones do you think might help sense the clamworm's prey?
3. What may be the advantage to the polychaete of having segmented bodies?
4. What may be the functions of the parapodia and setae?
5. What advantages may there be in having the blood vessel system found in procedure 4?
6. Fill in phylum Annelida on your Animal Phylum Comparison sheet.

## Further Investigations

1. Maintain one or several worms in an aquarium. Study their behavior and observe their feeding habits. Watch for food preferences.
2. Ask people familiar with fishing and at bait stores which worms are best as bait for local fish, or find out for yourself by going fishing.
3. Find out how long it takes different worms to build new burrows.

## References

Barnes, R. 1965. Invertebrate zoology. W.B. Saunders and Co.
Buchsbaum, R. 1974. Animals without backbones. University of Chicago Press.

Storer, T. and R.L. Usinger. 1965. General zoology. McGraw Hill.

## 11. Marine Bivalve Anotomy

The phylum Mollusca includes bivalves (e.g. oysters, clams), gastropods (snailis), and cephalopods (e.g. squid, octopus). Mollusca are bilaterally symmetrical with three features that distinguish them from other organisms. They have a specialized foot which they use for digging, grasping, and creeping. They have a mantle which encloses their internal organs and which secretes their shell. They have a radula, a horny, rasp-like structure, which is used for feeding.

In this topic we will study marine bivalves. Most marine bivalves are filter feeders. They use one siphon (tube) to take water, dissolved oxygen, and food particles into the body. A second siphon expels water and waste materials from the body. Radulas of marine bivalves are extremely modified and are not used for feeding.

The shape of the foot varies among marine bivalves. The clam's foot is large and spade-like and is used for digging burrows in muddy sand. By contrast, the oyster's foot is very small because oysters attach themselves to hard objects very early in life.

In some bivalves such as oysters, mantle tissue secretions form pearls around foreign particles which Todge between the mantle and shell. Pearls are an important marine resource.

Bivalves such as clams, oysters and scallops are valuable as food and make up a major portion of the marine invertebrate cash crop for the world. Except for the shell, bivalves can be eaten whole. When water becomes polluted with chemicals or disease
organisms, bivalves should not be eaten until harmful substances are flushed from their bodies.

## Activity

Observe the external and internal characteristics of a bivalve.

Trace the pattern of nutrient, waste and water flow through a bivalve.

## Materials

-1 clam
-1 scalpel
-1 dissecting pan or newspaper
-paring knife

## Procedure

1. Look at the outside of your clam. Examine it carefully from all angles and write in the correct part near the letters in Fig. 11-1. Table 11-1 defines these terms. The parts to be labeled are:

## Umbo

Anterior
Posterior
Lines of growth
c. $\qquad$
A. $\qquad$
B. $\qquad$ 0. $\qquad$


Fig. 11-1. Clam external features.
2. a. Position your clam on the dissecting pan and insert a paring knife between the valves.
b. Move the blade along the valve margin to cut the adductor muscles at positions $A$ and $B$ on Fig. 11-2. Then, 11ft the upper valve to expose the clam's interior anatomy.
c. Gently separate the mantle from the upper shell.
d. Draw two outlines of your clam.
e. Using your clam and Table 11-l draw and label the following parts on one of the outlines.

```
Hinge ligament Foot
Hinge teeth
Excurrent siphon
Incurrent siphon
Mantle
Gills
Palps
Adductors
```

3. Carefully cut away the gills to expose the rest of the internal organs.
4. Use your second clam outline and refer to Table 11-1 to draw in and label the following parts: incurrent siphon, excurrent siphon, palps, mouth, stomach, intestine, liver and anus.
5. Use different colored arrows to show the pathway of food, waste and water into, through, and out of the body of the clam that you drew.


Fig. 11-2. Clam-internal features.

## Table 11-1. Glossary

Adductors - Muscles which close the valves and keep them shut.

Anterior - The end of an organism where the mouth and principal sense organs are located. In bivalves, this end is closest to the umbo.

Anus - The exit opening from the intestines found at the posterior end of a bivalve. The anus opens into the excurrent siphon.

Excurrent siphon - A tube through which filtered water and waste materials are pumped out. It is dorsal to the incurrent siphon and opens to the posterior end of the bivalye.

Gills - Respiratory organs which remove dissolved $\mathrm{O}_{2}$ from water and also used for catching food particles.

Hinge ligament - A tough elastic ligament which connects the valves and opens them.

Incurrent siphon - A tube through which nutrients and oxygen-rich water is pumped in. It is ventral to (below) the excurrent siphon at the posterior end of the bivalve.

Intestines - The coiled part of the food tube extending from the stomach to the anus.

Lines of growth - Major concentric ridges which represent the shape of the animal at previous stages of development.

Liver -. A gland connected to the stomach. The liver produces digestive juices.

Mantle - The external opening to the stomach, located at the anterior end of the bivalve.

Palps - A lip-like structure which sorts out food material collected by the gills and transfers the edible food to the mantle. They are located at the anterior end of the bivalve.

Posterior - The end where the siphons are, farthest from the umbo.

Radula - A horny beak or strip containing teeth.
Stomach - a large pouch-like swelling in the food tube where food is stored and mixed with digestive juices.

Umbo - The smallest and oldest part of the bivalve shell. It is located near the hinge and is swollen.

## Surmary Questions

1. How does a bivalve filter feed?
2. What are three features which make mollusks different from other phylia?
3. What is the function of hinge teeth on the shell?
4. Fill in mollusca in the Animal Phylum Comparison Sheet.

## Further Investigations

1. If you have a live clam:
a. Remove one valve and roll back the mantle. Place the clam in a bowl of salt water. Slowly add a carmine dye solution to the posterior region of the gill using an eyedropper. Observe particle flow.
b. Remove a $3 \mathrm{~cm}^{2}$ piece of gill from your clam. Spread it out and pin it in a petri dish with a waxed bottom. Cover the gill with sea water. Add carmine dye solution, and watch the particle flow pattern under the dissecting microscope. Modify by adding water which has varying temperatures and salinities.
2. Grind and polish shells to make ornaments.
3. Visit a local mollusk culture station and write a report on its management.
4. Make something edible for the class using a mollusk. Some suggestions are clam chowder, clam fritters, and linguini (spaghetti with' clam sauce). Give your recipe to your instructor for a class recipe book.
5. Find out why bays and estuaries are good locations for oyster beds. Why are some bays and estuaries bad locations?

## References

Bolootian, R. and D. Heyneman. 1962. An 1llustrated laboratory text in zoology. Holt, Rinehart and Winston, Inc.

Buchsbaum, R. 1974. Animals without backbones. University of Chicago Press.

Sherman, I.W. and V.G. Sherman. 1970. The invertebrates: function and form. Macmillan and Co.

## 12. Head-Foot Mollusks

Cephalopods are mollusks. The term cephalopod means head-foot, aptly describing the squid, octopus, cuttlefish and nautilus which belong to this group. A characteristic of cephalopods is the foot, which has become specialized and divided into numerous arms.

Although cephalopods are mollusks, not all cephalopods have complete shells. The nautilus is an exception, having a complete well-developed shell. The squid has an internal remnant of a shell, called a pen, that looks like a thin sheet of clear plastic. A harder, more brittle plate, called a cuttlebone, is found in the cuttlefish. The octopus has no shell at all. Its only hard body part is its beak, a mouth part, but this is not a remnant of a shell.

The eyes of cephalopods are large. The deep water nautilus has the most primitive eyes. Other cephalopods have well-developed eyes which are somewhat similar to human eyes.

Although most cephalopods are of relatively small size, the giant squid is the largest of all invertebrates, reaching lengths of 15 meters (Fig. 12-1).


Fig. 12-1. Some cephalopods.

## Activity

Determine the internal and external features of squid.

Cook and eat squid.

## Materials

Per class:
-hot plate or frying pan
-1 can stewed tomatoes ( 16 oz )
-basil, oregano and bay leaves
-15 cm piece Portuguese sausage, sliced (80z)
-1 can chili beans ( 16 oz )
-1 onion, sliced

- paper plates, plastic forks
-15 cm square ziplock baggie
-liquid soap
Per team:
-1 thawed squid
-newspapers
-several paper towels
-dissecting microscope
- 1 razor blade
-3 test tubes with rack
-alcohol or carbon tetrachloride
-salt water
-soap
-1 glass slide


## Procedure

1. Read over the Summary Questions and keep these in mind as you begin this topic. Refer as needed to Fig. 12-2, Squid anatomy.

2. Lay squid flat on a newspaper with head, or anterior end, to the left and siphon facing up so that the ventral side is showng. See Fig. 12-3.
3. Reach under animal and remove pen from the dorsal side by grasping firmly with your fingers and pulling the pen free from the mantle.
4. Using a razor blade, cut the mantle from its anterior edge next to the siphon to its posterior tip. Do not cut into the internal organs.
5. Locate the structures listed below and describe their function(s). Sketch them in Fig. 12-3.
a. siphon
b. gills
c. pallial cartilage
d. ink sac
e. ovaries or testes
f. arms
g. fins
h. mantle
6. Observe features of a single sucker on the arm.
a. Cut off a 0.5 cm piece of arm and place on a glass slide.
b. View under the dissecting microscope.
c. Draw a single sucker in your lab notebook.
7. Remove beak.
a. Separate head from arms with a razor blade at line $A$ as shown in Fig. 12-3.

Fig. 12-3. Squid ventral view.
b. Pull out the beak. Wash and save it. Make a sketch of beak in your lab notebook.
c. Remove and place viscera in a plastic bag or newspaper. Give to the teacher or save for feeding aquarium organisms.
d. Wash the mantle and arms. Save.
8. Slice and cook the mantle and arms:

Saute the sliced Portuguese sausage and onion. Add tomatoes, chili beans and herbs. Bring mixture to a boil. Add sliced arms and mantles. Simmer until mantle turns white (2-3 minutes). Serve hot.

## Summary Questions

1. What are the distinguishing features of cephalopods? What features relate cephalopods to other mollusks? What features of mollusks are found in other phyla?
2. What is the primary food of the octopus? How does it locate, catch, and eat its prey?
3. How does the chemical compostion of the cephalopod's "ink" aid in protecting the squid?
4. Describe the jet propulsion of a squid.
5. List several specialized methods of escape (defense mechanisms) used by cephalopods.
6. How does an octopus differ from a squid? List differences.

## Further Investigations

1. Collect discarded food debris from around octopus dens. Identify the species used as food.
2. Design and conduct behavioral studies on octopuses.
3. Try different cephalopod recipes and different cooking methods such as boiling, baking, broiling and smoking.


## 13. Gastropod Shell Identification

Gastropods are the largest group of mollusks. Each species can be identified by the shell's distinct features. Most have a calcareous shell that protects the soft-bodied animal inside. (Some gastropods lack a shell or have a reduced shell buried in the folds of the mantle. Some examples are sea slugs and sea hares).

Most gastropods feed using a radula to scrape algae from surfaces or to grind up animal prey. They creep about on a flattened foot.

## Activity

Describe differences among gastropod shells. Construct a key using shell features.

## puterials

-3-5 gastropod shells

## Procedure

1. Using Figs. 13-1 and 13-2 identify the features that are listed there on each of your shells. Shell books contain similar and further information on how to identify shells. Unless you are very interested in shells don't learn the names of the features, merely use them to separate your shell types.
2. In the appropriate box on Table 13-1, check off the presence or absence of the features listed.

## Terms describing gastropod features.

A. Whorl - the distinct turns of the spire between sutures.
B. Sutures
C. Shoulder
D. Aperture
E. Lip spiral lines of the spire, where one whorl touches another.

- outer portion of a whorl.
- margin of the aperture.

Cana:

- tubular extension of the lip.
G. Callus
H. Notch

I and J.

- calcareous buildup on the inner lip of the aperture.
- indentation at the bottom of the shell beside the tip of the canal.
K. Umbilicus
L. Varices
- shell ornamentation
- small hollow at the base of shell.
- prominent raised ribs, caused by periodic thickening of the outer lip during shell growth.
M. Spire

Operculum

- part of shell from its apex (top) to the lowest whorl.
- plate that seals the aperture in many shells.


Fig. 13-1 Diagrams of two shells.

$$
\begin{aligned}
& \text {-1 } \\
& \text { (1) }-\underline{Q} \underline{\underline{Q}}
\end{aligned}
$$

3. Using your data sheet, construct a key so that you can identify your shells.

Table 13-1. Data sheet for gastropod shell identification.

$w$

## Summary Questions

1. List the differences among your shells.
2. What might be some advantages to gastropods in having various shell shapes?

Further Investigations

1. Join a malacogical association (shelt club).
2. On a local map, indicate gastropod habitats and seasonal fluctuations in population.

## References

Morris, $P$. 1966, Field guide to shells of the Pacific coast and Hawail. Houghton Miffilin and Co.

Quirk, S. 1972. Hawaiian seashells. Robert Boom and Co .

## 14. Growth of Mollusk Embryos

Mollusks, with over 100,000 different species, make up the second largest phylum of the animal kingdom and include both marine and freshwater species. Most marine snail embryos are not easy to observe or maintain, so freshwater snail eggs will be studted in this laboratory. The eggs are laid in a single clear, oval, jelly-like sheet called an egg mass. The young embryos can be easily seen under a dissecting microscope.

## Actiylty

Determine the stages in snał1 embryo growth and the rate of snail embryo development.

## Mater Ials

-snail egg mass
-single-edged razor blade
-small petri dish
-dissecting microscope
-metric ruler

## Procedure

1. Locate snall egg masses on the side of the aquarium and remove one by carefully scraping away the egg mass with a single-edged razor blade. Do not break the egg capsules as you remove the egg mass.
2. Put the egg mass in a small petri dish and cover the eggs with aquarium water. Using a felt pen, label the petri dish with the date the egg mass was put into it. Record this date on Fig. 14-1.
3. Observe the egg mass under a dissecting microscope.
4. Draw your egg mass in your lab notebook. Show the position of each egg in the mass.
5. Measure the longest part of each embryo in the egg mass in metric units. Measure the longest part of the embryo, not the egg. Determine the average embryo length for the entire egg mass and plot it and the date on Fig. 14-1 each day until the snails hatch.


F1g. 14-1. Growth of embryo chart.
6. Observe and draw one of the embryos each day. Label the drawing with the date.
7. If an embryo dies, cross out its number on your egg mass drawing.
8. Record or determine the following data.
a. Date experiment was initiated.
b. Original number of eggs.
c. Percent mortality.
d. Average rate of growth.
e. Date of first hatching.

## Summary Questions

1. What is the best way to measure growth increments in developing embryos?
2. Why do you think that only the average embryo length is plotted on the chart?
3. If some or all of your snail eggs died, what do you think caused their death?
4. On what day did the snail embryos first have shells?

## Further Investigations

1. Experiment with snail embryo development by setting up a series of small petri dishes, each with a snail egg mass in water of a slightly different temperature. Record data (as in Procedure 5). Make a graph showing growth rates for each set of eggs. Compare graphs.
2. Do the same experiment, but vary other factors. For example, add growth stimulants or growth depressants. Record data and make a growth chart for each set of eggs. Compare data.

## 15. Intertidal Zonation of Gastropods

Intertidal zonation reflects the ecological tolerances of organisms that live between the tides. The upper limit of their habitat is primarily determined by physical factors such as temperature and lack of water. The lower limit seems to be set by biological factors such as competition for living space and food.

Three local marine snails, the pipipi, the pupu, and the granulated drupe are found together in rocky intertidal areas.

It has been demonstrated experimentally that:

1. Two of these species live above the waterline and are resistant to drying.
a. One of the above waterline species lives farther above the water than the other and has a stronger mucous thread for securing itself to rocks.
b. The species with the weaker mucous thread becomes dislodged more often and must creep back up the rocks so it is located below the species with the stronger mucous thread.
2. The third species lives below the waterline and is a predator on the other two snails.

## Activity

Demonstrate which marine snail lives in the highest intertidal habitat, which lives in the middle, and which is the predator.

Table 15-1. Behavior of intertidal snails.

| Average trate To Retach 梳rker |  |  |  | py | $$ | $\frac{p e}{\mid T r i t} 2$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 25 ml |  |  |  |  |  |  |
| 50 ml |  |  |  |  |  |  |
| 75 m1 |  |  |  |  |  |  |
| 100 ml |  |  |  |  |  |  |
| Average Height <br> In 15 Minutes |  |  |  |  |  |  |

## Materials

-1100 ml graduated cylinder
-1 watch with second hand
-4 pipipi
-4 pupus
-4 drupes
-seawater
-1 small, shallow aquarium with about 3 mm of seawater and 1 partly exposed rock
-newspaper

## Procedure

1. Put three snails, one of each species and a rock in an aquarium. Fill with about 2 cm of seawater. Surround and cover aquarlum with newspaper or place in an empty room.
2. Fill a 100 ml graduated cylinder with 25 ml of seawater.
3. Place 9 marine snails, 3 of each species, into cylinder.
4. The moment they touch the bottom of the cylinder record the time.
5. Record the time when the first of each species reaches the $25 \mathrm{ml}, 50 \mathrm{ml}, 75 \mathrm{ml}$, and 100 ml marks on Table 15-1.
6. Run the experiment for about 15 minutes, then take the average height above the waterline for each species. Record on Table 15-1, Trial 1.
7. Repeat with same specimens, marking this under Trial 2, Table 15-1.
8. Uncover the aquarium and record where the remaining 3 animals are located on Table 15-2 under "position".
9. Gently push each of the three species in the aquarium. Estimate and record adhesion strength as "most, medium, least." Record on Table 15-2.

Table 15-2. Position and adhesion strength.

| Mollusk | Position | Adhes ion strength |
| :--- | :--- | ---: |
| pipipi |  |  |
| pupu |  |  |
| drupe |  |  |

## Summary Questions

1. Which species is the predator? Which lives farthest above the water? Which has the strongest mucous thread?
2. Examine the animals. What structure(s) prevent excess water loss in the two intertidal species?
3. Which intertidal species has the thickest and roundest shell? Why do you think it might have a thicker shell than the other species?

## Further Investigations

1. By experimentation or field observations, determine other local species that exhibit intertidal zonation.
2. Observe the differences in shells of the same species of intertidal mollusks from different habitats (e.g. protected shoreline vs. wavebattered coasts).
3. Set up experiments to determine temperature, dessication and salinity tolerances of intertidal mollusks.

## 16. Shrimp Anatomy

Glass shrimp along with lobsters and crabs are members of the phylum Arthropoda. More species of Arthropoda have been described than all other animals combined. The fact that $75-80 \%$ of all known anlmal species are arthropods is mainly due to the enormous number of insect species in the world (Fig. 16-1).


Fig. 16-1. Some larger crustacean arthropods.
Marine arthropods mostly belong to a group called Crustacea. Only one marine insect lives on the sea surface although insects, especially their young (larvae), are common in fresh water.

The numerous jointed appendages (body extensions such as legs) of arthropods are extremely variable in number and function. Many appendages are not involved in movement at all but are used for feeding, sensing, defense, mating or respiration.

Most Crustacea have developed hard, protective exoskeletons (outer shells). Crustaceans must molt
(shed) their exoskeletons before they can grow larger. During the molt, a larger exoskeleton is formed to allow room for growth.

Glass shrimp are small benthic crustaceans commonly found along the shoreline. The internal anatomy of the adult is easily studied because it is transparent. Young glass shrimp are also transparent, but the different parts of their internal anatomy are more difficult to see.

## Activity

Study the structures of a live shrimp and determine their functions.

Observe the behavior of a shrimp.

## Moterlols

-1 probe
-dissecting microscope
-1250 ml beaker half-filled with salt water

- paper towels
-2 living adult glass shrimp
-1 9 mm petri dish
-1 8" piece of sewing thread
$-1 \frac{1}{4}$ " piece of fish
-1 eyedropper


## Procedure

1. Place one shrimp in a petri dish containing a small amount of seawater so that it is lying on its side.
2. Place the shrimp under the dissecting microscope.
3. Every minute or so, fill the eyedropper with seawater and drop the contents on the shrimp so that its gills are wet.
4. Locate and label the following in Fig. 16-2.

## Body Parts

a. cephalothorax (the front section of the shrimp, including the head and middle or thorax)
b. abdomen (the tail section of the body behind the carapace)
c. $\frac{\text { antennules }}{\text { antennae) }}$ (branched first pair of
d. antennae (second pair of antennae)
e. stalked eyes (the eye's surface has many lenses and is called a compound eye)
f. carapace (a shield like structure covering the head and thorax)
9. rostrum (the extension of the carapace between the eyes)
h. walking legs (five pairs of leg-like appendages attached to the thorax)
i. swimmerets (leaf-like appendages used for swimming and for aerating gills and eggs, when present, attached to abdomen).
j. $\frac{\text { uropods }}{\text { merets) }}$ (paddle-like last pair of swim-
k. telson (tail or extension of last segment in the abdomen)


Fig. 16-2. Diagram of a generalized crustacean.
5. Fill the petri dish with water and examine the following internal organs of the shrimp dorsally under a dissecting microscope. Make a diagram and show each of the structures.
a. heart (an internal pulsating structure seen in the posterior region of the carapace)
b. stomach (large dark internal mass in midsection of the carapace)
c. intestinal tract (dorsal dark line run-
6. Look up through the bottom of the petri dish and locate the ventral nerve cord (a second dark tube running from head to tail).
7. Return the shrimp to its aquarium.
8. Observe the natural behavior of the shrimp. Fill the 250 ml beaker with salt water and add another liye shrimp. Hold the beaker up to a window and observe the shrimp.
a. Tie a small piece of fish on a thread and hang it halfway down the side of the beaker. What does the shrimp do? Note the action of the antennae, antennules and mouth appendages. How do they move? Record in Table 16-1.
b. How do the walking legs move?
c. Touch the shrimp with a probe until it moves its abdomen. Describe how the shrimp moves in Table 16-1. Observe how it defends itself.
d. Observe how the swimmerets move.

Table 16-1. Shrimp behavior.

| Structure | Behavior |
| :--- | :--- |
| antennae |  |
| antenules |  |
| feeding (mouth <br> bait movenent |  |
| walking legs |  |
| abdomen and |  |
| telson |  |

e. Add $1 / 2$ drop of food coloring to the water near the front of the animal. Note the dye pathway. Sketch it in Fig. 16-2.

## Summory Questions

1. What anatomical parts of the shrimp were used for:
a. swimming
b. eating
c. sensing food
d. defending itself
2. List the functions of the different appendages of the shrimp.
3. What might be the functions of the rostrum?
4. Describe respiration in shrimp. What are the structures used and pathways of respiration?
5. There are no veins in a crustacean, yet stores sell "deveined" shrimp. What anatomical part is removed when a shrimp is deveined?
6. How do arthropods grow in size?
7. How does the location of the nerve cord of arthropods compare with that of vertebrates?
8. What is the difference between a simple eye (such as a vertebrate eye) and a compound eye of the arthropods? Use reference books to find out the answer.

## Further Investigations

1. Compare the anatomy of the following: crab, lobster, ant and bee.
2. Make a report on the culture or catching of shrimp, crab, or lobster. Compare the shrimp and prawn industry in this state and other states.

## References

Buchsbaum, R. 1974. Animals without backbones. University of Chicago Press.

Edmondson, C. 1946. Reef and shore fauna of Hawaii. Bishop Museum Special Publication \#22.

Storer, T. and R.L. Usinger. 1965. General zoology. McGraw Hill.

## 17. Behavior of Crustaceans

Crustaceans exhibit the greatest variety of behaviors of all marine invertebrates. Many of these behaviors can be observed in the laboratory if one is patient enough. Some behavior, however, is almost instantaneous because the animal must quickly perform it to survive.

In this activity we will experiment with two crustaceans, the hermit crab and the snapping shrimp.

## Activity A

Observe the behavior of hermit crabs as different numbers of animals and shells are placed in a small area.

## Background

Only the front part of the hermit crab's body is enclosed in a hard carapace. It's soft abdomen is protected by an empty mollusk shell (Fig. 17-1). When a hermit crab grows too large for its shell it must find a larger, empty shell.

## Materials

```
-6 adult hermit crabs
-bunson burner
-tweezers
-2 petri dishes with seawater
-6 shells of varying sizes and shapes
-4 colors of nail polish
-paper towel
```


tig. 17-1. Hermit Crab.

## Procedure

1. Remove four hermit crabs from their shells using a small flame.
a. Place seawater moistened paper towels for the hermit crabs to fall on.
b. Heat the apex of the shell holding it with tweezers until the crab emerges from the shell.
2. Mark the hermit crabs.
a. Mark the large claw of each of 4 hermit crabs with a dot of nail polish. Each crab should be marked with a different color.
b. Place an upside down petri dish over the crabs until the polish is dry.
3. Place the shell-less hermit crabs in a salt water filled petri dish and let them "rest" for 5 minutes. Put a dot of color representing each crab on Tables 17-2 and 17-3 under the hermit crab 1, 2, 3, 4 column.
4. Label six empty shells $1-6$.
5. Place the two remaining unmarked hermit crabs with unmarked shells in a salt water filled petri dish.
a. Observe and test for 5 minutes.
b. Record the behavior on Table 17-1.
c. Return the hermits to the holding tank.

Table 17-1. Behavior of hermit crabs with and without she11s.


Table 17-2. Behavior shell-1ess hermit crabs.

| harait crab | $\begin{aligned} & \text { In shell at } \\ & \text { end of test } \end{aligned}$ | Tally <br> number of attemots to capture shelt |
| :---: | :---: | :---: |
| 1 |  |  |
| 2 |  |  |
| 3 |  |  |
| 4 |  |  |

Table 17-3. Behavior shell-1ess hermit crabs.
Enters Shall *

| Harmit Crab | 1 | 2 | 3 | 4 | 5 | 6 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| 1 |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |
| 4 |  |  |  |  |  |  | | $\mathbf{W}$ |
| :---: |

6. Place two marked hermit crabs without shells into a salt water filled petri dish.
a. Observe and test for 5 minutes.
b. Record the behavior on Table 17-1.
7. Place shell $\# 1$ into the petri dish with all four shell-less hermit crabs.
a. Observe what happens for 5 minutes.
b. Record the behavior on Table 17-2.
8. Place the other five unnarked shells into the petri dish with the three shell-less and one shelled hermit crab.
a. Observe what happens for 10 minutes.
b. Record on Table 17-3.
9. At the end of the period, put an " $x$ " in the box indicating the shell in which each hermit was found, e.g., if crab 2 was found in shell 3 put an "x" in the second row, third column of Table 17-3.

## Activity B

Observe how the behavior of snapping shrimp change as different numbers of animals and plastic tubes are placed in a small area.

## Background

Snapping shrimp ase. so called because of the loud noise they make when their large claw is snapped shut. There are often thousands of these small burrowing shrimp in coral, sandy or muddy areas. The crackling noises one often hears when swimming are caused by these tiny animals (Fig. 7-2).

## Materials

```
-10 snapping shrimp
-10 3 cm lencths of 1 cm diameter clear
    plastic tubing
    -small aquarium with salt water
```



Fig. 17-2. Snapping Shrimp.

## Procedure

1. Place 2 similar sized snapping shrimp in a small bowl filled with salt water. Record your observations for 5 minutes on Table 17-4.
2. Add a tube and record your observations for 5 minutes on Table 17-4.
3. Place 10 pieces of tubing into a small aquarium as in Fig. 17-3. Place 10 snapping shrimp in the aquarium and record the results on Table 17-5 after 10 minutes.
4. Repeat the experiment with the same animals and the tubes grouped together as in Fig. 17-4 below. Record on Table 17-6 after 10 minutes.

Table 17-4. Behavior of snapping shrimp.

| Snapping_Shrimp | observations |
| :--- | :--- |
| 2 animals |  |
| 1 <br> 2 tube and |  |



Table 17-5. Number of shrimp in each tube.


Table 17-6. Number of shrimp in each tube.

| Tubes in circle | Number of shrimp |
| :---: | :--- |
| 1 |  |
| 2 |  |
| 3 |  |
| 4 |  |
| 5 |  |
| 6 |  |
| 7 |  |
| 8 |  |
| 9 |  |
| 10 |  |



Fig. 17-3. Arrangement of plastic tubes.


Fig. 17-4. Arrangement of plastic tubes.

## Summary Questions

1. In the ocean what would happen
a. if there were too many hermit crabs for the number of shells?
b. if there were more shells than the number of crabs?
2. Do the number and size of shells affect the number and size of hermit crabs in a population?
3. How do shell-less hermit crabs behave when they find a shell?
4. There are 15 parallel tubes in a $\mathrm{m}^{2}$ area. Based on your experiment, how many snapping shrimp do you think would live in the area?
5. How would more or fewer tubes affect the number of snapping shrimp in a $1 \mathrm{~m}^{2}$ area?

## Further Investigations

1. Try various types of tubes as living places for snapping shrimp. Use other substrates such as small rocks, shells and the like. Write a report on the substrate preference of your shrimp.
2. Write a report on where different types of hermit crabs or snapping shrimp live. Do different kinds live in different places?
3. Present hermit crabs with different kinds of shells. Does a particular species prefer a certain type of shell?

## 18. Sea Urchins

Sea urchins are members of the phylum Echinodermata ("spiny skin"). All members of this phylum are radially symmetrical and usually divided into five parts or multiples of five. Shallow water echinoderms include several major classes. The most commonly known of four of these classes are sea urchins, sea stars, sea cucumbers and brittle stars. All of these animals have a water vascular system which is explained in this topic, a nerve ring and skeletons made of calcium carbonate plates from microscopic to visible size. Members of this phylum are entirely marine.

Sea urchins are herbivores and rasp algae from hard substrates with five tooth-like structures located on the ventral (oral) side of the body. The anus is on the dorsal side. They are protected by a hard test, or outer layer, composed of plates and armed with spines. See Fig. 18-1.

Most sea stars in Hawaii are carnivores. Although a sea star does not have teeth, it can still eat coral polyps and mollusks by pushing its stomach out over its prey and digesting it. After the prey has been digested, the stomach is pulled back in and the digested foods are abosrbed into the body. The mouth and stomach of the sea star are also located on the ventral (oral) side of the body and the anus on the dorsal side. See Fig. 18-2.


Fig. 18-1. Dorsal view of a sea urchin.


Fig. 18-2. Dorsal view of a sea star.
Brittle stars have long flexible arms which often break off if the animal is captured. The broken arm is left wiggling while the rest of the brittle star crawls rapidly away. Brittle stars are mainly nocturnal omnivores. See Fig. 18-3.


Fig. 18-3. Dorsal view of a brittlestar.

Sea cucumbers are cylindrical animals, having a mouth at one end and an anus at the other. Their mouths are surrounded with tentacles which may be used to rake in nutrient rich sand or extend into the water to catch food particles. Nutrients on or in the sand are digested in the gut and the sand is then expelled through the anus. See Fig. 18-4.


Fig. 18-4. Lateral view of a sea cucumber.
You have probably seen a cartoon where someone wearing suction-cup shoes walks up a wall and across the ceiling. Most sea stars, sea urchins, and sea cucumbers, but not brittle stars, have suction cups at the end of their tube feet. These cups are the terminal structure of the water vascular system (Fig. 18-5) which is used for locomotion and feeding.


Fig. 18-5. Water-vascular system of sea urchin.

Tube feet work in the following way: Water enters and leaves the radial canal through a sieve plate. The radial canal is connected to the tube feet and ampullae, which act like the bulbs of eye droppers. A valve connects the ring canal with an ampulla. When this is closed it prevents water from flowing back into the radial canal (Fig. 18-6).


Fig. 18-6. How the valve, tube foot and ampulla work.
When the valve closes and the ampulla muscies contract squeezing the ampulla, water shoots into the tube foot and extends it (Fig. 18-6b). When the tube foot's tube foot comes in contact with the substrate, the center of the tube foot is withdrawn, producing a vacuum. In operation it is much like a plumber's helper. Holding fast to a surface occurs due to a lower pressure inside the sucker than the water pressure outside on the edges of the tube foot. After the tube foot is attached, water is forced back into the ampulla (Fig. 18-6c).

## Activity

Observe how tube feet and spines work in the sea urchin.

## Materials

-1 aquarium or a large culture dish ( 20 cm wide by 10 cm tall)
-1 m of string
-l probe
-1 liter of seawater
-1 piece of cardboard
-1 spring scale
-1 live sea urchin
-assorted debris

## Procedure

1. Place a sea urchin in your observation aquarium and cover with seawater.
a. Look for the thin tube feet extending out of the spines onto the glass. Observe how they attach and detach from the glass surface.
b. Observe if there is a difference in the extended length of tube feet in various regions in the sea urchin.
2. Perform the following test and record results in Table 18-1.
a. Touch the urchin lightly with a probe in the following places: tube feet, single spine, several spines, body. After each probe let the animal relax. Record the results in Table 18-1.
b. To produce rapid light changes, wave your hand or a piece of cardboard over the urchin. Record the action of the spines and tube feet in Table 18-1.
c. Turn the urchin upside down and observe. Record what the spines and tube feet do in Table 18-1.
d. Place urchin in center of aquarium. Provide a current around the urchin by moving your hand clockwise through the water. Record the movements of the spines and tube feet in Table 18-1.

Fig. 18-1. Sea urchin behavior.

|  | Fesponse |
| :---: | :---: |
| Arint touched <br> -tuba fort |  |
| -single spint |  |
| -tent |  |
| -savarti splins |  |
| Rapid 11 ifht chengat -splmes |  |
| -cube feat |  |
| Inverted andinal $-4 p 1$ mus |  |
| -tube feet |  |
| Wetar Current -spirint |  |
| -tube fent |  |

W
3. Measure the holding strength of different sea urchins in the following manner.
a. Prepare a string bridle to hold the urchin by tying two strings together in the center.
b. Place this bridle about the urchin as shown in Fig. 18-7.
c. Return the bridled urchin to the observational aquarium and allow it to reattach itself to the bottom glass surface.
d. Attach a spring scale to the bridle for measuring the urchin's adhesive strength (see Fig. 18-8).


Fig. 18-7. Diagrams of string bridle and its use on sea urchin.
e. Slowly pull on the spring scale until the urchin releases. Record total holding strength of your urchin in your notebook.
f. Place the urchin back on the bottom glass of the observation aqurium. Let the urchin rest for five minutes, then repeat Procedure 3. Record the adhesive strength of the second trial.


Fig. 18-8. Diagram of sea urchin in bridle being measured for holding strength.
g. Determine the average strength of the urchin. How would you do this?
4. If a debris-collecting urchin such as Tripneustes is available for aqurium observation, notice which objects are transported onto its dorsal surface. Try different kinds of objects of various sizes. Exampies are listed in Table 18-2.

Table 18-2. Debris selection.

| Kinds of Objects | size | Selection <br> (+ or + ) |
| :---: | :---: | :---: |
| algae |  |  |
| coral rubble |  |  |
| sand |  |  |
| paper towel bits |  |  |
| sticks |  |  |

## Summory Questions

1. Explain with words and diagrams how the tube foot works.
2. Explain with drawings and labels how a suction cup works.
3. Where would you expect urchins with long brittle spines to live? Where would urchins with short, thick spines live?
4. How does a sea urchin right itself when upside down?
5. If you have eaten echinoderms, which kinds and what parts have you eaten?
6. From your observations, do you think that sea urchins can sense light changes?
7. Can sea urchins sense water movement?
8. What are the possible advantages of debris collecting by some kinds of sea urchins?
9. If we had to hang by our hands from a bar, we'd get tired in a very short time. We might possibly be able to hang on for $10-15$ minutes. Yet most echinoderms hold to objects for long periods of time. Why do you think they can hold on for a long time?
10. Review your observations in testing holding strength. What other variables should be taken into account in holding strength calculation in this experiment to arrive at a more exact result?
11. Fill in the Animal Phylum Comparison sheet.

## Further Investigations

1. Determine the holding strengths of urchin species on a given reef. Draw an aerial map of this area and locate each species. Include in your report a discussion of the relationship of the urchin's natural habitat to its ability to hold on and not be tossed about by waves.
2. Do tube feet regrow? Design experiments or make observations to determine the answer.
3. Dissect and study the urchin's water vascular system. Make a model of this system for class.
4. Measure the length of the spines in different populations of sea urchin species and relate this to the habitats in which they are found.
5. Make a working (mechanical) model of the tube foot/suction cup system.
6. Investigate the toxic properties of sea urchin spines and pedicellaria in the literature and make a report.
7. Make a study of debris selection by different urchins.
8. Use a key to identify urchins for your class collection.

## References

Buchsbaum, R. 1974. Animals wi thout backbones. University Chicago Press.
Edmondson, C. 1946. Reef and shore fauna of Hawaii. Bernice P. Bishop Museum Press.

Storer, T. and R.L. Usinger. 1965. General zoology. McGraw Hill, Inc.

## CHAPTER 5

## WAVES

Waves seem to change color and form endlessly. On a beautiful summer's day, beach-goers are entranced by their rhythmic sound and motion. Further out to sea, surfers watch these same waves trying to catch the longest and best rides possible. Boaters and divers too may be studying these waves -- but for far different reasons.

Waves can become violent and destructive. Waves may take the lives of hapless swimmers who do not understand rip currents, or it may take the lives of tens of thousands when a coastal town is unexpectedly struck by tsunami waves which are generated by distant or local earthquakes in the ocean.


## 1. Waye Watch

In this topic, we will study where waves come from, how they are formed, and how they behave.

Activity
Observe and describe waves.

## Procedure

1. Read the list of suggested observations in Table 1-1.
2. Go to a safe vantage point at your favorite beach or surfing spot. Sit quietly and watch the waves.
3. After watching the waves, record your observations.
4. In class, share your observations and opinions. Also describe things you noticed which are not included in the suggested observations below.

Table 1-1. Suggested observations.

1. What shapes do waves have? Sketch the shapes of the waves you observe.
2. How do waves change in shape and size as they come toward shore?
3. In what directions do waves move? Is there a pattern to their movement? At
what angle(s) do waves approach the shoreline?
4. What colors are waves? How do colors vary in different types of waves?
5. How do waves compare in height? Where in relation to the shore are the largest waves found? Do the largest waves always form at the same place?
6. Are the waves arriving on shore always the same height? If not, is there any pattern in how the wave heights change?
7. How many times do waves break before they reach the shore? Do all waves break at the same place? Do they all look the same as they break?
8. Close your eyes. Describe the sounds and rhythms of waves as they approach and break on shore.
9. Look for protruding rocks, sea walls or offshore islands. How do these affect the waves?
10. Watch as waves break on sandy beaches, on rocks or on sea walls.
a. How high up on the shore does the water go when the waves break?
b. Where have the highest waves broken recently on the shore? Look for wet areas, for marks on the sand, for litter or seaweeds which may have been washed onto the beach, for salt crystals on rocks, and for limpets and periwinkles on the rocks.
11. Is the tide in or out? Notice whether or not seaweeds or barnacles on rocks, walls or pilings are exposed. Observe whether waves advance up to the highest swash marks (marks in the sand formed as waves rush up the beach).
12. Watch the "advance and retreat" of waves on shore. How much of the water in a wave actually returns to the ocean? Are there times when the amount of water that rushes onto the beach seems greater than other times? When does this happen?
13. Notice the patterns formed in sand as waves advance and retreat. Look also for evidence of sand being sorted by color or size along the beach. Sketch your observations.
14. Notice the shape and slope of the beach. Does the beach slope gradually or abruptly to the sea? Does it have sudden step-like drops? Is the beach wider in some areas than in others?
15. Do waves advance evenly up the slope of the beach? Are there regular indentations, called cusps, along the beach where the waves advance farther up the beach?
16. Does the beach appear to be eroding or enlarging? Look for the presence of sandbars and spits. If a stream empties out on the beach, does it flow directly into the sea, or is the stream diverted or closed off by sand? How do waves seem to be associated with beach erosion or enlargement?
17. Observe how experienced swimmers, surfers, and boaters enter the water. How do they maneuver through waves? Are there any areas they seem to avoid? What are the areas like where they enter? What are the areas like that they avoid?

## 2. Wind Waves

Most waves are formed by wind blawing over water. As winds continue to blow, ripples form and grow into waves. Waves which are still growing under the force of the wind are known as wind waves. Factors which influence the formation of wind waves are duration, wind velocity, and fetch. Duration is the length of time that the wind blows over the water, or how long a storm has been "blowing." The average wind velocity, or speed of the wind in a particular direction, will determine the amount of energy imparted to the forming waves. Fetch, an old sailor's term, refers to the distance over which the wave is acted on by the wind.

Fig. 2-1 identifies typical beach features, some of which are affected by wave action.


Fig. 2-1. Profiles of a beach showing typical beach features.

## Activity

Simulate wind wave formation and movement and observe the effects of summer and winter waves on the leeward and windward sides of a simulated sand island.

## Materiols

-large, floor-type ripple tank, about
$1 \mathrm{~m} \times 2 \mathrm{~m} \times 12 \mathrm{~cm}$, constructed from boards
lined with 6 ml plastic sheeting (see Aquarium Reference)

- $\overline{4}$ liters washed sand, assorted grain sizes
$(2 \mathrm{~mm})$
-l variable speed fan or hair dryer
-metric ruler
-toothpicks


## Procedure

1. Assemble a large floor-type ripple tank or a plastic tide pool and fill with water to a depth of about 4 cm .
2. Simulate wind blowing over an open ocean in the large ripple tank. Use a variable speed fan to simulate a storm at sea.
a. Set up a high speed fan or hair dryer as shown in Fig. 2-2.
b. Position the fan so that it blows down at an angle of $10-30^{\circ}$ onto the surface of the water.. Turn the fan on to high speed.
c. Observe wind wave formation. Move around the ripple tank to find the best angle for observing the waves.
d. Compare waves at the beginning, at the middle, and at the end of the tank. Sketch your observations.


Fig. 2-2. Simulating wind waves in ripple tank.
3. Make a simulated sandy beach at one end of the ripple tank.
a. Form the sand into a gently sloping beach that rises at the far end to about 5 cm above the waterline.
b. Place toothpicks every 5 cm along the shoreline of the beach. The shoreline is where water and sand meet.
c. Sketch a profile view and an aerial view of the beach. Use the diagrams in Fig. 2-3 as a guide.


Fig. 2-3. Profile and aerial views of beaches.
4. Simulate the effects of summer and winter wind wave action on the beach in the ripple tank.
a. Begin by simulating winter waves. Turn the fan to high speed to generate short period wind waves which reach the beach.
b. Describe what occurs to the waves and to the beach as the wind waves reach shore.
c. After about 5 minutes, turn off the fan. Resketch the aerial and profile maps of the beach. Include in these sketches the waterline and toothpick locations. Use arrows to indicate the direction of sand movement.
d. Compare your "after sketches" with your "before sketches." Be prepared to describe changes in the beach.
e. Repeat procedures $b, c$, and $d$, this time simulating surmer waves. Begin again with a smoothly sloping beach. Turn fan on lowest speed.

NOTE: If you are unable to vary the fan speed enough to generate noticeably differ.. ent surmmer and winter waves, use a wooden paddle to generate summer waves. Rock it about once per second for summer waves and more energetically (about three times per second) for winter waves.
5. Simulate wave interactions on the leeward and windward coasts of an island.
a. Using the large ripple tank, place sand about $2 / 3$ way down the length of the tank to form an island. The island should be about 5 cm higher than the waterline and
narrow enough so that water can flow freely around all sides. Mark the shoreline with toothpicks.
b. Make accurate profile and aerial sketches of the island. Show its height, width, and the slopes of the beaches.
c. Turn the electric fan on high and adjust it to generate wind waves which travel to the island.
d. After 5 minutes, turn off the fan. Observe and sketch the effects of wind waves on the windward and leeward coasts of the island. The windward beach is on the side facing the prevalling winds and the waves they form. The leeward beach is on the opposite side of the island, or the side protected from the prevailing wind. A prevailing wind is the wind that is most common to an area.

## Summary Questions

1. Assume water closest to the fan is a storm center. In the open ocean, what do you suspect waves are like close to the center of a storm with high winds? How do these waves change as they move farther and farther away from the storm?
2. Using the terms wind velocity, duration, and fetch, what conditions probably existed at the place of generation of summer waves? When winter waves arrive at a beach, what are the probable wind conditions at the place of generation?
3. Compare a summer beach and a winter beach in terms of width, slope, and the formation of sandbars and sand dunes. Use sketches.
4. Describe the effects of winds and waves on shaping the windward and leeward beaches of an island. What statements can you make about erosion? On which side(s) of the island are sand dunes and sandbars not likely to form?
5. As waves interacted with the sandy beach, what happened to the sand? What evidence supports your observation?

## Further Investigations

1. Carry out a photographic study of beach changes that occur at a nearby beach site over a period of several months. Locate several favorable positions for showing the width and slope of the beach. Record the locations of their position so you can return to them. For each photo, record information on time of day and tide height. Try to get pictures showing effects of summer and winter waves.
2. Simulate sand dune formation and erosion. Set up a ripple tank. Keep it dry. Put sand into the tank. Using a fan to simulate the wind, observe the process of sand dune formation. Simulate various ways that dunes are eroded. Test ways that dunes can be protected from erosion.
3. Investigate local problems or issues related to the increased values of shoreline real estate and increased popularity of ocean sports that might involve construction of buildings or roadways along sand dune areas.

## 3. Woves, Currents, and the Shoreline

Most waves are formed by wind blowing over water. Wind waves in open ocean are called deep-water waves. As waves approach shallower coastal areas where the water depth is less than half the wavelength, the waves begin to touch the bottom and are then called shallow-water waves.

Shallow-water waves slow down, crowd together, and change directions as they travel toward shallower water. In Activity A of this topic, we will be observing some of the patterns formed as waves interact with sloping bottoms, underwater obstacles, and other shoreline features. In Activity $B$, we will study how waves form currents near shore and how waves and currents transport sand along a shoreline. Refer to the diagrams and information below as you carry out Activities $A$ and $B$.
-Simulate a parallel sandy beach by adding washed sand at one end of the ripple tank (Fig. 3-1a).
-Simulate offshore reefs or shorelines, sea walls, groins, or other features by using small pebbles, rocks, or other objects (Fig. 3-1b).
-Simulate a nomparallel beach with and without reef (Fig. 3-1 c-d).
-Simulate a bay or headland with and without an island by shaping sand into these forms (Fig. 3-1 e\&f).
-Simulate more rapidly deepening coastal waters by raising one end of the ripple tank.

-Simulate constructed features such as jetties, sea walls, and breakwaters (described below and illustrated in Fig. 3-2).

- Jetties are usually built in pairs extending into the ocean at the mouths of bays or at entrances into rivers (Fig. 3-2a).
-Breakwaters are constructed offshore, usually parallel to the beach or to the pattern of prevalent incoming waves. They are built to protect a beach, harbor, or anchorage from wave action (Fig. 3-2b).
-Sea walls are built at the shoreline separating land from water. They are designed like a vertical wall, a curved or sloping wall, or in steps. They are built to reduce shoreline erosion (Fig. 3-2c).


Fig. 3-2. Man-made shoreline features.

## Activity A

Determine relationships between shoreline features and the formation of various types of wave patterns.

## Background

In this activity, we will be looking at patterns formed by waves as they interact with the shoreline. Two of these patterns are radiating waves and parallel waves. Radiating waves move outward in concentric rings from the generating source. Parallel waves are sets of waves travelling together in the same direction with crests about equally distant from each other

Simulating offshore situations in a ripple tank, we will be looking for evidence of reflecied, refracted, converging, and diffracted waves. A reflected wave is formed by water bouncing off an object. A refracted wave is bent as parts of the wave touch the bottom. Converging waves come together creating a high waye which focuses
on a small area. A diffracted wave spreads out and decreases in height and energy. A diffracted wave may occur, for example, when part of a wave passes through a small opening in a reef.

## Materials

-wave tank, table-sized (about $1 \mathrm{~m} \times 1 \mathrm{~m}$ $\times 10 \mathrm{~cm}$ ), use cardboard strip taped together ( $10 \mathrm{~cm} \times 4 \mathrm{~m}$ ) or notched wood; line with 6 ml plastic sheeting or use plastic tide pool (see Aquarium Reference)
-1 paddle
-21 washed sand, mixed grain sizes ( $<2 \mathrm{~mm}$ ) 8-10 dense objects for use in simulating shoreline features (coral pieces, rocks, rubber stoppers, etc.)
-dye (food coloring)

## Procedure

1. Set up ripple tank and wave paddle.
a. Assemble frame to fit table top. Frame may be constructed of notched wood or of cardboard strips taped together with masking tape.
b. Line frame with plastic sheeting. Fold plastic as needed for smooth fit on bottoms and sides. Hold sheeting in place with clothespins or masking tape.
c. Fill tank with 5 cm of water.
d. Obtain a piece of wood almost as wide as the ripple tank for use as a wave paddle.

## Background

2. Generate parallel waves and observe water patterns.
a. Beginning with a smoothly sloping sandy beach, generate waves. Observe wave patterns forming as the waves interact with the beach. Make sketches of your observation.
b. Repeat, testing the effect of the steepness of the bottom. Raise one end of the table.
3. Determine how various types of topographic and bathymetric shoreline features affect the formation of wave patterns. Refer to Figs. 3-1 and 3-2 for suggestions on how to simulate features.
a. Change only one shoreline feature at a time. Make profile and aerial sketches before and after generating waves.
b. Generate waves for about 5 minutes.
c. Look for wave patterns. Sketch your observations, showing both wave patterns and how they affect the beach.
4. Label sketches. Indicate types of wave patterns using the terms reflection, refraction, diffraction, and convergence.

## Activity B

Study the formation of currents and how they are affected by shoreline features. Simulate the
movement of sand by waves and currents and determine how sand transport is affected by coastal features.

## Currents

A current is a flowing body of water. An ocean current is much like a river of water.

Longshore currents are currents which flow roughly parallel to the beach. Rip currents flow towards the sea. Rip currents flow to sea forming the typical pattern shown in Fig. 3-3. At the beach, the rip current usually begins when longshore currents flowing in opposite directions meet, turn and flow together back to sea. The rip current is strongest at its neck, where the currents merge and flow back to sea through a deeper channel. The strength and speed of the rip current dissipates as it heads out to sea where the channel widens and becomes shal lower.

As seen in Fig. 3-3, waves are usually flatter and choppier in the area of a rip current. Because the rip current often carries sediment with it out to sea, water in the rip current may appear Iighter colored than the surrounding water.

Eddies (plural for eddy) are the circular motion of water currents. The interaction of longshore currents and eddy currents with shoreline features produce nearshore circulation patterns.


## Sand Transport

Sand transport refers to the movement of sand by waves and currents. Sand grains are moved by both waves and currents. We have already simulated summer and winter waves and studied their effects on a gently sloping sandy beach. Depending on how waves and currents interact with shoreline features, sand may be carried away from some beach areas and deposited elsewhere.

The study of these interactions contributes to understanding the process of beach erosion and build-up. Although beach erosion is normally viewed as a problem, beach sand build-up can also be a problem as, for example, when sandbars block boat channels or sand deposits fill in harbors.

As sand is moved by waves and currents, it is sorted by size and density. Knowledge of this sorting process is useful in trying to understand such beach formations as sand dunes, sand bars, and spits. A spit is like a curved sandbar, but usuatiy connected at one side to the beach.

In this activity, we will be studying how waves interact with shoreline features to form tongshore currents, rip currents, and eddy currents. Currents are usually not easily seen in a ripple tank. Sand transported by the currents is a good indication of net water flow near the bottom. The movement of floating semi-submerged objects likewise may indicate the presence of surface currents. A drop of dye in the water will help to follow currents.

## Materials

## As in Activity A.

## Procedure

1. Set up ripple tank.
2. Generate parallel waves. Observe the movement of sand or other objects that shows the presence of currents.
a. Begin with a smoothly sloping sandy beach and generate waves for about 5 minutes. Look for sand movement as evidence of bottom currents. Float pieces of paper on the surface and note their movements as evidence of currents. Place a drop of dye where currents are in evidence. Make both aerial and profile sketches. Use arrows to indicate current directions.
b. Test the effect of steepness of bottom. Raise one end of the ripple tank. Sketch your observations.
3. Determine how various types of shoreline features affect sand transport and the formation of currents.
a. Changing one shoreline feature at a time, simulate various types of shorelines. Refer to suggestions on simulating features.
Make aerial and profile sketches before and after generating waves for about 5 minutes.
b. Look for evidence of currents. Notice the movement of sand and other objects carried by waves or currents. Use arrows to indicate currents in your sketches.
c. Sketch the final location of sand. Look for evidence of sand sorting. Describe the sorting by sand color or size (fine, medium, coarse).
4. Label your sketches as follows:
a. Identify the types of currents you have observed (longshore, various types of rip currents, eddy).
b. Label the types of sand features and processes using the terms sand transport, erosion, build-up, sandbar, and spits.

## Summary Questions

1. How can longshore currents or rip currents affect swimmers? How would swimmers know they are in a current? What should swimmers do?
2. What effects do offshore islands or submerged reefs have on the waves which arrive on a beach? Which parts of the beach seem to be the most protected from waves by these offshore features? Where on the beach behind such features do the highest waves appear?
3. How can you account for the observation that no matter what the direction of incoming waves, as they approach land they become more parallel to the shoreline?
4. If you were on an island with waves arriving from the North, what kinds of waves and currents would you observe at the southern part of the island? How would waves at the south end compare with waves and currents at the north end? How would this affect erosion at each end of the island?
5. How do sea walls and jetties affect waves arriving on a beach? How might these structures focus waves elsewhere along a beach?
6. What effects would sudden shallow areas (e.g., a concave shoreline) or sudden deeper areas have on incoming shallow water waves?
7. Discuss the following saying, "The points always draw the waves."
8. Some sailors can detect the presence of an island long before they can actually see it. How is this possible?

## Eurther Investlgations

1. At your favorite beach site, look for evidence of currents.
a. Notice whether swimmers tend to drift parallel or perpendicular to shore.
b. Study wave action for evidence of rip currents. Waves are smaller and choppier and rarely break in a rip current. How might this be explained?
c. Look for evidence of sand being transported out to sea in a rip current. The water may appear darker or lighter depending on the color and composition of the sand.
2. Make a study of currents at your favorite beach by plotting movement of objects. Report your findings to the class. Note: Use objects that will not be affected by wind.
a. Place various objects in the path of advancing waves. Use objects of various size, density, and color (beached seaweeds, plain or colored pebbles, or easily spotted debris may be used). Record observations on how these objects are moved by the waves.
b. On a day with little wind, release plastic bottles, coconuts, or other floating objects at various locations. Observe how these move over a period of an hour or more. Sketch their movement.
c. Obtain and release a small amount of fluorescein or other dye which will not harm the environment. Notice how the dye spreads through the water.
d. Ask lifeguards and others familiar with the area to tell you what they know about currents.
e. Prepare sketches showing the flow of water in nearshore circulation patterns.
3. Compare Polynesian stick chart patterns with ripple tank patterns. Stick charts are navigational aids for finding islands or atolls using the waves and stars as guides. Each shell (or pebble) tied to the chart represents an island and the zenith star which passes directly over a given island. Curved sticks on the chart represent reflected wave patterns. Navigators learned to recognize reflected waves coming back at them which interfered with the main series of waves.
a. Make your own stick chart based on ripple tank simulations. (Begin with a simple situation such as one island and one predominant wave pattern.)
b. Learn how a stick chart is used (a) as a teaching tool to train navigators and (b) as a navigational aid to locate islands without the use of a compass, a watch, or a sextant.

## REFERENCES

Bescom, W. 1964. Waves and beaches. Doubleday and Co., Inc. New York.

Bryan, E. 1923. Stick charts from the Marshall Islands. Hourglass Special Supplement.

Lewis, 0. 1972. We, the navigators. University of Hawaii Press. Honolulu, Hawaii.

## 4. Reproduciole toves

Scientists began to understand waves when they were able to generate reproducible waves and obtain accurate pictures showing the properties of the waves they produced. A variety of techniques, including photography, are used to study their properties.

In this investigation, we will generate waves of various sizes. These waves will travel in wave trains, groups of waves of the same wavelength. We will then make simple, but accurate pictures of the waves which can be used to measure wave properties, including wavelength, wave height, and wave speed (see Fig. 4-1 below).


Fig. 4-1. Wave profile.

## liaterials

-plastic tide pool (See Aquarium Reference) -construction paper ( 5 pieces, $2 / 3$ the length $x$ the height of the tank)
-meter stick

## Activity

Make pictures of wave trains generated in a wave tank and analyze them.

## Procedure

1. Set up your wave tank as shown in Fig. 4-2. Fill halfway with water.


Fig. 4-2. Classroom wave tank.
2. Tape a paddle guard across the top of the tank to limit the distance the paddle can move. Begin this activity with the paddle guard 4 cm from the backstop.
3. Generate waves by moving the wave generator paddle back and forth rhythmically. One back and forth motion is one pulse. Make two pulses every second for five seconds. Observe the waves you generate.
4. Make water-marked pictures of waves generated in the wave tank.
a. Obtain a sheet of construction paper approximately the height of the tank and $2 / 3$ its length.
b. Hold the construction paper lengthwise by its corners close to the back side of the tank and just above the wave level. See Fig. 4-3.


Fig. 4-3. Making a "water-marked picture."
c. Once the water is still, have your partner generate waves, two pulses per second.
d. Just before the first wave reaches the far end of the tank, dip the sheet very quickly in and out of the water. The watermarks on the paper show the pattern of the waves at the instant the sheet was dipped into the water.
e. Immediately, trace the profile of the waves in pencil.
f. Label the outline with (1) paddle guard setting (cm) and (2) pulse rate (pulses per second). See Fig. 4-4.


Fig. 4-4. Length and height analysis of watermarked wave picture.
5. Repeat Procedure 4, using the following combinations:
a. 4 pulses per second, paddle guard setting 4 cm .
b. 2 pulses per second, paddle guard setting 8 cm .
c. 4 pulses per second, paddle guard setting 8 cm .
6. Analyze each of the four water-marked pictures for wavelength and wave height.
a. Determine the wavelength. Draw a straight line connecting two adjacent crests. See Fig. 4-4. Measure the length of the line. Record wavelength above the line.
b. Determine the wave height. Measure the distance from the trough to the wavelength line. Draw a straight line from the trough to the wavelength line. Record the wave height beside the line.
c. Repeat steps above for the three other water-marked pictures.
7. Record your wave height and wavelength data in Table 4-1.

## Summary Questions

1. What relationships, if any, exist between the paddle guard setting, the distance the paddle is moved, and the characteristics of the waves produced? Use data in Table 4-1 to support your answers.
a. Does the distance the paddle moves increase, decrease, or not affect wave height?
b. How does increasing the distance the paddle moves change wavelength?
2. What relationships, if any, exist between pulse rate and the characteristics of waves produced? Use data in Table 4-1 to support your answers. .
a. Does the distance the paddle moves increase, decrease, or not affect the height of the waves?
b. How does increasing the pulse rate change the length of the wave?

Table 4-1. Effects of pulse rate and paddle guard setting on wavelength and height.


## Further Investigations

1. Determine the relationship between distance the paddle moves and wave speed and between pulse rate and wave speed. The speed of a wave can be calculated by mutliplying the wavelength (1) times the pulse rate (f). For example, if a wave has a wavelength of 10 cm and the pulse rate is $3 / \mathrm{sec}$., then
wave speed $=1 \times f=10 \mathrm{~cm} \times \frac{3}{\sec }=\frac{30 \mathrm{~cm}}{\mathrm{sec}}$
2. Compare the movement of one wave and of a wave train, or set of waves. Generate one wave and carefully observe its movement down the wave tank. Then, generate a wave train of 4-6 waves. Observe carefully the first and the last wave of the train.
3. Observe when progressive waves become standing waves. Progressive waves move lengthwise down the tank; standing waves do not advance but appear to move up and down in place. To do this, increase the number of pulses to 20 or 30 consecutive pulses or until standing waves are observed.
4. Analyze water-marked pictures showing wave interference patterns. Generate two sets of waves, one from each end of the wave tank. Determine what conditions produce cancellation. Cancellation results when waves have smaller crests or troughs than either of the component wave trains. What are the conditions that produce reinforcement or higher wave crests than those of the component waves?

## References

Bascom, Willard. 1964. Waves and beaches. Anchor Press. New York.

## 5. More About Waves

This topic will give you some of the basic principles which oceanographers and sailors use to predict what waves will do in the open ocean and what causes their formation.

## Activity

Read "More About Waves" and answer the questions.

## 1. Description of Waves

A profile of a simple water wave is shown in Fig. 5-1. The highest part of a wave is its crest, the lowest part its trough. Wavelength is measured from crest to crest or trough to trough. The crest and troughs of a wave usually move in one direction. Different waves may have different speeds or velocity. Most ocean waves move at 20-40 miles per hour, and certain kinds move as fast as a jet plane. The time it takes for a wave, measured from crest to crest, to pass a point is its period.


Fig. 5-1. Profile of a simple water wave.

By counting the number of waves that pass a fixed point in a given length of time we get wave frequency.

## Terms and Symbols

a. Still water level: water level when surface is flat and smooth with no waves. Still water level is slightly lower than halfway between the crest and trough because crests are usually steeper and narrower than the troughs.
b. Crest: the highest point of a wave.
c. Trough: the lowest point of a wave below the still water level.
d. Wave height $(H)$ : the vertical distance from crest to trough.
e. Wavelength (L): the horizontal distance from crest to crest. ( $\mathrm{L}=$ meters/wave)
f. Wave period ( $P$ ): the time it takes for one complete wave (from crest to crest) to pass a fixed point. Wave period is expressed as seconds per wave ( $P=\mathrm{sec} /$ wave).
9. Wave frequency ( $F$ ): the number of wave crests that pass a fixed point per unit of time, usually minutes ( $F=$ number of waves $/ \mathrm{sec}$ ).
h. Wave velocity (V): the speed of the wave in a certain direction expressed as distance per unit of time ( $V=$ distance $/ s e c$ ).

## Quantification

We can calculate the velocity of a wave from the length and period using the formula $V=L \div P$.

We can demonstrate this by substituting the equivalent of length and period into the formula.

Thus, $V=$ distance/wave $\div$ time/wave $=$ distance/wave $x$ wave/time $=$ distance/time. Knowing a wave has a length of 20 m per wave and a period of 4 sec per wave we can calculate the velocity as follows:

$$
V=\frac{20 \mathrm{~m}_{\mathrm{i}}}{\text { wave }} \times \frac{\text { wave }}{4 \mathrm{sec}}=5 \mathrm{~m} / \mathrm{sec}
$$

## Questions

1. A wave has a length of $24 \mathrm{~m} /$ wave and a period of $4 \mathrm{sec} /$ wave. What is its velocity?
2. A wave has a velocity of $30 \mathrm{~m} / \mathrm{sec}$ and a period of $20 \mathrm{sec} / \mathrm{wave}$. What is its length?
3. Demonstrate that a correct formula for wavelength is $L=V \times P$.
4. The velocity of another wave is $4.2 \mathrm{~m} / \mathrm{sec}$. Its length is 12.6. What is its period?
5. Demonstrate that a formula for period is

$$
P=\frac{L}{V}=L \div V \quad P=L \div V
$$

6. The frequency of a wave is . 2 wave/sec. What would be the period?
7. Demonstrate that the formula for frequency is $F=1 / P$.
8. What is the frequency of a wave with a period of $.1 \mathrm{sec} / \mathrm{wave}$.
9. Demonstrate how you would find the velocity of a wave from its frequency and wavelength.
10. A wave print is shown in Fig. 5-2. Use this graph to answer the following.


Fig. 5-2. Wave print.
a. What is the height of the wave?
b. What is the wavelength?
c. Can you calculate the wave frequency from this information? If so, what is it?
11. The print in Fig, 5-2 was made of a wave moving to the right. When the first crest passed point $(x)$ the watch read 0.00 sec . When the second wave crest passed point ( $x$ ) the watch read 10.00 sec .
a. Which lettered crest passed point (x) first?
b. What is the period of the wave?
c. What is the velocity of the wave?
12. What is the meaning of the following terms?
a. period
b. wavelength
c. speed
d. frequency
e. height
f. velocity
g. crest
h. trough
i. profile
2. Wave Energy

Ocean waves are carriers of huge amounts of energy. The energy of a wave is its ability to do work such as moving objects. The vast energy of waves also cuts the faces of sea cliffs, builds and carries away beaches, and grinds great boulders into pebbles.

Energy comes in many wave forms, heat, electricity, light, sound, and water all of which can be trans formed into work.

Ocean waves work when they break rock and carry sand away. They produce heat and sound when they slam into the shore. Further, they can drive generators to produce electricity, which then can be transformed into light.

We can measure the amount of energy in joules (J) of work, or kilocalories (kc) of heat, or kilowatts hours (kwh) of electricity, and each can be equated with the others. For our purposes we will use the joule (J). One joule is the energy needed to lift about 1 kg of matter one meter at sea level. The same amount of energy is produced if the matter falls back to the point from which it started.

The amount of energy in a wave depends on its height. The higher a wave, the more energy it releases when it falls back to sea level. Comparing two waves, if one has double the height of the other, the increase in energy per square meter of wave surface will be 4 times as much as the other. Energy per square meter is proportionate to the square of the height (see Fig. 5-3).

In comparison, one gallon of gasoline produces about $160,000,000 \mathrm{~J}\left(1.6 \times 10^{8} \mathrm{~J}\right)$ of energy. This
is equal to 44 kilowatt hours of energy, the energy consumed by an average Anerican home each day. That same $1.6 \times 108 \mathrm{~J}$ is equal to the energy of a wave which has a surface area of about 32,000 square meters and is 2 m high.

Calculation of the number of square meters of wave surface needed to produce a given amount of energy can be made using Fig, 5-3. For example, a 2 m high wave produces $5,000 \mathrm{~J}\left(5 \times 10^{3} \mathrm{~J}\right)$ of energy per square meter. Since we wish to find the number of square meters of surface area to produce 1.6 x 108 J , we divide as follows:
Surface area $=1.6 \times 10^{8} \mathrm{~J} \div \frac{5 \times 103 \mathrm{~J}}{\mathrm{~m}^{2}}$

$=3.2 \times 10^{4} \mathrm{~m}^{2}$


Fig. 5-3. Wave height and energy per $\mathrm{m}^{2}$ of wave surface.

## Questions

1. What is energy?
2. What is work?
3. What is meant by energy transformation?
4. What are some of the different forms of energy?
5. How can wave energy be transformed into electricity?
6. What is a joule?
7. From Fig. 5-3, how much energy is produced by one square meter of a 4 meter high wave?

## 3. Winds and Waves at Sea

Winds are the primary source of energy for waves. Light winds blowing over calm water ruffle the surface. As the winds continue to blow, ripples begin to appear which grow into waves.

Most ocean waves are produced by the force of the wind. The force of the wind is influenced by:

1. its duration, or the length of time it has been blowing,
2. its fetch, an old sailor's term for the distance over which the wind is blowing, and
3. its average velocity over the fetch.

Imagine that a wave tank is a large section of the ocean. A hair dryer represents the source of wind. It could be either a storm or an area of prevailing winds such as the "Prevailing Westerlies." We can then describe how wind-generated waves begin as ripples, become chop, grow to wind waves, and finally become swells.

Refer to Fig. 5-4 as you read what happens to waves as they develop and move away from the generating area.


Fig. 5-4. Developing wind-generated waves.

Aboard a ship, an observer might view the waves around the ship and describe the sea state as ripples, chop, swell sea, or storm waves. See Table 5-1.

Ripples form when local winds create pressure on the surface of the water; the air moving across the water causes frictional drag. Ripples are small, with heights averaging about 8 cm .

Table 5-1. Visual estimates of winds, waves, and sea conditions.

| BEAUFORT FORCE | $\begin{aligned} & \text { SEA } \\ & \text { STATE } \end{aligned}$ | DESCRIRED SEA CONDITIONS | ESTIMATED <br> WAVE HT. (m) | ESTIMATED WIND SPEED DESCRIPTION (knots) |
| :---: | :---: | :---: | :---: | :---: |
| 0 | st111 | Sea smooth and mirror-like. | . OB | Catm (0-1) |
| 1 | 4 | Scaie-like ripples without foam crests. | . 75 | Light air (1 - 3) |
| 2 | Aripples | Small, short wavelets; crests have a glassy appearance and do not break. | . 61 | Light breeze (4-6) |
| 3 |  | Large wavelets; some crests begin to break; foam of glassy appearance. occasiomal white foam crests. | 1.22 | Gentle breeze (7-10) |
| 4 | $\frac{9}{4}$ | Small waves, becoming longer; fairly frequent white foam crests. | 1.82 | Moderate breeze (11-16) |
| 5 |  | Moderate waves, taking a more pronounced long form; many white foam crests; there may be some spray. | 3.05 | Fresh breeze (17-21) |
| 6 |  | Large waves begin to form; white foam crests are more extensive everywhere; there may be some spray. | 4.27 | Strong breeze (22-27) |
| 7 | \% | Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind; spindrift begins. | 5.49 | Near gaie (28-33) |
| 8 |  | Noderately high waves of greater length; edges of crests break into spindrift; foam is blown in well-marked streaks along the direction of the wind. | 7.01 | Gale (34-40) |
| 9 |  | High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple, tumble, and roll over; spray may reduce visibility. | 8.84 | Strong gale (41-47) |
| 10 | $\stackrel{*}{*}$ | Very high waves with long overhanging crests. The resulting foam in great patches is blown in dense white streaks along the direction of the wind. On the whole, the surface of the sea is white in appearance. The tumbling of the sea becomes heavy and shock-like. Visibility is reduced. | 11.28 | Stom ( $48-55$ ) |
| 11 | a Ef ¢ ¢ | Exceptionally high waves that may obscure small and mediumsized ships. The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Vistbility reduced. | 13.72 | Yiolent storm (56-63) |
| 12 |  | The air is filled with foam and spray. Sea completely white with driving spray; visibility very much reduced. <br> (Courtesy National sleather Service) |  | Hurricane (64-71) |

When the sea state is described as chop, local winds form short-period waves (2-5 seconds). Chop waves are not very high ( 0.1 m ). When these conditions are observed, winds may be increasing and the ship may be in or near a low-pressure (storm) center.

Swells are sets, or wave trains, of fully developed waves (waves which are no longer growing). They have travelled beyond the generating area. Swells with periods of 22-24 seconds, for example, were generated about 800 to 1,100 miles away. They may be formed by winds of short duration and high velocity blowing over a fairly large fetch. Or, swells may have been generated by prevaiting winds, such as the "tradewinds," which blow over long fetches for long durations. Swells may carry the energy of storms thousands of kilometers, for example, from the Antarctic to Alaska.

Storm waves begin to form when there are winds of strong gale force intensity, or more than 70 $\mathrm{km} / \mathrm{hr}$. The size of such waves may not be very high if the storm is of short duration, or if the fetch is short, or opposing waves already existing correct them. However, if several short duration storms follow each other and each blows in the same general direction, wave size may increase dramatically from $8-14 \mathrm{~m}$ and higher.

Hurricanes, called typhoons or tropical cyclones, are violent storms with winds exceeding $118 \mathrm{~km} / \mathrm{hr}$. They may form unusually large storm waves of over 14 m in height. A hurricane is a circular storm with winds sometimes up to $200 \mathrm{~km} / \mathrm{hr}$ generated over fetches extending 240 to 345 kilometers from the center of the storm.

Seas are a confused mixture of waves that are often observed from ships. Seas may contain rip-
ples, chop, wind waves, 5 torm waves, and swells. With careful observation each of these types of waves may be distinguished. Seas are characterized by waves that seem to be coming from many different directions and heights. See Fig. 5-5.


Fig. 5-5. Waves in a sea viewed from the deck of a ship.

## Questions

1. What are the factors that determine the size of waves?
2. Suggest a reason why the length of the fetch is important in wave size.
3. What are the two principle conditions under which swells are formed?
4. What role do ripples play in wave formation?
5. How might a hurricane force wind develop very large waves?
6. What is meant by the following terms?
a. swell
b. ripple
c. chop
d. sea
e. storm wave
f. hurricane
g. sea state

## 4. Organization of Waves

Open ocean waves are organized in a variety of ways including wave trains, cross seas, developing seas, and fully developed seas.

A wave train is a group of waves of about the same wavelength moving at about the same velocity. Ocean swells travel at relatively evenly spaced distances and are examples of wave trains.

Cross-seas are the interference patterns formed when two or more wave trains intersect each other. Waves may cross each other at different angles or they may come from the same direction but have different wavelengths and periods. Because of these differences, shorter waves may appear superimposed on longer waves (Fig. 5-6). Fig. 5-7 shows interference patterns photographed from a plane flying over the ocean.

Polynesian navigators knew the prevailing wave patterns in the Pacific Ocean. They were able to interpret them and get their position in the open ocean.

We have already seen that as winds continue to blow, small waves grow to larger waves. When waves

long swel
short swell- -
cross swell $\rightarrow \rightarrow$


Fig. 5-6. Superimposition of local swell on distantly generated long swell.


Fig. 5-7. Aerial photograph showing wave interference patterns.
are growing, the sea state is described as a developing sea.

Waves do not continue to grow indefinitely. When the waves have stopped growing, the sea state is described as fully developed sea. A fully developed sea is one where the energy supplied by the wind is equal to the energy lost in breaking waves. Table 5-2 shows characteristics of fułly developed waves for winds blowing at $18.5,37,55.5,74$ and $92.5 \mathrm{~km} / \mathrm{hrs}$.

Table 5-2. Characteristics of fully developed wind waves.

| Wind <br> $\mathrm{km} / \mathrm{hr}$ <br> Speed <br> $\mathrm{mi} / \mathrm{hr}$ |  |  |  |  |  |  |  | Average <br> Height <br> $(\mathrm{m})$ |  |  |  | Wave Characteristics <br> Length <br> $(\mathrm{m})$ | Velocity <br> $\mathrm{km} / \mathrm{hr}$ | $\mathrm{mi} / \mathrm{hr}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 18.5 | $(11.5)$ | 0.27 | 9 | 11.2 | 18 |  |  |  |  |  |  |  |  |  |
| 37 | $(23)$ | 0.76 | 33 | 18 | 29 |  |  |  |  |  |  |  |  |  |
| 55.5 | $(34.5)$ | 4.3 | 77 | 29 | 47 |  |  |  |  |  |  |  |  |  |
| 77 | $(4.6)$ | 8.5 | 136 | 40 | 65 |  |  |  |  |  |  |  |  |  |
| 92.5 | $(57.5)$ | 14.6 | 212 | 49 | 79 |  |  |  |  |  |  |  |  |  |

Wind speed tells only part of the story. Remember it takes time to make fully developed waves. To become fully developed a wave must be pushed by the wind over a long fetch. Table 5-3 shows how long a time and how long a fetch is required by winds at the same speed to produce a fully developed sea.

Ocean engineers have been able to determine probable wave size for winds of given velocity, fetch and duration using wave tank simulations. Table 5-3 for example, shows that if winds of 40 $\mathrm{km} / \mathrm{hr}$ blow 10 hours over a fetch of 140 km , then the seas would develop to an average wave height of 1.6 meters ( 5 feet). About $10 \%$ of these waves will be twice as high (about 3,0 meters).

Marine forecasts issued by the National Weather Service include reports of offshore swell heights and predictions of changing winds and sea states. Predictions are also made of the time of arrival and the approximate size of large waves generated by storms at sea. Coastal areas can thus be warned in time to take precautions against unusually large, potentlally destructive storm waves.

Table 5-3. Limiting factors for mature maves and fully developed seas.

| Wind (limiting factors) |  | Probable Wave Size |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{array}{\|c\|} \hline \text { Velocity Duration } \\ \text { mi/hr } \\ \hline \end{array}$ | $\begin{gathered} \text { Fetch } \\ \mathrm{km} / \mathrm{hr} \mathrm{mi} / \mathrm{hr} \end{gathered}$ | Average meters | $\begin{aligned} & \text { Helght } \\ & \text { (fott) } \end{aligned}$ | hlghes meters | $t{ }_{(\text {feet })}$ |
| 18.5 | 18.5 (11.5) | 0.27 | (0,9) | . 55 | (1.8) |
| 37 | 140 (8.7) | 1.6 | (5) | 3.0 | (10) |
| 55.5 | 520 (323) | 4.3 | (14) | 8.5 | (28) |
| 74 | 1315 (817) | 8.5 | (28) | 17.3 | (57) |
| 92.5 | 2630 (1633) | 14.6 | (48) | 30.1 | (99) |
| * $1 \mathrm{kn} / \mathrm{hr}$ - 621 m/ |  |  |  |  |  |

The National Weather Service cooperates with the World Meteorological Organization in making weather charts and marine forecasts available to ships, planes, and coastal areas throughout the world. Ships and planes at sea cooperate in reporting wind speeds, sea states, and other weather data to centralized weather agencies. Additional weather information is obtained from weather satellites.

The surf zone is the area near the shore where waves break. How far from the shore a wave breaks depends on the length of the wave and the depth of the water. How a wave breaks depends largely on the steepness of the bottom slope, whether the slope is smooth or irregular, and whether the bottom is composed of shifting sands or solid rock.

Four types of breaking waves may be observed: plungers, spillers, surging breakers and a combination of the above.

Plunging breakers form where there is a steep sloping bottom. Plungers are high, forming tubes or curls that cascade water in a circular motion
downwards into the trough. Plungers break with a forceful crash, rapidly releasing energy. Air trapped inside the curl of the wave may "explode," forming geysers of whitewater as the wave collapses (Fig. 5-8).


Fig. 5-8. Plunging breakers.

Plungers breaking in shallow water can be very dangerous to swimmers because the waves literally pound against the coast. Surfers like the high speed ride they can get on a plunging wave as they drop steeply down the front of the moving wave with the chance of "getting locked in the tube." Body surfers sometimes catch rides on plunging breakers breaking in only a few centimeters of water.

Spilling breakers form where the bottom slopes gradually. Spillers advance to shore with a 1 ine of foam tumbling steadily down their front (Fig. 5-9). Unlike plungers, they break slowly over considerable distances. Surfers get their longest rides on spilling waves.


Fig. 5-9. Spilling breakers.
Surging breakers form when deep water waves suddenly hit bottom in shallow water. Surges look like walls of white water advancing towards shore (Fig. 5-10). These can be seen when deep water swells suddenly encounter submerged reefs.


Fig. 5-10. Surging breakers.

Waves may break more than once as they advance to shore. Each time the wave breaks it gives up energy forming into smaller, shorter waves which in turn break in shallower water.

Estimate the height of the surf using one of these methods:
a. Judge the relative height of the waves as compared to a surfer, a boat in the water, or some other reference. (If the surfer appears as long as your thumb and the surf about twice that, then the wave is about twice the surfer's height.) See Fig. 5-11.


Fig. 5-11. Diagram showing how to estimate wave height.
b. Walk down the slope of a beach until your eye is in line with the breaker and the horizon. Measure the vertical distance from your eye to the lowest point of the retreating wave at the edge of the beach. (See Fig. 5-12). This vertical distance is the wave height.


Fig. 5-12. Diagram showing how to estimate a two meter wave height.

## Questions

1. How many wave trains are shown in Fig. 5-6?
2. What happens to the size of waves when crests come together? When two troughs coincide? When a crest and trough of two waves coincide?
3. In Fig. 5-6 draw the profile of the waves along line $A$.
4. Why would the breaking of a wave result in a loss of energy?
5. Use Tables 5-1 and 5-2 to compare the following:
a. the speed of long waves with short waves.
b. the height of long waves with shorter waves.
c. the fetch required to produce a fully developed sea of short and long waves.
d. the characteristic conditions of waves produced by storm winds with those by light breezes.
6. What would be the frequency of the waves in Table 5-2?
7. What is meant by the following terms:
a. cross-sea
b. interference patterns
c. wave train
d. fully developed sea
e. developing sea
f. spillers
g. surging waves
h. plungers
8. The person shown in Fig. $5-12$ is 1.8 m tall. How high is the wave?

## 5. Tsunamis

A tsunami is a wave or series of waves produced by the sudden movement of a large volume of water in the ocean. Tsunamis are potentially the most destructive of all waves. Tidal wave, the popular name for these waves, is misleading because tsunamis are not caused by tides.

Most commonly, tsunamis are formed when large land masses suddenly rise or sink because of an earthquake. Volcanic eruptions and landslides may also generate tsunamis (Fig. 5-13).

A. Earthquake faulting causes part of the sea floor to drop rapidly. Water above the fault also drops, generating a series of seismic waves.

B. Volcanic explosions (or man-made nuclear explosion) raises the water level.
C. Large landslides into the sea displaces large volumes of water generating local damaging tsunamis.

Fig. 5-13. Diagrams showing large water displacements in the ocean (after Bascom).

Tsunami waves are usually no more than about 30 cm high with wave crests 120 to 720 km apart. Unlike wind-waves, tsunami waves extend down to the bottom of the ocean which has an average depth of 4,000 meters. They travel at speeds of about 700 km per hour and the fr periods range from 12 to 20 minutes. Because tsunamis are such long, deep, low waves, ships at sea do not notice tsunami waves passing by.

When a tsunami wave enters shallow water, it slows and grows in height. Like other waves, the form and height of the tsunami as it strikes shore depends on the shape of the bottom and on the direction from which it approaches shore. The tsunami may look like a gently rising tide which within 10 to 20 minutes floods low coastal areas. A tsunami may also form a turbutent, surging wave which travels to shore looking like a massive wall of water.

The height of a striking wave may vary considerably along a coastline. Some of the highest waves have occurred on headlands and in funnel-shaped bays.

Advance warnings of approaching tsunamis are given through the National Weather Service. The Pacific Tsunami Warning Center now monitors instruments around the clock for first signs of potential tsunami-generating earthquakes. When such an earthquake occurs, a tsunami watch is issued to all stations in the Pacific advising where the earthquake has occurred and that the possibility of a tsunami exists. The estimated time of arrival of the tsunami wave is then calculated.

Fig. 5-14 shows the reporting stations of the Pacific Tsunami Warning System and estimated
tsunami travel time to Honolulu. For example, a tsunami generated by an earthquake at Crescent City, California would take 5 hours to reach Honolulu.

Once there is evidence that a tsunami may have been formed, a tsunami warning is issued. Agencies like the Civil Defense alert the public, coastal residents are evacuated and other emergency actions are taken. In Hawaii, residents are alerted by a steady one-minute blast of a siren. Information is broadcast over radio stations advising which coastal areas to expect incoming tsunami waves and what action to take. Generally, potential danger areas for tsunamis of distant origin are those less than 15 meters above sea level and within one kilometer from the coast. For tsunamis of local origin, danger areas are less than 30 meters above sea level within one kilometer of the coast.

## Questions

1. Do all earthquakes cause tsunamis?
2. Is a tsunami a single wave?
3. Can a small tsunami wave arrive at one beach and a giant wave arrive a few miles away?
4. Where would a tsunami wave probably cause more damage- 100 km from the epicenter of an earthquake or 1,000 miles away?


Fig. 5-14. Tsunami warning system.

## CHAPTER 6

## MARINE PLANTS

Marine plants live in the ocean or along the shoreline. Those along the shoreline must be able to withstand ocean spray and periodic salt water flooding.

Whether they are seaweeds (algae) or flowering plants, marine plants have adapted to the ocean environment in many ways different from those of other plants.

In this chapter we will discover the uses and adaptations of marine plants and learn how to preserve and identify the common forms.


## 1. Water and Land Plants

## Activity A

List the differences between water and land environments.

List the differences between the plants that live in water and land environments.

## Activity B

Determine how abundant gas exchange holes (stomates) are on the surface of land and water plants.

## Background

Stomates are holes in the epidermis (surface layer) of leaves and blades of plants. They are entrances and exits for gases, including carbon dioxide, $\left(\mathrm{CO}_{2}\right)$, oxygen $\left(\mathrm{O}_{2}\right)$, and water $\left(\mathrm{H}_{2} \mathrm{O}\right)$. The most prominent feature of the stomate is the pair of guard cells which surround it and regulate its size (Fiq. 1~1). In this activity we will use a nail polish "cast" method for finding the number of stomates and their distribution on leaves or blades.


Fig. 1-1. Generalized drawing of stomates.

## Materials

-plant samples, land, fresh water and sea water (alga)
-2 slides
-4 coverslips
-1 grease pencil

- 1 small bottle of clear or pale-colored
fingernail polish
-1 forceps or toothpick
- paper towels
-microscope


## Procedure

1. With tap water, wash salt off surfaces of the leaf or blade of a land, fresh, and seawater plant. Pat with a paper towel and air dry.
2. Paint a thin patch of fingernail polish about $1 \mathrm{~cm}^{2}$ on the upper and lower epidermal surfaces of each blade or leaf. (Patches may be narrow and long on aquatic plants.)
3. Place leaves and blades so that the polish can dry wi thout touching any other surfaces. The dried polish will hold a cast, or impression, of the stomates.
4. Prepare slides of the polish casts.
a. When casts are dry, peel them off using the tip of the forceps.
b. Place casts from one plant in a drop of water on a slide as shown in Fig. 1-2. The side of the cast that touched the plant's surface faces upward.
c. Add a drop of water and coverslips. Label with a grease pencil as shown in Fig. 1-2.


Fig. 1-2. Placing polish casts on a slide.
5. Examine casts with a microscope.
a. Place slide on the microscope stage. Focus under low power, then turn to high power (100X). Stomates, if present, will resemble Fig. 1-1.
b. Draw and describe what you observe in Table 1-1.

Table 1-7. Stomate patterns and numbers at 100 X magnification.

| Plant | Lepat Epiderais | Lomprepidernis |  |
| :---: | :---: | :---: | :---: |
| Land Plant |  |  |  |
| Frush Weter Plant |  |  |  |
| 504 <br> Wtan Plant |  |  |  |
|  |  |  |  |

## Activity $C$

Test for the presence of a waxy waterproofing coat (cuticle) on land and water plants.

## Background

In land plants, water loss can be decreased by a waxy coat over the epidermis called the cuticle. In this activity, the Sudan IV staining method will be used to look for waxy cuticle layers on the epidermis of a land plant and a water plant.

## Materials - per 2 students

-plant samples--land, fresh water and seawater -1 dropper bottle of Sudan IV staining solution
-2 slides and coverslips
-1 new single-edged razor blade
-1 compound microscope

## Procedure

1. Cut land plant cross section directly on a glass slide. Your teacher can demonstrate the best technique, but the directions below should be helpful
a. Place 2 cm piece of leaf onto a glass slide.
b. Begin by putting an index finger on the material at a $45^{\circ}$ angle to the slide. Hold the razor blade in a vertical cutting position as shown in Fig. 1-3.


Fig. 1-3. Technique for slicing tissue.
c. Slowly lower index finger as you make rapid, thin cuts into the plant with the razor blade. When finished, your finger should be at the $25^{\circ}$ position shown in Fig. 1-3. Make 20-30 slices.
d. Select two or three of the thinnest, most transparent cross-sectional slices. Remove the other slices from slide.
e. Add 2 drops of Sudan IV stain. Cover with a coverslip.
2. Observe cross sections under low power magnification.
a. Look for cuticle on the lower and upper epidermis. If the cuticle is present, it will be pink or light red in color. Note any differences in the thickness of the cuticle.
b. Record your observations as drawings in Table 1-2. Label upper and lower epidermis. Darken stained areas.
3. Repeat directions 1 and 2 using pieces of fresh and sea water plant leaves and blades.

Table 1-2. Comparison of cuticle in land, marine, and freshwater plants.

| Plant | Drawing of Cross Sections |
| :--- | :--- |
| Land plant |  |
| Saltwater alga |  |
|  |  |
| Freshwater plant |  |

## Activity D

Test for the presence of a stiffening substance (lignin) in land and water plants.

## Background

Lignin is a material which makes plants stiff and woody. It does this by stiffening plant cell walls. Phloroglucinol stains lignin pink. In this activity we will test water and land plants for woodiness.

## Materiols

-plant samples, land, freshwater and marine. alga
-1 dropping bottle of phloroglucinol stain
-1 dropping bottle of 6 N HCl
-1 new single-edged razor blade
-2 slides and coverslips
-2 paper towels
-1 microscope

## Procedure

1. Prepare and stain a thin cross section of a land plant stem.
a. Cut 6 thin cross sections from a beach plant stem on a slide. Add 2 drops of phloroglucinol stain. Keep the stain on the tissues for 2 minutes. Remove the stain with the edge of a paper towel.
b. Use an eyedropper. Add 2 drops of 6 NHCl . (CAUTION: HCl will produce chemical burns. If any gets on your skin or clothing, immediately wash it off with a large quantity of water. Notify your teacher.)
c. Cover with a coverslip. Wait about 30 seconds.
2. Observe under low power magnification.
a. Look for tissue areas which stain pink. These contain lignin.
b. Draw your cross-section in Table 1-3. Show with arrows the structures that turned pink with this selective stain.

Table 1-3. Cross sections of land, fresh water. and marine plants.

3. Repeat Procedures 1 and 2 using a piece of algal stipe and piece of aquatic plant stem.

Summary Questions

1. Fill in Table 1-4. Use a (+) to indicate the presence of a characteristic and (-) to indicate the absence of a characteristic.

Table 1-4. Characteristics of plants.

| Plant | Stantens |  | Cuticle | Liqnin |
| :--- | :--- | :--- | :--- | :--- |
|  | Upper | Lower |  |  |
| Alga |  |  |  |  |
| Land plant |  |  |  |  |
| Fresh witer plant |  |  |  |  |

2. How might the presence or absence of these structures be related to the environment in which the plant is found?
3. Are land plants better prepared than algal for preventing water loss? Explain.
4. What advantages are there for a plant to have lignin? What disadvantages?
5. When stomates are absent, how does a plant get gases into its system?
6. When lignin is absent, how does a plant support itself?
7. When a cuticle is absent, how does a plant prevent water loss?
8. Predict what the long leaf of the Eucalyptus tree, which is found in a semi-desert area, would look like in regard to lignin, stomates and cuticle.
9. Read the following material and add this new information to answers to your Summary Questions 1-7. Also answer questions at the end of the reading.

## Controsting Environments

Land environments have more rapid dafly and seasonal changes and greater extremes
in those changes than do aquatic, especially ocean, environments. On land, for example, temperatures change widely from day to night and from summer to winter. In the ocean, by contrast, temperatures remain almost the same from day to day. Coastal land environments often have harsh, desertlike conditions in which plants are often dried by shore winds and airborn salt. By contrast, high salinities are a constant part of ocean environments, and ocean plants have adapted to the presence of dissolved minerals.

Plants living on land and in water reflect the differences between the environments in which they live. Some of these differences are listed in Table l-5.

Table 1-5. Contrasting environments for land and aquatic plants.

| $\begin{aligned} & \text { Environatental } \\ & \text { Fattor } \\ & \hline \end{aligned}$ | Terrertrial Plants | Water Plants |
| :---: | :---: | :---: |
| Wrter | Plants subject to denydretion from winds and salt spray. | Plants strrounded by wate |
| Temptrature | Terperatures fluctuatit widely. | Taperatures relatively comstant, changing showly |
| Gravitational 5tress | Plants have supportive 11 gnifited tissubs. | Water bucyancy supports plant. |
| Mutrient Supply | Hutrients obtained from soll via roots are transported to lenves. | mutrients dissoived in water and diffust through thellus. Mo ronts. |

## Land Plants

The flowering land plant has roots, a stem, leaves, and flowers as shown in Fig. 1-4. The vein of the leaf from a flowering plant contains xylem cells that function to transport water and minerals from the roots to the leaves and phloem cells that transport sugar from the leaves to other parts of the plants. Xylem and phloem cells are shown in Fig. 1.5 .


Fig. 1-4. Structure of a land plant (naupaka).


Fig. 1-5. Internal structure of a land plant leaf.

The xylem and phloem cells along with the strengthening lignified fibers form the vascular bundle.

Shown also in Fig. 1-5 is the epidermis, or cellular covering layer of the leaf, with openings called stomates. A thick, waxy noncellular cuticle over the epidermis protects the plant against drying. Stomates are holes in the leaf through which water vapor and air pass. The passage of these gases is regulated by a pair of guard cells, which close when they lose water and open when they are full of water. When the stomates are open, water vapor can readily pass out of the plant. When they are closed, it can't readily leave the plant. By this means the plant can conserve moisture.

## Algae

A typical alga (singular is alga, plural is algae) includes a blade, which is snmetimes broken up Into leaflets, a stipe, and a holdfast. Although it looks somewhat like a root, the holdfast is not a root because it has no vascular tissue for absorbing water from the soil although it secures the plant to the substrate. The stipe looks like a stem and connects the blade to the holdfast, but it has no vascular tissue, which is an essential feature of stems. A typical alga is shown in Fig. 1-6.

Algae are supported by surrounding water. Nutrients pass in from and waste materials pass into surrounding water.

The cuticle and stomates, which regulate water flow in and out of land plants, are not necessary in algae. Fig. 1-7 shows the internal structures of three different algal cross sections.


Fig. 1-6. Structure of a typical alga.


Fig. 1-7. Cross sections of three different algae.

Marine algal growth is limited by wave action, by predation from grazing animals, and by inadequate sunlight. Sunlight penetrating the water varies with the amount of algae present in the water and with the amount of turbidity (suspended solid particles in the water).

## Zonation

Zonation is easily seen in stationary shoreline and intertidal communities where bands of differing flora can be seen at a glance. Plant communities above the high tide level vary in their composition because of differences in substrate, climate, and species interaction. As shown in Fig. 1-8, the most common land flora are the seed-bearing, flowering plants. Only a few seed-bearing plants have entered the sea. The mangroves have partially entered the marine environment; the sea grasses totally. There are relatively few algae on land, and they are found only in moist areas.


Fig. 1-8. Exampies of coastal flowering plats.

Some marine algae and sea grasses live in the intertidal zone, probably the most difficult ocean environment in which to survive. The intertidal zone extends from the high to the low tide mark. Growth of plants in the upper part of the intertidal region is limited by the same factors that control the growth of coastal land plants: the daily exposure to dehydration, burning by the sun's rays, and temperatures which can change daily as much as $20-45^{\circ} \mathrm{C}$, especially on the surface of sand or rocks or in high tide pools. The few marine algae which live in the upper intertidal zone are either extremely hardy or fast growing. In the lower intertidal zone, algae are usually continuously surrounded by water, thus making them subject to the same kinds of population controls as subtidal algae (those below the tidal zone).

In Hawaii, most of the terrestrial seashore plants have been introduced to the Islands by humans, or as seeds carried in bird droppings or by winds and currents. Like algae, many of the local coastal flora can be used for food, compost, medicine, and decoration.

## Further investigations

1. Compare plants which are found in humid shade with plants that are found in dry, hot conditions.
2. Test for lignin in a variety of plants of different sizes and environments.

## 2. Seoweed: An Uncerused Resource

Seaweeds are large marine algae that are an important, although underused, resource for humans. Seaweeds have many uses. They are a food for humans and animals, a fertilizer or compost for agriculture, a source of medicine, and a source of many products for industry. For example, algin is one of the seaweed products used for making products like ice cream and toothpaste smooth and creamy.

Most seaweeds can be eaten raw, cooked or preserved. Although most seaweeds can be eaten raw, boiling softens them and takes out any bitter taste. How seaweeds are prepared for eating depends largely on cultural preferences.

As a human food source, seaweeds contain more vitamins, for example, than does processed rice. About three ounces of dried seaweed has more than the minimum daily requirements of Vitamins $A, B 1$, riboflavin, and B2, and half the requirements of Vitamin C (as defined by the U.S. Department of Agriculture). Seaweeds also contain other essential vitamins and minerals. Table 2-1 compares seaweeds with some other foods in selected nutrient content.

Table 2-1. Content of wet seaweed and other foods.

|  | Percentage per 100 Grose |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| [yphot fogt material | meter | Protetn | $\begin{gathered} 7 \\ \text { Fat } \end{gathered}$ | " hydrete | $\begin{aligned} & \text { :"Asht } \\ & \text { fibur } \end{aligned}$ | Cal/Lh. |
| Ulve [dried seamed] | 15.2 | 19.0 | 0.6 | 15.7 | 18.1 | 230 |
| Gractlinfat (met semmed) | 83.5 | 31.8 | 0.2 | 11.5 | 3.0 | 4 |
| Coding [-mt seamexa] | 92.9 | 1.0 | 1.8 | 1.8 | 4.4 | 11 |
| Whant breed enricrec | 31.6 | 6. ${ }^{\text {a }}$ | 1.2 | 57.1 | 4.5 | 282 |
| Rtre (cooker, polished) | 78.5 | 1.0 | 0.0 | 20.1 | 0.1 | 88 |
| coaked nocelies | 75.2 | 2.7 | 2.1 | 19.4 | 0.7 | 198 |
| Aol (frem tare planti | 83.0 | 0.6 | 0.1 | 16.8 | 0.1 | 5 |
| Mulles (fresh fisn) | 74.1 | 20.7 | 3.9 | 0.0 | J | 1.24 |

## Activity

Prepare several common seaweeds for eating.
Compare the nutritional values in seaweeds with values in other foods.

## Materigls

```
-3/4 1b. of fresh ogo (Gracilaria) (Fig. 2-2)
-1/4 7b. of fresh Codium
-4 beakers, 600 ml each
-3 hot plates
-4 tablespoons
-paper towels
-4 measuring cups
-4 knives
-4 forks or chopsticks
-ingredients for recipes given on the next page
    (shoyu, vinegar, sugar, garlic, hot sauce,
    chives, diced tomato, etc.)
```


## Procedure

1. Obtain $\frac{1}{2}$ bag of seaweed.
2. Wash plants thoroughly with tap water.
3. Get a clean 600 ml beaker
4. Fill the beaker with 300 ml of tap water. Boil the water.
5. Place seaweed in the boiling water. Cooking time to soften the seaweed is up to you. Test, as you would spaghetti. (Some people do not like to cook their seaweed and prefer to eat it raw.)
6. Follow the recipe assigned to your group. (See Table 2-2.)
7. After completing your cooking assignment and tasting the results, you might want to modify the recipe. Record your modifications.
8. Begin a class seaweed recipe booklet. Include recipes from this activity.

Table 2-2. Seaweed Recipes
A. Kim Chee Ogo (Korean Style)

1/4 Ib. ogo
1/2 cup shoyu
1/4 cup vinegar
1 tbsp. mirin (Chinese sweet vinegar)
ginger, grated (add to taste)
chili pepper, grated (add to taste)
garlic, chopped fine (add to taste)
Clean ogo and boil for a short time, just enough to soften the ogo, Drain. Mix the seasonings and add to the boiled ogo, (May be bottled and kept in the refrigerator.)
B. Kailua Ogo

1/2 cup red wine-vinegar
1/4 1b. ogo
1 tsp. sugar
1 tsp. chives (diced green onions)
1/4 cup diced tomato
hot sauce to taste
Follow the same directions as in the above recipe for Kim Chee Ogo.
C. Pickled Codium

1/4 1b. Codium
1/2 cup wine-yinegar
T/2 tsp, sugar
1/4 diced tomato
Clean Codium using only cold water. Add sauce to cleaned Codium immediately before serving. Codium toughens rapidly in the sauce. Better still, try using the sauce as a dip.
D. *Limu Tsukudani (Use on hot rice dishes)

1/4 1b. ogo
2 tbsp. brown sugar
1/4 cup mirin (vinegar)
1/2 cup shoyu (soy sauce)
T/4 tsp. MSG (monosodium glutamate)
Clean limu. Bring sugar, shoyu, and mirin to a full boil in a beaker. Place cleaned limu into the beaker with the sauce. Cook to a "mush." (Be careful that it doesn't burn; stir frequently.) Sesame seeds and chili pepper may be added to taste.
*Limu is the Hawaiian word for seaweed.

## Summary Questions

1. Why do you think a marine plant that you can eat is called a seaweed and not a sear vegetable? Why are seaweeds not popular as a human food in the United States?
2. When cooking seaweeds, how does heat affect their color? Why might this change occur?
3. Of the foods listed in Table 2-1, which is:
a. Highest in protein?
b. Lowest in fat?
c. The most balanced; carbohydrate, fat, protein?
d. Most calories?
e. Most ash and fiber?
4. Is water considered a food? Explain your answer.
5. Which recipe was the most popular with your class? Why? How does individual food preference or taste affect the popularity of a recipe?
6. Define the following terms. Use references to look up the terms.
a. seaweed
b. protein
c. fat
d. carbohydrate
e. ash
f. Kcal
g. minerals

## Student Reading

## How Useful Are Seaweeds as a Source of Food?

Most seaweeds can be eaten, but some are more commonly eaten than others. However, seaweeds which contain calcium deposits are generally not edible. A few of the most commonly eaten seaweeds are described in the sections which follow.

Nori, one kind of dried seaweed, is popular in in Japanese and Chinese cooking. Sheets of dried seaweed are wrapped around rice, making a popular
dish called sushi. Dried seaweed is also used in soup and meat dishes to add flavor and color. West Coast American Indians and Eskimos used this seaweed as a source of salts and trace eiements in their diets.

Nori, is usually made from collected and dried Porphyra species (also called red laver). A single, flattened blade with ruffled margins, Porphyra is red when young and greyish-purple when older. Fig. 2-1. It can grow to 15 cm in length and width. Porphyra, commonly found in shallow, temperate coastal waters, is also grown on poles and lines set out in shallow waters along sheltered shores.


Fig. 2-1 Nori.

Of all the seaweed harvesting industries in the world, the Nori industry is the largest.

Limu is the Hawaiian name for seaweeds. Early Hawaiians ate a large number of different types of limu. Unfortunately, much of the traditional Hawaiian knowledge about picking and eating limu has been lost.

One limu which is very popular for eating in Hawaii today is limu manauea, also called by its Japanese name, ogo. This seaweed is Gracilaria, a red alga that is easy to collect because it grows in crisp clumps in very shallow water. It is often found along the margins of fringing coral reef flats. After storms, it is picked in large quantities as it drifts ashore (Fig. 2-2).


Fig. 2-2. Gracilaria.

After collecting it, limu manauea, or ogo, is washed thoroughly with cold water, then picked clean of encrusting coral, shrimps, and other
organisms. The Japanese use more ogo than all other racial groups put together. In Hawaii, it is eaten raw or after boiling for a short time. When raw fish is added, the dish is called poki. Ogo is al so served mixed with other cooked vegetables or added to stews to thicken the gravy. Fresh limu and prepared limu dishes are sold in the vegetable sections of many grocery stores in Hawaii. Limu dishes are served at most Hawaiian luaus.

Dulse, known by other names such as red kale throughout Europe, is the red seaweed Palmaria palmata. Dulse was eaten with potatoes by the Irish during times of famine. It is used in Maine, along the Eastern Coast of Canada, and along the Mediterranean as a food in stews and other dishes, or served as a relish. Sometimes it is chewed raw, like gum. Dulse is added to foods to give color and to aid in thickening sauces or gravies (Fig. 2-3).

Rhodymenia, another kind of dulse, is found in tide pools and on rocks at the low tide line along the northern portions of the Atlantic and Pacific coasts of the United States. Numerous thin, rubbery blades $2-8 \mathrm{~cm}$ tall and $1-2 \mathrm{~cm}$ wide grow from a short stipe. Blades are flat and without distinctive markings. Their shapes may vary from ribbonlike to oval.

Irish moss is the seaweed Chondrus crispus that is widely used in the United States and Europe (Fig. 2-4). Colonists boiled it with milk and added fruit and vanilla in preparing pudding desserts. Because of its thickening properties, carrageenan extracted from this seaweed has important industrial use today in the production of foods. It is used to stabilize or thicken ice cream, sherbets, and other frozen foods.


Fig. 2-3. Dulse.
It is added to pudding and soups as an aid in making products smoother and thicker. Chondrus crispus is found from Nova Scotia to Cape Cod, Massachusetts.


Fig. 2-4. Irish Moss.

## What are Other Uses for Seaweeds?

Seaweeds are used as food for animals. Farmers have long known that their cows, sheep, and goats can feed on algal beach drift with no effects on the milk or meat obtained from the livestock. Experimentation began on processing seaweeds to produce animal meals or powders when there was a grain shortage during wars in Europe. Today, for example, the animal feed industry harvests the top meter or so of the rapidily growing brown algae, kelp (Macrocystis), off the California coast (Fig. $\overline{2-5) .}$


Fig. 2-5. Kelp (Macrocystis).

Because of their high potash content ( $\mathrm{KOH}, \mathrm{K}_{2} \mathrm{O}$ ) and high concentrations of other minerals, seaweeds make good fertilizers. After storms, when detached seaweeds have drifted to shore, seaweeds are collected and mixed directly into the soil or are partially composted for use as a fertilizer.

Industrial and medicinal products are extracted from seaweeds. Before modern medicine and the pharmaceutical production of drugs, specific seaweeds were ptaked and used as remedies for various ailments. Today, seaweeds are harvested and processed to obtain products from them. Some examples are given below.

1. Algin, a substance found in the cell walls of brown algae, has the property of being very water absorbent. It is widely used for thickening, suspending, and emulsifying such products as polishes, cosmetics, and ice cream. Algin is so important to U.S. industries that much time, money, and effort has gone into research on ways to increase the harvesting of kelp without damaging the ecology of the kelp beds.
2. Carrageenan, a red algal extract discussed under Irish Moss, is mostly extracted today from the seaweed Eucheuma. Eucheuma is cultured in the warm Pacific waters off such countries as the Philippines. As noted earlier, carrageenan is used to make processed foods thicker and smoother.
3. Agar is a jelly-like substance that is obtained primarily from the seaweed Gelidium. It is used in processed foods as a substitute for gelatin and as an anti-drying agent for foods like cheese, ice cream, and canned meats. Agar is also obtained from Gracilaria and is important as a growth medium for laboratory cultures of bacteria.
4. Ashes of burned seaweeds, containing soda (Na compounds) and potash, are used in the manufacture of glass and soap.

## Further Investiaations

1. Find out how seaweeds are harvested commercially, and for what purposes the seaweeds are harvested.
2. Find out how people in other societies who live along the coastal areas use seaweeds.
3. Report on aquacultural (farming) techniques for raising and harvesting seaweed.
4. Look for more seaweed recipes. Make a recipe booklet for use in your classroom and community.
5. Find out more about the value of seaweeds as a food resource. What vitamins, minerals, and nutrients do seaweeds contain?

## References

Abbott, I.A. and E. H. Williamson 1974, Limu: an ethnobotanical study of some edible seaweeds. Pac. Trop.Botanical Garden Publication. Hawaii.

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Madlener, J. 1977. The sea-vegetable book. Clarkson N. Potter, Inc. New York.

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## 3. Seaweed Identification

What Are Seaweeds?

Seaweeds refer to macroscopic marine plants which can be seen without a microscope. Other marine plants which are microscopic in size are not considered seaweeds. Although some seaweeds are only a few centimeters in size, others, such as the kelps, can grow to 50 meters or more in length. Most seaweeds are algae.

Like all plants, marine algae contain chlorophyll and carry out the process of photosynthesis in the presence of sunlight and carbon dioxide. Thus, algae need light, dissolved gases, and water to survive.

Living algae are usually classified on the basis of their color into four groups: green, red, brown, and blue-green algae. Within each color group the algae can be further classified into genera by structural characteristics. Individual species are identified on the basis of their unique features. In a few species, microscopic examination of internal features is necessary for positive indentification.

## Activity

Identify a member of each of the four common groups of algae by using a key.

## Materiols

-1 sample each of red, green, brown, and bluegreen algae
-pictoral keys
-1 single-edged new razor blade (stainless steel)
-1 glass slide and coverslip
-1 dissecting microscope
-1600 ml beaker containing 400 ml of seawater
-1 eyedropper bottle containing 6 NHCl

## Procedure

1. Take fresh algal samples and place them into a beaker of seawater so that they will stay crisp.
2. Select one of the seaweeds to be identified. Decide whether it is green, red, brown, or blue-green.
3. Most seaweed keys are organized by color. Locate the correct color section in the key you are using.
4. Identify your seaweed by using the drawings in the key. Observe carefully the features of the seaweed you are trying to identify. Compare your seaweed with the pictures in the key. Find the drawing in the key which best matches your seaweed.
5. Record the name of your seaweed as found in the key in Table 3-1.
6. Learn how the seaweed key is organized. Follow either procedure 6a or 6 b below.
a. Turn to the first page of the key. Following the key step by step, use the written identification and key numbers until you are able to identify your seaweed.
b. Go backwards through the key by number. Begin with the picture that you identified as your seaweed. Note the number and the number in parentheses. Keep turning back using the numbers in parentheses until you are back at Step 1 of the key.
7. Write a short description of each of your seaweeds. After you have identified them by name, use the descriptions given in the keys. Record information in Table 3-2.

Table 3-1. Key to seaweed groups.


```
Plant brown, sometimes with olive,
    greenish or yellowish
    casts but without pink
```



```
Plant pink or red (including
    Acanthophora which is
    brown in cotor)......Red Algae
```

Plant hairlike, dark green or
blackish........................ Algae-Green

Table 3-2. Scientific names of seaweeds.

| Stameta Group | Eenus, Spatics | Uritten Description |
| :---: | :---: | :---: |
| Gratin |  |  |
| Brom |  |  |
| Bacd |  |  |
| Alue-green |  |  |

## Summory Questions

1. Are there any anatomical characteristics that you were not able to identify? Which ones and why?
2. Most biological keys are called dichotomous keys, meaning that each step is built around two choices. Rewrite the information given below in the form of a dichotomous key.

## Further Investigations

Locate and use keys to determine the names of the water plants (temporary or permanent) found in. pools, lakes, reservoirs, and ditches in your neighborhood.

## References

Abbott, I. and E.Y. Dawson. 1978. How to know the seaweeds. W.C. Brown. Iowa.

Bussey, P. 1979. "Key to the limu at Kualoa Reef" In: Fielding A. and B. Moniz. Coral: A Hawaiian resource. State of Hawaii Department of Education, Office of Instructional Services.

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## 4. Pressing Seaweed

Pressing is a good way to preserve seaweed, Plants collected on a field trip can be pressed for future reference. Pressed seaweed is artful and may be used in making collage designs, In this topic you will be learning how to make sets of pressed algal specimens.

Algal specimens which are preserved in 4\% formalin solutions can be dissected to study their internal anatomy. Oried, preserved specimens lose their internal structures.

## Activity

Make a collection of pressed seaweeds.

## Materidls - per group of 4

-4 algal specimens

- 1 pencil
-1 pan, at least $30 \mathrm{~cm} \times 30 \mathrm{~cm} \times 5 \mathrm{~cm}$
-4 white paper, $8 \frac{1}{2} \times 11$
-4 clean newspapers (4 pages thick)
-2 probes or skewers
- 1 razor blade or 1 pair of scissors
-4 pieces of waxed paper ( $12 \mathrm{~cm} \times 20 \mathrm{~cm}$ ), or clean cloth
-1 plant press (2 boards)
-weight or rope
-4 sheets corrugated cardboard ( $8 \frac{1}{2} \times 11$ )
-1 camel hair paintbrush or eyedropper
-gum labels ( $5 \mathrm{~cm} \times 8 \mathrm{~cm}$ )
-1 plastic sheet, flexible ( $8 \frac{1}{2} \times 11$ )
-1 pipette
-eyedroppers


## Procedure

1. Record data.
a. Get a sheet of white paper, $8 \frac{1}{2} \times 11$.
b. Record in pencil the following information on the lower right corner: location, date, depth, substrate, seaweed name, and name of collector. See Fig. 4-1.
c. Later, you will cover this penciled information with an official, neatly printed gum label.


Fig. 4-1. Recording information.
2. Press specimen.
a. Center algal specimen. Remember to allow a wide margin on the left side so the paper may be punched later and put in a binder. Also, leave space in the lower right corner for the label.
b. Arrange specimen to show all the important details of the plant. Use fingers or probe to position specimen. Center the seaweed. Using two probes, separate branches and arrange seaweed. Remove some of the overlapping branches of fronds with scissors or razor blade.
c. For finely branched or hair-1ike seaweeds, float out the algae by submerging the paper and the specimen in a pan of sea water about 1 cm deep. Use jets of water from a pipette to arrange seaweeds on paper.
d. Insert plastic sheet under paper. Gently lift paper and plastic carrier out of the pan by holding one side or one corner and allowing water to drain away slowly. See Fig. 4-2.


Fig. 4-2. "Floating out" fine seaweeds under water.
e. Holding the paper horizontally, inspect the position and arrangement of specimen. Use a paintbrush or jets of water from a pipette to further separate overlapping branches and expose plant features as needed.
3. Dry specimen.
a. Place the wet sheet with the mounted specimen on top of half of an opened newpaper about four pages thick. The newspaper acts like a blotter. It absorbs
excess water. Cover specimen with waxed paper or clean cloth, but not with newspaper. Close the newspaper. Write your name on the outside of the newspaper. See Fig. 4-3.


Fig. 4-3. Preparing specimens for drying.
b. Stack specimens like sandwiches on a desk or a board. Insert a thin piece of corrugated cardboard between every fourth specimen-sandwich. Limit the height of the stack to about 30 cm high. The paper on which the specimens are mounted tends to crinkle in stacks higher than 30 cm .
c. Press specimens by putting a board on top of the stack and adding a heavy weight or by tying a cord tightly around the stack.
d. Open the pressed stack every 24 hours. Replace the newspapers and cardboard as needed. Repeat procedure until pressed specimens are completely dry (about 1 week).

## Summary Questions

1. When is "floating out" necessary in preparing a specimen?
2. List several uses of pressed algae.
3. How might you rehydrate a pressed specimen? Compare appearance with a fresh specimen.
4. Did any of your pressed specimens stain the white mounting paper? Which species? What use might be made of this observation?

## Further Investigations

1. Make a pressed collection of seaweed, Identify the specimens pressed. See Topic 5 for further details.
2. Compare the seaweeds from two or more beaches. Provide a map of each beach showing the location of seaweeds. Describe substrate, depth of water and seaweed, and the distance from shore that the seaweed was collected.
3. Make collections at several times of the year. Compare collections. Look for evidence of seasonal changes affecting the presence or absence of algae.
4. Design seaweed stationery or placecards. Arrange seaweed artistically on sheets of paper. Use two or more pieces to form an algal collage.

## 5. Seaweed Slide Preparation

Seme seaweeds, which may appear similar externally, have different internal structures. As an aid in identifying different seaweed species, cross sections are prepared as wet mounts on slides and examined using a microscope.

## Activity

Prepare a collection of seaweed slides.

## Materials

-various species of seaweeds ( 2 cm pieces)
-razor blade with one cutting edge - new, stainless steel
-2 adhesive white labels
-two slides and coverslips
-several paper towels
-slide box (for class)
-compound microscope ( 40 x to 100x)

## Procedure

1. Cut seaweed cross section directly onto a glass slide. Use the same method as in Topic 1.
2. Select two or three of the thinnest, most transparent cross-sectional slices. Remove the other slices from slide. Cover slices with a few drops of water and a coverslip. Examine slides microscopically at 100 X and 400 x .
3. Make cross-sectional drawings of two different seaweeds in your lab book. Record magnification and species name.

## Surmary Questions

1. Group together cross-sectional drawings which appear to have similar internal structures. Compare the external features of these seaweeds. How, if at all, do they appear similar externally?

## Further Investigotions

1. Compare the cross-sectional drawing of two or more seaweeds that are similar externally. Describe their internal structures.
2. Make a key using only cross sections from each seaweed species.
3. Try using biological stains to accent internal features in seaweed cross sections. Ask your teacher for suggestions.

## References

Abbott, I. and E. Y. Dawson. 1978. How to know the seaweeds. W.C. Brown. Iowa.

## 6. Seaweed Beach Drift Study

Seaweed beach drift refers to detached seaweeds that wash ashore. Seaweed beach drift is often found lying in clumps or rows on a beach near the high tide line. Seaweed beach drift is a seasonal event, usually caused because large waves dislodge the holdfasts of offshore seaweeds. Tides, currents, and waves carry the drifting seaweeds ashore.

Every year large amounts of seaweeds are washed onto beaches where they rot and disappear. Unfortunately, very little of this potential source of food and fertilizer is used by humans. In this topic, we will estimate how much seaweed drifts ashore on a beach and where it cones from.

Sorting through fresh areas of seaweed beach drift helps to give an idea of the kinds and amounts of seaweed that live offshore. Studying marine animals found in the beach drift seaweeds also provides information on animals in the seaweed,

## Activity

Estimate the amount of seaweed drifted onto a beach:

Identify the generic composition of the sear weed drift and seaweeds offshore.

Look for animals living in the seaweeds,
Optional: Compare the composition of seaweed beach drift with the composition of offshore seaweeds.

## Bockground

Most seaweeds are attached by their holdfasts to rocks, pilings, or other hard surfaces. Along the coastine, seaweeds can be found on rocky shores, coral reef flats, or in tidepools. When collecting, walk carefully as the seaweed-covered substrate may be slippery. Look on the tops and sides of rocks and corals and into their crevices. Only a few seaweeds are found living on sandy, muddy, or gravel substrates.

Because waves can dislodge the holdfasts or tear the stipes and blades of seaweeds, deeper water, offshore seaweeds can be collected as they drift ashore after storms. Free-floating, detached seaweeds usually do not survive long. One exception is the seaweed Sargassum, which can live more or less permanently, but cannot reproduce while drifting at sea. Colonies of Sargassum drifting in oceanic currents gave name to that area of the ocean called the Sargasso Sea.

Sunlight and water depth also affect where seaweeds grow. Seaweeds need sunlight and, therefore are found in the top layer of the ocean, where sunlight penetrates the water. The transparency of the water determines the thickness of this layer, which in turn determines the distribution of seaweeds.

Water temperature and salinity also affect the distribution of seaweeds. Seaweeds do not thrive well in very warm waters because of the low oxygen concentration in the water. In very cold northern waters, seaweeds grow well during the summer. Seaweeds also vary in their ability to tolerate changes in salinity. After heavy rains, freshwater runoff along some coastal areas can reduce the normal $350 \%$ salinity of open ocean
water to a salinity close to that of fresh water. In very shallow seas, enclosed inlets, and in tidepools, evaporation can increase the salinity to $100 \%$. Only a few seaweeds can tolerate wide ranges in salinity.

## Materials

-1 transect line ( 50 m )
$-1 m^{2}$ quadrat
-2 large plastic bags or buckets
-1 balance
-10 plastic bags and labels or waterproof marker

- large paper for map, white or graph
-compass
-key to local common seaweeds
-magnifying glass
-1 safety line with float or innertube
-small aquaria or gallon glass jar


## Procedure

1. At the beach, select a study site about 30 to 50 meters long that has a typical deposit of seaweed beach drift.
a. Measure the length and width of the area. Use either a transect line or pace off the distances.
b. Calculate the area of the study site. Record this information.
2. Make a map of the area to be studied, including:
a, Prominent landmarks or other features that help to locate the study area. Record north and other compass points.
b. Draw to scale the length and width of the study area.
c. Show on the map the location of quadrat or bucket samples.
3. Decide on the sampling method to be used, Select one of the options described below:
a. If the seaweeds are evenly distributed, collect spaweeds on the basis of area. Use a $1 \mathrm{~m}^{2}$ quadrat. Place quadrat randomly within the study area. Collect all the seaweed in the quadrat, place seaweeds in a plastic bag. Label with quadrat number. Collect seaweeds from a second randomly placed quadrat.
b. If the seaweeds are unevenly distributed, collect seaweeds on the basis of volume. Collect a bucket of seaweed from two locations along the drift line. If large quantities of seaweeds are drifting in the water at the shorebreak, you may want to collect a bucket of that seaweed.
Transfer each bucket of seaweed to a separate plastic bag. Label with bucket number and location.
4. Optional: Go offshore to collect a sample of each kind of the attached seaweeds. Stay with a buddy as you wade offshore. Check with your teacher to find out whether swimming is permitted.
a. Collect a sample of each of the attached seaweeds, Place samples in labeled plastic bags.
b. Add a small quantity of seawater to the bags. The seawater will help keep alive
the animals attached to or living in the seaweeds.
5. As soon as possible, examine seaweeds for living animals. Record your findings in Table 6-1. Make additional tables as needed.
a. Open a bag of seaweed collected from one quadrat or bucket location. Pour excess water out of bag into a gallon glass jar or small aquarium. Look for small, swiming animals. Record names and descriptions.
b. Carefully examine seaweeds for animals. Try swishing the seaweeds first in the seawater in the small aquaria. Then, pick out the small shrimps, crabs and other animais. Encrusting animals such as sponges, tunicates, or coral should be left attached to small pieces of the seaweed. Place these in the small aquaria. Record data in Table 6-1.
6. Determine the mass of the seaweeds found in each quadrat or bucket. Record information in Table 6-2. Make additional tables as needed.
a. Rinse sand off seaweed. Drain off water. Put seaweeds into a dry plastic bag. Weight the total wet mass of seaweeds. Record total.
b. Separate seaweeds into piles according to genus. Put each pile into a separate, dry plastic bag. Weight each pile separately. Record.
7. Identify each genus (and when possible, species) of seaweed using a key to common seaweeds.

Table 6-1. Animals found in seaweed beach drift quadrat \# $\qquad$ ——.

| Group $\qquad$ <br> Location $\qquad$ | Area of Quadrat $\left(\mathrm{m}^{2}\right.$ ) $\qquad$ Vol ine of Bucket $\qquad$ |
| :---: | :---: |
| Animal Pryla | Sketches and descriptions of animals |
| Procists <br> (Foraminifera, Protozou) |  |
| Porifera <br> (sponges) |  |
| Cnidaria (coelenterates) |  |
| Platyminiminthes (flatworms) |  |
| Annelida segnented worms) |  |
| $\begin{aligned} & \text { Echinodermata } \\ & i \text { spiny skinned) } \end{aligned}$ |  |
| $\begin{aligned} & \text { Mollused } \\ & \text { (seatheils_ octopus) } \end{aligned}$ |  |
| Arthropoda (folnted legs) |  |
| thowdeta [Backbroness\} |  |

8. Calculate the percent composition of the seaweeds in the quadrat or bucket.


## Summary Questions

1. Estimate the total mass of seaweed in the area surveyed. Explain how you made your estimate.
2. Which seaweed had the greatest biomass in the area? What might account for this at this time?
3. Are there any drift seaweeds that were not found attached to substrate offshore? If so, how could this be accounted for?

Table 6-2. Seaweed beach drift in quadrat (bucket) \# $\qquad$ -

| Group * $\qquad$ <br> Location $\qquad$ <br> Bate $\qquad$ | weight of | a1) |
| :---: | :---: | :---: |
| Genus (or species) | Het mass | : Composition |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
| Tocal Mass (g) |  | 1005 |

4. How, if at all, are animals found in seaweeds specifically adapted to living in seaweed habitats? Give examples.
5. What kinds of scientific or technological use could be made of the study you have just completed?

## Further Investigotions

1. Each time drift occurs on your beach, look for seasonal change in the generic composition of the drift. Identify the dominant seaweed genera at each drift period or season.
2. Use some of the seaweed drift for food or fertilizer at home.

## CHAPTER 7

SHARKS,

## TURTLES AND WHALES

The legends and sagas of sea peoples are filled with references to sharks, turtles, and whales. Because of their great biomass and particular qualtities of oils, shell, bone and meat, all are agressively hunted.

In this chapter we will study these creatures to get a clearer understanding of their economic potential, behavior, and biology.


## 1. Sharks

Sharks are cold-blooded vertebrates with skeletons of cartilage instead of bone. Cartilage is tough but flexible (our external ears are formed of cartilage). Sharks have gills, but unlike fish, lack gill covers. Their skin is sandpapery in texture and the upper part of the caudal fin is curved upward and is longer than the lower part (Fig. 1-1).


Fig. 1-1. Generalized diagram of shark anatomy.

Many people of the world find shark meat a delicious food. It is marketed in this country under such names as whitefish. Fishing for sharks, however, is time consuming, requires expensive gear, and handling of captive sharks is very dangerous. In many parts of the U.S., most shark fishing is currently done by state or government operated shark control programs as well as by specially equipped fishing vessels.

Most sharks are too small, live too deep in the ocean, or lack teeth large enough to harm humans. Fhere are, however, about 27 shark species in the world known to have attacked either humans or boats.

In nearshore Hawaitan waters, there have been very few deaths due to shark attacks. In most attacks, the person was bitten and not killed. Sharks known to have attacked people in Hawaii are the large tiger shark, the mako shark (an infrequent offshore visitor), the hammerhead shark, and the great white shark (another infrequent visitor).

The smaller, more common reef sharks (galapagos, grey reef, sandbar, black tip, white tip) are territorial and usually attack only to defend their territories. However, they may take bloody fish from a diver or attack a person when they only see part of the person's body such as a hand or foot splashing in the water. In most cases these sharks do not kill people. The outlines of some of Hawaij's sharks are shown in Fig. 1-2.

Recently, throughout the world, there have been numerous shark studies. The data given in this topic is based on those studies.

## Activity A

Determine the latitude and month of most shark attacks.

Materials per person
-1 world atlas

## Directions

1. Plot the data in Table 1-1 on Fig. 1-3. The data gives the number of attacks per month and the latitude of each attack. The month of May is shown as an example on Fig. 1-3.


Fig. 1-2. Some Hawaiian sharks.


Fig. 1-3. World distribution of shark attacks (after Gilbert).

Table 1-1. World Distribution of Shark Attacks.

| Month | North Hemisphere | South Hemisphere |  |  |
| :--- | :---: | :---: | :---: | :---: |
|  | $0^{\circ}-23^{\circ}$ | $24^{\circ}-43^{\circ}$ | $0^{\circ}-23^{\circ}$ | $24^{\circ}-43^{\circ}$ |
| Hay | 3 | 7 | 10 | 2 |
| Jun | 5 | 10 | 7 | 0 |
| Ju1 | 9 | 26 | 4 | 1 |
| Auq | 5 | 9 | 4 | 1 |
| Sep | 1 | 7 | 4 | 0 |
| Oct | 1 | 5 | 5 | 2 |
| Nov | 1 | 0 | 12 | 9 |
| Cec | 1 | 2 | 6 | 25 |
| Jan | 3 | 0 | 11 | 44 |
| Feb | 3 | 2 | 11 | 20 |
| Mar | 4 | 0 | 7 | 18 |
| Apr | 3 | 4 | 11 | 7 |

## Directions

1. Refer to the daily attack data in Table 1-2. Indicate on the clock (Fig. 1-4) how many attacks occurred at a given time by placing a dot above the attack time. (Example: 4 shark attacks occurred at 11 a.m. Therefore, 4 dots have been placed above 11 a.m. on the clock.)

Table 1-2. Time of shark attack during 1971 (after Gilbert).

| Time | \# of Attacks |
| :---: | :---: |
|  |  |
| $5: 30$ A.M. | 1 |
| $7: 30$ | 1 |
| $9: 00$ | 1 |
| $9: 30$ | 2 |
| $10: 00$ | 1 |
| $10: 30$ | 1 |
| $11: 00$ | 4 |
| $11: 30$ | 2 |
| $12: 00$ Noon | 1 |
| $12: 30$ P.M. | 3 |
| $1: 00$ | 1 |
| $1: 30$ | 1 |
| $2: 00$ | 2 |
| $3: 00$ | 8 |
| $3: 30$ | 5 |
| $4: 00$ | 8 |
| $4: 30$ | 4 |
| $5: 00$ | 4 |
| $5: 30$ | 6 |
| $6: 00$ | 5 |
| $7: 00$ | 1 |
| $8: 00$ | 1 |



Fig．1－4．Time of shark attack．

## Activity C

Record shark catch data for 1971.

## Directions

1．Refer to Table 1－3 and answer the Summary Questtons．Fig．1－5 shows the fishing areas and divisions used in the Oahu shark fishing log．

Table 1－3． 1971 Shark Control Program Catch Log for Tahu

|  | $\begin{aligned} & \text { t. } \\ & \stackrel{\rightharpoonup}{t} \end{aligned}$ |  |  |  |  | 咢 | 总菏菏 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 15 |  |  |  |  | 1 |  |  |
| 16 |  | 3 |  |  |  |  |  |
| 1 |  | 5 | 1 |  | 1 |  |  |
| 2 | 9 | 10 |  |  | 2 |  |  |
| 3 | 2 | 2 | 1 |  |  |  |  |
| 4 | 5 | 1 |  |  |  |  |  |
| 5 |  | 1 |  |  | 1 |  |  |
| 6 | 4 | 1 |  |  |  |  |  |
| 7 | 1 | 3 |  |  |  |  |  |
| 8 |  | 1 | 1 |  | 1 |  |  |
| 9 | 2 |  |  |  |  | 1 |  |
| 10 | 3 | 3 | 1 |  |  |  |  |
| 11 | 1 | 4 | 1 |  | 1 |  |  |
| 12 | NOT | IISHED |  |  |  |  |  |
| 13 |  |  |  |  |  |  |  |
| 14 |  | 3 | 1 |  |  |  |  |
| Total |  |  |  |  |  |  |  |

## Summary Questions

1．a．In which season did the most shark attacks occur in the Northern Hemisphere？
b．Did the most shark attacks occur in the same month in the Southern Hemisphere？


Fig. 1-5. Map of Oahu showing fishing areas 1-16 and divisions ( $E=$ east coast, $N=$ north coast, $W=$ west coast, $S=$ south coast). Divisions are separated by heavy black lines. Area 12 is Kaneohe Bay.
c. Suggest reasons why there are more shark
attacks in this season.
2. a. Does the number of shark attacks vary with latitude? Suggest an explanation.
b. Which are the most dangerous latitudes? (e.g., between $0-23^{\circ} \mathrm{N}$ )
3. Based on this shark attack data, put an $\chi$ before each of the following areas if you would expect a shark attack during the month of July.

```
South Pole
Brisbane, Australia
Miami, Florida
Capetown, South Africa
Eleuthera, Bahama Islands
San Diego, California
Philippine Islands
```

4. Do more shark attacks occur in the morning, at noon, in the afternoon, or at night?
5. Suggest an explanation for why there are no recorded shark attacks at night?
6. Which of the following activities might provoke shark attacks? Explain.
a. spear fishing
b. photographing sharks
c. swịmming
d. shoreline fishing
7. In which fishing division of Oahu (north, south, east, west) was
a. the least number of sharks caught?
b. the largest number of different kinds caught?
8. In which fishing division were
a. the most tiger sharks caught?
b. the most sandbar sharks caught?
9. What was the total number of sharks caught on Oahu during 1971?
10. In which area(s) of Oahu were
a. the most sharks caught?
b. the fewest sharks caught?
11. Tiger sharks are seldom seen by divers. Why do you think so many tiger sharks were caught? Use references if you need help with this question.
12. Why do you think grey reef sharks were not caught when divers report that they are the most commonly seen shark? Use references to help you answer this question.

## Further Investigations

1. Visit local fish markets, fish auctions, and the Department of Fish and Game. Collect data on species caught (e.g., when and where) and find out which species are eaten immediately or processed into other foods.
2. Using a map of Hawaii, find the location of all shark attacks that have occurred in our waters. Also note the date of each attack. Try to correlate time of day, month, bathymetry, what the victim was doing, etc., with the place and nature of the attack.
3. Cook different species of local sharks and try different recipes for class presentation and personal use.

## References

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## 2. The Hawai ian Green Turtle

## Activity

Read the material and answer the questions.

For centuries sea turtles have played an important role in the diets of native peoples that inhabit tropical regions. Turtle products such as turtle eggs, steak, calipee (belly cartilage for soup), oil (for cosmetics), and shells (from the hawksbill) are in great demand.

The green turtle (Fig. 2-1) is the only species that still occurs in any number in Hawaii. This species declined so in number that in 1978 the U.S. Department of Interior made it illegal to capture green turtles for any purpose without a permit.

The greater portion of the Hawaian green turtle's life cycle is spent in shallow coastal waters feeding on marine plants (algae and sea grasses). The important feeding pastures exist around the major islands as well as in the northwestern portion of the island chain.

Although green turtles formerly laid eggs on island beaches throughout the archipelago, the only remaining breeding site is at French Frigate Shoals located 480 mi les northwest of Honolulu in the Hawaian Islands National Wildlife Refuge. Adults ( 20 to 180 kg and 5 to 13 years of age) migrate from the main Hawaitan Islands to French Frigate Shoals and nest between May and August. (Fig. 2-2). The method of navigation used for these long distance travels is unknown, but scientists think that these turtles return to the beach where they were born.

Recent studies at French Frigate Shoals have indicated that fewer than 200 females are present during each breeding season. This is probably about one-half to one-third of the total female population since most lay eggs every two years and but others every three to four years.

Marine turtles are cold-blooded, air-breathing vertebrates with paddle-shaped legs called flippers. Because they breathe air, the females must find a safe beach in which to lay their eggs. Were the eggs laid in the sea, the unhatched young turtles would drown. The female selects an area far from the water's edge, just before the beach plant zone. She lays about four clutches averaging 100 eggs each during her three month nesting task. Each egg laying may take several hours. Only when the eggs are covered with about three feet of sand are they safe from predators. The eggs take 60 days to hatch.

After the young hatch, in a joint effort they dig their way toward the surface. As the young turtles surface, they seek the ocean immediately. When the young turtles enter the ocean at French Frigate Shoals, they disappear and turtles smaller than 12 kg are rarely found. These observations lead scientists to believe that young turtles drift with the currents and eat open ocean plankton until they are strong enough to swim against the currents to reach coastal feeding grounds.

Although there are eight different kinds of sea turtles, only two, the green turtle and the hawksbill (Fig. 2-1), are found in Hawaii. A third turtle, the leatherback (Fig. 2-1), only occasjonally visits local waters. This rare jellyfisheating species is the world's largest turtle. It has a rigid black carapace, or shell, covered with white dots and primarily inhabits the open ocean and nests in places other than Hawaii. Hawksbills


Green turtle


Fig. 2-1. Hawaiian Turtles.

Fig. 2-2. Recent green turtle migrations recorded in the Hawailan Archipelago. Broken lines represent migrations previously recorded by Federal Wildilife personnel. Lines do not necessarily represent actual route. (G.H. Balazs)

eat a variety of invertebrates. The number of hawksbill turtles in Hawaii is very small. Only single nestings on the islands of Molokai and Oahu have been recorded in recent years. Both the hawksbill and the leatherback are officially listed as being endangered and their full protection is provided by the United States government.

## Summary Questions

1. Why is it illegal to catch green turtles for home consumption in Hawaii?
2. How do turtles differ from other vertebrates?
3. Whit kinds of food do the following eat?
green turtle
hawksbill turtle
4. Why must marine turtles lay their eggs on land?
5. Why is French Frigate Shoals the only location in the Hawaiian Island chain where green turtles lay their eggs?

## Further Investigations

1. Visit your local aquarium to view living examples of these marine reptiles. Make a report on their life cycles and problems of maintenance in the aquarium environment.
2. Report on other kinds of marine turties.

## References

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## 3. Whales

Of all creatures in the seas today, whales are perhaps the most remarkable for their large size and great strength. Whales are mammals. They are warm blooded and have sparse bristle-like hair. Their ancestors, who many millions of years ago lived on land, gradually adapted themselves to living in the sea. They now have huge tails with flukes, front legs called flippers and*remnants of hind legs hidden beneath their skin. Modern whates have a thick layer of blubber which keeps in body heat. They have lungs and breathe air through one or two blowholes (nostril-like openings in the top of the head). Whales use sound for hunting, communication, and direction finding.

There are two main types of whales, toothed and baleen whales. Toothed whales include sperm whales, killer whales, and their smaller relatives, dolphins and porpoises.

Toothed whales prey on fish and squid. Sperm whales are the only known predators of giant squid. Sperm whales can dive to more than 1,100 meters and can remain under water for up to 80 minutes.

Sperm whales mate and calve near the equator and head for the cooler waters (about $35-40^{\circ} \mathrm{N}$ or S latitude) in the late spring. The other toothed whales do not make such lengthy migrations as sperm whales.

Instead of teeth, baleen whales have horny plates suspended from the sides of the upper jaw. The plates are made from whale-bone, or baleen. Baleen whales use these plates to strain plankton
from the water. They take in large mouthfuls of water and squirt it out through the baleen plates trapping the plankton. The plankton contains large numbers of krill, a cold water shrimp.

There are three groups of baleen whales:

1. Right whales were so named by whalers because these whales are slow, easy to catch, and do not sink when killed. In other words, they are the "right" ones to catch.
2. Gray whales are similar to right whales but have smaller baleen plates. Like right whales, they also do not have a dorsal fin.
3. Rorqual whales include the blue, fin, sei, and humpback whales. Blue whales, the world's largest animals may reach up to 30 meters in length. Rorquals differ from right whales in body structure, having a dorsal fin, longer and more slender bodies, and lengthwise grooves on the throat. They also swim at 8 to 10 knots, twice as fast as right whales.

Baleen whales feed during the warmer part of the year in the Arctic or Antarctic Oceans (about $60^{\circ}$ N or S latitude). These waters are too cold for young baleen whale calves, which are born without thick coats of blubber. In the late fall the adults migrate to subtropical areas (about $20^{\circ} \mathrm{N}$ or S latitude), where some mate and others calve.

Baleen whales migrate in small groups called pods while sperm whales travel together in pods of several hundred. Large pods made it easier for the whaling ships to spot and catch sperm whales.

For ten years, from 1850 to 1860, Hawaii was the commercial hub of the North Pacific whaling industry. The Islands offered rest and recuperation
for crews and repair and reprovisioning for hundreds of vessels which engaged in hunting sperm and right whales, but not humpback whales.

There is no evidence of humpback whaling by native Hawaiians, though the humpback whale breeds and calves in the Hawaiian Islands. The Hawaiian language seems to contain no special word for humpback whale, although a general word for whale, "kohala," exists.


Fig. 3-1. Humpback whale.

The humpback whale has rough skin on its head and mouth and has long flippers (Fig. 3-1). Humpbacks seem to be gentle and not afraid of humans. Historically, the humpback whale was hunted as early as the 17 th century, but major whaling for humpback didn't occur until the 20th century invention of the explosive harpoon and "chaser" boats fast enough to catch them. The North Pacific humpback whale was then hunted extensively throughout its northern feeding grounds until humpback whaling was banned in 1966 by most countries because of dangerously low whale populations.

Table 3-1. Humpback whale sightings February, 1977.

| . Lat. | Long. | \# | Lat. | Long. | \#. | Lat. | Long. | $\#$ \#. | .Lat. | Long. | \# |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $22^{\circ} 15^{\prime}$ | $159^{\circ} 45^{\prime}$ | 3 | $21^{\circ} 15^{\prime}$ | $157^{\circ} 35^{\prime}$ | 6 | 20055' | $156{ }^{\circ} 45^{\prime}$ | 22 | $20^{\circ} 15^{\prime}$ | $155^{\circ} 55^{\prime}$ | 15 |
| $22^{\circ} 05^{\prime}$ | $160^{\circ} 05^{\prime}$ | 1 | $21^{\circ} 15^{\prime}$ | $157^{\circ} 15^{\prime}$ | 5 |  |  |  | $20^{\circ} 15^{\prime}$ | $155^{\circ} 45^{\prime}$ | 2 |
| $22^{\circ} 05^{\prime}$ | $159^{\circ} 15^{\prime}$ | 6. | $21^{\circ} 15^{\prime}$ | $156^{\circ} 55^{\prime}$ | 3 | 20055' | 156015' | 5 | $20^{\circ} 15^{\prime}$ | $155^{\circ} 35^{\prime}$ | 2 |
| $21^{\circ} 55^{\prime \prime}$ | $160^{\circ} 15^{\prime}$ | 1 | $21^{\circ} 05^{\prime}$ | $157^{\circ} 45^{\prime}$ | 7 | 20055' | $156{ }^{\circ} 05^{\prime}$ | 2 | $20^{\circ} 05^{\prime}$ | $155^{\circ} 55^{\prime}$ | 7 |
| $21^{\circ} 55^{\prime}$ | $160^{\circ} 05^{\prime}$. | 1 | $21^{\circ} 05^{\prime}$ | $157^{\circ} 35^{\prime}$ | 15 |  |  |  | $19^{\circ}{ }_{55}$ | $156^{\circ} 05^{\prime}$ | 1 |
| $21^{\circ} 55^{\prime}$ | $159^{\circ} 45^{\prime}$ | 2 | $21^{\circ} 05^{\prime}$ | $157^{\circ} 25^{\prime}$ | 10 | 20045' | $156^{\circ} 45^{\prime}$ | 4 | $19^{\circ} 55^{\prime}$ | $155^{\circ} 55^{\prime}$ | 23 |
| $21^{\circ} 55^{\prime}$ | $159^{\circ} 25^{\prime}$ | 21 | $21^{\circ} 05^{\prime}$ | $157^{\circ} 15^{\prime}$ | 6 |  |  |  | $19^{\circ} 55^{\prime}$ | $155^{\circ} 05$ | 3. |
| $21^{\circ} 45^{\prime}$ | $160^{\circ} 35^{\prime}$ | 2 |  |  |  | $20^{\circ} 35^{\prime}$ | $156^{\circ} 45^{\prime}$ | 2 | $19^{\circ} 35^{\prime}$ | $156^{\circ} 05^{\prime}$ | 7 |
| $21^{\circ} 45^{\prime}$ | $160^{\circ} 15^{\prime}$ | 7 |  |  |  | $20^{\circ} 35^{\prime}$ | $156^{\circ} 35^{\prime}$ | 16 | $19^{\circ} 25^{\prime}$ | $155^{\circ} 55^{\prime}$ | 2 |
| $21^{\circ} 45^{\prime}$ | $158^{\circ} 05^{\prime}$ | 1 | $21^{\circ} 05^{\prime}$ | $156^{\circ} 45^{\prime}$ | 9 | $20^{\circ} 35^{\prime}$ | $156025^{\prime}$ | 12 | $19^{\circ} 05^{\prime}$ | $155^{\circ} 35^{\prime}$ | 1 |
| $21^{\circ} 35^{\prime}$ | $160^{\circ} 35^{\prime}$ | 2 | $20^{\circ} 55^{\prime}$ | $157^{\circ} 45^{\prime}$ | 43 | $20^{\circ} 25^{\prime}$ | $156^{\circ} 45^{\prime}$ | 1 | $18^{\circ} 55^{\prime}$ | $155^{\circ} 45^{\prime}$ | 2 |
| $21^{\circ} 35^{\prime}$ | $158^{\circ} 15^{\prime}$ | 5 | $20^{\circ} 55$ | $157^{\circ} 35^{\prime}$ | 22 | $20^{\circ} 25^{\prime}$ | $156^{\circ} 15^{\prime}$ | 3 |  |  |  |
| $21^{\circ} 25^{\prime}$ | $157^{\circ} 45^{\prime}$ | 4 | $20^{\circ} 55$ | $157^{\circ} 05^{\prime}$ | 6 | $20^{\circ} 25^{\prime}$ | $155^{\circ} 55^{\prime}$ | 2 |  |  |  |
|  |  |  | $20^{\circ} 55$ | 156 ${ }^{\circ} 55^{\prime}$ | 17 | $20^{\circ} 35^{\prime}$ | $156^{\circ} 05^{\prime}$ | 3 |  |  |  |

The Hawaiian humpback populattion is now being studied in detail. Table 3-1 is one of the sets of data obtained from whale sightings. Humpback whales arrive in Hawaii from the Bering Sea as early as November for mating and calving. The population is largest in mid-February until midMarch. In June the last whales (humpback mothers with calves) leave and return to their northern feeding grounds.

## Activity

Determine where humpback whales are located in the state of Hawaii by plotting them on a chart.

Formulate hypotheses explaining humpback whale distribution patterns in the state.

## Procedure

1. Using the latitude and longitude data on Table 3-1, locate the square of each whale sighting on Fig. 3-2. $X$ in the square where the whales


Fig. 3-2, Locations of whale sightings in Hawaii, February, 1977.
were seen. Remember $1^{\circ}=60^{\prime}$, since there are six squares per degree and each square $=10^{\prime}$. Because the number of degrees in longitude increases as you go west, count from right to left.
2. In class compare Fig. 3-2 with an overlay supplied by your teacher and formulate your hypothesis to explain the humpback whale distribution in Hawaii. Write it in your lab book.

## Summary Questions

1. The location of the majority of humpback whales is associated with which of the following: water depth, currents, wind, windward or leeward sides of islands? Explain your answer.
2. During what months are the majority of humpback whales sighted within Hawaiian waters?
3. Is Hawaii primarily a feeding ground or a nursery for the humpback whale?
4. The humpback whale is a member of which group of whales?
5. In what ways is this data biased?

## Further Investigations

1. Contact Greenpeace, Sea Life Park, the Department of Fish and Game, and National Marine Fisheries for current information on whale sightings. Then make a chart of whale sightings.
2. Visit your local aquarium or museum to view whate displays.
3. Compare whale and human communication systems.
4. Report on whale diving physiology.
5. Report on international whaling problems.

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## CHAPTER 8

## AQUACULTURE

Aquaculture means raising animals and plants
in water. People usually think of aquaculture as farming of organisms in ponds and selling them for food or other uses. However, many animals and plants are cultured in systems as small as test tubes.

This chapter's topics deal with the basic problems that aquaculturists have in maintaining their animals and plants in systems such as ponds or aquariums.


## 1. Food Chains and Webs: Recycling Food and Wastes

To raise aquatic organisms, the farmer must control what is put into and taken from the aquaculture system. Choosing the best food for the organisms to be grown is important. Recycling of food and wastes can also make aquaculture systems more productive.

## Background

This activity, an aquaculture experiment, involves a cyclic food chain. We will feed to guppies daphnia, which eat green microscopic algae. The algae in turn use waste products from guppies (Fig. 1-1).


Fig. 1-1. Cyclic food chain.
In their natural environments, micro-algae use nutrients besides those produced in the decomposition of guppy waste. Daphnia may eat things other than micro-algae, and guppies may eat things other than daphnia. In fact, in a stream or pond, guppies eat some of the same things as daphnia.


Fig. 1-2. Food web.

Such a complex food system is called a food web (Fig. 1-2).

If the total number of each kind of organism in a food chain or web does not change drastically over time, the system is called a balanced system. A system becomes an aquaculture system when human needs are served by the controlled growth of aquatic organisms.

## Activity

Establish an aquaculture system with a cyclic food chain.

## Materials

-4 guppies
-daphnia culture
-l gallon jar
$-1,5$ or 10 gallon fresh water aquarium
-1 galion green water (algae water)
-1 siphon
-cheesecloth
-1 1 mm mesh aquarium net:
-scissors
-string or rubber band

## Procedure

1. Place daphnia in a gallon jar containing $\frac{1}{2}$ gallon of tap water and $\frac{1}{2}$ gallon of green water. Cover jar mouth with cheesecloth and tie on with string or rubber band to prevent mosquito growth.
2. Put guppies into a freshwater aquarium. Pour $\frac{1}{2}$ gallon algae water into the aquarium.
3. Place both the fish and daphnta cultures in a north facing window or out of direct sunlight.
4. Observe what happens to algae in the guppy tank and in the daphnia culture over a period of months.
a. Every 10 to 14 days, harvest the larger daphnia with a 1 mm mesh fish net and put them into the guppy tank. At the same time, siphon off the bottom sediment along with half of the water from the daphnia culture.
b. Replace the water taken from the daphnia culture with $\frac{1}{2}$ gallon of water from the top of the guppy tank.

## Summory Questions

1. What is the color of the water from the guppy aquarium when you add it to the daphnia culture? Explain.
2. What is the color of the daphnia water when you harvest daphnia?
3. Were there enough daphnia to feed your guppies? Did you have to feed the guppies more food?
4. What evidence, if any, is there that a cyclic food chain has been established.
5. What evidence, if any, is there that a balanced system has been established.
6. Would this aquaculture system work in a single jar?

## Further Investigations

1. Determine how many daphnia must be removed to maintain one adult guppy.
2. What size of daphnia is preferred by different sizes of guppies?
3. Set up a large scale daphnia generator for feeding the classroom aquarium fish.
a. Obtain lay tubing (Aquarium Reference, Part A, Section 10), 4 ml thick, 8 inches in circumference and from 10 to 100 feet long, depending upon available counterspace.
b. Select a counter top near a window and a sink on which to place the generator.
c. Place a few boards 2 inches high across the width of the counter top at 3 foot intervals. Place short 3 inch high boards where indicated (see Fig. 1-3).



Fig. 1-3. Counter top daphnia generator.
d. Run the tubing back and forth on the countertop over the boards. Both ends of the tubing should reach the sink. When filled, a number of isolated ponds will be created.
e. To start the gemerator, add tap water and green water with daphnia to the inflow end of the system until water starts to overflow the other end.
f. Add guppies to the inflow end.
g. Daily, add slowly one gallon of tap water to the inflow end; meanwhile, harvest the daphnia overflowing at the outflow end with a net. Feed these daphnia to your classroom fish. (Once a week give generator guppies flake food.)

## References

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Morhold, E., P.F. Brandwein, A. Joseph. 1966. A sourcebook for the biological sciences. 2nd Ed. Harcourt, Brace, and World, Inc. San Francisco. pp. 596-597.

Speitel, T., D. Marutani and T. Fujita. 1980. Lay tubing aquaria. Current / the Journal of Marine Education. Vol. 1, p. 27.

## 2. Sealed Aquariumi Ecological Balance

Ecological balance exists in an aquarium when the the number of living animals and plants present remains stable over a long period of time.

A sealed, stable aquarium is an excellent example of ecological balance. This aquarium is a selfsufficient life support system, requiring only sunlight for photosynthesis. This is the type of self-sufficiency that would be needed by man in space flight on a long interplanetary voyage.

## Activity

Decide which plant to animal ratio in a sealed aquarium provides the best ecological balance for the species involved.

## Materials

-1 test tube rack
-5 test tubes (approximately $6^{\prime \prime}$ long $\times 3 / 4^{\prime \prime}$
diameter)
-5 corks to fit test tubes
-9 freshwater snails

- 1 black felt-tip pen
-3 five-inch pieces of Elodea
-1 two-inch piece of Elodea
-tap water


## Procedure

1. Place test tubes in rack, label them 1-5, and date them with a pen
2. Add fresh water to within 2 inches of each test tube rim.
3. Place snails into the test tubes as follows (see Fig. 2-1):
a. One snail in test tubes $1,2,3$.
b. Six snails in test tube 4.
c. No snails in test tube 5 .


Fig. 2-1. Sealed test tube aquaria.
4. Place Elodea in the following test tubes as follows:
a. None in test tube 1.
b. A two-inch piece in 2 .
c. One five-inch piece in tubes $3,4,5$.
5. Place a cork into the mouth of each test tube.
6. At weekly intervals, record your observations in your lab notebook. Look for dead and living snails and Elodea leaves.
2. Which test tube is the control, or is there more than one control?
3. Were any snail offspring/eggs produced? Under what circumstances?
4. Did Elodea grow in any of the test tubes?
5. What were the requirements of Elodea in this experiment?
6. What were the requirements of snails?
7. What relationships, if any, does this experiment have to long-term manned space flight? To other human activities?

## Further Investigations

Start a large, sealed aquarium. Determine which plant-to-animal ratio provides the best balance. Try different plant/animal combinations.

## Summary Questions

1. Which test-tube "communities" are heal thy? Explain your answer.

## 3. Malaysian Prown Farming

On your property is a shallow pond ( $25 \mathrm{~m} \times 40 \mathrm{~m}$ ) in which you decide to stock Malaysian prawns. How does one grow prawns and how can one tell whether the farm will be profitable?

## Activity

Use biology, life tables, maintenance cost, and sale value of prawns to tell whether your prawn farm might be profitable.

## Background

Let's look at how a commercial prawn farm works in Hawaii. Here the Malaysian prawn Macrobrachium rosenbergii) is raised.

## 1. Population Biology

The life cycle of the Malaysian prawn is very similar to other crustaceans. Hild prawns live on river bottoms. The eggs are carried on the abdomen of the female until they hatch. After hatching, the larvae are carried down by river currents to the ocean. They do not behave or look like adults. instead they are planktonic, free swimming, and go through eleven developmental stages before they look like miniature adults called post-larvae. Depending on food, temperature, and other factors, the larvae become post-larvae from 18 to 45 days after hatching. In about 60 days, when they are about 5 cm long, post-larvae become juveniles.

They no longer swim and leave salt water to crawl back up the rivers.

On a prawn farm, some adults are kept in freshwater breeding tanks. Given the proper environment, they breed year round. A mature female can produce about 30,000 eggs each time she lays. After hatching, the larvae are transferred to saltwater tanks until they are 60 days old. Juveniles are then transferred to fresh or slightly brackish ponds. In 7 months, when the adults have grown to about 22.5 cm in length and 0.1 kg in weight, they are harvested.

Looking at a closed system, such as a prawn farm where only one species is raised, usually makes it easier to see now food and space can influence a population of animals. Too many animals in the system can result in starvation or crowding. Crowding can lead to damage through fighting. Some may die of disease which easfly spreads under crowded conditions. Some may eat others. It has been found that the optimum (or best) density (\# of animal/bottom area) for Malaysian prawns is 15 animals for each square meter of pond. Thus, if we want to farm a pond $200 \mathrm{~m}^{2}$, we should plant only 3,000 juveniles. In a commercial prawn farm, the population is not restricted or limited by the amount of food (although both how much and what the animals eat is obviously very important).

## 2. Life Tables

Even under ideal conditions, at each stage in their growth, some prawns die so that not all the eggs hatched grow up to be adults. The term mortality rate is used to describe the number of
animals which die within a given time period after hatching. Malaysian prawns in most Hawaiian ponds show a mortality rate of $50 \%$ at each life stage. This means that half the larvae will not live to be post-larvae, half of the post-larvae will not live to be juveniles, and half of the juveniles will not live to be adults.

Let us use mortality rates and our knowledge of its life cycle to construct a life table for the Malaysian prawn. Table 3-1 shows how the prawn population changes at different times in its life cycle. We will assume that a mortality rate of $20 \%$ is the same at each stage in the animal's development. In this case we will start with 1,000 newly hatched larvae.

$$
\frac{\text { Table 4-1. Malaysian prawn life table }}{\text { (20\% mortality rate). }}
$$

| Age Class | Number of Anima 1s <br> Per Original 1000 |
| :---: | :---: |
| Larvae | 1000 |
| Post-larvae | 800 |
| Juvenites | 640 |
| Adults | 412 |

You can see how each stage (or age class) starts out with $20 \%$ less animals than the number of animals in the previous stage. Now let's see what would happen to the number of animals in each class if the mortality rate is variable: assume a larvaemortality rate of $75 \%$, post-larvae of $50 \%$, and juveniles of $20 \%$ (Table 3-2).

Table 3-2. Life table (variable mortality rate) of MaTaysian prawns.

| Age Class | Number of Animals |
| :---: | :---: |
| Larvae | 1000 |
| Post-larvae | 250 |
| Juveniles | 125 |
| Adults | 100 |

## 3. Economics

Recent studies have estimated that the selling price for prawns is about $\$ 5.00$ per kg. Maintaining each $1 \mathrm{~m}^{2}$ of prawn farm costs $\$ 2.50$ per $\mathrm{m}^{2}$ per 7 months. This cost includes utilities, repair, feeding, taxes, etc.

## Procedure

1. From the Background material, fill in Table 3-3.
a. Generate life table (\#5) in Table 3-3 using the optimum density of the juvenile prawns you placed in the pond at a $50 \%$ mortality rate.
b. Project how many adults you will have.
c. Fill in the rest of the table.

Table 3-3. Prawn farm statistics.

| 1. \# eggs carried by one female |  |
| :--- | :--- |
| 2. mortality rate ( $50 \%$ of all stages) |  |
| 3. size of pond in $\mathrm{m}^{2}$ |  |
| 4. optimum density of juveniles |  |
| 5. Life table |  |
| \# juveniles |  |
| \# adults |  |
| 6. weight of harvestable adults |  |
| 7. sale value of prawns |  |
| 8. maintenance costs |  |
| 9. net |  |

## Summary Questions

1. How many females would it take to stock your pond with the optimum density of juveniles?
2. How much money would you make or lose on your prawn farm in 7 months?
3. If you wish to make twice as much money, how big must your pond be?
4. If the mortality rate went up to $80 \%$ how much money would you make or lose?

## Further Investigations

1. Obtain information about oyster farming and plan your own farm.
2. Visit a local prawn farm.

## 4. Solar Still Greenhouse

Seawater can be used for agriculture by using a solar still greenhouse. Within this greenhouse, seawater is distilled by the following means:
a. Seawater is solar evaporated.
b. The gaseous fresh water condenses on the cool inner surface of the glass or plastic.
c. The water droplets drip on the soil, providing fresh water for plant roots.


## Materials

```
-planter
-potting soil
-petri dish (100-200 mm)
-l gallon clear plastic bag
-30 cm wooden stick
-seawater
-bean or alfalfa seeds
-polyethylene bag
```


## Procedure

1. Place a planter by a sunny window. Fill with wetted potting soil.
2. Place a petri dish filled halfway with seawater on the soil.
3. Sow bean or alfalfa seeds around the dish, 1 cm apart.
4. Place wood stick in clear polyethylene bag, with one end of the stick touching the bottom center of the bag. Invert the bag over petri dish and seeds, placing end of stick in center of dish. Secure the edges of the bag down with dirt. Your experiment should look like Fig. 4-1.


Fig. 4-1. Solar still greenhouse.
5. Observe and keep a record of plant germination and growth.
6. When seawater dish dries out, wash out minerals and replace with more seawater.

## Summary Questions

1. Why doesn't the salt get into the soil?
2. What other distillation processes do you know of?
3. What problems did you encounter with this system? For instance, could the distilled water be too fresh?

## Further Investigations

1. Design a better solar still greenhouse.

## Reference

Speitel, T. et al. 1976. Seawater agriculture utilizing a solar still greenhouse. Oceans 176. pp. 1:73A7-A3.

## CHAPTER 9

## TRANSPORTATION

Modern boat builders are faced with the same problems that faced the first human who fashioned a canoe from a log: to create a boat with bouyancy, stability and strength. These problems, along with streamlining, will be examined in this chapter.


## 1. Ship Flotation

Buoyancy is the force which supports things in a liquid or gas. When a ship is floating in still water the pressure of water on the boat below the waterline pushes upward, causing a buoyant force. See Chapter 3 Topic 4.

## Activity

Determine the net buoyant force for materials used to construct boats.

Determine the effect of boat shape on cargo carrying capacity.

## Background

Net buoyant force of an object is a measure of the ability of the object to sink, float or rise.

When the net buoyant force on the object is (0), the object floats and is stationary.

When net buoyant force is positive (+), the object will rise.

When net buoyant force is negative ( - ), the object will sink.

The equation for the net buoyant force of a boat is:
(Net Buoyant Force) = buoyant force - weight of boat.
The buoyant force is equal to the weight of the water displaced by the boat. See Fig. 1-1. In this experiment we will use the unit of weight called the gram force (gf). One gram force is the force of gravity on one gram of mass at sea level. A kg force is 1000 times larger.

Materiols - per team

- 200 ml of dry sand
- 100 g chunk of metal
-100 g of water base modeling clay
-100 g piece of wood
-250 ml graduated cylinder
-overflow displacement tank
-balance (centigran)
-tablespoon


## Procedure

1. Obtain samples of about 100 g each of clay, metal, and wood. Shape the clay into a solid sphere. Weigh each sample and record its weight (gf) in Table 1-1.
2. Determine the net buoyant force for each of the materials.
a. Obtain an overflow displacement tank. Fill with water until it just starts overflowing. Start procedure b after overflowing stops.
b. Determine the weight of water displaced in (gf) when each of the materials is placed in the tank. Catch overflow in a graduated cylinder and record the weight in Table 1-1. (Since 1 ml water $=1 \mathrm{~g}$ of water, the volume of water displaced can be converted to gram force.)
c. Observe and record whether the object floats or sinks.
d. Calculate the net buoyant force (in gram force).

e. Repeat Procedures b-d using samples of other . materials.

| Object | Floats or Staks | weight of Object (a) (gf) | Weight of Displaced Water (b) (q9) | Net Bucyant Force <br> (b) $\cdot(\mathrm{a})$ (gf) |
| :---: | :---: | :---: | :---: | :---: |
| clay sphere |  |  |  |  |
| metal |  |  |  |  |
| wood |  |  |  |  |
| clay boat |  |  |  |  |

3. Determine what hull shape has the greatest carrying capacity. Record your data in Table 1-2.
a. Shape clay into a hollow boat. Check to see if it floats. Sketch your design in Table 1-2.
b. Determine the net buoyant force for your boat and record in Table 1-1.
c. Determine the carrying capacity of your boat. Slowly pour dry sand into the boat until it is just about ready to swamp. Do not let it swamp. Weigh the sand and record your model's carrying capacity in (gf). Record carrying capacity in Table 1-1.
d. Record in Table 1-2 a sketch and the carrying capacity of the class hull with the greatest carrying capacity.

Table 1-2. Hull design and carrying capacity.

Your Hul

| Sketch of Hul1 Shape | Carrying Capacity |
| :---: | :---: |
|  |  |



## Sumary Questions

1. Describe clay, metal, and wood materials in terms of their buoyancy.
2. In a calm harbor, gravitational force and buoyant force are the only two forces acting on a ship. These forces act in opposite directions.
a. If the ship floats, are the sizes of the opposing forces equal or unequal? If unequal, which force is greater?
b. Explain your answer in terms of net buoyant force.
3. How does the flotation behavior of your solid sphere of clay differ from the flotation of the clay hull? Based on this comparison, explain why metal chunks sink, but metal ships float.
4. What relationship, if any, is there between the shape of a hull and its carrying capacity. How is shape related to net buoyant force?

## Further Investigations

1. Using outside references, find out what kinds of construction materials are used today for building:
a. the largest supertankers,
b. submarines,
c. high speed motor boats, and
d. racing sail boats.
2. Read the following material and answer the questions at the end.

## "WOOD CAN SWIM, SO CAN IRON?"

Archimedes, perhaps relaxing in his bath one day in 250 B.C., hit upon the principle of buoyancy: a body partially or completely immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced.

Wood floats, because wood is less dense than water. The weight of the water displaced is equal to the weight of the wood (see Fig. 1-2). Solid
metal, however, is denser than water. A kilogram chunk of metal dropped into a tub of water will sink. Yet, the same kilogram of metal, hammered into a thin, shallow bowl, will float.

Why doesn't the metal bowl sink? Though the bowl displaces 1 kgf of water, the volume of the bowl is much greater than the volume of 1 kgf of water. The density of the bowl, plus the air inside it, is much less than the water it displaces.


Fig. 1-2. Flöating and sinking objects.

A force equal to the weight of the displaced water is buoying the bowl, keeping it afloat. So, objects such as steel ships can float despite the fact that the material they are made of is denser than water.

Although Archimides' principle could be demonstrated easily, iron ship advocates were still being called fools in the late 18th and early 19th centuries. "Wood can swim, iron can't," old sailors would say. But, in 1787 John Wilkinson's 70 -foot barge Trial
constructed of iron plates, did stay afloat. This vessel was the forerunner of the steel ships seen on the oceans today.

## Ship Tonnage

Ship tonnage, a measure of what a ship can carry, can be confusing. There are five different tonnage figures. There are two major categories: tonnage by weight and tonnage by volume.

Tonnage by weight, or displacement, is the weight of water displaced by a loaded vessel. This weight is expressed in metric tons. A metric ton is the weight of $1 \mathrm{~m}^{3}$ of fresh water:

$=1$ metric ton $=1000 \mathrm{~kg}$.
1 metric ton $=2200$ 1bs.
Tonnage by volume, is based on the English system of meaşure of cubic capacity. In this system, $100 \mathrm{ft}^{3}$ is called a ton. It is equal to $2.83 \mathrm{~m}^{3}$. For example, a ship that has a tonnage by volume of 1,000 tons can hold $100,000 \mathrm{ft}^{3}$ of cargo.

4.64 ft .

To gauge a ship's weight or its displacement at any time during loading or unloading, the ship's officers take the average of the bow and stern drafts (the vertical distance from the waterline to the keel-see Fig. 1-3.)


Fig. 1-3. Bow to stern estimate of displacement.
Draft marks on a vessel's bow show the distance in feet from the keel to the waterline. The ship in Figs. 1-3 and 1-4 has a bow draft of 30 feet.

Look at the displacement curve (Fig. 1-5) for a particular ship. If this ship was loaded to its 15 foot draft mark, it would have a displacement of approximately 10,000 metric tons.

Load line, or Plimsoll marks, show the maximum depth to which a ship can be legally loaded in different zones and seasons. They are used for ship safety. An example of Plimsoll marks is shown in Fig. 1-6. Their placement on the hull of a ship is shown in Fig. 1-7. In Plimsoll marks, $T=$ tropical; $S=$ summer; $W=$ winter; $F=$ fresh water; and $T F=$ tropical fresh water. Because of bad winter weather


Fig. 1-4. Draft marks on vessel's bow.
in the North Atlantic Ocean (WNA), ships heading there in this season are not heavily laden. A-B stands for American Bureau of Shipping, the agency which has validated the ship's Plimsoll marks.



Fig. 1-6. Plimsoll marks.


Fig. 1-7. Fulty loaded tanker.
Questions
a. Why are summer load-line markings higher than winter markings? Explain.
b. Why are freshwater load-line markings higher than saltwater markings?

Fig. 1-5. Displacement curve.
c. Sailors refer to tonnage by volume more commonly than displacement. Suggest a reason explaining why this is the case.

## References

Lewis, E.V. and R.O. 0'Brien. 1965. Ships. Time Inc.

## 2. Stability

Stability is the tendency of a floating object rolling from side to side to return to an upright position A rocking chair has stability It is a vita. +aclor in ship's design.
like stability on land, stability on water can be accomplished in two ways:

1. By having a wide stance at the base. This is called leverage stability. Examples of leverage stability are seen in the construction of barges or catamarans. See Fig. 2-1.


Fig. 2-1. Examples of leverage stability.
2. By anchoring the base.

This is called weight stability. On land, the base of an object is cemented into the ground or is placed deep in the ground. In water, an object with weiyht distributed toward the bass will have weight stability


Fig. 2-2. Examples of weight stability.

## Forces Affecting Stability

Gravitational force and buoyant force operate in opposite directions and affect the stability of every ship.

1. Gravitational force (G) is the sum of the entire weight of a ship acting straight downward on $i$ ts center of gravity (CG). The center of gravity of an object of uniform density is at the geometric center of, the object. Fig. 2-3 shows the center of gravity as a dot. The arrow represents the gravitational force.

The center of gravity of an object not uniformly dense, however, is close to the densest portion of the object. Notice location of the center of gravity (the dot) in Fig. 2-4 as compared to Fig. 2-3. Keep in mind that most ships are objects with unevenly distributed density.


Fig. 2-3. Center of gravity in objects of untform denslty.


Fig. 2-4. Center of gravity in objects of uneven density.
2. Buoyant force (B) is the force of a liquid acting straight upward at the center of buoyancy (CB) of the submerged part of an object. Fig. 2-5 shows the center of buoyancy as a dot. The center of buoyancy is always the geometric center of the submerged part of a ship's hull.


Fig. 2-5. Center of buoyancy.
For a vessel in a calm harbor, the two forces of gravity and buoyancy are in a line and are balanced, as shown in Fig. 2-6.

If the ship is stable, it will right itself when tilted. In the Fig. 2-7, the center of buoyancy of the tilted ship is shifted to the right because the


Fig. 2-6. Ship in upright position.
area submerged has been shifted. The two opposing forces acting at their CB and CG will twist the ship back to an upright position.


Fig. 2-7. Example of ship stability.

A ship which is unstable will not right itself. It will continue to fall over, since the buoyant and gravitational forces act on the ship to keep it moving in the direction of list or tilt. See Fig. 2-8.


Fig. 2-8. Example of an unstable ship.

## Activity

Determine whether given ship designs are stable using cross-sectional models.

## Materials

-test tank
-styrofoam ship cross sections
-weights
-oil-base modeling clay
-plumb line and weight
-pen
-knife or fine-tooth saw
-toothpick
-nail ( 6 cm )

## Procedure

1. Obtain a styrofoam cross-sectional model of a ship.
2. Tank-test the model for stability. (Note: we are only testing for side to side stability. If a model tends to fall forward or backward, support it gently with your hands.)
a. Place the model in the test tank in a vertical position.
b. Test to determine whether it is stable. Push down on one side so that the model tilts about 30 degrees and see if it returns to an upright position. If it does, it is stable.
c. Again push the model down on one side so that it lists approximately 30 degrees and mark the $30^{\circ}$ waterline across the face of the model.
3. Locate the center of gravity of the model in the following manner:
a. Place a nail through the model in any position close to an edge. Hold the nail so that the model swings easily.
b. Hang plumb line from the nail as shown in Fig. 2-9.


Fig, 2-9. Starting position to locate center of gravity.
c. Draw a line on the model where the plumb line hangs. Repeat the above step, placing the nail at an edge at least 5 cm away from its original position.
d. Locate the point where the lines intersect. This is the center of gravity. See Fig. 2-10.


Fig. 2-10. Locating center of gravity.
4. Determine the center of buoyancy of the model at a $30^{\circ}$ angle in the following manner:
a. Remove weights from models and fill any holes with styrofoam plugs.
b. Cut each model in two along the $30^{\circ}$ waterline
c. Use the section of each hull that was submerged. Find its center of gravity. Since this section has uniform density you are locating its geometric center, which is also the center of buoyancy. Mark the center of buoyancy.
5. Show the interaction between gravitational and buoyant forces on a piece of paper.
a. Reconstruct the complete hull (except for weight) of each model by attaching the two parts with tooth picks.
b. Trace the outline of the complete hull at a 30 degree list, as shown in Fig. 2-11.
c. Mark the waterline, the center of gravity, and the center of buoyancy.
d. Draw the buoyant and gravitational force arrows at the centers of buoyancy and gravity. Show the direction of force. Recall that these forces are always straight up and down.
e. See if the two forces acting at their respective centers restore the ship to an upright position or capsize it. Draw an arrow in the direction it will roll. Is the ship stable?
*6. Without placing your model in the water, predict the maximum list that it can have before it capsizes. Record your prediction and your reasoning in your notebook.
*7. Restore the weight and test your prediction made in Procedure 6.
a. Record in your notebook how you tested your prediction.
b. Explain why you were or were not successful in your prediction.

* To be done if time allows.


Fig. 2-17. Outline of hull at 30 degree list.

## Summary Questions

1. Define buoyant force and gravitational force.
2. Define stability for a floating object. Use the terms buoyant force and gravitational force in your answer.
3. Describe two characteristics of a ship which tend to make it more stable.
4. Explain how the plumb line technique finds the center of gravity.
5. A ship is considered tender if it slowly rolls back and forth to a stable position. It is considered stiff if it rights itself quickly, with little roll. What characteristics might determine if a ship is tender or stiff? Give a few examples of crafts that are tender or stiff.

## Further Investigations

1. Load a model container ship with high and low density containers so that it has a stability of a stiff nature. It should be balanced fore (in front) and aft (in back) and loaded to its summer freshwater load marks.
2. Using references; look up and make a report on hull design and stability.

## References

Dodman, F.E. 1973. The observers book of ships. Frederick Wayne 8 Co. Ltd.

Lewis, E.V. and R.O. 0'Brien. 1965. Ships. Time Inc.

## 3. Transport Convevances

There are often tremendous differences in size and weight of different vehicles. For example, a Volkswagen bug is four meters long and weighs 643 kg ( 1800 pounds). By comparison, some oil tankers are 350 meters long (about four and a half football fields) and weigh $500,000,000 \mathrm{~kg}(500,000$ metric tons). Although we can readily visualize the dimensions of a Volkswagen, most of us cannot easily picture the size of a huge supertanker. A profile of a supertanker is shown in Fig. 3-1.


Fig. 3-1. Supertanker.

## Activity

Construct profiles to scale of various transport conveyances and compare the sizes and carrying capacities of the various conveyances.

Moteriols
$-3 \times 5$ inch card
-meter stick
-construction paper or plasterboard
-penci!
-scissors or sharp cutting tool
-sand

- scale (centigram)
-spoon


## Procedure

1. Choose one type of conveyance to study. Select one of the land, sea, or air transport vehicles described in Table 3-1 "Conveyance Statistics" or choose another type of interest to you.
2. Describe the size of the conveyance you selected. Using Table 3-1 or other references, describe the size of the conveyance. Record data on a $3 \times 5$ card using the following terms or others that are appropriate.
a. overall length (distance between extreme ends)
b. greatest width (the beam of a ship)
c. height (the distance from a ship's top deck to its hull bottom including keel)
d. cargo capacity (either as weight or volume)
e. speed
f. cruising range
g. fuel efficiency
3. Construct a profile to scale of your transport conveyance.
a. Using the scale $1 \mathrm{~cm}=2 \mathrm{~m}$, draw the outline of the conveyance on poster board.
b. Attach your index card describing the features of the conveyance.
c. Post the profile on the bulletin board.
4. Demonstrate the cargo weight capacity of your conveyance. Represent this by using 1 gram of sand for every 100 tons of cargo. Display the sand on a piece of paper labeled with the name of the type of conveyance.
5. Compare the relative sizes of conveyances in terms of length and cargo capacity.

Table 3-1. Conveyance Statistics
A. Sedan automobile - Volkswagen Bug


```
-built: 1940's - 1970's
    -weight: 818 kg ( 1800 pounds)
    -length: 4 m
    -speed: up to \(80-90 \mathrm{mph}(128-144 \mathrm{~km} / \mathrm{hr}\) )
```

Volkswagen bugs can carry up to four (cramped) passengers and get 20-30 miles per gallon (or 8-12 $\mathrm{km} / 1$ ). They are no longer being built for the United States.
B. Supertanker - S.S. Ardshiel (see Fig. 3-1.)

```
    -length: \(\quad 330 \mathrm{~m}\)
    -width: \(\quad 52 \mathrm{~m}\)
    -displacement: 214,000 metric tons or 214,000,
        000 kg
    -speed: \(\quad 20\) knots or \(39 \mathrm{~km} / \mathrm{hr}\)
1 metric ton is 1.103 tons or 2204 lbs.
```

C. Airplane - Boeing 747


```
-built: 1967-1970
-weight: 375,000 lb (143,000 kg)
-length: 70.5 meters
-speed: }600\textrm{mph}(960\textrm{km}/\textrm{hr}\mathrm{ )
```

The 747's first went fnto service in 1970. They can carry up to 590 passengers and can fly around the world in record time ( 46 hours, 50 seconds) for a subsonic aircraft. 747's have proven to be extremely safe and reliable.
D. Container ship - Hawaiian Enterprise


```
-length: }245\textrm{m
-height: }45\textrm{m
-displacement: 1,363,000 kg or 3,000,000,000 lbs.
```

Most of the nonpetroleum cargo entering and leaving the Hawalian Islands is transported on container ships.


The George Washington is armed with 16 Polaris missiles which are 10 m long, 1.3 m wide, and possess nuclear warheads.
F. Fishing boat - Tuna Clipper


$$
\begin{array}{ll}
\text {-built: } & 1960 \mathrm{~s}, \text { U.S. } \\
\text {-length: } & 160 \mathrm{ft} . \text { or } 42 \mathrm{~m} \\
\text {-width: } & 30 \mathrm{ft} . \text { or } 9 \mathrm{~m} \\
\text {-speed: } & 12 \mathrm{knots} \text { or } 22 \mathrm{~km} / \mathrm{hr}
\end{array}
$$

This type of boat is used for tuna fishing. Individual fishermen have their own poles and lines and fish from a platform which projects all around the hull. Live bait is kept in tanks on toe decks.

## Surmary Questions

1. How does your conveyance compare in size and capacity with:
a. the largest conveyance in the class?
b. the smallest conveyance?
2. How large is a supertanker? How many Volkswagens would you need to equal the carrying capacity of a supertanker? How many Boeing 747's? Show how you arrived at your answers.
3. Some supertankers are so large that only a few harbors in the world can hold them. What possible advantages could there be in making supertankers so large? What disadvantages?

## Further Investigations

1. Construct profiles to scale of large marine animals. Include porpoises, whales, and giant squid. Compare animals sizes with the sizes of transport conveyances.
2. Check your knowledge on the following questions regarding transportation and Hawaii.

Hawaji is a geographically unique state. Is it unique because it is the smallest state?

No. There are three states with less land areaConnecticut, Rhode Isiand and Delaware.


## Is it the least populated state?

No. Nine states have fewer people.
Is Hawaii the westernmost state?
No, Alaska is. (And the easternmost too.)
What then makes Hawaii a geographically unique state?
Hawaif is the only island state.
What else makes Hawaii unique?
Hawait is 2300 miles from California. It is the most isolated land mass in the world.


What are the consequences of Hawai''s isolation?
Unlike other states, Hawaii is not linked to highways, railroads, and pipelines. People in Hawait depend on ocean and airline transport for most of their food, clothing, and shelter.

Why doesn't Hawaii produce all of its own food, shelter, and clothing materials?

Hawaii is dependent on outside sources because it has few mineral resources, little lumber, and a limited amount of land suitable for agriculture and grazing. It does not have the labor force and industrial base to produce a wide range of products. Most of the things needed can be produced more efficiently elsewhere.

## How does Hawaii support itself?

Mostly through tourism, agriculture, and military spending.

How is the transportation network in Hawaii different from those in other states?
Hawait is the only state which must rely entirely upon sea and air, transport for exports and imports.

Due to its island nature, Hawait is the only state which must have ocean or air transportation between various counties of the state. There are no overland connections between islands.

The major cities in Hawali are located near the water. Because of mountainous interiors, major traffic corridors are restricted in many places to narrow belts of 1 and near coasts, with feeder roads running up into valleys.

Hawai is the only state in the union without a common carrier railroad system. An amusement railroad on Maui and a private freight transport for sugarcane and pineapple are the only railroads.

Almost all land transportation in Hawait involves motor transport (car, truck, bus).

How is inter-island cargo carried?
Most inter-island freight travels by barges. Local airlines carry $9 \%$ of the cargo (mostly bread, newspapers, clothing, small appliances and parts, and all first-class mail).

Is most cargo brought into Hawaii by air or sea?
By sea. In 1970, 300 times more cargo was brought in by ship than by plane. The total cargo for that year was 7.8 million tons.

Why is most cargo brought in by ship?
Ship transport is over 10 times more fuel efficient (in terms of kcal/ton/mile) than air transport.

Energy Efficiency of Transport

| METH00 | KCALS consumed/TON/MILE, |
| :--- | :---: |
| Pipeline | 112 |
| Rallroad | 167 |
| Haterway (ship, garge) | 170 |
| Truck | 950 |
| Alrolane | 10,500 |

Do ships bring the most passengers to and from Hawall?
No. Many times more passengers are carried by plane. America's last passenger liner, the Mariposa, went out of operation in Apri1, 1978.

## What is the major shipping port in the islands?

Honolulu is by far the most important commercial port, accounting for over $50 \%$ of the overseas and interisland cargo tonnage.

## How does Honolulu rate as a world port?

Because of its strategic position in the center of the Pacific Ocean, Honolulu is an important worid port. However, it handles only a small fraction of the tonnage handled by ports such as New York or Sidney.


Who owns the port facilties in Hawail?
Docks and container yards in Hawaif are owned by the State of Hawail.

What is Hawail's most valuable export?

## What is Hawai's main import?

Over five million tons of oil enter Hawait every year by tankers, barges and container ships This accounts for more tonnage than all other cargo combined. Fossil fuel is Hawai1's biggest import.

## What

s the balance of trade?
The value of goods shipped into Hawait is four times the value of goods shipped out. Over $\$ 2$ billion worth of goods is imported each year. This includes most food and lumber. Only about $\$ 500$ million worth of goods $\rightarrow$ mostly sugar and molasses, pineapple and other agricultural products, and aloha wear are exported. Most of the money needed to pay for imports must come from good and services sold in Hawaii, mostly to the Federal Government and to tourists.

## What are some of the effects of this imbalancerof trade on the shipping industry?

Since Hawaii imports more than it ships out, the cost of ships coming to Hawaii must be paid for by importers since outbound ships are relatively empty. This inefficiency causes an increased freight rate, a major reason why Honolulu has the second highest cost of living among major American cities. Because of the light loads on ships leaving Hawaii, many shipping companies have gone out of business. One example is Sea-Train, which had a large operation from 1970 to 1974.

A large container ship costs about $\$ 65$ million and has a use life of about 30 years. Eight years ago the same shtp cost $\$ 29$ milition. (Inflation causes the increased cost.)

Sugar.

## Are shipping rates regulated?

Yes. Rates are regulated by the Federal Maritime Commission and are structured around a maximun profit allowable of 10.5 cents on every dollar invested by shipping companies in ships and shore facili:ies.

What are some of the most recent innovations in cargo and passenger transport in the Hawaiian Islands?
a. Container ships allow for rapid and modular movenent of goods on and off ships. Most cargo shipped into Hawaif comes in containers. Over 200,000 containers were handled at the Diamond head terminal of Honolulu Harbor in 1976.

b. Trailer ships provide an efficient way to transport cargo which does not fit in containers. vehicles can roll on and off under their own power.


## References

Geography Dept., UH 1974 Atlas of Hawaii
Matson Navigation Co. 1976 What's so different about Hawaii?

## 4. Ship Design and Construction

A ship designer must give a ship the strength to absorb and withstand a combination of mighty forces: the upward force of buoyancy, the downward force of gravity, and the powerful force of ocean waves. The ship must also be streamlined for speed.

For thousands of years, the design of ships has been based on the yertebrate animal form. The ship's ribs are covered with a skin of hide, bark, planks, or metal plates. The skin not only makes the ship watertight and buoyant, but also, along with the skeleton, provides the necessary strength for the hull. See Fig. 4-1.


Fig. 4-1. Primitive animal hide boat with skin stretched over wooden ribs. From Tibet.

## Activity A

Design a ship and blueprint it.

## Background

Ship hulls are usually planned using scale models. Before 20th century computers, approved models were sawed into sections and their measurements enlarged to full scale.

## Moterials per team

-1 sheet of $8 \frac{1}{2}{ }^{\prime \prime} \times 11$ " graph paper
-ruler
$-1000 \mathrm{~cm}^{3}$ of oil base clay
-knife (blade approximately 15 cm )

## Procedure

1. Draw a line lengthsise down the center of a piece of graph paper. See Fig. 4-2.
2. Shape a clay model of a ship hull which you hypothesize will be the fastest shape in the class.
a. Place $1000 \mathrm{~cm}^{3}$ of clay on your graph paper.
b. Shape a solid ship with the hull facing up and the flat deck facing down. Use the graph paper to assure that your ship is symmetrical about either side of the graph center line. See Fig. 4-3.


Fig. 4-2. Marking a line.


Fig. 4-3. Shaping a clay ship hull.
3. Make a blueprint of your boat.
a. Start at the stern, or rear, of the clay ship model. Cut stations (cross sections) every 3 cm along the length of the ship (see Fig. 4-4). Use the graph paper as a guide in making the section cuts parallel. Use care in cutting the clay so as not to change the shape of your model.
b. Trace each station on a piece of graph paper as shown in Fig. 4-5.

- Place the aft section (transom of the boat) on the graph paper and trace it.
- Number this station 1 on the graph paper.
- Follow the same tracing procedure with each station, numbering them consecutively.
c. Reassemble the clay hull and carefully cut it lengthwise.
d. Place half of the hull on the graph paper as shown in Fig. 4-6 and trace the keelson on the graph paper. Mark and number the position of the stations as shown in Fig. 4-7.
e. Label blueprint with student architects' names and the date as shown in the example (Fig. 4-7).


Fig. 4-4. Cutting stations in clay boat model.


Fig. 4-5. Tracing a station (transom) of clay boat model.


Fig. 4-6. Tracing keelson blueprint.

## Activity B

Construct a ship using the blueprint drawn in Activity A.

## Sample BLUEPRINT

ARCHITECTS: Jeanne Mal- Joe Schwartz 3/2o/co


Fig. 4-7: Sample blueprint.

## Materials per team

$$
\begin{aligned}
& \text {-scissors or single-edged razor blade } \\
& \text {-9" } \times 17^{\prime \prime} \text { manila folder } \\
& \text {-carbon paper } \\
& -\frac{1 / 4}{4}-\frac{114}{2} \text { masking tape ( } 15 \text { feet long) }
\end{aligned}
$$

## Prodecure

1. Nake a tracing onto a half of manila folder of the following using carbon paper and your blueprint:
a. the keelson with station positions and numbers, and
b. the stations with numbers.
2. Cut out the manila keelson and stations. The stations (2-6) will become the bulkheads for your ship. These will become the framework of your ship.
3. Cut slits in transom, keelson and all transverse bulkheads (stations 2-6).
a. Starting at the bottom of the keel son, cut a slit halfway down from the deck at each bulkhead position mark.
b. Cut a slit in each bulkhead starting at the midpoint of the bottom of the bulkhead going
4. Assemble keelson and bulkheads upside down on a cardboard construction base as shown in Fig. 4-8.
a. Draw a straight line lengthwise down the center of the manila base.


Fig. 4-8. Ship framework construction.
b. Position keelson along center line. Tape lightly in place so that it is perpendicular to the cardboard base.
c. Interlock bulkheads on the keelson. Tape bulkheads lightly to the base, making sure that each bulkhead is perpendicuiar to the keelson.
5. Using masking tape for planking, lay planking over hull.
a. Cut about 20 strips of masking tape about 6 cm longer than the hull.
b. Lay the first masking tape plank along the deck edge (gunwale) of the ship, sticking it tautly to the bulkheads and keelson. Repeat for other side of the ship.
c. Fasten a plank over the length of the keelson and rear bulkhead (transom).
d. Lay the second plank parallel to and slightly overlapping the keelson plank as shown in Fig. 4-9.
e. Continue planking the ship in the same fashion. The ship can be removed from the base to make planking easier.


Fig. 4-9. Planking the keelson ship framework.
6. Test for leaky areas and repair them.
a. Remove model from base, if you haven't done so already.
b. Press planks together in areas where overlapping planks are not making contact.
c. Test for leaky areas by floating ship in an aquarium.

- If there are a few leaks, dry the ship with a paper towel and patch with additional tape.
- If there are many leaks, add a complete second layer of planking at right angles to the first layer.

7. Based on work done in Topic 2, decide upon a method to stabilize your ship. This is an engineering contest. The winner will be the group that can produce a self-righting ship that will recover from the greatest possible list. A perfect hull would be one that can~ not be capsized.
a. Stabilize ship.
b. Plank over upper deck. The ship should be water proof.
c. Test model in contest: Ship must float and is stable only as long as it returns to an upright position (keel down) on its own.

## Summary Questions

1. Explain how the skin of a ship gives strength to the rib and keelson structure. What is your evidence?
2. What are the advantages, if any, of building bulkheads and keelson before constructing the skin of a ship?
3. Suggest structural similarities between a tratitional ship and the following:
a. A wooden frame house.
b. An umbrella.
c. A suspension bridge,
4. Which ship designed in class was most stable? Explain why it was the most stable.

## Further Investigations

1. Read "Ships on the Assembly Line", pp. 16-29, in Lewis and 0'Brien, 1965.
2. Look up and report to the class on how supertankers are constructed.

## References

Landstrom, B. 1973. The ship. Doubleday \& Company, Inc.

Lewis, E.V., and R.0. $0^{\prime}$ Brien. 1965. Ships. Time
Inc.

## 5. Ship Dynamics

Speed and fuel efficiency are extremely important when considering transporting materials by ship. Speed is the distance traveled per unit of time. Fuel efficiency is the weight of cargo $x$ distance traveled/fuel consumed. In this topic we will examine the relationship of ship design to speed and efficiency.

## Activity A

## Materials

```
-long wave tank (\geq2m)
-stop watch
-2 pulleys
-meter stick
-balance (centigrams)
-string (5 m)
-6 one gram weights
-model boats (< 30 cm}
```


## Procedure

1. Assemble a tow tank.
a. Obtain a wave tank at least 2 meters long. Fill tank with water to within 10 cm of the top edge.
b. Set up the pulley device as shown in Fig. 5-1. Attach pulley \#1 to the end of the tank. Attach pulley \#2 to a ring stand.


Fig. 5-1. Towing Tank.
2. Determine speeds of various ship models.
a. Obtain four ships ( 30 cm each). Sketch each hull design in Table 5-1.
b. Measure the weight of the ship (gf) record in Table 5-1. Measure the distance that it will travel in the tow tank (bow to pulley \#1).
c. Beginning with the first boat, attach the bow of the ship to the tow line. Place a 2 gram weight in the cup. Release the ship, clocking the time it takes to reach pulley \#1. Record time in seconds in Table 5-1.
d. Compute the speed of the ship. Record speed in Table 5-1.

$$
\text { speed }=\frac{\text { distance traveled }(\mathrm{cm})}{\text { time }(\mathrm{sec})}
$$

e. Repeat procedure b-d for each of the other three ships.
f. Graph ship speed versus ship weight in Fig. 5-2.

Table 5-1. Ship sketches and speeds.


Weight (gf)
Fig. 5-2. Ship speed plotted against ship weight.

| Activity B |
| :---: |
| Efficiency testing of ship models at <br> different speeds. |

## Backaround

E.fficiency is a measure of work done per unit of energy used. The less energy used to do a given amount of work, the higher the efficiency. Imagine a captain of a cargo ship which is carrying redwood from Oakland, California to Honolulu. The captain has no arrival deadline, so he is not concerned whether the voyage takes 5 days or a month.

But, the captain does want to complete the voyage (the work to be done) using the least amount of fuel (the energy to be used) possible. To get the best efficiency, the captain must determine what ship speed will require the least fuel to complete the voyage. We face a similar problem in this activity. Remember, work is the muttiple of force (weight) $x$ distance traveled.

Materials - per class
Same as Activity A plus:
$-4020 \mathrm{~cm} \times 60 \mathrm{~cm}$ pieces of cardboard

## Procedure

1. Measure the effect of powering force on ship speed. Weights tied to the end of the tow line will serve as the powering force. Work wit' a partner to do the following:
a. Begin by using a 2 g weight. Attach the other end of the line to your ship's bow as shown in Fig. 5-1.
b. Release the ship, clocking the time it takes to travel the length of the tank. Record distance and time in Table 5-2. Calculate ship speed.
c. For use later in Procedure 3 make a watermarked picture profile of the waves formed by the ship. Standing at mid-two tank, have one partner hold a sheet of cardboard lengthwise a few cm above water level and out of the path of the ship. Just as the rear (stern) of the boat passes the cardboard, quickly dip the cardboard in and out of the wake (the waves formed by the boat). Immediately pencil in the wake profile. Label the cardboard with the powering force and your name.
d. Repeat procedures 4a-c using additional weights. Record data in Table 5-2.

Table 5-2. Powering force and ship speed.

| Powering Force (gf) <br> $($ meight in cup) | Distance <br> $(\mathrm{cm})$ | Time <br> $(\mathrm{sec})$ | Boat Speed <br> $(\mathrm{cm} / \mathrm{sec})$ |
| :---: | :---: | :---: | :---: |
| 2 |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

2. Determine the efficiency of your ship at different speeds.
a. Graph speed versus powering force in Fig. 5-3. Draw a smooth line connecting data points.
b. Place an $X$ through the line where the efficiency is highest. Efficiency is greatest when speed divided by powering force yields the largest value. (This is when the slope of the graph is steepest.)


Fig. 5-3. Ship speed plotted against powering force.
3. Determine the effect of ship speed on wave size. The amount of water above and below the still water line is a measure of wave size. It is also related to the energy in the waves.
a. On each of the wave profiles made in Procedure 1, draw a straight line across the paper midway between crests and troughs. Use a meter stick. This line represents the still water level. Darken the areas between the still water level and the crests and troughs with a pencil (see Fig. 5-4).


Still water level

Fig. 5-4. Darkened wave profile.
b. For each profile, cut out the darkened area and determine its weight in grams. This is the wave energy index in grams.
c. Graph ship speed versus wave energy index


Wave energy index (grams)


Fig. 5-5. Ship speed plotted against wave energy

## Summary Questions

1. In Activity A, which of the four models traveled the fastest?
2. What effect did ship weight and ship design have on speed?
3. Does ship speed increase constantly as the powering force increases?
4. As ship speed increases, how is the size of waves affected? Show examples.
5. At what speed does your ship travel most efficiently? Apply this information to the following:
a. If you were building a small electric motor for your ship, what propulsion force would you have the motor exert so that your ship would go as far as possible with the charge from one battery?
b. Travelling at fuel efficient speed is not always desirable in real situations. Comment on this statement.
6. The formula for work energy is: energy = force $x$ distance. Make a graph similar to that in Fig. 5-3 displaying speed ( $\mathrm{cm} / \mathrm{sec}$ ) and energy
7. How is the graph produced in 6 above similar to Fig. 5-5? How is it different? Explain the differences and similarities.
8. If additional force does not increase speed by much, where does all the excess energy go?
9. Hypothesize whether there is a maximum speed that your ship could go? If so, what is it? How do you arrive at this speed? How could you test your hypothesis?
10. Compare the efficient hull speed of your ship with that of other boats in the class. What relationship, if any, is there between efficient hull speed and hull length? Between efficent hull speed and hull shape?

## References

Mostert. N. 1974. Supership. Knopf. New York.
Sweeney, J. B. 1970. Pictorial history of oceanographic submersibles. Crowy. New York.

Collin, F. 1967. The world's passenger ships.
Allen. London.

## CHAPTER 10

## CHEMICAL PROPERTIES

## of water

The world around us is seen as objects and events. When drained into a container, blood is seen as a red liquid. When it is seen under the optical microscope in the tail of a fish, it appears as couratless moving cells bumping through Tong passageways. Under the electron microscope, clusters of filaments are seen in each of the cells. Still further magnification reveals long chains of molecules with thousands of atoms.

Ultimately all matter is made up of atoms and molecules. All the chemical reactions we see are caused by the tiny events occurring with ultramicroscopic particles. Therefore, to better understand how the large scale world of the ocean operates, we study the world of atoms and the molecules.

## 1. Electrostotics

When we leap into the air, gravity pulls us back to earth. There is no rope, nothing hidden to grab us, but there is a force acting at a distance. There are other forces that pull and push matter without contacts between objects. We will study one of these forces, electrostatics, to get some idea of how matter is held together in atoms.

## Activity

Determine how charged surfaces react with uncharged matter.

Find the conditions under which charged surfaces attract and repel each other.

## Moterials

-1 comb
-1 glass rod
-1 piece of silk or nylon
-2 pith balls on nylon thread
-1 ringstand and ring
-paper
-1 metal foil strip on nylon thread
-1 ring stand

## Procedure

1. Put a negative (-) electrostatic charge on a comb by running it rapidly through dry greaseless hair.
a. Attach a thread holding a pith ball to a ring stand (Fig. 1-7). Bring the charged comb near the ball and record your observations in your notebook.


Fig. 1-1. Charging objects attached to ring stand.
b. Charge the pith ball by touching it with the charged comb. Record your observations.
c. Bring the charged comb next to the charged pith ball. Approach the ball from various sides and from the bottom. Record your observations.
d. Attach a piece of metal foil by a thread to the ring stand. Bring the charged comb next to the foil. Record your observations.
e. Carry out Procedures ib and lc using the foil. Explore the interaction between foil and comb.
2. Produce a ( + ) charge by rapidly rubbing a glass rod with a piece of silk.
a. Discharge the pith ball and metal foil by touching them with your finger.
b. Bring the rod next to the pith ball and metal foil. Record your observations.
c. Touch the pith ball and foil with the rod to charge them. Record your observations.
d. Bring the charged rod next to the charged pith ball and foil. Approach the ball from various sides and bottom. Record your observations.
3. Charge two pith balls. One with the comb (-) and one with the glass rod (+). By holding the threads bring the two balls as close together as possible without touching them. Record your observations.
4. Discharge the pith balls by touching them. Charge both pith balls by touching them with the charged comb. By holding the threads, bring the two balls as close together as possible without touching them. Record your observations.
5. Discharge the pith balls by touching them. Charge both pith balls by touching them with the charged glass rod. Bring the two balls as close together as possible without touching them. Record your observations.
6. Make a small pile of torn bits of paper. Charge the comb and bring it near the paper. Record your observations. Charge the glass rod and bring this next to the paper pile. Record your observations.
7. Explore with static surfaces as time allows. Record all observations.

## Summary Questions

1. How did the positively ( + ) and negatively ( - ) charged rods interact with paper and with discharged pith balls? What were the similarities and differences?
2. What charge, if any, was on the pith ball and foil before the charged comb touched them? Explain your reasoning.
3. What charge, if any, was on the pith ball and foil after the charged glass rod touched them?
4. Fill in Table 1-1. Use the terms: repel, attract, and no interaction.

Table 1-1. Interaction of charges.

5. Generalizing, what can be said about the interaction of:
a. like charges
b. unlike charges
6. From the information assembled in Table 1-1, what must have been the charges on the paper and discharged pith balls? Explain your reasoning.
7. Paper is considered a nommetallic substance. Aluminum foil is metallic. Do electrostatic charges interact differently or similarly with these two kinds of substances? Explain your answer.

## 2. El ements and Ions

Our understanding of the chemistry of the ocean is really quite new. It was less than two hundred years ago, in 1789, that the French scientist Antoine Lavoisier defined elements and compounds, the basic classes of the matter that surrounds $p$ us. He said that elements are substances that cannot decompose and always fave the same properties under the same environmental conditions. Compounds, he said, are substances with two or more different elements chemically combined. Compounds can be decomposed into elements. Compounds have different properties than the elements of which they are composed.

## Activity

Read the material and answer the questions at the end of each section.

## Elements

Each of the elements has a name which we abbreviate with a symbol of one or two letters (Table 2-1). Of the 92 elements found in nature, some 80 have, at this time of writing, been detected in seawater.

A little more than a hundred years ago, in 1870, the Russian chemist Dmitri Mendeleev arranged 70 elements in columns and rows. Elements in a column are called a group of elements. Those in a row are said to be in a period. We will be using a table similar to Mendeleev's throughout our work (Table 2-2). Each of the elements is identified by a chemical symbol.

Table 2-1. Names, symbols and atomic numbers of







*Hydrogen is shown twice since it acts like both a Group IA and Group VIIA element.

Table $2-2$ is read from lef, to right, top to bottom. The order of appearance of each element is determined by its chemical properties, which are in turn determined by electrical structure. Each element in a column or group has very similar chemical properties. By similar chemical properties, we mean that they react similarly with other elements and compounds. To designate the order in a period, each element is given an atomic number. Hydrogen ( $H$ ), the first-appearing element, has atomic number 1 . Helium ( He ), the second element, has atomic number 2, Lithium (Li) has atomic number 3 , and so 0 .

## Questions

1. What are the names of the elements with atomic numbers 7? 15? 33?
2. What are the symbols for the elements making up group IA? Group IB?
3. What are the symbols of the elements making up period 2? period 3?
4. List the atomic numbers of the first 5 elements not yet found in seawater?

Atoms and Compounds
About 1803, John Dalton, an English chemist, theorized that all matter, either elemental or compound, is composed of units called atoms. In other words, a sample of the gaseous element helium (He) is composed of countless trillions of tiny atoms of helium. The compound water ( $\mathrm{H}_{2} \mathrm{O}$ ) is composed of atoms of the elements hydrogeh ( H ) and oxygen ( 0 ). Two atoms of hydrogen combine
with one atom of oxygen to form the smallest unit of water called a water molecule ( $H_{2} 0$ ). A molecule is the basic unit of a compound or eiement. Many trillions of molecules of water make up a visible droplet of the compound water.

## Atoms and Charges

Opposite electrical charges attract each other, and like charges repel, as we saw in the topic on electrical charges. In 1811, the Swedish chemist John Berzelius suggested that atoms could be held together in compounds by these electrical forces. Berzelius was proven correct. Today, we know that atoms are composed of three kinds of "sub-atomic particles," each of which is much smaller than the atom. They are the positively ( + ) charged proton, the negatively ( - ) charged electron, and the neutral neutron. Of these, the charged particles, protons and electrons, account for most of the chemical properties of compounds and elements. By chemical properties we mean the way atoms combine to form compounds and compounds break up to form elements or new compounds. In this work we will not need to discuss the neutron.

Atoms possess equal numbers of protons $(+)$ and electrons (-), and thus are neutral. This is due to the fact that electrons and protons have charges which are equal but opposite. The number of protons and the number of electrons in an atom is equal to the atomic number of the element.
Looking at Fig. 2-1, we see that neutral hydrogen $(H)$ has an atomic number of 1 , and therefore has one electron and one proton. A helium (He) atom has an atomic number of 2 and has 2 electrons and 2 protons. A lithium (Li) atom has an atomic number of 3 and has 3 electrons and 3 protons.

| Neutral State of Atoms |  |  |
| :--- | :--- | :--- |
| Atomic Number | 1 | 2 |
| Atomic Symbol | Humber of Protons (+) | He |
| Number of Electrons (+) |  |  |

Fig. 2-1. Atoms of the first 3 elements showing atomic number and proton and electron counts.

## Questions

5. How many protons does the beryllium (Be) atom have? Carbon (C)? Sulfur (S)?
6. How many electrons does the carbon (C) atom have? Oxygen ( 0 )? Phosphorus ( $P$ )? Beryllium ( Be )?
7. How many electrons and protons do elements with atomic numbers 45,57 and 62 have?

## Ions

Protons are 1,830 times more massive than alectrons. They are found in the nucleus, or center of the atom, where they remain unmoved even during most violent chemical reactions. The very light electrons, however, can be easily removed from or added to atoms. Electrons are found orbiting around the atomic nucleus like bees buzzing around a hive. (Fig. 2-2).


Hydrogen


Helium

> Fig. 2-2. Schematic pictures of atoms.

It is through the addition and removal of alectrons that atoms in a neutral state become charged. Charged atoms are called ions. If a neutral atom such as chlorine (Cl) gains one electron, it will be changed into an ion which has a charge of $1^{-}$ because there are not sufficient protons ( + ) to neutralize the added electron ( - ). Sulfur on gaining two electrons becomes an ion with a charge of $2^{-}$(Fig. 2-3).
The charge on the ion is written as a superscript.

$*^{-}+\mathrm{Ct} \rightarrow \mathrm{Cl}^{-}$
$2 e^{*}+s \rightarrow s^{2-}$
Fig. 2-3. Ion formation by electron addition. The + between the electron and atom shows addition by collision. The arrow $\rightarrow$ is the symbol for reaction.

## Questions

8. What would the charge be if a neutral fluorine ( $F$ ) atom gained one electron? If a neutral selenium (Se) atom gained two electrons?
9. What would be the charge if a neutral nitrogen $(N)$ atom gained three electrons?

When an electron (-) is removed from a neutral atom, the atom gains a positive ( + ) charge because a proton ( + ) is no longer neutralized. This positively charged atom is also called an ion. A neutral lithium atom which loses one electron will be changed into an ion with a charge of $1^{+}$(Fig. 2-4).

$$
\begin{aligned}
& \begin{array}{l}
\mathrm{Li} \\
3+ \\
3- \\
2- \\
3+ \\
\hline i^{+} \\
\hline
\end{array} \\
& \mathrm{Li} \rightarrow \mathrm{e}^{-}+\mathrm{Li}^{+}
\end{aligned}
$$

Fig. 2-4. Formation of an ion by loss of an electron.

## Questions

10. What would the charge be if a neutral sodium (Na) atom loses one electron? What would be the charge of a magnesium (Mg) ion after the neutral atom loses two electrons?
11. How many more protons than electrons has an ion with a charge of $2^{+}$? or $3^{+}$? or $4^{+}$?
12. Which particle is in excess (proton or electron) when the charge on an ion is $1-$ ? $3^{+?}$ 4-?

## Atomic Structure

Surrounding the nucleus are the electrons moving in regions described as shells. Hydrogen ( $H$ ) and helium (He) have only one shell. Atoms of elements with large numbers of electrons have many shells, one within another. For example, lead, which has 82 electrons, holds it electrons in six shells.

The outer shell is the one involved in determining the way that atoms chemically react or combine. When the number of electrons in the outer shells of different atoms was discovered, it became possible to explain why groups of elements have the same kinds of chemical properties. Members of the same group have the same number of outer shell electrons.

We will concentrate our discussion on the (A) groups of the periodic table. Members of group IA have one electron in their outer shell; those of group IIA have two electrons; those of group IIIA, three electrons, and so forth.

## Questions

13. How many electrons are there in the outermost shells of group IVA, VIA, and VIIIA?
14. What is the number of electrons in the outer shells of nitrogen ( N ), phosphorus ( P ), and potassium ( $K$ ) atoms?

A convenient way of representing outer shell electrons is to show them as dots placed around the atomic symbol of the element. These representations are called electron dot formulas (see Table 2-3). The electron dot formilas for hydrogen and lithium, which each contain one electron in their outer shell, are $\dot{H}$ and $\dot{L}^{\circ} \dot{\text {. }}$. The electron dot formulas for the members of period 2 in order are

Question
15. Draw the electron dot formula for each period 3 element on Table 2-3.

Table 2-3. Electron dot formulas for elements of Groups I-VIII.

| Period | IA | IIA | HLA | IVA | VA | VIA | VLIA | VILIA |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | $\stackrel{H}{H}$ | He |  |  |  |  |  |  |  |
| 2 | $\stackrel{+1}{ }$ | 3e. | $8 \cdot$ | - $\stackrel{c}{\text { c. }}$ | - $\sim_{\sim}^{*}$ | -8: | $\stackrel{*}{\text { F }}$ | F"Ne: |  |
| 3 | Na | Mg | Al | Si | $P$ | $s$ | C1 | Ar ${ }^{\text { }}$ |  |
| 4 | K | $\stackrel{\text { ca }}{ }$ | Ga. | - Ge* | - Ás. | - Šés | - Br: | : $\ddot{\mathrm{kr}} \mathrm{r}=$ |  |
| 5 | R ${ }^{\text {b }}$ | $\stackrel{\circ}{\text { Sr }}$ | In. | - sin | - 56 | - T Te: | - I': | : X ¢ |  |
| 6 | Cs | Ba. | $\stackrel{1}{1+}$ | - Pb* | - Bri $^{\text {d }}$ | - Po: | - At, | -8n: |  |
| 7 | $\stackrel{F}{\text { F }}$ | Ra ${ }^{\text {a }}$ |  |  |  |  |  |  | W |

## Ionic Charge

The members of each of the groups of the Periodic Table have a characteristic tendency to lose or gain outer shell electrons. Again considering (A) qroup elements, those elements on the left side, or Groups IA-IIIA, tend to lose their outer shell electrons. Those in the right side, or groups VAVIIA, tend to gain enough electrons to fill their outer shells to the maximum capacity of their period. First period elements ( $H$ and $H$ ) have a maximum capacity of 2 electrons. The (A) group elements of other periods have a maximum outer shell capacity of 8 electrons. Group VIIIA elements have filled outer shells and do not tend either to gain or lose electrons (see Table 2-3). All the elements in group IA, the lithium (Li) group, tend to lose one electron and acquire a $1^{+}$charge.

$$
\dot{L i} \longrightarrow \mathrm{Li}^{+}+\mathrm{e}^{-}
$$

Those in the second group, the beryllium (Be) group, tend to lose two electrons and acquire a $2^{+}$charge.

$$
\dot{\mathrm{Be}} \rightarrow \mathrm{Be}^{2+}+2 \mathrm{e}^{-}
$$

## Question

16. What is the expected charge of atoms in group IIIA?

The VA group tends to gain three electrons and have a $3^{-}$charge.

* An $x$ is used to represent the electrons to be given up or acquired. This is a bookkeeping device. All electrons are identical.


## Questions

17. What would the expected charge be for phosphorus ( $P$ )? arsenic (As)? iodine (I)?
18. What would be the charge on the following elements: sodium ( Na ), magnesium ( Mg ), a) uminum ( $A 1$ ), sulfur ( $S$ ), bromine ( $B r$ )?
19. The VIIIA group has no tendency to gain or lose electrons. What would be the charge of this group of elements?

When dealing with ions, it is often more convenient to show the charge alone without regard to outer shell electrons. The chtoride ion is formed by adding one electron. We can write the chloride ion as $\mathrm{Cl}^{-}$.


A table of common ions can be constructed which is very similar to that for electron dots (see Table 2-4).

Table 2-4. Some elemental ions.

| $\mathrm{Li}^{+}$ | $\mathrm{Be}^{\mathrm{e}^{+}}$ | $\mathrm{g}^{3^{+}}$ | $X$ | N | $\mathrm{o}^{2^{-}}$ | F |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $\mathrm{Ha}^{+}$ | Ma | Al | $X$ | P | $\mathrm{s}^{2^{-}}$ | Cl |
| K | Ca |  | $X$ |  | Se | Br |
| Rb | Sr |  | $X$ | $X$ |  |  |

Questions
20. Fill in the charge on each of the positive ions not marked in Table 2-4.
21. Fill in the charge on each of the negative ions not marked in Table 2-4.
22. What charge would be expected for the ion of iodine (I), atomic number 53? for the ion of gallium (Ga), atomic number 31? for cesium (Cs), atomic number 55?
23. Complete Table 2-4 showing the groups and periods represented.
24. Suggest a reason which might explain why group IVA is x-ed out.

## Electrovalent (Ionic) Compounds

When seawater evaporates, a mixture of solid compounds is formed. A large number of these are ionic compounds. Ionic compounds are formed from ions that possess opposite charges. Such ions are formed by a process of electron exchange. For example, a lithium atom (Li) can give up one electron to a fluorine atom (F). This forms a $\mathrm{Li}^{+}$ion and a $F^{-}$ion. These two ions can hold onto each
other, or bond, by the attraction of their opposite charges. The neutral compound formed is LiF or lithium fluoride.


When using electron dot formulas to depict combining ions, we place brackets around the electron dot pictures and put the charge outside the brackets. We use arrows to indicate that a reaction has taken place. The reaction equation reads: one lithium atom reacts with one fluorine atom to produce the neutral ionic compound lithium fluoride.

We have seen that some elements have a characteristic tendency to gain or lose more than one electron. Sulfur, when charged, is an ion with the form $5^{2-}$. In an electron exchange with magnesium, a sulfur atom takes 2 electrons from the magnesium atom and forms the compound MgS , called magnesium sulfide.


Question
25. Use electron dots to draw a picture of the electron exchange between atoms of calcium (Ca) and oxygen (0), sodium (Na) and chlorine (C1).

## Writing formulas

Once the nature of the electron exchange is understood, it is more convenient to write formulas without using electron dot symbols. Some rules will simplify the writing of formulas withelectron dots.
a. Only positive and negative ions will combine to form ionic compounds.
b. In an ionic compound, the total quantity of positive charge must equal the total quantity of negative charge.
c. The symbol of the element forming the positive inn is always written first.
d. The formula represents an electrically neutral compound; therefore, it does not include the charges on the component ions.
e. The number of ions in a compound are indicated with subscripts.

Will Aluminum $\left(\mathrm{Al}^{3+}\right)$ forin an ionic compound exclusively with iron $\left(\mathrm{Fe}^{2+}\right)$ ? No, both are positive ions.

## Question

26. Will iodine ( $\mathrm{I}^{-}$) form an ionic compound exclusively with calcium ( $\mathrm{Ca}^{2+}$ )? Will magnesium ions ( $\mathrm{Mg} 2^{+}$) form ${ }^{2}$ compound exclusively with calcium ( $\mathrm{Ca}^{2+}$ )?

We can now write an equation for a reaction between two ions. Given two ions that will combine, such as the aluminum ( $\mathrm{A} 7^{3+}$ ) ion and the sulfur ( $s^{2-}$ ) ion, we have to insure that there is as much positive charge as negative charge. To do this, we find the smallest common multiple of the charges on the fons. In this case $(A)^{3+}$ and $\left.S^{2-}\right)$, the smallest common multiple is $3 \times 2$, or 6 . This tells us that the total charge provided by aluminum must be $6+$, and sulfur, $6^{-}$. Put in the form of a
balanced chemical equation we show 2 aluminum ions combining with 3 sulfur ions. In the equation, notice that we write the 2, which tells us that we have 2 aluminum ions, in front of the symbol for the ion $\left(A 1^{3+}\right)$. Likewise we write the 3 , which indicates there are 3 sulfur ions, before the symbol for the $\mathrm{s}^{2-}$.
opposite charged ions


The formula for aluminum sulfide is $\mathrm{Al}_{2} \mathrm{~S}_{3}$, which means 2 atoms of aluminum have combined with 3 atoms of sulfur. Note that the number of atoms or ions in the compound is shown as a subscript, or number below and after the symbol.

Other examples:


When only one ion is found in the formula, no subscript is used. In other words, there is no subscript 1.


Here there is one calcium with no subscript and two bromine ions with a subscript of 2.

## Summary Questions

27. Aluminum $\left(3^{+}\right)$and oxygen ( $2^{-}$) combine. What is the smallest common multiple of their charges? What would be the formula for the ionic compound that they would form? What is the subscript on the aluminum? Write the equation for the formation of the compound from its ions.
28. Write the formulas for the following ion pairs: $\mathrm{Ni}^{2+}$ and $\mathrm{Cl}^{-}, \mathrm{K}^{+}$and $\mathrm{S}^{2-} \mathrm{Ca}^{2+}$ and $0^{2-}, \mathrm{K}^{+}$and $\mathrm{Cl}^{-}, \mathrm{Na}^{+}$and $\mathrm{S}^{2-}, \mathrm{Fe}^{3+}$ and $\mathrm{S}^{2-}$.

Naming Two Elenent Ionic Compounds
Ionic compounds are easily named. The rules for naming ionic compounds of 2 elements are listed below:
a. Determine which ion is positive.
b. Write the name of the positive ion followed by the name of the negative ions.

We are given the formula CaS. Looking at Table 2-5, we find the $\mathrm{S}^{2-}$ is the symbol for sulfide ion and $\mathrm{Ca}^{2+}$ is the symbol for the calcium ion. Putting this together, we get calcium sulfide.


Another example:


Table 2-5. Names, formulas, and charges of some elemental ions.

| Positive Ions |  | Megative Ions |  |
| :---: | :---: | :---: | :---: |
| Aluminum | $\mathrm{Al}^{3+}$ | Bromide | $\mathrm{Br}^{-}$ |
| Gariun | $\mathrm{Ba}^{2+}$ | ChIoride | $\mathrm{Cl}^{-}$ |
| Calctum | $\mathrm{Ca}^{2+}$ | Fluoride | $\mathrm{F}^{-}$ |
| Cobalt (II) | $\mathrm{Co}^{2+}$ | Iocine | $\mathrm{I}^{-}$ |
| Copper (II) | $\mathrm{Cu}^{2+}$ | Oxide | $0^{2-}$ |
| Hydrogen | $\mathrm{H}^{+}$ | Sulfide | $s^{2-}$ |
| Iron (II) | $\mathrm{Fe}^{2+}$ |  |  |
| Iron (III) | $\mathrm{Fe}^{3+}$ |  |  |
| Lead (II) | $\mathrm{Pb}^{2+}$ |  |  |
| Lithium | $41^{+}$ |  |  |
| Magnesilum | $\mathrm{m}_{4}{ }^{2+}$ |  |  |
| Manganese (II) | $\mathrm{mm}^{2+}$ |  |  |
| Mercury (11) | $\mathrm{Hg}^{\text {2+ }}$ |  |  |
| Potass ium | $\mathbf{x}^{+}$ |  |  |
| stlver | $\mathrm{Ag}^{+}$ |  |  |
| Sodium | $\mathrm{Na}^{+}$ |  |  |
| Strontium | $5 \mathrm{r}^{2+}$ |  |  |
| Tin (1I) | $\mathrm{Sn}^{2+}$ |  |  |

29. Write the names of the following compounds: $\mathrm{FeCl}_{3}, \mathrm{MgI}_{2}, \mathrm{~K} 2 \mathrm{~S}, \mathrm{CuO}, \mathrm{NaBr}$.
30. Write the formula for the following compounds: tin II chloride, silver oxide, calcium sulfide, barium flouride, manganese II oxide, iron III oxide.

## Polyatomic Ions and the Naming of their Compounds

In addition to elemental ions there are also polyatomic ions. The word polyatomic means "more than one atom." These polyatomic ions act in much the same way as elemental ions. Some common polyatomic ions are listed in Table 2-6.

Table 2-6. Some polyatomic ions found in seawater.

| 2 Kinds of Atoms |  | 3 Kinds of Atoms |  |
| :---: | :---: | :---: | :---: |
| $\mathrm{mH}_{4}^{+}$ | Antioniun | $\mathrm{HCO}_{3}{ }^{-}$ | Dicerbencte * <br> (Hyaregen cerbonate) |
| $\mathrm{CO}_{3}{ }^{2-}$ | Carbonate | $\mathrm{HPO}_{4}{ }^{2-}$ | Hydrogen Phosphate |
| $\mathrm{OH}^{+}$ | Hydroxide | $\mathrm{HSO}_{3}^{-}$ | Bisulfite ${ }^{+}$ (Hydrogen mifite) |
| $\mathrm{Ma}_{2}{ }^{-}$ | Mitrite |  |  |
| $1403{ }^{-}$ | Hitrate |  |  |
| $\mathrm{PO}_{4}^{3-}$ | Phosphate |  |  |
| $\mathrm{SlO}_{3}{ }^{2-}$ | Siltcate |  |  |
| $\mathrm{SO}_{4}{ }^{2-}$ | Sulfate |  |  |
| $50_{3}{ }^{2-}$ | Sulfite |  |  |

*Some compounds have both scientific and conmon names; the names in parentheses () are scientifc names.

The carbonate ion $\left(\mathrm{CO}_{3}{ }^{2-}\right)$ forms compounds just as any elemental ion with a $2^{-}$charge such as sulfur ( $\mathrm{S}^{2-}$ ). For example, there is a $\mathrm{Li}_{2} \mathrm{~S}$ and there is a $\mathrm{Li}_{2} \mathrm{CO}_{3}$.

$$
\begin{aligned}
& 2 \mathrm{Li}^{+}+\mathrm{s}^{2-} \longrightarrow \mathrm{Li}_{2} \mathrm{~S} \\
& 2 \mathrm{Li}^{+}+\mathrm{CO}_{3}^{2-} \longrightarrow \mathrm{Li}_{2} \mathrm{CO}_{3}
\end{aligned}
$$

## Question

31. What would the formula be for an ionic compound of sodium ( $\mathrm{Na}^{+}$) and sulfate ( $\mathrm{SO}_{4}{ }^{2-}$ )? For magnesium $\left(\mathrm{Mg}^{2+}\right)$ and sulfate ( $\mathrm{SO}_{4}{ }^{2-}$ )?

One new feature in writing formulas of polyatomic ions comes when subscripts must be used. For example, aluginum ( $\mathrm{A} 1^{3+}$ ) forms a compound with sulfate $\left(\mathrm{SO}_{4}^{2-}\right)$. We find that the subscript on $\mathrm{SO}_{4}{ }^{2-}$ is 3.4 But where does the 3 go? We place parentheses around the $\mathrm{SO}_{4}^{2-}$ ion and put the 3 outside and at the end of ${ }^{4}$ the parentheses.

```
\(\begin{gathered}\text { sinallest } \\ \text { common }\end{gathered} \quad 2 \mathrm{Al}^{3+}+3 \mathrm{SO}_{4}{ }^{2-} \mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{3}\)
common
\(\left[2 \times\left(3^{+}\right)=6\right]\) and \([3 \times(2-)=6-]\)
```

The formula for a compound of magnesium $\left(\mathrm{Mg}^{2+}\right)$
and nitrate ion ( $\mathrm{NO}_{3}^{-}$) is:
smallest
common
multiple


## Questions

32. What are the formulas for the compounds made of the following combinations?
a. $\mathrm{Na}^{+}$and $\mathrm{OH}^{-}$
b. $\mathrm{Fe}^{2+}$ and $\mathrm{HCO}_{3}^{-}$
c. $\mathrm{Al}^{3+}$ and $\mathrm{HSO}_{4}^{-}$
d. $\mathrm{Pb}^{2+}$ and $\mathrm{PO}_{4}^{3-}$
e. $\mathrm{Ca}^{2+}$ and $\mathrm{OH}^{-}$
f. $\mathrm{Cu}^{2+}$ and $\mathrm{CO}_{3}{ }^{2-}$
33. $\mathrm{Fe}^{3+}$ and $\mathrm{SO}_{4}{ }^{2-}$

Do not be confused by the fact that a $\mathrm{Fe}^{3+}$ and a $\mathrm{Fe}^{2+}$ are shown. Some elements form more than one kind of ion.

The naming of polyatomic (ionic) compounds follows the same rules as those used to name two-element ionic compounds. The compound $\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ is called iron III sulfate. Remember that the element, or polyatomic group, forming the positive ion is read first.
33. Write the names of the following compounds:
a. LiF
e. $\mathrm{HgSO}_{4}$
b. $\mathrm{NH}_{4} \mathrm{I}$
f. $\mathrm{Ag}_{2} \mathrm{SO}_{4}$
c. $\mathrm{BaCO}_{3}$
g. KOH
d. $\mathrm{Ca}_{3}\left(\mathrm{PO}_{4}\right)_{2}$
h. $\mathrm{FeSO}_{4}$

Knowing the name of a compound and charges of the ions forming it, we can rapidly write its formula.
a. Write the symbols for the positive ion followed by that of the negative ion.
b. Determine the proper subscripts.

For example, given the name iron II njtrate, we
first write the symbols and charges, $\mathrm{Fe}^{2+}$ and $\mathrm{NO}_{3}{ }^{-}$.
Then, using the smallest common multiple method, ${ }^{3}$
we adjust the subscripts to $\mathrm{Fe}\left(\mathrm{NO}_{3}\right)_{2}$.

$$
\begin{gathered}
\text { Iron II Ion }+ \text { Nitrate Ion } \rightarrow \text { Iron II nitrate } \\
\mathrm{Fe}^{2+}+2 \mathrm{NO}_{3}^{-} \rightarrow \mathrm{Fe}\left(\mathrm{NO}_{3}\right)_{2}
\end{gathered}
$$

34. Write the formulas for each of the following compounds:
a. Sodium hydrogen phosphate
b. Mercury II nitrate
c. Lead If phosphate
d. Silver bromide
e. Calcium sulfate
f. Magnesium hydroxide

## 3. Composition of Water

We have seen that ionic compounds are held together by electrical forces. To form an ionic compound, one substance gives up electrons to become a ( + ) ion, the other substance receives electrons and becomes a ( - ) ion. For example, the following reaction occurs with formation of sodium and chloride ions.


A sodium atom gives its outermost electron to a chloride atom. The sodium becomes a $1+$ sodium ion and the chlorine atom a 1 -chloride ion. As oppositely charged ions, they attract each other tending to combine to form solid sodium chloride crystals.

In a sample of rock salt, the size of a pin head, there are billions of sodium and chloride ions, about $10^{20}$ of each. All these ions are arranged to form an orderly cubic crystal.


When a rock salt crystal is put into a solvent like water, the water breaks up or dissolves the crystal, forming a liquid mixture called a solution. In a solution, sodium ions and chloride ions are spread evenly throughout the water so that each milliliter of the solution contains the same number of the two ions. If we add enough heat to melt a sodium chloride crystal, we get the same kind of random distribution of ions as we do in a water solution. From such
a melt we can recover the elements, sodium and chloride, by applying a direct or battery current. Recall that a current of electricity is a flow of electrons. A battery simply pumps electrons from one place to another. Since the ions are free to move in a melt, a $(+)$ sodium ion will move to the $(-)$ pole where it picks an electron up to become a neutral sodium atom. A (-) chloride ion is attracted to the electron poor $(+)$ pole where it gives up an electron. By returning the electron to the sodium and removina an electron from the chloride, we decompose the compound or reverse the process of ion formation. This process is called electrolysis (Fig. 3-1).


Fig. 3-1. Electrolysts

## Activity

What happens to water in electrolysis.

## Materiols

-1 ring stand
-2 utility clamps
-1 500 ml beaker
-250 ml syringe barrels
-26 cm piece tubing to connect syringe
-2 strong pinch clamps
$-130-50 \mathrm{ml}$ syringe
-1 6-9 volt battery
-250 cm pieces of solid copper wire
$-15 \mathrm{~cm} \times 5 \mathrm{~cm}$ piece sand paper
-1 2-3 ml test tube
-400 ml of water
-sand paper

## Procedure

1. Set up the equipment shown in Fig. 3-2.
a. Burnish or brighten with sand paper, 10 cm of the ends of two copper wires. Bend the burnished part of the wires into loose coils to fit into syringe barrels. Also, burnish 3 cm at the other end of the wires. These will be connected to the battery.
b. Place a 500 ml beaker on the base of the ring stand. Attach tubing to the small end of each syringe barrel. Attach utility clamps to the barrels.

Put a wire coil in the large end of each barrel and support the syringe barrel in the beaker so that the large open end is at least halfway into the beaker. Clamp the syringes to ring stand.
c. Add 400 ml of the water provided by your instructor to the beaker.

Fill each syringe barrel completely with water using another syringe to draw off the air. Clamp the tubes.
d. Attach the ends of the copper wire to separate terminals of the battery.


Fig. 3-2. Equipment for the electrolysis of water.
2. Make the following observations and record in your notebook.
a. What happens at the coil end of the wires in the water when only one wire is attached to the battery?
b. What happens at the coil end of the wires when two wires are attached to the battery?
c. Which barrel has a coil attached to the negative ( - ) pole of the battery? Which has a coil attached to the positive ( + ) pole? Make a drawing to show the connection.
d. Compare the amount and rate of reaction at the coil connected to the ( + ) pole and the coil connected to the $(-\rangle$ pole.
3. When 2 to 3 ml of the water have been displaced in one barrel, draw off the contents into a syringe, refilling the barrel. Replace clamp. Eject the contents of the syringe into a clean, dry, small test tube, placing your finger over the end so that the contents do not escape.
a. Light a straw from a broom. Blow out the flame but keep the tip end glowing.
b. Hold the test tube horizontally, remove your finger and push the glowing straw into the tube. Record your results.
c. Look at the walls of the test tube and record any evidence of reaction.
4. When 2 to 3 ml of water have been displaced in the other barrel, follow Procedure 3 above.
5. Investigate the system as time allows.

## Summary Questions

Table 3-1 shows the physical properties of hydrogen ( $\mathrm{H}_{2}$ ) and oxygen ( $\mathrm{O}_{2}$ ). Some atoms such as hydrogen and oxygen immediately react to form molecules. Hydrogen forms $\mathrm{H}_{2}$ and oxygen, $\mathrm{O}_{2}$.

Table 3-1. Physical properties of hydrogen and oxygen.

|  | Densty | melting point | Botling point | Solubility\| | Gmeustibility |
| :---: | :---: | :---: | :---: | :---: | :---: |
| :Hyorrogen | .099/1 | -259 ${ }^{\circ} \mathrm{C}$ | - $25 z^{\circ} \mathrm{C}$ | $21 \mathrm{ma}^{3} / 1$ | momit in oxypon |
| Oxygon | 1.439/1 | $-288{ }^{\circ} \mathrm{C}$ | $-182^{\circ} \mathrm{C}$ | $49 \mathrm{~cm}^{3} / 1$ | Supports eombustion |
| ${ }^{\text {Ajr }\left(O_{2}+\mathrm{H}_{2}\right)}$ | $1.32 \mathrm{~g} / 1$ | $\begin{gathered} \text { wide } \\ \text { range } \end{gathered}$ | $\begin{gathered} \text { nithe } \\ \text { range } \end{gathered}$ | mide range | supports combustion |

1. What was the gas evolved at the coil connected to the ( + ) pole of the battery? Give your evidence.
2. What was the gas evolved at the coil connected to the (-) pole of the battery? Give your evidence.
3. Is there evidence in the investigation to indicate that one reaction might be represented in the equation

$$
\left(2 \mathrm{H}^{+}+2 \mathrm{e} \rightarrow \mathrm{H}_{2}\right) ?
$$

What is that evidence, if any? If such a reaction took place, what pole of the battery was the wire coil attached to?
4. Assume the equation in Question \#3 is correct, what would be the equation for the reaction at the other coil?
5. Was there evidence of reformation of water? If so, under what conditions was water reformed?

## 4. Chemical Composition of Seawater

The most abundant elements making up seawater are, of course, hydrogen and oxygen found in the water itself. There are also other elements in the dissolved components of seawater, and these are classified as the major, minor, and trace elements.

## Activity

Read the material and answer the questions.

## Major Elements

The 60 most conmon elements in seawater are shown in Table 4-1. Hydrogen ( H ) and oxygen ( 0 ), which compose both water ( $\mathrm{H}_{2} \mathrm{O}$ ) and many complex ions, account for about $97 \%$ of the mass of average seawater. Of the remaining $3 \%$ of the mass, ions of six elements make up all but . $04 \%$. These so-called major elements and their principal ions are listed in Table 4-1. Arbitrarily a major element in the dissolved components of seawater is one of whose ions make up more than $0.1 \%$ or, $.0001 \mathrm{~g} / 1000 \mathrm{~g}$ of seawater.

$$
\% / 00=\text { parts per mille }=\text { parts per thousand }
$$

Note that major elements are also conmon elements in the earth's crust.

## Constant Composition

Under normal circumstances the common ions of the major elements show a constancy of composition.

This means that the ratio of one ion to another is constant regardless of concentration or total amount of dissolved sal ts per unit of mass of water. If a sample of ocean water is diluted by fresh water, the ratio of the ions of the major elements remains the same. Likewise, if evaporation occurs, the ions become more concentrated, but the ratio remains the same. Natural variation in the ocean is 10 per cent. If we know the concentration of one of the common ions of one of the major elements, we can calculate the concentration of any of the other common ions of the major elements.

This constant proportionality provides the basis for easy determination of salinity. Salinity is the total mass of dissolved ions in 1000 g of seawater. In open ocean, the salinity range runs between $33.5-37.0 \%$; in Hawait it is about $35.0^{\circ} \%$. The chloride ( C$)^{-}$) ion concentration in grams of $\mathrm{Cl}^{-} / 1000 \mathrm{~g}$ seawater or $\%$ is called chlorinity. It has been determined experimentally that:

$$
\text { Salinity } \% / 00=1.80655 \times \text { chlorinity } \% 00
$$

Problem: What is the salinity when the chloride ion $\left(\mathrm{Cl}^{-}\right)$is $19.00 \%$ ?

$$
\begin{aligned}
\text { Salinity } \% & =1.80655 \times 19.00 \% / 00 \\
& =34.32 \% / 00
\end{aligned}
$$

Problem: What is the sodium $\left(\mathrm{Na}^{+}\right)$ion concentration when the chloride ( $\mathrm{Cl}^{-}$) ion concentration is $19.00 \%$ ?
Table 4-2 gives the ratio of ( $\mathrm{Na}^{+}$) to ( $\mathrm{Cl}^{-}$) as 0.552 .

$$
\frac{\mathrm{Na}^{+} / 00}{\mathrm{C}]^{-0} / 00}=0.552
$$

Therefore: $\mathrm{Na}^{+} \%=.522 \times \mathrm{Cl}^{-\%} \% 0$

Table 4-2. Principal elements found in seawater.

| Element Name | Most Conimon Ion | $\begin{gathered} \text { Syntol } \\ \text { of } \\ \text { Ion } \end{gathered}$ | Ratio of, Ion Mass to Chloride Ion Mass | Concentration \% \% * * |
| :---: | :---: | :---: | :---: | :---: |
| Chloride | Chloride | $\mathrm{Cl}^{-}$ | 1.00 | 19.5 |
| Sodium | Sodium | $\mathrm{Na}^{+}$ | . 552 | 10.7 |
| Sul fur | Sulfate | $5 \mathrm{OL}_{4}{ }^{2+}$ | . 139 | . 885 |
| Magnesium | Magnes ium | $\mathrm{Mg}^{2+}$ | . 0652 | 1.29 |
| Calcium | Calcium | $\mathrm{Ca}^{+}$ | . 0211 | . 42 |
| Potassium | Potassíum | ${ }^{+}$ | . 0194 | . 38 |

** parts per thousand; per mille

$$
\begin{aligned}
& \text { Substituting the concentration of } \mathrm{Cl}^{-} \\
& \text {in } \% \mathrm{OO} \\
& \mathrm{Na}^{+} \% \% \\
& =.522 \times 19.00 \% \% \mathrm{O} \\
& \\
& =10.49 \% \%
\end{aligned}
$$

Questions

1. If the $\mathrm{Cl}^{-}$concentration is $19.00^{\circ} \%$, what is the concentration of:

$$
\mathrm{SO}_{4}{ }^{2-}, \mathrm{Mg}^{2+}, \mathrm{Ca}^{2+}, \mathrm{K}^{+} ?
$$

2. What is the salinity of the water in $\%$, where the $\mathrm{Cl}^{-}$concentration is $19.50 \%$ ?

In maintaining an aquarium we can determine the salinity of seawater from density and temperature data. Knowing salinity we can calculate chlorinity:

$$
\text { chlorinity } \%=\frac{\text { salinity } \%}{1.80655}
$$

Problem: An aquarium is found to have a salinity of $34.00^{\circ} \%$. What is the chlorinity?
chlorinity $\%$ oo $=\frac{34.00^{\circ} \% 0}{1.80655}=18.84 \% \%$
Questions
3. An aquarium is found to have a salinity of $39.2 \%$. What is its chlorinity?
4. In the aquarium referred to in Question 3 , what is the concentration of:

$$
\mathrm{SO}_{4}^{2-}, \mathrm{Mg}^{2+}, \mathrm{Ca}^{2+}, \mathrm{K}^{+}, \mathrm{Na}^{+} ?
$$

Conditions Where Composition is Not Constant
When evaporation takes place minerals may precipitate to form solids. When this occurs the ratios of the major elements are not constant. The ratios of the major ions also may vary when river water with high ion content mixes with seawater.

Ions of the major elements of seawater are the principal "chemical environment" of the ocean. Organisms have evolved in this chemical environment for hundreds of mitlions af years, and thus have become adapted to it. Sudden changes in the proportions of the ions of the major elements have sertous, if not fatal, effects on many organisms.

## The Minor Elements

The minor elements in seawater are those that have a concentration of more than .00010/00 and less than $0.1 \%$. While the concentrations of major elements are constant, those of the minor
elements are more variable. This variability is particularly true of elements that make up the so-called nutrient chemicals. Nutrient chemicals from seawater are taken into the bodies of plants and animals as they grow. These chemicals return to seawater when organisms die. In Table 4-1, the principal elements that make up nutrients (other than hydrogen and oxygen) are indicated with an asterisk (*).

## Trace Elements

Trace elements are those that have a concentration of less than . 0001\% \%o of seawater. The nature of the trace elements and their reactions in seawater are not well known. They seem to vary in concentration from place to place and from time to time. Many of them are involved in biological processes. Table 4-1 lists reported concentrations of some of these elements in seawater and identifies those that are known to be essential to organisms.

Biologically, vanadium (V) is highly concentrated in the blood of certain tunicates and manganese ( Mg ) is thought to be important in the metabolism of some bacteria. Iron ( Fe ) is in hemoglobin of the blood of vertebrates while cobalt (CO) is an essential part of vitamin B12. Copper (Cu) is a pigment in the blood of arthropods.

Many of the elements in Table 4-1 can be detrimental or poisonous to organisms. An element may be essential in low concentrations but poisonous in high concentrations; arsenic (As) is an obvious example. In the concentrations of normal seawater, the elements are apparently not poisonous. However, when some industrial wastes enter the sea, poisonous levels of many trace elements can be quickiy reached.

Nutrient Chemicals
Some of the chemicals in seawater are essential to the growth of primary producers, plants such as algae. The nutrient chemicals of seawater include the nitrate ion ( $\mathrm{NO}_{3}^{-}$), nitrite ion $\left(\mathrm{NO}_{2}-\right)$, ammonium ion ( $\mathrm{NH}_{4}+$ ), phosphate ion ( $\mathrm{PO}_{4}^{3-}$ ), a and silicate $\left(\mathrm{Si}_{\left.(\mathrm{OH})_{4}\right) \text {. They also include organic }}\right.$ compounds and the bicarbonate ion ( $\mathrm{HCO}_{3}^{-}$). These substances have highly variable concentrations in the ocean because they are all involved in biological processes. Their concentrations are, in most cases, inversely proportional to the amount of biological activity in a given parcel of water. (The more activity, the lower the chemical concentration.) Thus, in surface seawater, where most of the life in the sea exists, nutrient chemicals approach zero concentration, while in deep sea, where living organisms are few and far between, the concentrations are much higher.

The principal uses of nitrogen compounds by plants and animals is for the formation of amino acids, the basic units of protein. Phosphorous is used by plants and animais to form many substances molecules such as ATP (TP stands for triphosphate).

Silicone is used in the skeletons of plants (Diatoms and Silicoflagellates), and animals (Radiolarians and Sponges).

These nutrient chemicals are commonly considered to be the fertilizers of the sea. However, these same materials, particularly nitrogen and phosphorous chemicals, can also be called pollutants when they occur in high quantities from sewer outfalls and runoff from heavily fertilized agricultural areas.

Questions
5. What conditions must an element meet to be considered a major elemental component of seawater? A minor element? A trace element?
6. Why are the concentrations of the nutrient elements variable when the concentrations of the major elements are constant?
7. How could a chemical be both a nutrient and a pollutant?
8. How could a chemical be both essential to our biology and poisonous to living things?
9. How is nitrogen ( $N$ ) used in our bodies?
10. How is phosphorous ( $P$ ) used in our bodies?

## Comparison Seawater and Crust Elements

We have discussed some of the properties of elements in the Periodic Table and we have classified the elements dissolved in seawater as major, minor, and trace elements.

## Questions

11. Refer to Table 4-1. Circle the symbol of the elements used in biological processes on Table 4-3. Identify with shading the elements in nutrient chemicals.

Table 4-3. Periodic table showing elements essential to biological processes.

12. Use different colors to show the major, minor, and trace elements found in seawater. Use Table 4-4. Identify only the first 20 trace elements.

Table 4-4. Periodic table showing major, minor, and trace elements of seawater.

13. Circle the major, minor, and trace elements found in the earth's crust in the same colors as the elements found in seawater. Use Table 4-5. Identify only the first 20 trace elements.

Table 4-5. Periodic table showing major, minor, and trace elements in the earth's crust.

14. Is there any periodic pattern to the distribution of the major elements found in seawater? (Are they found mostly in certain regions of Table 4-4?) What about the minor elements? The first 20 trace elements? If so, what are the patterns?
15. Is there any relationship between the distribution of the biologically essential elements and the first 35 elements in seawater? If so, what is it?
16. Is there any periodic pattern to the distribution of the major crust elements? If so, what is it?
17. Is there any relationship between the distribution of the biologically essential elements and the major crust elements? If so, what is it?
18. Is there any relationship between the first 35 elements found in seawater and the first 35 elements found in the crust elements? If so, what is it?
19. How might this information support the hypothesis that life began in the sea?

## Residence Time

To help understand why the oceans have the composition that they have, we use a concept called residence time. The residence time is the average length of time that an atom of an element or ion stays in the ocean. It is the time from the moment it enters the ocean from glaciers, rivers, ground water, etc., to the time it leaves the ocean as mud on the bottom or in sea spray or some other way.

We need to know only two things to calculate residence time.
a. The total amount of an element in the ocean (concentration $X$ mass of salt water).
b. The total amount of an element added by rivers and other sources each year.

The basis for such a calculation is that we have a great deal of evidence that the composition of the ocean has not changed significantly in millions of years.

$$
\text { residence time }=\frac{\text { total amount in the ocean }}{\text { amount added per year }}
$$

Calculating residence time for Na (sodium) we use the data from Table 4-6.

$$
\begin{aligned}
& \frac{14.1 \times 10^{21} \mathrm{~g}}{20.7 \times 10^{13} \mathrm{~g} / \text { years }}=.69 \times 10^{8} \text { years } \\
& \begin{aligned}
69 \times 10^{8} \text { years }=69 \times 10^{6} \text { years } & =69,000,000 \\
& =69 \mathrm{million} \text { years }
\end{aligned}
\end{aligned}
$$

## Questions

20. Calculate residence times for the remaining chemicals as shown in Table 4-6.
21. Compare the residence times with concentration from Table 4-1. How are they similar? Different?
22. Suggest an explanation of your finding in Question 21.

Table 4-6. Examples of data to calculate residence time.

| clemut |  | manat theed to comentar a $1 a^{13}$ w | Rasidumen - $\mathrm{T}_{\text {ma }}$ | Concmintrition :an */.. |
| :---: | :---: | :---: | :---: | :---: |
|  | 4.4 | 30.7 | 164 antitimy |  |
|  | 1.9 | 11.1 | ; |  |
| Pressilum ( $\mathrm{K}^{\circ}$ ) | 5 | 1.4 |  |  |
| Calcsue $\left[\mathrm{Ca}^{2+}\right]$ | 6 | 4.4 |  |  |
| $3111004508)$ | 900 | 42.6 |  |  |
| Ohlorme ( $\mathrm{Cl}^{\circ}$ ) | 4.1 | 25.4 |  |  |
| Sulow $\mathrm{CsO}_{4}{ }^{2+}$ \} | 1.1 | 36.4 |  |  |
| $\left.\underline{L r}\left(0_{0}\right)^{2+1}\right)$ | . 9000014 | 2.2 |  |  |
| Copper ( $\mathrm{cc}^{2+}$ ) | Denemid | . 207 |  |  |

## 5. Determininc Components of Seawater

We have seen that the concentration of the ions of the major elements can be calculated if we know the salinity of the seawater. We have seen that salinity can be calculated if we know the density and temperature of seawater.

## Activity

Find the concentrations of the ions of major elements of seawater found in your aquarium.

## Materials

-1 hydrometer -salt water
-1 graduated cylinder
-1 thermometer
Table 5-2. Data on aquarium water.

## Procedure

1. Standardize your hydrometer.
a. Determine the reading on the hydrometer for each of two standard solutions. Record in Table 5-1.

Table 5-1. Density and hydrometer reading.

| standard <br> density | hydrometer <br> reading |
| :--- | :--- |
| 1 |  |
| 2 |  |

b. Make a density and hydrometer reading graph. Graph the density on the horizontal axis, the hydrometer reading on the vertical axis.
2. Measure the temperature of the aquarium seawater sample.
3. Determine the density of the aquarium seawater sample using the graph (Fig. 5-I) as a reference. Record in Table 5-2.
4. Determine the salinity of the aquarium seawater using the salinity graph. Record in Table 5-2.
5. Calculate the concentrations of each of the major ions.

| Temperature |  |  |
| :---: | :---: | :---: |
| Density_._.___ |  |  |
| Salinity |  |  |
| Concentration | Concentration |  |
| $\mathrm{Cl}^{-}$ | $\mathrm{SO}_{4}{ }^{2-}$ |  |
| $\mathrm{Na}^{+}$ | $\mathrm{K}^{+}$ |  |
| $\mathrm{Mg}^{2+}$ | $\mathrm{Ca}^{2+}$ |  |



Fig. 5-1. Salinity determination by density

## Summary Questions

1. How did you determine the density of the aquarium seawater? Explain.
2. How did you determine the salinity of the aquarium seawater? Explain.
3. The salinity of seawater in the open ocean is $35 \%$. Why might the density of the seawater used in this experiment be different from $35 \%$ ? Explain.
4. How could a salinity of $40 \% / 00$ be adjusted to $35 \%$ ?
5. How could a salinity of $330 / 00$ be adjusted to $340 \%$ ?
6. Suggest reasons for keeping salinity of seawater relatively constant.
7. What happens to the density of seawater as the salinity increases? Explain.
8. As the temperature increases, what happens to salinity and the density of a liquid if it did not evaporate?
9. If the temperature were increasing, what would you have to do to keep the density constant?

## 6. Salts From Water

From early times, minerals have been recovered from seawater for human use. Minerals can also be recovered from fresh water, but in lesser quantity. In this investigation we will compare the minerals found in fresh and salt water. We will also attempt to recover and purify sodium chloride, or table salt, from seawater.

## Activity

Compare the relative quantity of minerals in fresh and sea water.

Recover table salt from sea water.

## Materials

- seawa ter
-3 watch glasses
-1 100 ml beaker
-1 ring stand
-1 ring and gauze
-1 burner
-1 stirring rod
-1 syringe $10-30 \mathrm{ml}$
-1 graduated cylinder
-1 balance
-1 magnifying glass
-1 metric rule
-3100 ml beakers


## Procedure

1. Determine the mass of 75 ml of seawater poured into a 100 ml beaker. Record your data in Table 6-1 (\#1, 2, and 3).

Table 6-1. Data table for seawater and stream water.

2. Reduce the volume of the seawater from 75 ml to about 50 ml by heating. Cool and record the mass of beaker and contents in Table 6-1 (\#4,5, and 6).
3. Set up a 100 ml beaker and weighed watch glass A for heating according to Fig. 6-1. Record the weight of watch glass $A$ in Table 6-1 (\#13).
4. Take the cooled 100 ml beaker of concentrated saltwater. Redissolve any mineral on the sides with the aid of a stirring rod.


Fig. 6-1. Method for evaporating seawater on a watch glass
5. Pour sufficient liquid from the 100 ml beaker to fill all but about the last 0.5 cm of the diameter of watch glass $A$. Determine the mass of the liquid remaining in the beaker. Record in Table 6-1 (\#7, 8, and 9).
6. Heat the 100 ml beaker slowly until the contents of watch glass A are dry. Caution: Do not let the liquid boil. Remove heat whenever boiling or splattering occurs.
7. Cool and weigh watch glass A, and the dry mineral. Record in Table 6-1 (\#12 and 14).
8. Draw a diagram of the mineral deposition on watch glass $A$ and make the following observations:
a. Observe the minerals with the naked eye and with a magnifying glass. Draw and indicate any areas with different crystals.
b. Taste a small amount of the mineral on the outermost edge of the watch glass A. Record what it tastes like in your notebook.
c. Taste a small amount of the mineral from the center of the watch glass A. Record what it tastes like.
d. By tasting, measure the width of the mineral on the outer edge of watch glass A. Indicate the width on your drawing.
e. Taste other areas in watch glass $A$ and record minerals with different tastes on your drawing.
9. Purify the mineral on the outer edge and at the center of watch glass A.
a. Mark the width of the outer ring with a pencil.
b. Dissolve the mineral at the center of watch glass A by adding fresh water. The pool of dissolving water should reach to the limit of the pencil mark.
c. Remove the dissolved mineral using a syringe. Put washing on a second weighed watch glass B. Table 6-1 (\#19). Wash the center twice and remove the liquid putting it on the second watch glass. An outer ring of mineral should remain on the original watch glass A.
d. Use the syringe and dissolve the outer ring of mineral with fresh water. Leave this liquid on the original watch glass A.
e. Heat each watch glass ( $A$ and $B$ ) as before in Procedure 6 or allow the watch glasses to stand overnight to evaporate.
f. Determine the mass of the mineral on each watch glass. Record in Table 6-1 (\#17 and 18).
10. Repeat observations a-e in Procedure 8 with each watch glass.
11. Follow Procedures 1-8 using stream water. Record in Table 6-1.
12. Complete Table 6-1 making all calculations for items \#10, 11, 15 and 16 .

## Summary Questions

1. Compare the quality of mineral content in fresh water and seawater. How many times greater is the salinity of seawater than the salinity of fresh water? (See Topic 5).
2. Compare the salinity of the seawater you calculated in Topic 5 and the salinity calculated by the evaporation technique. Suggest an explanation for any difference.
3. Which of the minerals on the watch glass tasted the most like table salt (sodium chloride)?
4. How much mineral was in the inner ring? The outer ring? Show how you made your calculation by identifying each measurement from Table 6-1.
5. What percent of the total mineral content of the seawater seems to be sodium chloride?
6. Explain how the sodium chloride was purified in Procedure 9. How could the NaCl be further purified?
7. How much seawater would it take to produce a kilogram of sodium chloride by this technique?

## Further Investigations

We count atoms, ions, and molecule, in units called moles. One mole is $6.02 \times 10^{23}$; therefore a mole of atoms is $6.02 \times 10^{23}$ atoms A mole of chloride ( Cl$)^{-}$) ions is $6.02 \times 10^{23} \mathrm{Cl}^{-}$ ions. In Table 6-2 are listed the masses of a mole of each of the major ions found in seawater.

Though individual ions have very small masses, moles of ions have measureable masses. A single calcium ion $\mathrm{Ca}^{2+}$ has a calculated mass of
. $000,000,000,000,000,000,000,065,6 \mathrm{~g} /$ ion
$\frac{40.1 \mathrm{~g} / \mathrm{mole}}{6.02 \times 10^{23}} \mathrm{ions} / \mathrm{mole}=6.66 \times 10-23 \mathrm{~g} / \mathrm{ion}$

Table 6-2. Data on ions found in average seawater.

| $\left\{\begin{array}{c} \text { Mame } \\ \text { of } \\ \text { ion } \end{array}\right.$ | $\left\|\begin{array}{c} \text { Symbor } \\ \text { of } \\ \text { ion } \end{array}\right\|$ | Mass of a mole $6.02 \times 10^{23}$ <br> ions: | Mass of ion $/ \mathrm{kg}$ in ayerage sea mater | ```Number of moles of ions/kg of averoge seawattr``` |
| :---: | :---: | :---: | :---: | :---: |
| Calcium | $\mathrm{Ca}^{2+}$ | 40.1 g | $0.4 \mathrm{~g} / \mathrm{kg}$ | . 01 mole/kg |
| Chloride | $\mathrm{Cl}{ }^{-}$ | 35.59 | $19.2 \mathrm{~g} / \mathrm{kg}$ | . $541 \mathrm{~mole} / \mathrm{kg}$ |
| Magnes iun | $\mathrm{Mg}^{2+}$ | 24.39 | $1.28 \mathrm{~g} / \mathrm{kg}$ | , |
| Potassium | K+ | 39.19 | $0.4 \mathrm{~g} / \mathrm{kg}$ | -- |
| Sodi unt | $\mathrm{Ha}^{+}$ | 23.09 | $10.7 \mathrm{~g} / \mathrm{kg}$ | . $465 \mathrm{~mole} / \mathrm{kg}$ |
| Sulfate | $\mathrm{SO}_{4}{ }^{2-}$ | 96.19 | $2.5 \mathrm{~g} / \mathrm{kg}$ | mole/k |

$$
\begin{aligned}
& \text { Also found in Table } 6-2 \text { are the masses of } \\
& \text { different ions found in a kilogram of seawater. } \\
& \text { From this, the number of moles of each ion can he } \\
& \text { found. For example, the number of moles of Ca } \\
& \text { ion in seawater is .01 moles } / \mathrm{kg} \text { of seawater. } \\
& \begin{aligned}
\text { Number of moles } / \mathrm{kg} & =0.4 \mathrm{~g} / \mathrm{kg} \div 40.1 \mathrm{~g} / \mathrm{mole} \\
& =\frac{0.4 \mathrm{~g}}{\mathrm{~kg}} \times \frac{\text { mole }}{40.1} \mathrm{~g}=\frac{0.01 \mathrm{~mole}}{\mathrm{~kg}}
\end{aligned}
\end{aligned}
$$

1. In Table 6-2, calculate the moles of ions per kilogram of seawater for each of the ions where this information is not given.
2. What is the mass of a single sodium ion?

## 7. Covalent Molecules and Compounds

In discussing ionic, or electrovalent, compounds we found they are formed when atoms exchange electrons. We noted a general tendency of the atoms on the left side of the periodic table to give up outer shell electrons. Elements on the right side of the table tend to attract and gain electrons. What happens when two or more atoms, each of which tends to attract electrons, are brought together? They tend to share electrons. This sharing of electrons can take place between: 1) atoms of the same element which form covalent elemental molecules, or 2) atoms of two or more different kinds of elements, both of which strongly attract electrons and form covalent molecular compounds.

## Activity

Read the materials and answer the questions.

## Elements Tending to Form Covalent Molecules

Certain of the elements form 2-atom, covalent elemental molecules. These are called diatomic, or two-atom, elemental molecules (see Table 7-1). Most of these diatomic elements are gaseous at room temperature. Other elements forming covalent bonds are also listed in the table. Atoms of these same elements combine to form covalent molecular compounds.

Table 7-1. Elements forming covalent molecules.
Diatomic elements are shown by formula.


## Covalent Molecular Compounds

Covalent compounds are different from ionic compounds. They are composed of those elements that tend to acquire electrons. In covalent compounds, atoms share pairs of electrons, rather than taking or giving up electrons. Recall that elements tending to form negative ions add electrons to complete their outer shell to two or eight electrons. In covalent bonding, two bonded atoms act as children trying to pull sticks away from each other. As long as neither releases the sticks (electrons), they remain "bonded" together.

For example, consider methane. It is composed of one carbon and four hydrogen atoms. A dot ( $)$ is used to represent an electron from a carbon atom; an "x" represents an electron from a hydrogen atom. The $x$ 's and 's represent the same kind of electrons. They are used only to show the source of electrons. Carbon has 4 electrons and needs 4 additional electrons to complete its outer shell of eight. The four hydrogen atoms each have one electron and need one electron more to fill the outer shell to two. By sharing electrons, both carbon and hydrogen
satisfy their needs to gain electrons. Each hydrogen atom has 2 electrons, its period maximum, and the carbon has 8 electrons, its period maximum.


Question

1. Show the electron dot structure of ammonia $\left(\mathrm{NH}_{3}\right)$, water $\left(\mathrm{H}_{2} \mathrm{O}\right)$, and hydrogen sulfide $\left(\mathrm{H}_{2} \mathrm{~S}\right)$.

## Valence Bond Notation

Now that we have seen how covalent compounds are formed by sharing electrons, we can simplify the notation slightly. This method is called valence bond notation. The resulting compound representation is called a structural formula. We use a single line ( - ) to represent an electron pair. For example, methane can be represented as:


The result is that both carbon and hydrogen have filled their outer shells by sharing electrons. The elements that combine to form covalent bonds can be placed in a Periodic Table showing their valence bond representation. See Table 7-2.

Table 7-2. Elements forming covalent compounds showing valence bond notation.


## Questions

2. Complete Table 7-2. Draw in the valence bonds of the elements, which lack bond notation and add the missing elements and their bond notation.
3. Label the groups and periods represented in Table 7-2.
4. What is the structural formula of water ( $\mathrm{H}_{2} \mathrm{O}$ ), ammonia ( $\mathrm{NH}_{3}$ ), and hydrogen sulfide $\left(\mathrm{H}_{2} \mathrm{~S}\right)$ ?

Atoms can share more than one electron pair with another atom. For example, nitrogen can share three electrons with another nitrogen atom, forming $\mathrm{N}_{2}$. Carbon can share two pairs of electrons with 2 oxygen atoms $\left(\mathrm{CO}_{2}\right)$.
$\mathrm{N} \equiv \mathrm{N}$
nitrogen $\left(\mathrm{N}_{2}\right)$
$0=\mathrm{C}=0$
carbon dioxide $\left(\mathrm{CO}_{2}\right)$
Question
5. What would the possible structural formulas for the diatomic elements be shown in Table 7-1?

## Polar Molecules

Water molecules are covalent and polar. We have seen that covalent molecules share electrons.
Water's oxygen atom shares two pair of electrons, one with each of 2 hydrogen atoms as illustrated.



By polar we mean that the water molecule has two electrically dissimilar ends. One end has an excess of $(+)$ charge and one end an excess of ( - ) charge. To be polar a molecule must meet two requirements:

```
1) it must be composed of atoms that have different amounts of attraction for electrons and,
2) it must be asymmetrical.
```


## Electronegativity

The measure of an atom's attraction for electrons is called electronegativity. The electronegativity of the elements forming covalent compounds is shown in Table 7-3.

Table 7-3. Electronegativities of elements forming covalent compounds

|  |  |  |  |  |  |  | 2.1 <br> $H$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2.0 <br> $B$ | 2.5 <br> C | 3.0 <br> N | 3.5 <br> 0 | 4.0 <br> F |  |  |  |
|  | 1.8 <br> Si | 2.1 <br> P | 2.5 <br> S | 3.0 <br> Cl |  |  |  |

An element with a larger electronegativity attracts electrons more stongly than one with a smaller electronegativity. Therefore,

$$
2.0<2.5<3.0
$$

Put another way, nitrogen (N) attracts electrons
more strongly than carbon ( C ), and carbon attracts electrons more strongly than boron (B).

## Questions

6. The atoms of what element shown in Table 7-3 attract electrons the strongest?
7. The atoms of what element shown in Table 7-3 attract electrons the least strongly?
8. What happens to the relative amounts of attraction for electrons of successive elements moving from left to right across Table 7-3?
9. What happens to the relative amount of attraction for electrons of successive elements moving top to bottom?

## Asymmetrical and Symmetrical Molecules

A water molecule is asymmetrical.


This molecule is obviously lopsided with hydrogen concentrated at one end, oxygen at the other. Examples of other asymmetric molecules are those of hydrogen chloride ( HCl ) and nitrogen trichloride $\left(\mathrm{NCl}_{3}\right)$.
$\mathrm{H}-\mathrm{Cl}$
hydrogen
chloride

nitrogen trichloride

Symmetrical molecules are exemplified by the molecule of chlorine $\left(\mathrm{Cl}_{2}\right)$ and methane.


chlorine
methane
In the case of the chlorine molecule, there is as much chlorine on one end of the molecule as the other. Because it has two atoms of the same size on each end it is symmetrical like a dumbell. Methane has its hydrogen evenly distributed around the carbon atom at its center.

## Question

10. Draw the valence bonds representative of the following molecules and indicate whether they are symmetrical or asymmetrical.

$$
\mathrm{H}_{2} \mathrm{~S}, \mathrm{NH}_{3}, \mathrm{HF}, \mathrm{CCl}_{4}, \mathrm{H}_{2} \mathrm{Te}
$$

## Strength of Polarity

We would predict that the asymmetrical H Te molecule would not be very strongly polar because hydrogen ( $H$ ) and tellurium (Te) attract electrons about equally. They both have electronegativity of 2.1. A hydrogen telluride $\mathrm{H}_{2}$ Te molecule is weakly polar.
However, hydrogen sulfide ( $\mathrm{H}_{2} \mathrm{~S}$ ) is polar. Sulfur has an electronegativity of 2.5 , hydrogen 2.1, with a difference of 0.4 in favor of sulfur. Therefore, sulfur is the negative (-) end of the molecule, hydrogen the positive ( + ) end.

## Questions

11. Calculate the electronegativity difference for the following molecule $\mathrm{H}_{2} \mathrm{O}, \mathrm{CH}_{4}, \mathrm{NH}_{3}$. between the elements of the following molecules: $\mathrm{H}_{2} \mathrm{O}, \mathrm{CH}_{4}, \mathrm{NH}_{3}$.
12. List the three compounds in Question 11 in order of anticipated strength of polarity from strongest to weakest.
13. List the four hydrogen compounds in the elements of the oxygen group according to the strength of their polarity.

$$
\left(\mathrm{H}_{2} \mathrm{O}, \mathrm{H}_{2} \mathrm{~S}, \mathrm{H}_{2} \mathrm{Te}, \mathrm{H}_{2} \mathrm{Se}\right)
$$

## Boiling Point of Molecules

The influence of polarity on the physical properties of compounds can be seen in comparing boiling and freezing points of the hydrogen compounds of several atomic groups. See Fig. 7-1.

Each of the molecules of the compounds has the same number of protons and electrons. For example, water ( $\mathrm{H}_{2} \mathrm{O}$ ) contains 10 electrons and 10 protons; 2 from hydrogen and 8 from oxygen. Ammonia $\left(\mathrm{NH}_{3}\right)$ also contains 10 electrons and protrons, 7 from nitrogen ( $N$ ) and 3 from hydrogen ( $H$ ).

## Questions

14. How many protons are there in methane $\left(\mathrm{CH}_{4}\right)$ ?
15. How many protons are there in $\mathrm{H}_{2} \mathrm{~S}, \mathrm{PH}_{3}$, and $\mathrm{SiH}_{4}$ ?
16. a. In Fig. 7-1 which group of hydrogen compounds is not polar? (Draw molecules).


Fig. 7-1. Boiling point of hydrogen compounds of groups IV, V and VI.

Notice the unusually high boiling point of water. This is attributed to the fact that molecules of water have an exceptionally strong polarity.

Molecules in water tend to attract and hold onto each other.

Molecules of $\mathrm{CH}_{4}, \mathrm{SiH}_{4}$, and $\mathrm{GeH}_{4}$ are nonpolar and have little attraction for each other.

The melting points of the same compounds are shown in Fig. 7-2.


Fig. 7-2. Me]ting points of hydrogen compounds of groups IV, $V$ and $V I$

## Questions

17. Compare the melting points of water $\left(\mathrm{H}_{2} \mathrm{O}\right)$, ammonia $\left(\mathrm{NH}_{3}\right)$, and methane ( $\mathrm{CH}_{4}$ ) with their relative polarities. How does polarity appear to relate to melting point?
18. Compare the melting points of the strongly polar hydrogen compounds of group-VIA with the melting points of the nonpolar hydrogen compounds of group IVA. How does polarity relate?

## Surface Tension

Polar molecules have some of the characteristics of ions. The positive ends of one polar molecule tend to attract the negative ends of another and they bind together. We have seen an example of this in Chapter 3, Topic 1, where the water's surface acted as if it were a thin membrane. Aluminum foil which has a density of $2.7 \mathrm{~g} / \mathrm{cm}^{3}$ floated on the water of density $1.00 \mathrm{~g} / \mathrm{cm}^{3}$. On the other hand, aluminum foil readily sank in alcohol which is made up of molecules that are only slightly polar.

Water and alcohol both tend to form spheres when they drop through the air. When drops of water and alcohol are placed on a surface they tend to form balls. On a surface such as aluminum foil, water forms more of a ball than alcohol. Surface tension can be considered a measure of the capacity of liquids to draw up into a sphere. (Table 7-4).

Table 7-4. Surface tensions of selected liquids.

|  | Surface <br> Tension | Nature of <br> $\mathrm{J} / \mathrm{cm}^{2}$ at 200 <br> liquids |
| :--- | :--- | :--- |
|  | 223 | slightly polar |
| ethyl alcohol | 223 | nonpolar |
| hexane | 784 | ionic solution |
| sea water | 728 | strongly polar |

From Table 7-4, strongly polar water is seen to have a surface tension which is about 3.3 times as great as that of the slightly polar alcohol.

## Questions

19. How do the surface tensions of nonpolar hexane and water compare?
20. What effect do dissolved ionic compounds have on the surface tension of water?
21. What phenomena observed in Chapter 3, Topic 1 might be explained by surface tension?

## 8. Comparison of Polar and Nonpolar Llauids

Many of the characteristic properties of water can be attributed to its polar structure. In this activity we will compare highly polar water with slightly polar ethyl alcohol and nonpolar hexane.

The formulas and selected physical properties of compounds used in the investigation are shown in Table 8-1.

Table 8-1. Structures and selected physical properties of compounds.


The properties we will investigate are:
conductivity - the ability of a substance to transmit electrical current, and solubility - the ability of one substance to dissolve another substance.

## Activity

Compare the solubility and conductivity properties of polar, slightly polar, and nonpolar liquids.

## Materials

- 1 watch glass
-3 100 m beaker, for liquids
-1 stopper to fit graduated cylinder
-1 10 ml graduated cylinder
-1 stirring rod
- 13 volt battery
-13 volt flashlight bulb
-13 volt bulb holder or arrangement as shown
-2 pieces insulated copper wire
-sand paper
-ethyl alcohol
-hexane
-water
-0i1
-sodium chloride
-sugar
- sea water
-toweling
-test tube brush
-distilled water


Fig. 8-1. Device for determining conductivity.

## Procedure

1. Make a conductivity testing device according to Fig. 8-1.
a. Strip the insulation from the last 5 cm from one end and 2 cm from the other end of each of two insulated copper wires.
b. Burnish the bare wire with sandpaper.
c. Wrap the 5 cm end of one wire around the screw track of a 3 volt flashlight bulb. The other end should be bent to act as a probe in solutions.
d. Secure the 5 cm part of the other wire to one pole of the battery and bend the 2 cm end to act as a probe.
e. Test by having one partner press the base knob of the bulb against the pole of the battery which is not attached to a wire. Hold the glass part of the bulb. Another partner should now touch the bare probes together. If the testing device works, the light will burn brightly.
2. Test the conductivity of each of the liquids shown in Table 8-2.
a. Pour 2 ml of the liquid to be tested into a watch glass.
b. Check the conductivity testing device by touching the bare wires together.

Table $8-2 . \frac{\text { Degree of conductivity measured }}{\text { by light intensity. }}$

| Compound | Bright | Dim | No <br> light |
| :--- | :--- | :--- | :--- |
| Alcohol |  |  |  |
| 0il |  |  |  |
| Hexane |  |  |  |
| Sea Water |  |  |  |
| Water |  |  |  |

W
c. Touch the bare ends of the probes to the watch glass. Place them about 1-2 cm apart in the liquid. Put an x in the column in Table 8-2 corresponding to the amount of light produced by the bulb.
d. Wash and dry the watch glass between each measurement.
3. Test the mutual solubility of pairs of liquids. Follow Table 8-3 and test the conductivity of the resulting solutions.
a. Pour 2 ml of each component of the liquid pair into a graduated cylinder. Stopper and shake the contents. Let the liquids stand until settling stops.

Table 8-4. Relative solubility and conductivity of solutions.

Table 8-3. Conductivity and mutual solubility of liquid pairs.

|  | Water |  | 017 |  | Hexane |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Compound | Volume Lower Layer | Conductivity | Volume Lower Layer | Conduc. tivity | Volume Lower Layer | Canduc- <br> tivity |
| Alcohol |  |  |  |  |  |  |
| Hexane |  |  |  |  | $x$ | 人 |
| 011 |  |  | $\times$ | Х | $\times$ | $\chi$ |

b. Record the volume and the name of the liquids on the bottom layer.
c. Shake the contents again and pour a sample of each pair onto a watch glass and test for conductivity as in Procedure 2. Record conductivity as bright, dim, or no light.
4. Test the solubility of different mineralliquid solvent pairs shown in Table 8-4. Then test the conductivity of the resulting solution.
a. Pour one ml of powdered or granular mineral into a clean dry 10 ml graduated cylinder. Add 5 ml of the indicated liquid solvent. Stopper and shake the contents. Record the volume of solid that does not dissolve.

b. Pour only the liquid solution into a watch glass and test for conductivity as in Procedure 2. Record as bright, dim, or no light.
5. From Table 8-4, which solids were soluble in water but not hexane? Suggest an explanation.

## Summary Questions

1. Which of the liquids listed in Table 8-2 conducted electricity? Suggest an explanation.
2. Which liquids listed in Table 8-3 dissolved readily in water? Compare their polarity. Which liquids listed in Table 8-3 did not dissolve in water. Compare their polarity.
3. Which liquids listed in Table 8-3 dissolved in hexane? Compare their polarity.
4. Assume other compounds with similar polar and nonpolar character act like the examples tested here. Make a general statement about which kinds of liquids will be mutually soluble and which will be relatively insoluble.
5. Which solids were soluble in hexane? Suggest an explanation

## Further Investigations

1. Oil spills at sea are a major environmental hazard. Detergents are of ten used to disperse them. What properties do detergents have that make them suited for this purpose?
2. Minerals are carried from the land in stream water. Most of these minerals are in an ionic state. Why would water be an effective solvent?

## 9. pH of Water

A compound that released hydrogen ions ( $\mathrm{H}^{+}$) in the solvent water is called an acid. The presence of large quantities of $\mathrm{H}^{+}$ions makes water solutions very active chemically. Some common acids and their reactions in water are shown in Table 9-1.

Table 9-1. Some common acids.

| Compound name | Acid name | Acid formation in water |  |
| :--- | :--- | :--- | :--- | :--- |
| Hydrogen carbonate | Carbonic acid | $\mathrm{H}_{2} \mathrm{CO}_{3}$ | $\mathrm{H}^{+}+\mathrm{HCO}_{3}^{-}$ |
| Hydrogen chloride | Hydrochloric acid | $\mathrm{HCl}^{+}$ | $\mathrm{H}^{+}+\mathrm{Cl}^{-}$ |
| Hydrogen nitrate | Nitric acid | $\mathrm{HNO}_{3}$ | $\mathrm{H}^{+}+\mathrm{NO}_{3}^{-}$ |
| Hydrogen sulfite | Sulfurous acid | $\mathrm{H}_{2} \mathrm{SO}_{3}$ | $\mathrm{H}^{+}+\mathrm{HSO}_{3}^{-}$ |
| Hydrogen sulfate | Sulfuric acid | $\mathrm{H}_{2} \mathrm{SO}_{4}$ | $\mathrm{H}^{+}+\mathrm{H}^{+}+\mathrm{HSO}_{4}^{-}$ |

Because of its polar character, water breaks up some of its own molecules to form hydrogen ions according to the equation

$$
\mathrm{HOH} \rightarrow \mathrm{H}^{+}+\mathrm{OH}^{-}
$$

where HOH is the same as $\mathrm{H}_{2} 0$. If a solution has more $\mathrm{H}^{+}$ions than found in pure water, it is said to be acid; if it has fewer $\mathrm{H}^{+}$ions than pure water is is said to be basic. Pure water has $10^{-7}$ moles/liter of $\mathrm{H}^{+}$ions. (One mole is 6.02 $\times 10^{23}$. Therefore, $10^{-7}$ moles of $\mathrm{H}^{+}$ions is $6.02 \times 10^{16} \mathrm{H}^{+}$ions.)

A scale has been devised which allows us to quickly get a sense of the amount of $\mathrm{H}^{+}$ions in a solution. We call the scale the pH scale (Table 9-2). The pH scale tells us the number of moles of hydrogen ions ( $\mathrm{H}^{+}$) in a liter of solution.

Table 9-2. pH Scale


We will use indicator papers to give us a measure of pH. When indicator paper is dipped into a water solution, it turns different colors according to the amount of $\mathrm{H}^{+}$ions present. We can match the color of the paper with a standard color scale and get a direct reading of pH .

In this topic we will investigate some of the conditions under which acids are formed and the effect of acids on the pH of fresh water and sea water.

## Activity

Observe typical acid and basic reactions.
Determine which gaseous compounds form acids. Find out how the pH of seawater and fresh-
water is affected by acids.

## Materials

```
-1 25 ml beaker
-4100 ml beakers
-1 10 ml graduated cylinder
- 1 stirring rod
-6 test tubes
- 1 test tube rack
-1 eye dropper
-1 deflagration spoon
-1 jar
-1 stopper for jar
-1 clothes pin or tongs
- pH paper, wide range with color chart
-solution pH 1
-solution pH 4
-solution pH 10
-solution pH 13
-limestone ( \(\mathrm{CaCO}_{3}\) ) chips
-iron filings (Fe )
-sea water
-wood splint
-sulphur
- copper filings (Cu)
-concentrated nitric acid ( \(\mathrm{HNO}_{3}\) )
-toweling
-goggles
-aprons
```


## Procedure

Caution: Be sure that your eyes and clothing are protected by goggles and aprons. If chemicals get on your skin or clothing, wash with large quantities of water and inform your teacher.

1. Investigate the reaction of the following combinations as shown in Table 9-3.

Table 9-3. Reactions of different chemicals
in different pH solutions.

| 2 ml <br> Solution | $\left.\begin{array}{c}\text { Limestone } \\ (\mathrm{CaCO}\end{array}\right)$ | Iron <br> $(\mathrm{Fe})$ | 2 ml <br> Base <br> $(\mathrm{pH} 13)$ | $\left.\begin{array}{c}2 \mathrm{ml} \\ \text { Acid } \\ (\mathrm{pH} \\ 1\end{array}\right)$ |
| :--- | :---: | :---: | :---: | :---: |
| pH 1 |  |  |  | $\cdots$ |
| pH 4 |  |  |  |  |
| pH 10 |  |  |  |  |
| pH 13 |  |  | $\cdots$ |  |

a. Pour 2 ml of each of the solutions shown in the first column into test tubes. Label each tube.
b. Add a small piece of limestone to each test tube.
c. Record ali changes produced by each reaction in Table 9-3.
d. At the end of 2 minutes measure and record the pH of each test tube in Table 9-3.
e. Discard the contents, rinse, and dry the test tubes.
2. Carry out Procedure 1 using a few pieces of iron (Fe) filings. Record changes in Table 9-3.
3. Carry out Procedure 1 using 2 ml of the pH 13 solution. Record changes in Table 9-3.
4. Carry out Procedure 1 using the pH 1 solution. Record changes in Table 9-3.
5. Test the interaction of fresh water with solutions of different pHs as shown in Table 9-4.

Table 9-4. pH change or reaction of water and seawater with solution of known pH .

|  | $\begin{aligned} & \text { Dorop } \\ & \text { pH } 1 \end{aligned}$ | $\begin{aligned} & 1 \text { Drop } \\ & \text { pH } \end{aligned}$ | ${ }_{\text {OH }}^{1} \mathrm{OrO}$ | $\begin{aligned} & 1 \text { Drope } \\ & \text { oH } 13 \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: |
| pH(T)fresh water <br> 9 drops |  |  |  |  |
|  |  |  |  |  |

a. Use an eyedropper and squeeze 9 drops of fresh water into a test tube. Measure its pH and record in Table 9-4.
b. Add 1 drop of solution of pH 1. Measure the new pH and record in Table 9-4. Wash the dropper and test tube in fresh water.
c. Repeat Procedure 5a and $b$ for each of the solutions indicated in Table 9-4.
d. Repeat Procedure 5a-c using sea water.
6. Collect each of the gases shown in Table 9-5 in a jar. Then test the pH of the dissolved gas in fresh and seawater ( see Fig. 9-1).


Fig. 9-1. Generating $\mathrm{CO}_{2}, \mathrm{SO}_{2}$, and $\mathrm{NO}_{2}$
a. Generate $\mathrm{CO}_{2}$ by burning a wood splint in a jar. When the fire goes out remove the splint. Add 1 ml of fresh or seawater, stopper, shake, measure the pH , and record in Table 9-5.

Table 9-5. pH of gases dissolved in water.

|  | $\mathrm{CO}_{2}$ | $\mathrm{SO}_{2}$ | $\mathrm{NO}_{2}$ |
| :--- | :--- | :--- | :--- |
| Fresh water |  |  |  |
| Sea water |  |  |  |
| $W$ |  |  |  |

b. Generate $\mathrm{SO}_{2}$ under a hood by burning sulfur in the oxygen of the jar. Place some sulfur in a metal spoon, ignite, and lower into the jar. When the fire goes out remove the spoon, add 10 ml of fresh or sea water, stopper, shake, and measure the pH and record in Table 9-5.
c. Generate $\mathrm{NO}_{2}$ under a hood by placing small pieces of copper in a small 25 ml beaker that can be lowered into the jar. Pour 1 ml of concentrated nitric acid into the beaker and lower it with tongs into the jar. When the jar is filled with gas, remove the beaker, and pour 10 ml of fresh water into the beaker to stop the reaction. Add 5 ml of fresh water or sea water to the jar, stopper, shake, measure the pH , record in Table 9-5.

## Surmary Questions

1. Compare acidic and basic reactions of solutions with limestone (calcium carbonate). What happens as the pH gets more basic?
2. Compare acidic and basic reactions of solutions with iron ( Fe ). What happens as pH gets more basic?
3. From the data taken from Table 9-3, is there evidence of reactions between solutions of different pHs?
4. Use Table 9-4 as a reference and contrast the change of pH in fresh water with the change of pH in seawater by responding to the
question belaw. Note that in the sequence the acid was diluted by $1 / 10$ in each case. ( 9 drops water +1 drop acid $=10$ drops solution). This should reduce the pH of the drop 1 pH point.
a. In fresh water what happened to the pH of each acidic solution on dilution? was it diluted by $1 / 10$ ? What is meant by diluting an acid?
b. In fresh water what happened to the pH of each basic solution? Was it diluted by $1 / 10$ ? What is meant by diluting a base?
c. In seawater what happened to the pH of acidic solutions on dilution? Were they diluted $1 / 10$ ?
d. In seawater what happened to the pH of basic solutions on dilution? Were they diluted $1 / 10$ ?
5. From Table 9-5, what effect do the three gases have on the pH of fresh water. Of salt water?
6. How do the previous results analyzed in Question 4 compare with the results in Question 5?

To understand acid reactions in water, we must keep in mind that water has a slight tendency to form ions according to this equation:

$$
\mathrm{HOH} \rightarrow \mathrm{H}^{+}+\mathrm{OH}^{-}
$$

In pure water the concentrations of $\mathrm{H}^{+}$and $\mathrm{OH}^{-}$ are the same, $10^{-7}$ moles of each per liter.

If the concentration of either of the $\mathrm{H}^{+}$or $\mathrm{OH}^{-}$ions gets larger than $10^{-}>$moles $/ 1$, the reaction reverses.

$$
\mathrm{H}^{+}+\mathrm{OH}^{-} \longrightarrow \mathrm{HOH}
$$

So we can write the equation with two arrows, one to the left and one to the right showing that under some circumstances water is formed and that under other conditions ions are formed.

$$
\mathrm{H}^{+}+\mathrm{OH}^{-} \leftrightarrows \mathrm{HOH}
$$

For water there is also a $\mathrm{OH}^{-}$ion scale.
Inspection of Table 9-6 shows that as the $\mathrm{H}^{+}$deçreases the $\mathrm{OH}^{-}$ion increases. Further, the $\mathrm{H}^{+}$ion and $\mathrm{OH}^{-}$ion are equal to each other in neutral fresh water.
Table 9-6. The $\mathrm{H}^{+}$and $\mathrm{OH}^{-}$concentration in water


| $\mathrm{H}^{+}$ion concentration moles/1 | $\mathrm{OH}^{-}$ion concentration moles/1 |
| :---: | :---: |
| $10^{-1}$ | $10^{-23}$ |
| $10^{-2}$ | $10^{-12} \quad \cup$ |
| $10^{-3}$ | $10^{-11}$ - |
| $10^{-4}$ | $10^{-10}$ - |
| $10^{-5}$ | $10^{-9}$ - |
| $10^{-6}$ | $10^{-8}$ |
| $10^{-7}$ | $10^{-7}$ neutral |
| $10^{-8}$ | $10^{-6}$ |
| $10^{-9}$ | $10^{-9}$ |
| $10^{-10}$ | $10^{-4}$ |
| $0^{-11}$ | $10^{-3}$ - |
| $10^{-12}$ | $10^{-2}$ is in |
| $10^{-19}$ | 10-9 |
| $10^{-14}$ | $10^{-0}$ |

## Questions

7. What is the relation of the $\mathrm{OH}^{-}$ion concentration to $\mathrm{H}^{+}$concentration in an acid solution?
8. What is the product of the $H^{+}$concentration and $\mathrm{OH}^{-}$concentration at pH 1 , pH 7 , and pH 14? (\#moles $\mathrm{H}^{+}$) $\times$(\#moles $\mathrm{OH}^{-}$). Recall that when we multiply powers we mechanically add them, (example: $10^{2} \times 10^{3}=10^{3}$ ).
It has been found that whenever we add $\mathrm{H}^{+}$ ions from an acid such as HCl to water, they react with the $\mathrm{OH}^{-}$ions, reducing the $\mathrm{OH}^{-}$ concentration. If we add $\mathrm{OH}^{-}$from a compound such as sodium hydroxide ( NaOH ), the $\mathrm{H}^{+}$ content of water is reduced. But the product of $\mathrm{H}^{+}$ion and $\mathrm{OH}^{-}$ion concentrate in water will always be $10^{-14}$.

Any reactions between an acid and another substance can be considered a way of reducing $\mathrm{H}^{+}$ ion concentration. There are many different ways of reducing the $\mathrm{H}^{+}$ion concentration. Three major ways were investigated in Procedures 1-4.

Hydrogen ion neutralization with hydroxide $\left(\mathrm{OH}^{-}\right)$ion was illustrated when a solution of pH 1 was combined with solutions of pH 10 and 13. This was simply

$$
\mathrm{H}^{+}+\mathrm{OH}^{-} \rightarrow \mathrm{HOH}
$$

Notice that when equal volumes of acid pH 1 were mixed with base pH 13 that the reaction showed ( + ) with a pH of about 7.

## Questions

9. Why should equal quantities of solutions with pH 1 and pH 13 produce a product of pH 7?
10. Why should a reaction between equal quantities of solutions of pH 1 and pH 10 remain acid? Inspect the list of concentrations shown in Table 9-3.
11. What other combinations of equa] quantities of solutions shown in Table 9-3 should produce a product with pH 7 ? Why?
Hydrogen ion can be removed from a solution using an active metal such as iron (Fe). Here the reaction is:

$$
\mathrm{Fe}+2 \mathrm{H}^{+} \rightarrow \mathrm{Fe}^{2}+\mathrm{H}_{2} \uparrow
$$

where $\uparrow$ indicates that hydrogen ( $\mathrm{H}_{2}$ ) escapes as a gas. We can see what happens using electron dots.


$$
\mathrm{Fe}^{2+}+\mathrm{H}: \mathrm{H} \uparrow
$$

Here the $\mathrm{H}^{+}$ion takes the electrons from the iron ( Fe ) to form $\mathrm{Fe}^{2+}$ ions and a covalent hydrogen molecule ( $\mathrm{H}_{2}$ ).

## Question

12. Other active metals such as magnesium ( Mg ) and calcium ( Ca ) form ( $\mathrm{Mg}_{2}{ }^{+}$) and ( $\mathrm{Ca}^{2+}$ ) ions respectively. Write an equation showing the reaction between the hydrogen ion $\mathrm{H}^{+}$and these metals.

Hydrogen ions can also be removed from solution when they react with a carbonate such as calcium carbonate $\left(\mathrm{CaCO}_{3}\right)$. Here, the hydrogen ions share electrons with the carbonate ions ( $\mathrm{CO}_{3}^{2-}$ ) and form the covalent compound hydrogen carbonate $\mathrm{H}_{2} \mathrm{CO}_{3}$.

$$
\mathrm{CaCO}_{3}+2 \mathrm{H}^{+} \rightarrow \mathrm{Ca}^{2}{ }^{+}+\mathrm{H}_{2} \mathrm{CO}_{3}
$$

As the quantity of hydrogen carbonate $\left(\mathrm{H}_{2} \mathrm{CO}_{3}\right)$ increases, it undergoes decomposition into water and carbon dioxide.

$$
\mathrm{H}_{2} \mathrm{CO}_{3} \rightarrow \mathrm{H}_{2} \mathrm{O}+\mathrm{CO}_{2}
$$

## Question

13. Show the two step reaction between $\mathrm{MgCO}_{3}$ and $\mathrm{H}^{+}$ions.

In Procedure 6, we explored one cormmon method of producing acids. Here we dissolved three gases in water. The most complex of the reactions produced two acid compounds according to the equation

$$
\mathrm{H}_{2} \mathrm{O}+2 \mathrm{NO}_{2} \longrightarrow \mathrm{HNO}_{2}+\mathrm{HNO}_{3}
$$

These two acid compounds are then ionized in water and $\mathrm{H}^{+}$ions are released.

$$
\begin{aligned}
& \mathrm{HNO}_{2} \rightarrow \mathrm{H}^{+}+\mathrm{NO}^{2^{-}} \\
& \mathrm{HNO}_{3} \rightarrow \mathrm{H}^{+}+\mathrm{NO}^{3-}
\end{aligned}
$$

Nitrogen dioxide $\mathrm{NO}_{2}$ and the 2 ions $\mathrm{NO}_{2}{ }^{-}$ and $\mathrm{NO}_{3}^{-}$are soluble in water.

Carbon dioxide also dissolves in water. In process some of it forms hydrogen carbonate, the reverse of the reaction was given previously.

$$
\mathrm{CO}_{2}+\mathrm{H}_{2} \mathrm{O} \rightarrow \mathrm{H}_{2} \mathrm{CO}_{3}
$$

However, most of the $\mathrm{CO}_{2}$ remains dissolved and is not converted into hydrogen carbonate. Of the $\mathrm{CO}_{2}$ that does form $\mathrm{H}_{2} \mathrm{CO}_{3}$, most will ionize forming hydrogen carbonate.

$$
\mathrm{H}_{2} \mathrm{CO}_{3} \rightarrow \mathrm{H}^{+}+\mathrm{HCO}_{3}^{-}
$$

A very small amount of the $\mathrm{HCO}_{3}{ }^{-}$ion will further ionize to form the carbonate ion

$$
\mathrm{HCO}_{3}^{-} \rightarrow \mathrm{H}^{+}+\mathrm{CO}_{3}{ }^{-}
$$

## Questions

14. Write an equation for the reaction of sulfur dioxide $\mathrm{SO}_{2}$ and water to form hydrogen sulfite ( $\mathrm{H}_{2} \mathrm{SO}_{3}$ ).
15. Write an equation to show the formation of hydrogen ion when hydrogen sulfite $\left(\mathrm{H}_{2} \mathrm{SO}_{3}\right)$ ionizes in water.

Carbon dioxide $\left(\mathrm{CO}_{2}\right)$, sulfur dioxide ( $\mathrm{SO}_{2}$ ), and nitrogen dioxide $\left(\mathrm{NO}_{2}\right)$ are all major industrial gases. Carbon dioxide and sulfur dioxide are produced in the burning of coal and oil. Nitrogen dioxide is formed when the nitrogen and oxygen of the air react within hot engines. The steady production of these three gases is now causing a major environmental pollution problem. As we have seen, each of these gases is soluble in water. In nature, they are regularly washed out of the sky in rain. In some places, the pH of rain has gone from around 6-5.5 range of earlier times to as low as 4.5 . The consequences of this condition are only now being realized.

Limestone in buildings and marble in statues is crumbling. More minerals are being leached from the soil. Lakes in the Adirondacks of New York state are so acidic that they can no longer support fish.

But what happens to acids when they reach the oceans? In Procedure 5 and 6 , we compared the effect of acid in fresh water and seawater. We found that acid in seawater reacts differently than in fresh water. It takes a great deal more acid to make a pH change of one unit in seawater than in fresh water.

To begin with, the pH of seawater is about 8. This is slightly on the basic side. But in addition, sea water contains a substantial amount of hydrogen carbonate ion ( $\mathrm{HCO}_{3}{ }^{-}$). As we have seen, this ion can react with $\mathrm{H}^{+}$producing hydrogen carbonate, which in turn produces $\mathrm{CO}_{2}$ and $\mathrm{H}_{2} \mathrm{O}$.

$$
\mathrm{HCO}_{9}^{-}+\mathrm{H}^{+} \rightarrow \mathrm{H}_{2} \mathrm{CO}_{3} \rightarrow \mathrm{H}_{2} \mathrm{O}+\mathrm{CO}_{2}
$$

It is through this so-called "buffer" reaction that the pH in salt water is kept constant when acid is added.

In Procedure 5 we found that seawater also resists large changes of pH when excess $\mathrm{OH}^{-}$ is added. Again the dissolved hydrogen carbonate helps to remove the excess $\mathrm{OH}^{-}$ion.

$$
\mathrm{OH}^{-}+\mathrm{H}_{2} \mathrm{CO}_{3} \rightarrow \mathrm{HOH}+\mathrm{HCO}_{3}^{-}
$$

## Questions

16. Why does fresh water respond so much more readily to the presence of $\mathrm{H}^{+}$and $\mathrm{OH}^{-}$ions than does seawater?
17. A common material used to regulate home fresh water aquaria is sodium hydroxide ( NaOH ). How would this act in an aquarium? Write an equation to illustrate your answer.
18. Currentiy, there is concern that too much $\mathrm{CO}_{2}$ may be accumulating in the atmosphere. How might the acidic condition of rivers act to increase $\mathrm{CO}_{2}$ content in the air when the river enters the ocean?

## 10. Light - A Limiting Factor

Sunlight is a major source of energy for the movement of the fluids of the earth. It is also a major source of biological energy for organisms in the oceans. It provides for the development of biomass of plants and the running of the bodily mechanisms of the organisms. In this topic we will investigate the growth of algae when exposed to different amounts of light.

## Activity

Determine the effect of light on the growth of algae.

## Materials

-4 pint jars with lids with small nail holes -Hyponex
-algal culture (unicellular)
-cheesecloth close knit
-gallon jar
-black tempera paint
-brush
-rubber bands

- paper
-funnel
-filter paper
-balance


## Procedure

1. Prepare 4 light chambers as shown in Fig. 10-1.


Fig. 10-1. Preparing a jar and completed jars for light experiment.
a. Wrap a piece of paper $6-10 \mathrm{~cm}$ wide around the sides of four jars and secure with a rubber band.
b. Paint the bottom and side area above and below the paper with black paint. Be sure there are no areas through which light can pass.
c. Wrap another piece of paper around one jar to insure it is light proof.
d. Once the paint is dry, remove the paper, from the remaining three jars.
e. Wrap the clear area of one jar with two layers of cheese cloth. Secure with rubber bands.
f. Wrap the clear area of one jar with four layers of cheese cloth and secure with rubber bands.
2. Prepare an algal culture and seal it in the jars.
a. Pour 600 ml of water into a gallon jar.

Add 3 g of Hyponex mix and 1 liter of algal culture. Shake and mix the contents.
b. Record the chemical contents of Hyponex in your record book.
c. Pour 100 ml of the culture into each jar. Seal the jars and place them in a location where they receive equal amounts of 1 ight.
3. Observe the open-sided jar for 1-2 weeks and record the following:
a. What evidence, if any, is there of chemical activity?
b. What evidence, if any, is there of growth?
4. In 1 to 2 weeks open the jars, filter, dry, and measure the mass of the algae.
a. Label 4 pieces of filter paper.

F for full light,
2 for 2 layers,
4 for 4 layers,
N for no light.
b. Weigh the filter papers and record their mass in Table 10-1.

Table 10-1. Light and mass of algae.

|  |  | 2 layers partial light | 4 layers partial light |  |
| :---: | :---: | :---: | :---: | :---: |
|  | $\begin{array}{r} \mathrm{ful11} \\ 1 \mathrm{ight} \end{array}$ |  |  | $\begin{gathered} \text { no } \\ \text { light } \end{gathered}$ |
| Mass of filter paper and algat |  |  |  |  |
| Mass of filter paper |  |  |  |  |
| Mass of algae |  |  |  |  |

c. Set up filter system according to Fig. 10-2.


Fig. 10-2. Folding filter paper to line funnel.
d. Filter the contents of each jar onto the correctly labeled paper and dry them.
e. Weigh the filter paper and dry algae and record in Table 10-1,

## Summory Questions

1. What relationship exists between the amount of algae produced and the amount of light entering the growing chamber?
2. What factors were controlled in this investigation?
3. We say that light is a limiting factor in algal growth. From the results of this investigation, what might this mean?
4. Suggest a reason for adding Hyponex.
5. Energy is defined as the ability to do work or to move objects. Energy can take many forms. For example, chemical energy in a fire can convert wood to carbon dioxide, water, and more heat; light energy can be used by plants to recombine carbon dioxide and water to form new wood or biomass. Though a much longer list of energy forms could be made, it is the formation of biomass by photosynthesis that we have investigated here.

Almost all of earth's light comes directly from the sun. We can picture light as a stream of very minute particles, much smaller than atoms. When these particles, called photons, strike atoms they interact with the electrons. If photons have the right amount of energy they can move the electrons of one atom so it can react with another. This is what happens in photosynthesis. Photosynthesis occurs in a series of steps, but for this purpose we will consider only the starting ingredients and final products.

In photosynthesis, carbon dioxide and water combine in the presence of light to produce the sugar glucose and oxygen as shown in the equation below.

$$
\text { Light }+6 \mathrm{CO}_{2}+6 \mathrm{H}_{2} \mathrm{O} \rightarrow \mathrm{C}_{0} \mathrm{H}_{12} \mathrm{O}_{6}+6 \mathrm{O}_{2}
$$

Once glucose has been formed, the energy necessary to run the plant is produced by reversing this reaction. This is an oxidation reaction called respiration.

Questions:
Write the equation for respiration, the oxidation of glucose ( $\mathrm{C}_{6} \mathrm{H}_{12} \mathrm{O}_{6}$ ) to produce body energy. This is the reverse of the photosynthesis equation.

What is energy?
6. The energy necessary for plants to produce fats, proteins, and other building materials comes from the oxidation of glucose. In plants, molecules of glucose also link together to form cellulose, a principal plant building material. Photosynthetic plants are called primary producers since other organisms consume them to satisfy their need for chemical energy and building materials. An eater of other organisms is called a consumer.

Because light is the primary energy source of plants that carry on photosynthesis, those that live in the ocean must live near surface water in the photic zone. The photic zone is that part of the water that receives photons of light. In some open ocean areas this zone may extend as deep as 100 meters. Even here, only $50 \%$ of the light entering the water can be detected at depths of 18 meters.

In nutrient rich shallow waters such as those off Chile and the east coast of the United States, the growth of plant microorganisms called phytoplankton may be so great that they block the passage of light and the photic zone may be no deeper than 5 meters.

## Questions:

What is meant by photic zone?
Why does the depth of the photic zone vary from one place to another?
7. Until the discovery of deep ocean hot springs off the Galapagos Islands in 1977, it was assumed that primary producers lived only in the vary narrow photic zone of the ocean surface waters. Now a new kind of plant, a single celled bacterium, has been found in the black darkness one and a half miles down (about 2.5 kilometers). These organisms use hot hydrogen sulfide ( $\mathrm{H}_{2} \mathrm{~S}$ ) as their energy source. This is remarkable for several reasons. First, hydrogen sulfide ( $\mathrm{H}_{2} \mathrm{~S}$ ) is normally a deadly poison to organisms. Second, these organisms live in hot $65-100^{\circ} \mathrm{C}$ water, (At one atmosphere, water boils at $100^{\circ} \mathrm{C}$ ). Third, the water samples in the Galapagos springs contain a million to a hundred million organisms per millititer of water. This is a very large concentration.

Here, at a depth where no light can penetrate, bacteria are producing the same glucose, fats, and proteins that photosynthetic plants produce. Like surface dwelling primary producers, they are being eaten by clams and giant red tube worms which in turn feed large white crabs. Even fish live in the ecosystem of the springs. Bottom waters are rich in oxygen and other nutrients so the only factor necessary to trigger life is the energy source, $\mathrm{H}_{2} \mathrm{~S}$. The overall reaction seems to be the one shown in the following equation:
$24 \mathrm{H}_{2} \mathrm{~S}+6 \mathrm{CO}_{2}+6 \mathrm{O}_{2} \rightarrow \mathrm{C}_{6} \mathrm{H}_{12} \mathrm{O}_{6}+24 \mathrm{~S}+18 \mathrm{H}_{2} \mathrm{O}$
The energy source is the bond holding hydrogen to sulfur.

## Questions:

From the equation what is the source of the hydrogen ( $H$ ) found in glucose of the deep water sulfide bacteria?

What is the role of oxygen ( $\mathrm{O}_{2}$ ) in the reaction shown in the above equation?
8. There are other limiting factors to plant growth in the ocean. Some chemicals that are essential to the development of plants are found in limited quantity in sea water. These include dissolved silicates ( $\mathrm{SiO}_{3}$ ), phosphates ( $\mathrm{PO}_{4}{ }^{3-}$ ) and nitrates ( $\mathrm{NO}_{3}{ }^{-}$). When the supply of these nutrients is used up, the growth of a plant population stops.

To get a sense of the imbalance of silica, phosphate, and nitrate, we need only look at the concentration of principal elements found in plankton biomass (Table 10-2).

Although the distribution of chemical substances is uniform throughout the ocean, as plants incorporate these nutrients into their bodies, their concentration decreases.

## Questions:

Why would the concentration of $\mathrm{PO}_{4}{ }^{3-}$ and $\mathrm{NO}_{3}{ }^{-}$ions increase at deeper ocean levels? See Fig. 10-3.

Table 10-2. The eleven most abundant elements in plankton biomass.

| Element | Symbol | Moles $/ \mathbf{1 0 0}$ | Principal source |
| :--- | :---: | :---: | :---: |
| Hydrogen | H | 4.6 | $\mathrm{H}_{2}$ |
| 0xygen | 0 | 2.75 | $\mathrm{H}_{2}{ }^{\mathrm{O}}$ |
| Carbon | C | 1.88 | $\mathrm{CO}_{2}$ |
| Stlicon | Si | .71 | $\mathrm{SiO}_{3}$ |
| Potassium | K | .128 | $\mathrm{~K}^{+}$ |
| Nitrogen | N | .27 | $\mathrm{NO}_{3}^{-}$ |
| Calcium | Ca | .02 | $\mathrm{Ca}^{2+}$ |
| Sodjum | Na | .03 | $\mathrm{Na}^{+}$ |
| Sulfur | S | .018 | $\mathrm{SO}_{4}{ }^{2+}$ |
| Chlorine | Cl | .014 | $\mathrm{Cl}^{-}$ |
| Phosphorous | P | .013 | $\mathrm{PO}_{4}{ }^{3-}$ |

9. How would the concentration of $\mathrm{PO}_{4}{ }^{3-}$ and $\mathrm{NO}^{-}$act as a limiting factor to growth?
10. How do the contents of Hyponex used in the experiment relate to chemical limiting factors?
11. Why don't the concentrations of carbon and hydrogen limit growth? See Table 4-2 in Chemical Composition of Seawater.



## AQUARIUM REFERENCE <br> A. Aquar ium Construction

Although aquaria need not be rectangular in shape, these are the easiest to construct and offer the least amount of distortion for viewing organisms.

## 1. Glass Aquaria

The most common of all aquaria are rectangular and constructed entirely of glass. Rectangular glass aquaria offer an undistorted view from all four sides sides. Glass is darable, but does crack if mishandled.

## Materials

```
-5 pieces of window glass, double strength
-newspapers or plastic sheet
-masking tape
-small knife sharpening stone or emery paper
-tube of silicone sealer
-popsicle stick or table knife
```


## Procedure

1. Obtain glass cut to size. Glass can be purchased from most hardware stores or specialized glass shops. Used plate glass can be used if it is not too badly scratched. Used plate glass sells for about half the price of new glass, but usually must be ordered ahead of time. If the fee is not excessive, request that the sharp edges on the glass be beveled (smoothed).

Table 1. Specifications for rectangular
glass aquariums.

| Capicity (gallans) | $\begin{aligned} & \text { End Hil1s } \\ & 2 \text { Preces } \\ & \text { (Inchen) } \end{aligned}$ |  | $\begin{aligned} & \text { B4st } \\ & \text { (lnenes) } \end{aligned}$ | 41ass Thickness Double Strength (inches) |
| :---: | :---: | :---: | :---: | :---: |
| $51 / 2$ | $8 \times 10$ | 16×10 | $16 \times 8 \mathrm{~m} / 4$ | 1/8 |
| 10 | $10 \times 12$ | $20 \times 12$ | $20 \times 103 / 8$ | 3/16 |
| 20 | $12 \times 12$ | $30 \times 12$ | $30 \times 121 / 2$ | 1/4 |
| 30 | $12 \times 16$ | $36 \times 16$ | $36 \times 125 / 8$ | 5/16 |
| 40 | $12 \times 16$ | $48 \times 16$ | 4t $\times 125 / 8$ | 5/16 |
| 50 | $18 \times 18$ | 38 $\times 18$ | $36 \times 185 / 8$ | 5/16 |
| 60 | $12 \times 16$ | $72 \times 16$ | $72 \times 123 / 4$ | 3/8 |
| 100 | $18 \times 18$ | $72 \times 18$ | $72 \times 19$ | 1/2 |

2. Prepare the glass.
a. If edges of glass are sharp, carefully round edges slightly using a small, finesurfaced, sharpening stone or an emery paper wrapped around a wooden block.
b. Clean and dry the glass. Clean with glass cleaner or soap and water. Rinse thoroughly. Remove heavy grease with xylene or alcohol.
3. Assemble aquarium.
a. Spread newspaper or plastic sheet over a flat working area.
b. Temporarily construct the aquarium holding assembled pieces of glass together with masking tape. The sides should sit on top of the base and the longer sides should overlap the shorter ends (see Fig. 1).


Fig. 1. Glass aquarium assembly.
c. Disassemble the aquarium. Leave a piece of masking tape on each piece of glass.
4. Construct aquarium using sealant.
a. Cut the nozzle of the tube of sealant so that a narrow ribbon can be squeezed out. Work rapidly but accurately after squeezing out the sealant. It remains pliable for about 5 minutes, after which a "skin" begins to form.
b. Place a narrow ribbon of sealant on the top of one long edge of the base (see Fig. 2A). Place a long glass side on top of this
ribbon (see Fig. 2B). Excess sealant will be forced out.


Fig. 2. G1ass aquarium assembly.
c. Have an assistant hold the long side in place while you squeeze ribbons of sealant along the short edge of the base and along the edge of the adjacent upright long side.
d. Insert short aquarium wall.
e. Tape pieces of glass together.
f. Repeat $b$ through e for second short end piece.
g. Apply sealant to remaining exposed edges and insert the remaining long wall. Tape it in place.
5. Clean off excess sealant on glass.
a. On the outside use paper towels to clean off sealant. Make sure the sides are flush with the glass.
b. Tool the sealant on the inside with the end of a large flat wooden popsicle stick, the
blunt end of a table knife or with your finger to produce a flat, triangular bead (see Fig. 3).


Fig. 3. Completed side and bottom.
c. Excess sealant can be removed later with a razor blade, after it is completely cured.
6. Cure and trim the seal. Allow sealant to cure and harden to a rubbery consistency for 24 to 48 hours. After curing, trim off the excess sealant with a razor blade. Trim carefully to avoid undercutting the seal.
7. Test for leaks.
a. After curing, make sure the aquariun bottom is fully and firmly supported on a flat, level surface to prevent straining and possible cracking of the glass. Fill the aquarium with a few inches of tap water. Allow to stand. Check for leaks. If there are no leaks, fill aquarium completely. Check again for leaks.
b. Mark spots where any leaks occur with a wax pencil or a small plece of tape.
c. Empty tank and allow to dry thoroughly; then add more sealant to the area around the leaks.
d. After curing, retest for leaks.
8. Supports.
a. Additional glass support can be added to a larger aquarium across the top between the two larger sides (see Fig. 4). Use sealant to attach pieces.


Fig. 4. Aquarium with support tab and position supports.
b. Small glass or plastic blocks can be sealed to the sides to support partitions that can be inserted to separate organisms (see Fig. 4). The partitions can be made of glass, plastic, or perforated hardboard. Wood will warp.

## 2. Plastic and Cardboard Aquarium

This aquarium is constructed from a cardboard box with a glass window in front. The inside of the box is 1 ined with plastic. Its advantages are that it is inexpensive, costing less than $\$ 2$ for a 15 -gallon tank, and that all materials are readily available from local distributors. When not in use, this aquarium can be folded flat for easy storage.

A plastic and cardboard aquarium has several 1 imitations. The height of the tank must be 1 foot or less, to prevent sides from bulging. It is not as permanent as an all glass tank, although aquaria of this type have been used successfully for over one yoar. Some animals such as sea urchins and large crabs may readily tear the plastic lining. With only one glass window, this aquarium has only one side for viewing.

## Materials

-strong cardboard box, such as a fruit box or a ditto paper box
-piece of glass, the same dimensions as the inside front face of the box. For the correct preparation and thickness, see Table 1
-strapping tape for reinforcement
-razor blade and handle for cutting
-decorative materials for inside and outside of box surface
-a sheet of heavy, transparent plastic such as a shower curtain, plastic table cover, or a tarpaulin used by painters to cover furniture Procedure

1. Obtain a substantial cardboard box, preferably one which is roughly 1-1/2 feet on a side.
a. If the height of the box is one foot or less, fold in the top flaps to give the box extra support. If the box is over one foot in height, cut it down to one foot with a straight edge and a razor blade (see fig. 5). The cardboard cannot withstand water pressures created by a higher water column.


Fig. 5. Cutting cardboard box.
b. Remove the bottom of the box if you desire an aquariun which can be folded flat when not in use.
c. Reinforce weak-looking areas with strapping tape.
2. Using a razor and straight edge, cut a window in the front face of the box. Leave a $1-1 / 2$ inch border all around (see Fig. 6).


Fig. 6. Border of glass window.
3. Paint the inner surface white, or line it with white paper. Use other colors if desired.
4. Position box on flat counter or table. The surface must be smooth if the box is bottomless.
5. Lay a pre-cut glass plate tnside the window frame. Hold it in place with tape, using the tape only in places which aren't visible to a person looking at the front of the tank.
6. Place plastic sheeting in the box, as shown in Fig. 7. A method of assuring that plastic fits snugly against the bottom of the box is to fill plastic with water to a 2 inch depth.
a. Carefully fold the sheeting into the corners, so that the box, not the sheeting, will support the weight of the water. Make sure all the edges of the plastic reach up to the top edge of the box.
b. Anchor the plastic sheeting around the top edge of the box with more strapping tape or any secure method.


## Fig. 7. Placing plastic sheeting in box.

7. Decorate the outside by painting or covering with paper or colored plastic.
8. Install filtration system as you would with a glass aquarium. Note that if a subsand air filter is used, be sure its sharp corners do not cut the plastic liner.
a. In placing rocks or sharp objects in the tank, remember the plastic can be pierced and will leak. Keep rocks and coral away from the sides.
b. If a leak occurs, take everything apart, dry out the plastic sheet, and mend the hole with plastic mender.
9. To store a bottomless aquarium:
a. Remove the plastic liner, then dry and fold it.
b. Place the aquarium on its side, glass face down (see fig. 8).
c. Place plastic inside, and then fold aquarium flat.


Fig. 8. Folding cardboard aquarium.

## 3. Wood and Fiberglass

A large flat aquarium can be constructed of wood, glass and fiberglass. Directions below are for the construction of an aquarium with dimensions of 48 inches long $\times 243 / 4$ inches high and $231 / 2$ inches wide. An advantage of this type of aquaria is that its large volume of water and large surface area
provide a relatively stable chemical environment for many marine organisms. In addition, its construction materials are relatively inexpensive. Construction, however, is a major undertaking. When full of water, rocks and sand, this aquarium weighs about 1,000 pounds. It requires an extremely strong stand.

## Materials

-1 sheet of $3 / 4^{\prime \prime}$ AA marine plywood, plus enough for 2 braces measuring $46-1 / 2^{n} \times 3^{\prime \prime}$ each
-1 piece $1 / 4^{\prime \prime}$ plate glass measuring 22-1/2" $x$ 45"
-2 tubes of $120 z$. silicone aquarium sealant -epoxy resin for three coats or fiberglass resin for 2 coats
-1 box of $2-1 / 2^{\prime \prime}$ finishing nails
-1 box of \#8 screws(1-1/2"), flathead wood
-1 tube of wood dough (plastic wood)
-1 tube of wood glue (waterproof)
-miscellaneous tools (drill, screwdriver, claw harmer, saw, saber saw, paintbrushes)

## Procedure

1. Either have the $4^{\prime} \times 8^{\prime}$ plywood sheet pre-cut or use a power saw to cut it to the dimensions shown in Fig. 9.


Fig. 9. Plywood sheet breakdown.
2. Assemble aquarium
a. Assemble box to insure proper fit, placing back and front on top of the bottom and inserting sides.
b. Disassemble and apply wood glue to joining surfaces.
c. Quickly assemble box and hold pieces together with nails that can be removed (not flush with wood).
d. Place a mark every 3 inches where a screw is to be placed (see Fig. 10).


Fig. 10. Screw placement.
e. After the glue has dried, drill holes for the screws. Insert 2 -inch screws alternate$1 y$ with $1-1 / 2$-inch screws to join the sides and bottom together.
f. Lay out the viewing port, leaving a $3^{\prime \prime}$ margin all around plus an additional 3/4" on the top for the braces. You may prefer a smaller viewing port, or two ports. Use
your imagination here. Cut out the port with a saber saw.
3. Waterproof the inside of the aquarium with either epoxy paint or fiberglass resin.
a. Epoxy comes in a variety of colors, and is mixed with a catalyst. It is expensive and three coats are required.
b. Fiberglass laminating resin is also prepared with a catalyst. It may be mixed with a colored pigment, or you can paint the box first and then apply the fiberglass resin over it. Two coats are usually enough.
c. Objects such as sea fans, pebbles, posters, etc., can be resined or epoxied into the background. Allow each coat to dry and cure. Read instructions that come with the product you are using.
4. Seal the seams of the aquarium's inner surface with silicone sealant. To do this, lay a bead of sealant along the seams with the nozzle pointed in the direction of travel. With your thumb, smooth the sealant. Let the seal cure for 48 hours. Then put on the final coat of resin (should be a waxy finishing resin).
5. Seal in glass viewing port. Turn the aquarium over on its front and lay a thick (little finger sized) bead of sealant around the inside margin of the viewing port about 1-1/2" away from the cut edge of the wood. Then immediately and carefully lay the glass evenly on the sealant. Get someone to help you, so that the glass may be laid down on all points at the same time. Press the giass down and keep it weighted. Don't worry about the excess sealant
oozing out; it may be trimmed later with a razor blade. Be sure the seal is solid all the way around. If there are gaps, lift the glass slight$1 y$ and insert more sealant.
6. Cover the wood frame and glass with newspaper and weight them with bags of sand or building blocks. Let the sealant cure for 48 hours.
7. Screw in the braces. They should be coated with epoxy or fiberglass. The corners where the brace meets the front and side of the box can be cut away or drilled with holes later to allow space for air lines and filters (see Fig. 11).


Fig. 11. Top view.
8. Paint the outside, stain it, or cover it with contact paper.

The typical rectangular, glass-sided aquarium for general display and observation is only one type of
aquarium that can be used in the classrom. A variety of alternative designs and construction materials can also be made for special uses and budgets. Here are a few ideas.

## 4. Plastic Tide Pool Aquarium

A low, wide aquarium ( $12^{\prime \prime}$ high, 2 feet wide, 3 feet long) can be used to contain reef flat or tide pool organisms for classroom observation. Organisms can easily be picked up for short periods of time for closer examination. Gentle handling does not usually damage or harm most hardy tide pool invertebrates.

The aquarium dimensions can easily be varied depending on space available. It should be placed on a low table so one can look down into the "tide pool" from above.

As in other aquaria, airstones or subsand filters should be used to insure proper water circulation. The large surface area of this aquarium permits good oxygen/carbon dioxide exchange with the air but presents a problem in rapid evaporation of the water. The water level in the aquarium should, therefore, be carefully monitored and tap water added as needed to maintain relatively uniform salinity. Since the shape of the aquarium is very long and wide, a small decrease in water level represents a large water volume loss.

Aquariums made of wooden or cardboard frames and heavy plastic film are easily constructed, inexpensive, and relatively durable. They are ideal for wide, shallow tide pool aquariums.

## Materials

-4 side pieces (can be made out of cardboard, 1/4" plywood, 1/2" compress board, etc.), 2 pieces $12^{\prime \prime} \times 3^{\prime} ; 2$ pieces $12^{\prime \prime} \times 2^{\prime}$
-1 piece of heavy ( 6 to 8 mil ) vinyl or polyethylene, $16^{12} \times 28^{11}$

- tools (saw to cut wood and razor blades to cut cardboard)


## Procedure

1. Assemble frame.
a. Put slits in all four cardboard pieces, as shown in Fig. 12. If side pieces are wooden, cut notches in the same location as the slits shown in Fig. 12. However, the notches for the wooden members should be the same width as the width of the wood. If you are using 1/4" plywood the notch should be 1/4" wide.


Fig. 12. Slit placement.
b. Interlock the sides, with the slits of the short sides pointing upward (see Fig. 13).


Fig. 13. Sides interlocking.
2. Place the frame on a low table to permit viewing the aquarium from above. The table should be sturdy to support the considerable weight. of water.
a. Place a thin, plastic sheet inside the frame, frame, fold the corners to fit, and staple in place.
b. Place sand or crumpled newspaper around the inside edges to serve as bottom contours. Over this lay in a second piece of thick plastic or vinyl film. A trashbag can be used for smaller tanks, using the double plastic layers. Clothespins can be used to hold the plastic in place. The sloping contoured sides can simulate the sides of a tidal pool (see Fig. 14).


Fig. 14. Cutaway of a completed aquarium.

## 5. Shoreline Tide Pool Aquaria

A. Plastic-Lined Tide Pool

This temporary aquarium is used during shoreline studies. Merely lay polyethylene or vinyl plastic into a natural sand or dirt depression at the shore. In some cases a depression may have to be dug in the sand with a shovel. Fill with seawater and add organisms for easy observation. A 6 foot $x$ 6 foot piece of plastic is adequate.

Temperature of the tide pool aquarium increases rapidly if it is constructed in the open sunlight. Organisms will be severely stressed if the temperature rises too high. New seawater should therefore be added at regular intervals to maintain normal temperatures.

盺e: A larger, semipermanent schoolyard freshwater pond can be constructed in the same manner.
B. Picnic Cooler

Ptenic coolers or buckets may be used for hold-
ing organisms collected during shoreline studies. By keeping the lid loosely closed on the picnic cooler, water in the cooler will not heat up rapidly. Avoid overcrowding containers. For prolonged periods, use a temporary aeration system (use either a battery operated air pump or a syringe bulb attached to tubing.)

## 6. Tidal Aquarium

This is a set of two aquaria in which the water level goes up and down, simulating tidal action.

## Materials

-2 aquaria of approximately equal volumes
Note: It is preferable that one face (side or bottom) of each aquarium be of nonglass construction, since a hole will have to be drilled. If only all-glass aquaria are availabie, a high speed glass grinding tool will be necessary.
-two 1/2" through-hull fittings (these may be purchased at a marine hardware supply store) -6 feet of $1 / 2^{\prime \prime}$ inner diameter plastic tubing -6 feet of $1 / 4^{\prime \prime}$ inner diameter plastic tubing -an air pump
-1 tube silicone sealant

## Procedure

1. Obtain two aquaria of roughly equal volume. It is preferable that they each have one side which is of nonglass construction.
2. Drill two $1 / 2^{\prime \prime}$ holes. Place the first hole near the top of an end wall of the aquarium $A$, Fig. 15. The second hole should be placed near the bottom of an end wall of the aquarium $B$.
3. Apply silastic to the area around the holes and then tighten through-hull fittings shown in Fig. 15.

4. Mount aqauria at two levels as shown in Fig. 15
5. Attach $1 / 2^{\prime \prime}$ tubing as shown in Fig. 15. It is important that the pumping tube be approximately $1 / 2$ foot telow the bottom of the lower tank.
6. Place small diameter tubing inside the pumping tube until it just passes the lowest point on the pumping tube. Attach the other end to aerator.
7. Set up the aquaria with subsand filters, sand, and other materials necessary to simulate an intertidal environment.
8. Fill lower aquaria to within 1 " of the top and the upper aquarium $1 / 3$ full of sea water.
9. Turn on air pump. Its stream of bubbles should carry water from the lower tank to the upper tank.
10. As bubbles rise in the tubing they carry water from the lower tank into the upper tank, gradually filling it. When the water level in the upper tank reaches the top of the siphon hose, a siphon action begins and water gradually dräins from the upper tank into the lower tank.
11. The rate of fill of the upper tank can be regulated by constricting the air inlet tube with clamp 1. The fill rate of the lower tank can be regulated by constricting the siphon tube with clamp 2.

## 7. Fish Photography Aquarium

A tall, narrow aquarium can be constructed for use primarily in photographing fish and other swimming organisms. A typical size for this special use aquarium is $12^{\prime \prime}$ high $\times 6^{\prime \prime}$ wide $\times 18^{\prime \prime}$ long. The narrow width prevents the organism from swimming out of the depth of field range of the camera and permits easier focusing. Fish can be further restricted in their movement during photographic sessions by inserting a piece of glass into the aquarium at an angle (see Fig. 16).

Proper aeration of water in this aquarium may becone a problem because of the smali surface area of the water. The aquarium, therefore, should not be overloaded with fish.


## Fig. 16. Photography aquariug.

## 8. Translucent Fiberglass Phytoplankton Aquarium

The translucent aquarium is used for growing phytoplankton and possibly primary consumers of the algae, such as brine shrimp or fish fry. Its advantages are that it is large ( 20 to 30 gallons), relatively inexpensive ( $\$ 5-10$ ) and it occupies relatively little counterspace. Although it is not transparent, enough light can penetrate through the translucent fiberglass to support algae growth.

## Materials

$-3 / 4$ gallon of surfboard laminating resin
-1 plastic garbage can ("mold")
$-1 / 4$ gallon surfboard finishing resin
-1 quart acetone
-2 ounces of catalyst
-few ounces of releasing compound
$-7^{\prime} \times 3.5^{\prime}$ piece of \#6 glass fiber cloth
$-22^{\prime \prime}$ fiberglass brushes or a $2^{\prime \prime}$ roller
-scissors
-razor blade

## Procedure

1. Obtain a plastic garbage can in the 10 to 35 gallon range. Can should be flexible. Those with lips are preferable (see Fig. 17). The garbage can will be the male mold for the phytoplankton tank.


Fig. 17. Inverted garbage can.
2. Clean the outside of the can and dry it thoroughly.
3. Invert the can and using a paper towel, apply a thin, invisible coat of releasing compound to the outside surface. Be sure to apply compound to the inside surface of the lip, too. Remove all excess.
4. Add 1 pint of finishing resin to mixing container. Pour in $1 / 4$ ounce of catalyst and immediately stir rapidly for $1 / 2$ minute. Pour half the resin on top of the container; then roll or brush it as evenly as possible over the entire can. (CAUTION: The resin will harden within 10 minutes.) Repeat with remainder of resin after first coat has hardened.
5. Place brush or roller immediately in an acetone bath and rub the bristles or roller against the side of the container until it is soft.
6. Cut two pieces of fiberglass cloth. One piece should be a rectangle slightly longer than the circumference of the can on one side and equal to the height of the can on the other. The second piece should be a circle whose radius is $2^{\prime \prime}$ larger than the radius of the bottom of the can. Make diagonal $2^{\prime \prime}$ deep cuts into the circle at regular intervals as shown in Fig. 18.


Fig. 18. Fiberglass cloth patterns.
7. Mix 1 pint of laminating resin and $1 / 4$ ounce of catalyst. Spread evenly over the top of the container. Then apply the circular piece of cloth, carefully rolling out bubbles to the periphery.
8. Repeat Procedure 7, applying the rectangular cloth around the sides of the can. If bubbles can't be rolled out, slit them with razor and press them flat. This step is the hardest part of the procedure.
9. Mix 1-1/2 pints laminating resin with $3 / 8$ ounce of catalyst. Apply over whole can. Allow to harden for 2 hours.
10. Mix 1 pint of finishing resin with $1 / 2$ ounce of catalyst. Apply over whole can. Allow to harden for 2 hours.
11. When dry, slowly squeeze garbage can away from fiberglass tank by inserting your hand and arm all around. Then pop them apart.
12. Sand away rough glass edges on lip of tank. Invert, and you are finished.
13. For aeration, a single air stone emitting 300 $\mathrm{cc} / \mathrm{min}$ is adequate for most plankton. To determine rate of air flow, submerge and fill a graduated cylinder with water. Hold inverted cylinder over operating airstone. Note the time required to displace 100 cc of water.

## 9. Wave Tank Aquaria

These aquaria are narrow, shallow, and very long. They are designed for ocean wave simulation. When not in use as a wave tank, the aquaria can be sectioned off into a series of smaller aquaria by insertion of plastic, glass, or hardboard partitions, held in position by small blocks of plastic glued to the side walls. Separate aerators and subsand filters should be used in each of these sections.

## A. Glass Wave Tank Aquarium

The aquarium described is a small, but adequate classroom aquarium. If a larger wave tank is preferred, increase all the dimensions in this plan proportionally, or else just increase the length.

## Materials

-2 side pieces of $1 / 4^{\prime \prime}$ plate glass, $48^{\prime \prime} \times 7^{\prime \prime}$
-1 bottom piece of $1 / 4^{\text {" }}$ plate glass, $48^{\prime \prime} \times 5^{\prime \prime}$
-2 end pieces of $1 / 4^{\prime \prime}$ plate glass, $7^{\prime \prime} \times 4^{\circ \prime} \times 1 / 2^{\prime \prime}$
-2 back stoppers of $1 / 4^{\prime \prime}$ plate glass ,4 $1 / 2^{\prime \prime} \times 7^{11}$
-4 pegs of $1 / 4^{\prime \prime}$ plate glass, $4^{\prime \prime} \times 3 / 4^{\prime \prime}$
-2 front stoppers of $1 / 4^{\prime \prime}$ plate glass, 1 " $\times 5^{\prime \prime}$
-2 Paddles ( $1 / 4^{1 "}$ hardwood), $4^{\prime \prime} \times 9^{\prime \prime}$
-1 tube of silicone aquarium sealant
-1 roll masking tape

## Procedure

1. Prepare glass.

Glass should have smooth edges and be clean. Procedures are described in the section on Glass Aauaria.
2. Assemble aquarium.
a. Follow the Assembly, Curing and Trimming, and Testing for leaks as described in Section 1 Glass Aquaria, Procedures 4-7. These procedures should only be used for the bottom and sides of the wave tank.
b. Use sealant to seal in the backstop pieces as shown in Fig. 19, placing them flush with the upper edges of the sides of the tank.


Fig. 19. Wave tank.
c. Use sealant to glue pegs for a paddle on the inner surface of the bottom of the tank (see Fig. 20). The pegs on each side should be placed about 3/16" apart, a gap which will hold the paddle in place, but still allow movement.


Fig. 20. Peg placement.
3. When all seals have cured for 48 hours, place wooden paddles between pegs. The paddle forestops straddle the side pieces and are held in place with masking tape.
4. When in use, the wave tank should be evenly supported along its entire length to prevent local strain and leakage of seams.
B. Wooden Wave Tank Aquarium

Pieces of glass of proper strength and length to construct a medium or long length wave tank are often expensive and difficult to obtain. An acceptable alternative is a wave tank made of plywood and plastic.

## Materials

-3 pieces $1 / 4^{\prime \prime}$ plywood, $8^{\prime}$ long $\times 9^{\prime \prime}$ wide
-2 pieces $1 / 4^{\prime \prime}$ plywood, $81 / 2^{\prime \prime} \times 9^{\prime \prime}$
-2 pieces $1 / 4^{\prime \prime}$ plywood, $2^{\prime \prime} \times 9^{\prime \prime}$
$-1-1 / 4^{\prime \prime}$ common nails
-1 tube waterproof glue (or epoxy glue)
-1 to 2 tubes silicone sealant
-1 roll fiberglass cloth, $3^{\prime \prime}$ side $\times 21^{\prime}$ long
-epoxy paint (enough for $3^{\text {coats) or fiber- }}$
glass resin (enough for 2 coats)
-1 piece $1 / 4^{\prime \prime}$ glass, $81 / 2^{\prime \prime} \times 36^{\prime \prime}$

Note: Marine plywood is waterproof but expensive. Regular plywood can be used if care is taken to seal all surfaces carefully and thoroughly with epoxy paint or fiberglass resin.

## Procedure

1. Assemble aquarium.
a. Assemble the bottom, sides, and ends of the plywood box. Apply glue along all joints and nail into place. All sides sit on top of the bottom piece and the long sides overlap the end sides.
b. Use fiberglass resin and fiberglass cloth to seal the inside corners. This will greatly strengthen and seal all seams to prevent leakage. A person experienced in constructing or repairing surfboards can be consulted for proper techniques in mixing resin and catalyst and applying to fiberglass cloth.
2. Cut out a rectangle on one side of the box 34 " long by $71 / 2^{\prime \prime}$ high using a saber saw or hand saw. Glue and nail the two cross braces to
the top of the box (see Fig. 21.)


Fig. 21. Wooden wave tank.
3. Use fiberglass resin ( 2 coats ) or epoxy paint to cover all surfaces of the box, both inside and outside. Pay special attention to seal plywood edges and all corners.
4. Install the viewing window. To do this, lay the box down on its cutout side. Place a thick ribbon of aquarium sealer near the edges of the cutout. Carefully lower the glass onto this ribbon. The glass should overlap the wood by 1" all around and be flush with the top of the box. Press the glass down onto the sealant to make a complete seal.

If there are gaps, lift the glass slightly and apply additional sealer. Excess sealer can be removed with a razor blade after it is cured. Allow 24-48 hours for the sealer to cure and harden into a rubbery consistency.
5. Test for leaks. Fill the tank with water to within 1 inch of the top. Look for leaks and
mark location with grease pencil or tape. Empty tank, dry thoroughly, and then seal leaks) with aquarium sealer. Allow to cure. Refill and retest for leaks.
6. Additional attachments, blocks, and inserts can be glued onto the box using aquarium sealer.
7. When in use, the wave tank should be evenly supported along its entire length.
10. Lay-Tubing Aquaria

Inexpensive classroom aquaria can be made from plastic material slightly thicker than the clear plastic bags you find in the supermarkets. This polyethylene material comes in long tubes and is known as lay tubing. It is available at local plastic bag manufacturers. Seamless and durable, it can be made into aquaria of any length. We prefer five mil thickness because of its durability and because thicker plastic is hard to tie. Bag circumferences range from eight to eighty inches.

The lay-tubing aquarium shown in Fig. 22 is made from a three foot length of sixteen inch circumference tubing. The bottom is tied with a tight overhand knot. After water, plants, and animals are added, the aquarium is tied to a nail on the wall. A slit cut near the top allows for aeration and feeding.

## 11. Miscellaneous Smat1 Aquaria

Baby food jars can be used in special instances, such as for plankton observation. Drinking glasses are equally useful.


Fig. 22. Lay tubing aquarium.
Large-mouthed gallon jars such as mayonnaise or pickle jars are an ideal size to hold individual organisms or a few small animals or algae for short term observational periods. Circular-shaped subsand filters designed to fit these jars can be purchased from local pet stores spectalizing in aquarium supplies.

Slide aquaria can be designed with three slides forming a square base, and with a single slide forming each side The slides are silicone sealed together; very sma31 aquariums can be constructed using $25 \mathrm{~mm} \times 75 \mathrm{~mm}$ ( $1 \times 3^{\prime \prime}$ ) microscope slides. These containers are especially useful when flat clear surfaces are required such as in photography.

## B. Aquarlum Maintenance

Aquaria are tools for simulating natural marine or freshwater environments. Successfully constructed and maintained freshwater aquaria have been in evidence for thousands of years, ever since the Chinese started raising carp and goldfish as ornamental pets. The first large marine aquarium was constructed in Monaco over 100 years ago, but it was not until the late 1950's that marine aquarium keeping started developing into a science.

Today, of about 5000 macroscopic marine animals and plants that can be kept in aquaria, less than 100 are maintained through their entire life cycles. The reason for this is that marine research is a new field and there is little information about the life histories of most of the marine animals and plants that are kept in aquaria. We do know that many invertebrates and fishes can be kept in an aquarium for several years. If they die after a month or two, this may be due to our lack of knowledge about them. Successful maintenance, therefore, is an exciting field for researchers and interested laymen because most of the information gathered is new. Just keeping an organism alive for a few weeks and determining what it eats or how it behaves may be a scientfic breakthrough.

## 1. Requirements of Plants and Animals in Nature

Each organism has unique requirements which can be generalized as follows:
a. Space. Different organisms have special space requirements. Space in water is measured three dimensionally and discussed in terms
of volume. The required space may be large or small depending on the organism and may
change depending on the following factors:

- Size. For example, small organisms do not need as much space as large organisms.
- Reproductive condition. For example, animals which care for their eggs may have a larger territory (a defended space) than those which are not reproducing.
- Food. For example, organisms require enough space to acquire the food they need.
- Social interactions. For example, during nonreproductive periods some organisms may naturally group together requiring little space. At other times, they may separate or require more space. 0thers may hold territories and exclude other organisms.
b. Shelter. Many organisms require shelter or physical protection from the environment or predators. Shelter may be in:
-Inanimate objects such as ledges, caves, dead shellis, small holes in or under rocks, and sand or mud.
- living objects such as crevices in living coral heads, seaweed, among sea anemone tentacles, or sea urchin spines.
- Some organisms do not need shelter because they are able to swim rapidly or are camouflaged (blending with the background).
c. Water conditions. The composition of water, its movement, light intensity, and quality and temperature affect organisms in different ways. Some can tolerate wide fluctuations in these conditions; some cannot. Thus, organisms tolerate specific ranges of:
- Salinity, a measure of the total amount of dissolved minerals per unit volume of water.
- Toxic substances, substances poisonous to organisms.
- Temperature, a measure of heat.
- Oxygen, amount of dissolved oxygen per unit volume of water. If the level of dissolved oxygen is too low, the organism will die.
- pH , a measure of the amount of dissolved acid or base per unit volume.
- Turbidity, the amount suspended particles in the water.
- Light intensity, the amount of light fatling on a unit area.
- Water movement, waves, and currents.
d. Food and nutrients. Marine organisms have developed various ways to eat food or absorb nutrients:
- Food capture. Animals may feed by filtering vast quantities of water through their bodies (sponges, oysters and clams). They may snap at their food (most fishes), catch it with their claws (crabs), sting and eat it (cone shells), surround it with their bodies and absorb it through their stomachs (sea stars, flat worms), weave sticky nets to trap it (some mollusks), or rasp it from rocks (parrotfishes).
- Feeding types. Most marine plants photosynthesize their food. They absorb nutrients directly from the water. Animals may be herbivores (plant eaters), carnivores (animal eaters), or omnivores (plant and animal eaters).
- Food preference. The stomach contents of animals are analyzed to determine their
natural food requirements. However, marine animal species are so numerous that most of them have not been studied. For example, the harlequin shrimp dines exclusively on seastar. This beautiful shrimp starved to death in aquaria for a number of years before someone noticed what it ate. As a result, aquarists usually observe their marine animals in the field and decide what types of food they might eat in the aquarium.
e. Social. Marine animals require a degree of social interaction with other animals. The different social groups are discussed in Chapter 2 Topic 9, "Fish Watch."


## 2. Requirements of Animals and Plants in the Aquarium

a. Space, shelter and social activity. A rule of thumb for keeping an animal aquaria is 8 liters of water for each 3 cm of animal. This rule has many exceptions, however, depending on the number and size of the animals and the temperament of each species. Most animals should be of similar size to prevent larger ones from eating smaller ones. If animals of different sizes are to be kept in an aquarium, fighting can be minimized by providing sufficient space shelter for all the animals. Sometimes it may be necessary to keep only a single animal in an aquarium.

Once an aquarium is well established, it is often best to leave it as it is. If you
want to add new animals consider doing the following:

- Rearrange all the decorations and objects in the aquarium. Doing so creates a new environment for the old animals and prevents them from defending old territories against the new animals.
- Introduce new animals at night after old animals have eaten. Feeding helps distract old animals from new animals. Turning out the aquarium lights allows old animals to settle down for the night, and allows new animals to adjust to new surroundings.

To provide shelter for your animals and to break up the living space, use anything that is nontoxic. Ceramic (kiln-fired) or plastic objects, driftwood, lava rock,or fiberglass molds can be used in both marine and freshwater aquaria. Bleached shells thoroughly washed/rinsed and corals are suitable only for marine aquaria. Use objects which will not tip over.

If seaweeds are to be used they should be attached to rocks. Isolate these rocks in seawater and eliminate the unwanted animals which live in them. Then place the seaweed-covered rocks in your aquarium.
b. Water quality. Since an aquarium is a closed system, anything added to the water or taken from it may harm the organisms. Part of the challenge of caring for an aquarium is learning what went wrong and why.

If something does go wrong, the first
thing to check is the aeration system. The organisms may not be getting enough dissolved oxygen from the water to breathe.

In aquaria or in natural aquatic environments, the water's surface area and the rate of water movement across the surface determines the amount of dissolved oxygen that slowly goes into the water to replace the oxygen used by organisms. Adding a bubbler or aquarium filter to the aquarium speeds up the process. Bubblers and filters keep the water constantly moving so that as oxygen is removed by organisms, it is replaced by oxygen from the air of the bubbles and from the air at the surface of the tank.

Dissolved Substances

- Oxygen. In warm marine waters the amount of dissolved oxygen is about $5 \mathrm{ml} / 1$. In cold, well-circulated water it may reach $9 \mathrm{ml} / 1$. When the dissolved oxygen $\left(\mathrm{O}_{2}\right)$ concentration drops to $1 / 2$ $\mathrm{ml} / \mathrm{l}$ most animals will die.
- Hardness. The hardness of water is a measure of the calcium or magnesium minerals dissolved in water (in parts per million). Water with over 200 parts per million is considered very hard. A simple test of hardness is soap. If soap doesn't lather, the water is very hard. Seavater is extremely hard (over 400 parts per million) so we do not measure hardness in marine aquaria. Coral rock, shells and sand are composed of calcium salts. If placed in fresh water, the water becomes hard.
- pH. The pH of seawater is measured by the acid concentration per liter of water. Neutral water has a pH of 7 . All values under 7 indicate acid water,


## all values above 7, alkaline water.

The optimal pH in sea water is about 8.0 with a range of 7.4 to 8.4. The control of pH is usually not a problem with salt water aquariums. Minerals in sea water tend to keep excess acid or base from developing. However, you may test for small pH changes. For example, when too much food is placed in the tank or when the $\mathrm{CO}_{2}$ level gets high, pH decreases and the water becomes acidic. When plants absorb $\mathrm{CO}_{2}$, the pH increases and the water becomes basic.

- Dissolved organic and biological byproducts. Many compounds produced from the decay of dead organisms, fish food, and the excretions of animals can be poisonous to animals in an aquarium if they build up to levels in excess of those found in natural environments. Dissolved organic compounds are removed by bubbles. Most dissolved organic molecules are large and long. They have one end that is attracted to water. They resemble oil molecules which form a layer on the surface of a water filled pan. Organic by-products in aquaria and in the open ocean also concentrate on the surface. As the concentration of these organic compounds increases, a film attaches around the bubble. When the bubble bursts, the organic film may be shot into the air as part of tiny water droplets so small that they are carried away by air movement.
c. Substrate quality. In both natural and simulated aquatic environments, a sand or mud bottom and the organisms living in it are important in filtering potentially poisonous biological substances out of the water. This process is called filtration. When water circulates through a bottom bed, the sand or mud mechanically traps large particles of organic matter. The organisms living in the bottom bed, mostly bacteria but also worms and protozoa, break down this organic matter by eating it.

For an effective filtration system in an aquarium, the bottom bed of sand or mud must contain filtration organisms. Therefore, when cleaning an aquarium, add some old sand to the new sand so a new culture of organisms can quickly establish.

Clams, oysters, and tubeworms also filter out organic matter. Marine plants can also serve as filters; they convert animal waste into oxygen and plant tissue. For large pieces of organic matter that these organisms cannot break down, a few snails, crabs, or sea cucumbers in the aquarium are good.
d. Equipment.

- Filters. The best and cheapest filter system to use is a subsand filter. The filter consists of a plate with two tubes. The plate sits on supports a centimeter or
so above the bottom of the tank. The space between the bottom of the tank and plate allows water to collect and then move upward through the tubes. More water is pulled through the sand filter bed on top of the plate to replace the water on the bottom. The size of the subsand filter plate should be at least $1 / 3$ of the aquarium bottom, but most aquarists buy or construct their filter plates to snugly fit the sides of the tank. A 4 cm layer of sand and stones smoothed over the top of the filter is adequate as a medium because the top 4 cm does most of the filtering. Make sure that all of the sand grains are larger than the holes in the subsand filter plate.

Once the sand filter has been established. It should not be disturbed. Many types of fishes and invertebrates are notorious diggers and when a hole is dug down to the filter plate, the water rushes through that particular spot and is not evenly filtered. This can be prevented by spreading a layer of sand over the filter plate and covering it with a sheet of flberglass screening. The screening should then be covered by another layer of sand. This allows antmals to dig but also prevents them from upsetting the fllter's balance.

- Pumps. Vibrator pumps are the simplest and cheapest. Larger piston or rotary pumps are usually more expensive and deliver more air or water. If water flows through the pump, be sure it is made of plastic and is meant for salt water aquarium purposes. Air pumps should be placed
at a higher level than the water in the aquarium so that if the electricity fails, water will not back up into the pump.
- Metal parts. Metals such as copper, zinc, iron, manganese, and cobalt have both positive and negative effects on marine systems. They are necessary to all organisms in small quantities but are poisonous in concentrations that are much above their level of need. The metal parts of an aquarium can corrode. When this occurs, the concentration of metal in the water can rapidly bujld up to poisonous levels. Since metals are commonly attached to organic molecules, bubblers will help remove these materials. Filters containing activated carbon will remove them temporarily.
- Temperature. Although in the ifterature $70^{\circ} \mathrm{F}\left(21^{\circ} \mathrm{C}\right)$ is usually given as optimal, tropical marine animals and plants are more sulted to temperatures of $75^{\circ}-80^{\circ} \mathrm{F}$ $\left(24^{\circ}-26^{\circ} \mathrm{C}\right)$. Even in Hawali, aquariums occasionally need heaters because temperature fluctuations, especially in the winter, may lead to outbreak of disease.
- Lighting. The amount of light is important in keeping marine organisms. Some animals such as nocturnal fishes and Invertebrates cannot tolerate high light intensities while most plants need light to photosynthesize and grow If animals and plants are to be kept tugether, provide shade for the animals. If an aquarium is put into direct sunlight, the sun's heat will increase the water temperature and "cook" the organisms. Generally aquaria should be kept in indirect sunlight or be lighted with
flourescent bulbs which give off little heat.
d. Testing and daily maintenance of the aquarium. Put one or two inexpensive animals
into the aquarium for about a week. If they die, retest the water and make sure no toxic substances are in the tank. Daily maintenance should include:
a. smelling the water for foul odors and observing whether bubbles are not breaking up rapidly and foam is developing. In these cases, waste materials is dangerously high.
b. watching the behavior of the animals to determine whether they hide in corners, are fighting, or are listiess. If there is unusual behavior, isolate those animals.
c. siphoning out uneaten food and debris from the tank.
e. Food. Studies on the foods of cultured fishes indicate that they need at least $50 \%$ protein in their diet and cannot use much carbohydrate ( $10 \%$ ), sugar ( $5 \%$ ), or fat ( $5 \%$ ). This principle has been applied to most of the pellets and flake foods on the market. Little is known about the diets of marine invertebrates. It is important to feed fishes and invertebrates a diet similar to their natural foods. Some animals will eat almost anything but this does not always mean that an animal can digest its meal. Signs of hungry or starving fishes are as follows:
- bites the fins of other fishes in the aquarium.
- bloated fishes with stringy feces.
- fishes with concave bellies.

New fish may not eat for one or two weeks. If fish which eat well are placed in the tank, the new animals may eat sooner. For optimal growth, most aquarists suggest that fish be given daily all they can eat in five minutes. If food remains after five minutes, it should be siphoned out. Place the food in contact with invertebrates. It is important to watch animals to see how much they will eat. From these observations you can determine how much to feed them. Many fishes will not eat unless the appearance and environment of the food is natural. For example, coral-feeding fish can often be induced to feed by pressing food into the skeleton of a dead coral. Types of food typically used are:
a. animal or plant flake foods, which often provide a basic diet for many animals.
b. seaweed
c. Live fish, worms rabs, shrimp, or other animals can be collected and raised to feed to fishes.
d. dead raw shrimp, fish and squid should be chopped, washed, and frozen until needed. Thaw before feeding.
e. if you buy adult brine shrimp, place them in the refrigerator or in brine
water and aerate. Dip out the desired quantity, wash in tap water to remove unwanted eggs and parasites.
f. Diseases. Diseases of fish and invertebrates result from many causes. Disease organisms such as viruses, bacteria, fungi, protozoans, metazoans (commonly called "worms"), and crustaceans are largely responsible for fish death. Other causes such as dietary deficiencies, wounds, poisons, temperature, and changes in water chemistry are also responsible.

Diagnoses and treatments of fish diseases are best known in the culture of temperate freshwater food fishes. Information regarding disease in tropical marine fishes and invertebrates is very limited. As a rule, new marine fish and invertebrates should be isolated in a separate "quarantine" aquarium for about two weeks before putting them into an established aquarium (two weeks is the life cycle of most parasites). A combined formalin/copper sulfate bath given every 3-4 days for 2 weeks to diseased fishes, not invertebrates, is a common marine aquarium practice. Consult aquarium keeping books or pet stores for further information.
g. State of Hawail Fish and Game Rules Summarized for Aquartum ColTectors.

You must obtain a permit to collect fishes and invertebrates with small mesh nets (less than 2" stretched mesh).

Another permit is required if you intend to sell your antmals. Obtain these permits
from the Ftsh and Game. You must go there in person.

You cannot use chemicals to obtain your animals.

Read the regulations about where you can and cannot collect animals.

You cannot take lobster and octopus less than one pound in weight. Lobsters and large crabs with eggs and native pearl oyster may not be collected. Introduced oysters, young weke, young threadfin, young gobies in streams, young opelu, and freshwater game fishes either cannot be caught, or a special permit is required.

# SHORELINE ECOLOGY REFERENCE 



## Shoreline Ecology Reference

When you visit the shoreline you may wish to use sampling techniques to study relationships between marine plants, substrates, organisms, and water quality. The data sheets at the end of your workbook will help you to organize your data.

## Materials

1. To be made before the trip by each team:

- 1 transect line marked at 1 -meter intervals
-1 meter2 quadrat, a square or circle made from reinforcing rods or another type of metal. It can be subdivided into quarters
-l lifeline (e.g., line tied to plastic jug, ring buoy, rescue tube, etc.)

2. To be understood before the field trip:
-data sheets--these may be found in the dent workbook.
3. To be assigned for each team:
a. Map and profile - data sheets, clipboard, pencil, compass, meter stick.
b. Water conditions - data sheets, writing equipment, thermometer, hydrometer, 100 ml graduated cylinder (plastic), oxygen test kit, water sampling bottles, secchi disc or white plastic sheets, watch with second hand, tide chart.
c. Substrate - data sheets, writing equipment, quadrats, 4 one-quart plastic bags with ties or rubber bands, water-proof marker, at least 12 small zip-loc bags. Equipment for analysis in class (sieves, cylinders, microscopes, probes, glue, etc.).
d. Animals - data sheets, writing eqipment, look boxes or masks, 1 large bucket, 12-16 one-quart plastic bags with ties, indelible markers.
e. Plants - data sheets, writing equipment, paint scrapers or dull knives, look boxes or masks, 20-30 one-quart plastic bags, indelible marker. Equipment for analys is in class (balance, newspapers, press, etc.)

## Procedure

1. Class will divide into teams.
2. Each team is responsible for assembling and taking necessary equipment to shoreline. Then afterwards to rinse and clean equipment in fresh water and return it to school.
3. Team member assignments:
a. Maps - This person prepares a map showing the study area and the location of the transect lines; also measures and sketches the bathymetry along the tran
b. Water conditions - This person (a) collects and analyzes water samples along the transect line and (b) describes wind, waves, tides, and currents affecting the study area.
c. Substrate - This person (a) assists the map maker in preparing the bathymetric map of the transect line and (b) collects and analyzes substrate samples from each quadrat.
d. Seaweeds - These persons (a) collect one sample of every seaweed found in the class study area, (b) harvest seaweed in quadrat areas, and (c) sort, identify, and weigh seaweeds.
e. Animals - This person (a) collects one sample of each animal found in the class study area, (b) identifies the organism to phylum class or family, (c) determines visuatly which animals are common, and (d) after showing organisms to team members, returns them safely to the ocean.
4. Give a team report on your findings.


## TOOLSHEET 1: INTRODUCTION TO MEASUREMENT

In science, we observe and describe the properties of things we see. Some of these properties such as size of objects can be measured.

Measurement involves determination of the amound or quantity of something by comparison with a standard. A standard is a defined value or quality that is used as the basis iof comparing the properties ot different things. For example, the second is used as a standard for measuring the passage of time.

## The Metric Syetem of Measurement

The metric system of measurement devised by the French in 1791. has been adopted by all of the major nations of the world. It is used by scientisis of all countries.
Some bitic units of measurement and measuring devices are llated in Table 1. Equivatent units of measurement and the uses of measuring devices are explained in the folkowing fooktheets.

| Measurement | Basic Unit of Measurement | Measuring Dovice |
| :---: | :---: | :---: |
| Length | Meter (m) | Melric ruler, meter stick |
| Mass | Grem (g) | Matric balance |
| Area | Square meter ( $\mathrm{m}^{2}$ ) | Metric ruler, metric area grid |
| Volume | Cubic meter ( $\mathrm{m}^{2}$ ) | Metric ruler, meluic area grid, overflow container |
| Capacity | Liter (1) | Metric graduated cylinder. graduated beaker |
| Temperature | Cotshus degres (\%) | Thermometer |
| Time | Second (rec) | Timing devices |

The units in the metric bystem of measurement are corveniently based on multiples of ten. Some of the profixes of unit measurements are lleted in Table 2. For oxempte, in measuring length thers 战 a mommeter; for mast there is a miligrem; and for time there is a m"isecond. The common profix anin reters to onetrousandth ( $1 / 1000$ ) part of the basic unit.

Table 2 Praliset in the Metric Syaipri of Metaturement

| Pretix of Unit Measurement | Aultiple of Unil Measurement | Example of Equivalent Measurements |
| :---: | :---: | :---: |
| Myria- <br> Kilo- <br> Hecto- <br> Deka- <br> Unit <br> Deci- <br> Centi- <br> Milli- <br> Micro- | Ten thousand One thousand One hundred Ten <br> One <br> One-tenth <br> One-hundredth <br> One-thousandth One-millionth | $\begin{aligned} 10,000 \mathrm{~m} & =1 \text { myfiemeter } \\ 1.000 \mathrm{~m} & =1 \text { kilometer }(\mathrm{km}) \\ 100 \mathrm{~m} & =1 \text { hectometer (hm) } \\ 10 \mathrm{~m} & =1 \text { dekameter }(\mathrm{dkm}) \\ 1 \mathrm{~m} & =1 \text { meter }(\mathrm{m}) \\ 1 / 10=.1 \mathrm{~m} & =1 \text { decimeter }(\mathrm{dm}) \\ 1 / 100=.01 \mathrm{~m} & =1 \text { gentimeter }(\mathrm{cm}) \\ 1 / 1000=.001 \mathrm{~m} & =1 \text { millimeter (mm) } \\ 1 / 1,000,000 \mathrm{~m} & =.000001 \mathrm{~m}=1 \mathrm{mic}(\mathrm{mon}(\mathrm{~m}) \end{aligned}$ |

## Uncertainty in Measurement

Every measurement we make contains some degree of uncertainty. This uncertainty in measurement ts due to several kinds of errora. These inctude human error since each person makes measurements differently and intrument error since no instrument is absolutaly perfect.
We essumg that come measurements are greater and some are smaller than a "true" measurement. There are limitations in reading a "true" measurement with any instrument. By averaging a large number of carefuit measuremente, we are likely to be closer to the "true" value than we are by taking a single meapurement.

## TOOLSHEET 2: METRIC LINEAR MEASUREMENT

Length is a measure of the distance between any two points. The basic unit of length in the metric system is the meter. The meter was orlginally defined as one len-millionth of the distance belween the Earth's pole and the equator.

A metric rular is the instrument used in measuring length. The units of length most commonly used include the meter (m), centimeter ( $\mathbf{c m}$ ), millimeter ( mm ), and kllometer ( $k \mathrm{~m}$ ).

## Use of the Metric Ruter

1. Measure the diatance between two points. Use Figure 3 for a reference
a. Put the zero mark of a ruter at one of the points.
b. Note the marking on the ruler at the other point.
2. Read the distance marked off on the ruter.
a. Count the number of marked unita between the points.
b. Estimate the remainder of the distence in tenths of the smailest marked unit.
c. Read the distance in one measurement unlt. For example, read 35 mm or 3.5 cm but never 3 cm and 5 mm .
3. Fecord the distance in the measured unit or its equivalent unit of length.
Equivalents of some units of length:



## TOOLSHEET 3: INTRODUCTION TO GRAPHING

A graph is a "picture" of numerical data. It presents data in a fosm that readily showe the relationthips between different measured observations. Graphs can be used to averege data and make predictiont.

## Making araph

1. Record the measurement in a data table. See Figure 4.
2. Mark and labed the axes on a aheet of grid papar. Set Fipure 5.
3. Draw the horizontal exis allong one of the lines running from leh to right.
b. Draw the vertical axis along one of the lines running up and down.
c. The horizonted and vertical axed meet at a point called the orgin.
d. Labol each wxis with the natme mod unit of measuremen.
4. Delermine a tiale for each axie. Mank and label each ecale. See Figure 6.
a. Choose a scate that it large enough to include all of the measurements.
b. Select simple and conwenient scaite unita. Note that equal spaces between lines represent equal acaled measurements.
c. Use enough space for the acale on each axis to keep from crowding the date. Begin the scales at the origin and extend upwarde on the verical axis and to the right on the horizontal axis.
5. Piot a point on the graph for each wet of measurements. Circie esch point so that it it clearly visible. See figure 7.
6. Put a box $\{D\}$ around any plotted pointe that feem unreasonable at thown in Figure 8.

| Date on the Movement |
| :---: |
| of $A$ Besloon |$|$| Time | Dtatance |
| :---: | :---: |
| (sec) | (m) |
| 0 | 0 (stert) |
| 1 | 4 |
| 2 | 17 |
| 3 | 12 |
| 4 | 16 |

Figure t Dala on the mowement of a belloon.


Floure 5 Lebed ine graph with ine name end unit of measurt: ment.


Figure 6 Scaling a greph
6. Draw a line or curve through the pattern of ploted points thal seems to best reprebent the relationships between the measured obsenvations. See Figure 8.

## Checking a Graph

1. A sample graph to shown In Figure e. Examine your graph and check to see il you have included the following:
a. The graph is identified with a tithe, date, and your name.
b. Axet ere labeled with the name of each measurement (distance. time. etc.) and unit oi mesteurement (meter, seconds, atc.).
c. Scales are marked and labeled for each axis.
d. Plotied points are circled and clearly viable.
e. The line or curve is smoothly drawn through the pattern of points.


Figute s Sample gript of the movement of a balloon.

|  |
| :---: |

figure 7 proting date.


Figure 目 Lint drawn throuph plotied pounts

## Use of a Graph

1. Graphs are used to show relationships between different measured observations.
a. If therg is a pattorn of plotied poinis. the observatione ars probebly folated
A straight Ine drawn on graph indicales that the ratio between the meazurements is about the same for mod of the plotted points.
b. If thers is no pattern in the plotted points on the graph, the obeervations are probably not resated.

2 Graphs are used in making predictions.
a. Making predictions from data on the graph beyond the range of measurements is called extripolation.
b. Making predictions from date on the greph within the range of measurements is called Interpofation.

3 Graphs are used to average data when several measurements are made for each observation. Duplicaled delta is thown by a line radteting from the piolled point each time thit the data point ts repeated. Points on the graph Hne represent the averago meaturements


Figure 10 interpetation of grapinc diata.

## TOOLSHEET 4: METRIC MASS MEASUREMENT

Mass is a measure of the amount of "stulf" or material that is in a thing. The gram is the basic unit of mass in the melric system. It was originally delined as the quantity of "stuff" in one cubic centimeter of pure water al $4^{\circ}$ Celsius
Weight is a measure of the pull of gravity on an object. II is often contused with mass. The weight of an object changes when the pull of gravity changes; however, the mass of an object does not change. For example, the force of gravity on the moon is one-sixth that of the Earth, and therefore. an astronaut on the moon weighs one-sixth as much as he does on the Earth. However, the mass of the astronaut remains the same since his body is composed of the same amount of "stuft" on the moon as on the Earth.
The instrument that is used to measure mass is commonly called a balance The kilogram $(\mathrm{kg})$, gram (g). and milligram ( mg ) are some of the more commonly used mass units.

## Use of the Balance

A sketch of a lypical Dial-O-Gram balance is shown in Figure 11. Each division on the uppar beam represents one hundred grams. The bottom bearn is subdivided into ten gram units. Each division on the dial represents one gram and the vernier sca/e allows you to measure onehundredih gram units. Your teacher will show you how to use the vernier.


The instructions for using a Diat-O-Gram balernce or a thinilar type of beem balance are ghen below.

## 1. Cleen the balance pan.

2. Put all of the betm rders on zero, turn the dial to Eero, and check for "bilance".
A. "Balance" if indiceted when the poinier owings an equal distance above and below the center of the scale.
b. Be aure that the beam ridera ere in their notchet.
c. If the pointer does not come to rest on zero, move the zero edjustment screw in or out th needed.
3. Moasure the anass of en object.
a. Put the object on the balance pan.
b. Approximate the mesa by mowing the riders on the beam. Be sure that the ridera me in the notehes.
c. Adjust the ridere and the dial until the pointer swings equal amounts above and betow the zero on the scale.
4. Fies the mass indicated on the balance. Add the masses indicaled by fiders on the beams and the dilad.
5. Record the mase in grame or its equivalent. Equivalents of some unite of mets:


## Care of the Balance After Use

1 Return the riders and the diel to whelr zero positiont．
2 Wipe off any spillage in the balance pan
3．Cover the balance．
Use of Contalners on the Batance
Containers are used to hold substances which cannot be put directily onto the balance pan such as liquids．gaseas， or fine solid perticles．Thersfore，the mass of the container must be considered when measuring the mass of these substances
The mass of a substance can be measured as follows：
1．Use the balance to determine the mass of an empty container．Read and record the mass of the container
2．Put the substance into the container．Measure and record the total mass of the container and subelance．
3．Determine the mass of the subsiance．Subtract the mass of the empty contelner from the total mass of the contalner and pubtiance．
$\begin{gathered}\text { Mass of } \\ \text { Substance }\end{gathered}=\begin{gathered}\text { Mass of Conlaifer } \\ \text { and Substance }\end{gathered} \quad \begin{gathered}\text { Mase of } \\ \text { Empty Conlaindt }\end{gathered}$


Figure 1a Datiermunng inase of enend
4．Fecord the mase of the eubatance in the messured unil or its equlvaiem．Refer to Instruction 5 on the ＂U⿻丷木大 of the Belance＂tor the equivaienta of some unite of mest．

## TOOLSHEET 5：METRIC AREA MEASUREMENT

Arte is measure of the amount of surface of an object．Ita two dimenalons，length and width，sre linear measurements．Some commonly used units of metric mrea meaturement are the square meter $\left(\mathrm{m}^{2}\right)$ ，equare centimeter（ $\mathrm{Cm}^{2}$ ），and square milimeter （ $\mathrm{mm}^{2}$ ）．
The metric area grid can be used to find the approximate area of flat a uriacea regardlest of shape．The aret of regularly shaped surfaces can also be found by calcutation．
A metric grid is a serles of crossed lines．The horizontal lines of the grid are equal distances apert as are the vertical dines．The crosed lines produce squares of equal eize．
The squares in the sample metric grid shown in Figure 13 are 1 cm long and 1 cm wide Each square in the grid has an area of one square centimeter（ $1 \mathrm{~cm}^{2}$ ）．



Use of the Metric Area Grid
The directions for using a metric area grid to find the area of any flat surface are given below

1. Put the object on a grid paper so that its edge corresponds to a grid line. Oulline the edges of the obiect. Remove the object.


Figure : 4 Measuring area using a metric adea grid
2. Measure the surface ares of the object.
a. Count the number of whole squares marked off
b. Estimale the amounl of each partlally merked squara
c. Add the total amount of squares marked oft
3. Record the ares in the mespured unit or its equivalent.
Equivalents of some units of areie:
$1 \mathrm{~m}^{3}=10,000 \mathrm{~cm}^{2}=1,000,000 \mathrm{~mm}^{2}$ $.0001 \mathrm{~m}^{2}=\quad 1 \mathrm{~cm}^{2}=100 \mathrm{~mm}^{2}$ $.000001 \mathrm{~m}^{2}=.01 \mathrm{~cm}^{2}=\quad 1 \mathrm{~mm}^{2}$

## Comculation of Area

The area of a square or rectangular surlace can be chlculated as follows:

1. Use a metric nuler to measure the fength and width of the object.
2. Calculate the aree of the surface. Mutiply the length tirges the width.


Frgure 15 Cascuating area.
3. Record the area of the calcutaled units or its equivalent. Rafer to Instruction 3 on the "Use ol the Metric Area Grid" for equivalents of some units of area measurement

## TOOLSHEET 6: METRIC VOLUME MEASUREMENT

Volume ts a messure of the amount of space occupied by an object. It has length, width, and height. Some units of volume measurament are the cubic meter ( $\mathrm{m}^{3}$ ), cubic centimeter ( $\mathrm{cm}^{3}$ ), and cubic millimetor (mm³).
Capacity ls a measure of the amount of epace tified by a liquid. gas, or collection of solid particies. it is the volume that can be filled by a substance. The fiter (i) is the basic unit of capacity measurement. Another commanly used capachy unit ts the millifter (ml).
The volume thled by one cubic centimeter of a substence is one milititer Thus, 1 mite equal to $1 \mathrm{~cm}^{2}$.
One method of finding the volume of a regularly shaped objectis by calculation from the linear measurement of its three dimensipns. The volume of an irregulafly shaped solid can also be measured by the amount of liquid it displaces in en overflow container ar graduated besker To measure liquid volume the graduated cyllnder is used.

## Calculation of Volume

The volume of a stendard cube messuring 1 cm on each edoe to one cublc centimeter Volumet of different object are measurad and expressed in lerms of this tlandard cube
The volume of a rectingule solid can be determined at tollows:

1. Find the base ares of the oblect. Reter to Toolsheet 5, "Metric Area Meazurement," for Iaformetion on masaring trep
2. Une metric rulet to measure the holght of the obpect.
3. Calculate the volume of the object Multiply the bese area times the heleht. Sed Figure is.


Figure it Calculating voiume.
4. Record the volume in the meagured unit or its equlvalent.
Equivilenis of some undts of velume:
$1 \mathrm{~m}^{3} \times 1,000,000 \mathrm{~cm}^{3}=1,000,000,000 \mathrm{~mm}^{3}$
$.000001 \mathrm{~m}^{2}: \quad 1 \mathrm{~cm}^{2} . \quad 1,000 \mathrm{~mm}^{3}$ $000000001 \mathrm{~m}^{3}$ : $\quad 001 \mathrm{~cm}^{3}=\quad 1 \mathrm{~mm}^{3}$

## Use of the Gradualed Cyilinder to Measure Volume

The greduated eylinder or graduate that is commonly uaed in the laboratory to mesture capecity it marked in millifitere. A capacity of 1 ml is equal to a volume of 1 cm ${ }^{1}$.

The volume of a liquid can be measured as follows

1. Pour the liquid into a graduated cylinder. Put tha graduate on a fiat, level surface.
2 Ering your eyes directly opposite the bottom of the meniscus. The meniscus ts the thick curved bend marking the surface of the siquid.
2. Read the volume of the liquid.
a. Read the marking on the graduate that corresponds to the boltom of the meniscus.
b. Estimate the volume in tenths of the unit marked on the graduale.
3. Record the volume in the measured unit or tis equivalent.

Equivalents of some units of capacity:

| 11 | $=100 \mathrm{cl}$ |
| ---: | :--- |
| 011 | $=1,000 \mathrm{ml}$ |
| 001 | $=1 \mathrm{cl}$ |
| 001 ml | $=1 \mathrm{ml}$ |

## Use of the Overflow Container to Measure Volume

When an object is put into an overflow container filled with liquid, it pushes some of the liquid out of the way es it sinks. The liquid that is pushed away is called displaced liquid. The displaced liquid flows through the spout of the overflow container and into a "catch container."

The volume of the object is equal to the volume of displaced liquid. if the object sinks completely in the liquid. However, if the object floats, only the volume of the submerged portion of the object is equal to the volume of displaced liquid


Tha volume of any solid object can be determined as follows:

1 Fill the overflow container with water Allow the excess water to flow through the spout and inio a catch beaker. Empty the excess water from the beaker.
2. Put the emply catch container under the spout of the overtlow conlainer.
3. Determine the volume of the object.
a. Put the object into the overfiow contalner
b. Allow the diaplaced water to flow into the catch container
c. Pour the displaced water into a graduated cylinder. See Figure 18
4 Fead the volume of displaced water in the graduated cylinder. Refer to Instrucitons 2 and 3 on the "Use of the Graduated Cylinder" for information on how to read the graduated cylinder.
5. Record the volume in the measured unit or its equivalent.

Equivalents of some units of volume and capacity.

| 11 | $=1,000 \mathrm{ml}=1,000 \mathrm{~cm}^{3}=1,000,000 \mathrm{~mm}^{3}$ |  |
| ---: | :--- | ---: |
| 0011 | $=1 \mathrm{~mm}=1 \mathrm{~cm}^{3}=$ | $1,000 \mathrm{~mm}^{3}$ |
| 0000011 | $=.001 \mathrm{ml}=.001 \mathrm{~cm}^{2}=$ | $1 \mathrm{~mm}^{3}$ |
| 11 | $=.001 \mathrm{~m}^{3}$ |  |

## Use of the Gradualed Beaker to Measure Volume

A beaker that is marked in millifiters or another unil of capacily measurement is called a graduated beaker
The volume of an object can be delermined by the volume of liquid it displaces in a graduated container. The total volume of an object that completely sinks or the submerged volume of a floating object is equal to the voiume of displaced ilquid.

kilura in Uting en overtion containet to meadure volume

## TOOLSHEET 7: INTRODUCTION TO DENSITY

Densify is the relationship between the mass and volume of an object or subatance. It may be expressed as the number of grams in one cublc centimeter ( $\mathrm{g} / \mathrm{cm} \mathrm{m}^{3}$ ) or the number ol grams in one millititer ( $\mathrm{g} / \mathrm{ml}$ ) of a substance.
The density of an object or substance can be determined from a greph of its masa and volume. Density can also be delermined from the calculation of the ratio between the mass and volume

## Use of the Densty Graph

A dengity graph shows the relationship between the masa and volume of an obfect or substanct. Mass mespurtements are plotted on the vertical axts and volume messurements on the horizontal axia.
Determine the denalty of an object made of the ame materlal throughout as follows:

1. Mopaure and record the mass and volume of tever al different eamples of the same object.
2. Make a density greph. Piot the mass on the vertlcal wis and volume on the horkontal axis.
Pefer to Toolaheet 3, "Introduction to Graphing." tor Information on the construction of a graph.
3. Read the density graph.
a. Find the density point on the greph. It is the point on the density line or curve that intersects the $1 \mathrm{~cm}^{2}$ or 1 ml line.
b. Read the number of grams on the vertlcal axis corresponding to the denelty point.
4. Record the density of the substance $\ln \mathrm{g} / \mathrm{cm}^{3}$ or $\mathrm{g} / \mathrm{ml}$.
$1 g / m^{3}=1 \sigma / m$

## Calculation of Density

1 Determine the mate and volume of a substance. Aefer to Toolthet 4, "Metric Mass Meanurement," end Toolsheet 6, "Metric Volume Mepsurement," for information on how to mplation mass and volume

| Data on the Density <br> of an Object |  |
| :---: | :---: |
| Mass of <br> Sample <br> $(\rho)$ | Volume of <br> Sample <br> $\left(\mathrm{cm}^{3}\right)$ |
| 9.0 | 3.0 |
| 7.0 | 2.5 |
| 6.0 | 2.0 |
| 4.5 | 1.5 |


|  |  |
| :---: | :---: |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

The number of arema for the denalty point is 3 g .

Density of object
$=3 \mathrm{~g} / \mathrm{cm}^{3}$
Equivalent densitios $3 \mathrm{~g} / \mathrm{cm}^{3}=3 \mathrm{~g} / \mathrm{ml}$

Figure 20 Devermining dennity trom 4 graph

## TOOLSHEET 8: TEMPERATURE MEASUREMENT

A thermometer is used to measure the temperature of a substance. It measures how hot or cold a substance is in degrees Celsius ( ${ }^{\circ} \mathrm{C}$ ) or other convenient units.

## Use of the Thermometer

1. Carctully take a thermometor out of its case.
2. Gently put the thermometer bulb in direct contact with the substance whose temperature is to be moasured.
3. Ering your eyes directly opposite the level of the liquid column in the thermometer.
4. Read the temperature.
a. Read the highest marking on the thermometer that corresponds to the helght of the liquid column.
b. Estimate the height of the liquid column beyond the highest marking in tanals of the units indicated on the thermorneter.
5. Record the temperature of the subatance in ${ }^{\circ} \mathrm{C}$.

## Care of the Thermometor

1. Prevent the thermometer from dropping or rolling.

2 Use the thermometer to measure temperature only within its renge. Do not overheat it.
3. Do not use the thermometer as a stirring rod.
4. If the mercury column is spitt, put the thermometer In a container of methanel and dry ice to recombine the mercury in the bulb.
5. After using the thermometer, rinse it with tap water end let it dry.
6. Carefully replace the thermometer in its case.


## meler.

## TOOLSHEET 9: TIME MEASUREMENT

Devices used to measure the pessage of time during an event include the metronome. watch, and clock. These timing devices meature how long an event takes place in seconds (sec), minutea (min), or hours (hr). Long perlods of time are measured in dayb, months, years, or centuries, while very short perlods are masured in mililseconds.

## Use of Timing Devices

1. Menture the time passing between the start and finiah of an ovent.
e. At the staft of the event, rand and record the fime registered on the timing device.
b. At the finiah of the ovent, read and record the time regitered on the timing device.
c. Determine the tirne of the event. Subiract the final time from the wtarting time.

Time of Event \& Final Thrib - Starting Time
2. fiecord the time of the event in the measured unit or
it equivalent.
Equivalants of mome unite of ilme:

| 1 hr | $=60 \mathrm{~min}$ | $=3,000 \mathrm{sec}$ |
| ---: | :--- | ---: | :--- |
| $1 / 80 \mathrm{hr}$ | $=1 \mathrm{~min}$ | $=60 \mathrm{sec}$ |
| $1 / 3,600 \mathrm{hr}$ | $=1 / 60 \mathrm{~min}$ | $=1 \mathrm{sec}$ |

## TOOLSHEET 10: WRITTEN SCIENTIFIC REPORTS

## Background

In ecience, an in other areae of humen effort, work done by one individual it often of vatue to other Individuals. Your work miny be useful to sivdents in other clasese or it mey be of great value to studente nexi yoar. They may want to try the same experimente, carry out your Invettigetion to the next atep, verity your work, or eftempt to solve some of the problem you had.
Scientiats have a way of sharling their experiences. They report their work in ectentilic journale. They follow a standard atyle in making thair reporte. The style of acientific reports difters In varlous flelde of sclence and from jotrnal to joumal, but the general structure is much the same.
The guldelines for witing scientific reporte which are given below are taken from the American Inatitute of Biological Sclencat (AIBS) Styia Manual. For other aubjects you may be asked to write your blbliography using a different style.

## Activity

Write a report of your inveatigation folliowing the procedures used by blological acienitigt.

## Procedure

Write the eections of your repert in the following order:

1. Titie Write a short deseriptlve phicese about 3 to 10 words, telling preciedy what the experiment to bout.
2. Table of Contente. List the toplos, diagramt, wnd deta tablet and the page number on which each can be tound For example:

## Table o: Contents

Table of Contents .............. 1
introduction
Materials and Methods .......... 3
Litst of Data Tables
Fable 1
Table 2
ist al Illustrations
(Sketches, photos
Figure 1.
3. Introduction. Except for your statement of the problem, this whole section comes from books and other relerences. You can be reading about the topic in other meterials and writing this section while you are setting up and running your experiment. You may find some things in other books magazines, articles, etc., that you can use in your own experiment
Record the author, year, title, publisher, and pages of each book from which you take inlormation. A good way to record this information is to write each on a separate file card. (See 7. BibHiography) Do this at you go along so that you will not have to go back and find the same books again when you assemble the bibliogrephy.

Include the following in the introduction
a. State the problem in one sentence.
b. Give the scientific and common names of the organism used in experimentation. include a sketch or picture.
c. Describe the kind of plant or animal it is; give its Hfe requirements as they are described in other materials: explain any special characteristics.
d. Describe briefly experiments which are similar to yours that you have read about.
4. Materialg and Methods. In this section, give instructions in detail. including skatches and diagrams, of your exact procedure. Describe amounts, concentrations. weights, conditions, construction of apparatus, and sources of supplies. The description of your method should be clear enough so that another person could repeat your experiment.
5. Results. The data you collected with explanations are reported here.
a. Make neat coples of your data tables. Give every data table a number and title.
b. Make graphs of your data. Give every graph a figure number, a title, and an explanation of what the graph shows.
c. Report your observations in your own words
6. Discussion and Conclusion. Interpret your experiment and write your conclusions.
a. Describe what your dete and graphs show and/or do not show.
b. Make comments on why you think things did or did not turn out as you expectied.
c. Draw a conclusion about your experiment. The conclusion should be an answer to the problem you stated al the beginning of your report.
7. Blbliography. Liat the books and articles you used for references.
a. Take out the list of references you used while you were writing the introduction and working on your experiment.
b. Liat the references in alphabetical order by using the latt name of the author.
c. Write the bibliography in the following order:

1) The author, last name first, foilowed by first name and Inltiai.
2) The dat the book was published.
3) Titie of book or erticle: Only the first word is Titie of book or articie: Only ine insi wordis
cepltilized. Al the other words in the title are lower case, uniesa proper names are inctuded in the titles. The title in not in quotetion marks nor underlined.
4) If it is a book, glve the publleher and place of publication.
5) If it is ie journal, name the journal, then atate the volume, number and pige. The following is an example of a |ournal entry.

## ACKNOWLEDGEMENTS

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## Reviewers

Our reviewers provided crucial constructive support and comments in reviewing the scientific and technical parts of the project.

1. Earth and Ocean Basins-Dr. K. E. Chave, Professor of Oceanography, University of Hawail
2. Fishes-Dr. Phil S. Lobel, Fellow in Ichthyology, Harvard University
3. Invertebrates-Dr. S. Arthur Reed, Professor of Zoology, University of Hawaii
4. Waves-Drs. George Curtis and Theodore Lee, Department of Ocean Engineering, University of Hawaii; Dr. Frank Lutz, Our Redeemer Lutheran School
5. Marine Plants-Dr. Isabella Abbott, Professor of Botany, University of Hawaij
6. Sharks, Turtles and Whales-Dr. Leighton Taylor, Director Waikiki Aquarium, University of Hawai
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## Pilot Teachers

Further guiding the development of the project have been the experiences of some teachers presently pilot testing the HMSS materials. We wish to thank Mr. Will Kyselka for his help with HMSS field liaison.

## 1977 HMSS Teacher Workshop, Hawaii

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1979 HMSS Teacher Workshops
Drs. James Centorino and Frank Sullivan of Salem State College were instrumental in setting up the first out-of-state workshop.

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[^0]:    ## Activity

    Make fish cake from several local fish species that are not usually considered good eating.

[^1]:    $\frac{1}{4}$ onion, diced
    $\frac{1}{4}$ c. carrot, diced
    2 t. celery salt
    1 t. cornstarch
    2 t. soy sauce
    1 egg, beaten

