LOAN COPY ONLY

NCU-E-90-001 C3

Science **E**xperiments and **A**ctivities

Marine Science for High School Students in Chemistry, Biology and Physics

LOAN COPY ONLY

CIRCULATING COPY
Sea Grant Depository

S.E.A. LAB

Science
Experiments and
Activities

Marine Science for
High School Students
in Chemistry, Biology
and Physics

NATIONAL SEA GRANT DEPOSITORY
PELL LIBRARY BLDG., GSO
UNIVERSITY OF RHODE ISLAND
NARRAGANSETT, RI 02882-1197 USA
(401) 792-6114

$ 12.00 including

CIRCULATING COPY

Table of Contents

PHYSICS

Acknowledgments

This set of curriculum materials was initiated to supplement science content activities for secondary schools. It is a cooperative effort combining talents and skills from universities, public and private schools, and education agencies. We thank those who made this project possible.

Project Direction and Funding

University of North Carolina Marine Science Curriculum
Dirk Frankenberg, Director

University of North Carolina Center for Math and Science Education
Russell Rowlett, Director

University of North Carolina Sea Grant College Program
B.J. Copeland, Director

The Max and Victoria Dreyfus Foundation, Inc., New York.

Project Coordinators

Dirk Frankenberg, Marine Science Curriculum, University of North Carolina at Chapel Hill, Chapel Hill, N.C.

Lundie Spence, UNC Sea Grant, North Carolina State University, Raleigh, N.C.

Jo Wallace, Semiconductor Research Corporation Competitiveness Foundation, Research Triangle Park, N.C.

Editor

Kathy Hart, UNC Sea Grant, North Carolina State University, Raleigh, N.C.

Designer and Illustrator

Ginny Petty, Paragraphics, Inc., Raleigh, N.C.

Writers

Cindy Carter, Consultant, Raleigh, N.C.

Steve Doughtery, New York City Public Schools, N.Y.

Elisabeth Edmondson, Senaca, S.C.

Dirk Frankenberg, Marine Science Curriculum, UNC-CH, Chapel Hill, N.C.

Judy Jones, Chapel Hill High School, Chapel Hill, N.C.

David Hartney, Smithsonian Institution, Washington, D.C.

Allison Merow Rasmussen, National Association of Biology Teachers, Reston, Va.

Ted Sakshaug, Scotland High School, Laurinburg, N.C.

Judy Smith, Supervisor, Durham County Schools, Durham, N.C.

A.K. Smith, Chapel Hill High School, Chapel Hill, N.C.

Larry Wakeford, Chapel Hill High School, Chapel Hill, N.C.

Advisory Committee and Master Teachers

Maxine Claar, Alamance County Schools, Burlington, N.C.

Judy Jones, Chapel Hill High School, Chapel Hill, N.C.

Paul Hounshell, School of Education, UNC-CH, Chapel Hill, N.C.

Ernest Knowles, Department of Marine, Earth and Atmospheric Sciences, NCSU, Raleigh, N.C.

Gerry Madrazo, Supervisor, Guilford County Schools, Greensboro, N.C.

Manley Midgette, Science Consultant—Region 3, N.C. Department of Public Instruction, Knightdale, N.C.

Art Schoolfield, Guilford County Schools, Greensboro, N.C.

A.K. Smith, Chapel Hill High School, Chapel Hill, N.C.

Judy Smith, Durham County Schools, Durham, N.C.

UNC Center for Math and Science Education Staff: Sara Cathey, Don Fish, Todd K. Ballenger, Tim Farless, Cadie Blalock, Tyringa Ambrose, Becky Brickhouse, Benjamin Heilman.

Reviewers and Pilot Testers

Justyn F. Abbott, Vance High School, Henderson, N.C.

Betty Abernathy, Fike High School, Wilson, N.C.

Donna Burns, Ravenscroft School, Raleigh, N.C.

Charles Calligan, Southeast High School, Gibsonville, N.C.

Eileen Camp, Orange High School, Chapel Hill, N.C.

Susan Campeau, Enfield Academy, Warrenton, N.C.

Cindy Copolo, UNC Center for Math and Science Education

Zannie Efird, Enloe High School, Raleigh, N.C.

John Everhart, North Davidson High School, Lexington, N.C.

Tom Feeney, Grimsley High School, Greensboro, N.C.

Don Grigg, Griley High School, Greensboro, N.C.

Myra Halpin, NC School for Math and Science, Durham, N.C.

Bobbie Hardaker, Durham Academy, Durham, N.C.

Mary Harget, Dudley High School, Greensboro, N.C.

Dot Helms, West Rowan High School, Mt. Ulla, N.C.

Mike Jackson, Camp Lejeune Dependents Schools, Camp Lejeune, N.C.

Larry Liggett, Asheville High School, Asheville, N.C.

Mary Ann Johnson, Weaver Education Center, Greensboro, N.C.

Nancy Kelley, Burlington, N.C.

Charlotte Manning, Page High School, Greensboro, N.C.

John Pashal, Discovery Place Museum, Charlotte, N.C.

Alma Phifer, Plymouth High School, Plymouth N.C.

Maureen Ramsey, Adelaide, South Australia

Bob Spurgeon, Central High School, High Point, N.C.

Shirley Viele, Dudley High School, Greensboro, N.C.

Charles T. Vizzini, Charlotte-Mecklenburg Schools, Charlotte, N.C.

Introducing You to S.E.A. Lab

S.E.A. Lab is a series of science experiments and activities designed for secondary school students taking biology, chemistry, physics, physical science or marine science courses. Each of the three major secctions—chemistry, biology and physics—addresses concepts that are generally covered in those courses but incorporates aspects of marine science. In many cases, you can substitute S.E.A. Lab activities for labs from your text.

Within each section, you will find major concepts, such as density, pH, photosynthesis, respiration or sound, that are supported by student activities. Each activity contains background reading for you or your students, a materials list, procedures for completing the activity and extension ideas. Some of the activities are challenging; some are simple. At the end of each concept division, references, resources and education competencies are listed.

Use the table of contents to get started. Check the different ideas presented. Mix and match activities to show how basic science solves problems in coastal waters and the ocean. Activities in the chemistry section can enrich a biology lesson. Marine science problems integrate all the science disciplines.

S.E.A. Lab is designed so new activities can be added. We want to keep an open line of communication between marine research and the teacher. If you want to share your labs with other teachers or make suggestions on existing ones, contact the UNC Sea Grant Marine Education Specialist, Box 8605, North Carolina State University, Raleigh, North Carolina 27695-8605

Welcome aboard.

CHEMISTRY

Chemical Reactions in the Marine Environment

Introduction

Stoichiometry is a core topic in introductory chemistry courses. It is often taught without practical applications. However, marine science offers many concrete examples of chemical reactions that can be used to write and balance equations. These reactions can be developed and easily explained to students. This approach provides students with an understanding of ocean processes and a framework for learning about chemical reactions.

This section contains background information for teacher lectures and student activities. The exercises and information are designed to be used as is or in parts. They vary in complexity. The list of elements can be used as individual examples when discussing chemical symbols, element names and the periodic table.

The first student activity involves naming elements and writing chemical symbols. The questions in this activity are good for review or test questions. The second activity offers equations to balance and an explanation of how the reactions these equations represent are important to the marine environment. These reactions would be good as a review worksheet or as test questions. The remainder of the exercises are lab activities.

Teacher Background Information

Below are elements and compounds important to the marine environment (Table 1).

Elements

Alkali metals—are major ions in seawater. They lack chemical reactivity in solution and exist mainly as cations. Sodium and potassium ions have long residence times. Residence time is the length of time a particle or substance spends in the ocean.

Calcium—is a major ion in seawater. It is concentrated in deep waters because of the abundance of calcium carbonate shells on the ocean floor. Clams have calcium carbonate shells. But below 4,000 meters calcium carbonate dissolves because its solubility increases in cold water. Thus calcium carbonate is commonly found topping seamounts, like snow on a mountain, and forms a "snow line" called the CCD line (carbonate compensation depth).

Strontium—is also a major ion in seawater. Its concentration is affected by absorption into living organisms.

Aluminum family—have short residence times in seawater. Aluminum is the most abundant, but the others in this family are low in abundance. Coastal waters have higher concentrations of thallium than ocean waters. Scientists cannot explain this trend, but they have observed it in numerous areas.

Germanium—has been found in high concentrations around hydrothermal vents. Hydrothermal vents are hot water springs on the sea floor. They are located near rifts, or breaks, in the ocean floor and cause a change in the temperature and chemistry of nearby seawater.

Nitrogen and phosphorus—are micronutrients. In seawater, nitrogen occurs in nitrates or ammonia, and phosphorus is found in phosphates.

Arsenic—has some chemical similarities to phosphorus. It may play a similar role to phosphates in metabolic processes. It is also known to interfere with conventional phosphate analysis through the formation of a molybdenum blue color.

Polonium—is concentrated by marine organisms. Because polonium's isotopes are radioactive, it is a good natural tracer of feeding pathways for marine animals.

Selenium—is quickly removed from seawater. Although toxic to organisms at high concentrations, at lesser concentrations it can be beneficial.

Chlorine—is abundant in the ocean. Historically, the amount of chloride ion in seawater has been used to determine salinity levels. Now, it is added to water as a disinfecting agent. However, the large input of chlorine by industry and water treatment plants may alter marine food chains, affecting larval organisms and small fish. Chlorine is also very reactive with organic compounds forming potentially dangerous chlorinated hydrocarbons.

Cadmium—a heavy metal, is a pollutant in the ocean. It is taken up by shellfish and in excess may cause a debilitating disease in humans.

Copper—is a metal found in the blood of crabs that is analogous to the iron in hemoglobin. It is used as an anti-fouling agent in marine paints for boats. When found in high concentrations, it is toxic to marine animals.

Vanadium—is a trace element found in the blood of creatures such as sea squirts and sea cucumbers. The concentration of vanadium in these animals is 106 times greater than in seawater. Research shows that it probably acts as an anti-predator agent.

Cobalt—is a trace metal found in lobsters and mussels.

Nickel—is a metal found in mollusks such as clams.

Iodine—is found concentrated in seaweeds.

Magnesium—is the eighth most abundant element in the earth's crust and the third most abundant element in seawater.

Manganese—forms metal nodules on the ocean floor. They grow slowly (10 to 200 millimeters per one million years) around a nucleus such as a shark's tooth.

Mercury and lead—are enzyme poisons. In high concentrations, they can contaminate and kill fish and shellfish. These metals affect the neurological system of humans.

Compounds

Magnesium sulfate—is important acoustically. Its concentration in seawater affects the transmission of sound.

Carbonic acid and boric acid—act as buffers in the marine environment.

Silicon dioxide—is used by many organisms to make skeletal structures.

Calcium carbonate—is absorbed by many organisms and secreted as a protective shell or skeleton. Organisms that use calcium carbonate include shellfish, corals and some tropical algae.

Table 1. 44 Trace Elements Found in Seawater and Their Concentrations

Element	Concentration (PPB)*	Element	Concentration (PPB)
Carbon	200–3000	Cobalt	0.2–0.7
Lithium	170	Mercury	0.15–0.27
Rubidium	120	Silver	0.145
Barium	10–63	Chromium	0.13–0.25
Molybdenum	4.0–12.0	Tungsten	0.12
Selenium	4.0–6.0	Cadmium	0.11
Arsenic	3.0	Manganese	0.1–8.0
Uranium	3.0	Neon	0.1
Vanadium	2.0	Xenon	0.1
Nickel	2.0	Germanium	0.07
Iron	1.7–150	Thorium	0.05
Zinc	1.5–10	Scandium	0.04
Aluminum	1.0–10	Bismuth	0.02
Lead	0.6–1.5	Titanium	0.02
Copper	0.5–3.5	Gold	0.015–0.4
Antimony	0.5	Niobium	0.01–0.02
Cesium	0.5	Gallium	0.007–0.03
Cerium	0.4	Helium	0.005
Krypton	0.3	Beryllium	0.0005
Yttrium	0.3	Protactinium	2×10^{-6}
Tin	0.3	Radium	1×10^{-7}
Lanthanum	0.3	Radon	0.6×10^{-12}

*Note all values in parts per billion.

ACTIVITY 1

Elements and Compounds in the Ocean

Purpose

To review chemical symbols and teach elements and compounds found in the marine environment.

Procedure

For each marine example, you will need to write the chemical symbol or name for the element(s) listed.

1. North Carolina has several large estuaries (Figure 1). Estuaries are partially enclosed bodies of water where seawater is diluted by fresh water that drains from the land. These estuaries act as filtering systems to remove some chemical elements and compounds from land runoff. But many elements are not removed. Some of these are: Ag, Sb, Cr, Co, Rb, Cs, Se and Mo. Name these elements.

Figure 1 North Carolina estuaries

2. Anoxic, or oxygenless, environments in the ocean have many causes. One is pollution. In anoxic environments, the precipitation of the following metal sulfides occurs. Write the formula for each compound.

Copper (II) sulfide ____________

Zinc sulfide ____________

Mercuric sulfide ____________

Silver sulfide ____________

Cadmium (II) sulfide ____________

Bismuth (III) sulfide ____________

Lead (II) sulfide ____________

3. Phytoplankton are single-celled plants moved by ocean currents. They absorb and accumulate metals in concentrations 103 times greater than is present in seawater. These metals are listed below. Name them.

Al ____________	Nb ____________
Pb ____________	Cd ____________
As ____________	P ____________
Mn ____________	Ce ____________
Be ____________	Pu ____________
Ni ____________	Cr ____________
C ____________	Sc ____________
Co ____________	I ____________
Ag ____________	Zr ____________
Cu ____________	Fe ____________
Zn ____________	

4. Zooplankton are tiny animals moved by ocean currents. Copepods, small crustaceans, are common zooplankters. Food availability is greatest for zooplankton that live in surface waters because of light penetration. As a result they grow faster and molt more frequently than zooplankton at greater depths. This increase in frequency of molts decreases the time available for absorption of metals. Notice the variability in metal concentration in surface and deep water zooplankton (Table 2). Write the correct symbol for each metal.

Table 2.

Variations in the elemental composition of zooplankton from surface and deep (>99m) waters (Riley, 1975).

	Concentration (ug/g ash)*	
Element	Surface	Deep
Lead	117	183
Zinc	657	1,909
Iron	2,900	4,200
Cadmium	16	15
Cobalt	44	37
Copper	115	132
Nickel	100	150
Manganese	<70	88
Strontium	890	1,140
Calcium	103,900	105,000
Magnesium	45,700	46,200

*Ash is the soft solid residue left after combustion with the zooplankton.

5. One of the most extraordinary examples of anomalies in elemental composition is found in the hot brines of the Red Sea. The hot brines are located in a section of the Red Sea that evaporated millions of years ago leaving salt deposits on the ocean floor. Hot solutions, like those at hydrothermal vents, have worked their way through the ocean crust and have dissolved the salt, forming dense brines that pool in depressions on the ocean floor. Write the name for each element or ion found in the hot brine.

Cl ______	Na ______
Mg ______	Zn ______
Br ______	Ca ______
Sr ______	Cu ______
SO_4^{2} ______	K ______
Fe ______	Co ______
Si ______	Ni ______
Mn ______	Pb ______

6. From 1872 until 1876, an English expedition known as the Challenger Expedition gathered and analyzed the chemical composition of 77 samples of seawater taken at various depths of the ocean all over the world. In 1884, William Dittmar reported the expedition's results (Table 3). Dittmar's results were so precise that it took scientists almost 80 years to get more exact data. Write the name for each ion or compound measured.

Table 3.

Dittmar's values for the major constituents of seawater (values in grams per kilogram, ppt) (Sverdrup, 1946).

	Original Values	
Ion/Compound	ppt	%
Cl^{1-}	18.971	55.29
Br^{1-}	0.065	0.19
SO_4^{2}	2.639	7.69
CO_3^{2-}	0.071	0.21
HCO_3^{1-}	....*	....*
F^-	....*	....*
H_3BO_3	....*	....*
Mg^{2+}	1.278	3.72
Ca^{2+}	0.411	1.20
Sr^{2+}	0.411	1.20
K^{1+}	0.379	1.10
Na^{1+}	10.497	30.59
TOTAL	**34.311**	

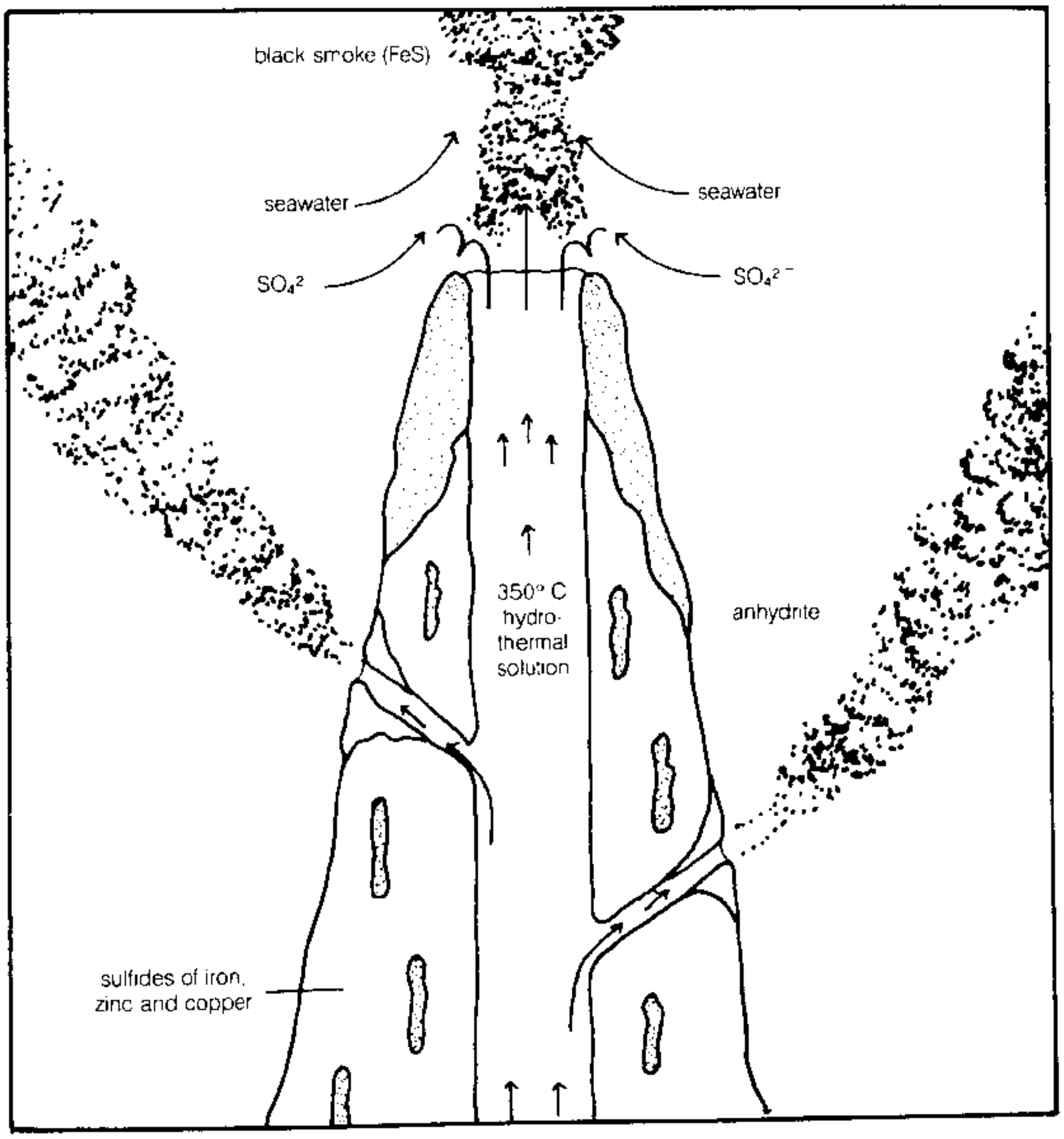
*(means that no measurement was made)

7. Manganese nodules have been found to be economically important sources of metals. Manganese nodules form slowly on the ocean floor. They contain large concentrations of manganese and iron, and smaller concentrations of nickel, copper and cobalt. Write the symbol for each of the metals found in the nodules.

8. Biological processes (photosynthesis, respiration, decomposition, etc.) involve the cycling of carbon, nitrogen and phosphorus. As these processes occur, carbon, nitrogen and phosphorus are usually found as CO_2, NO_3^-, NH_3, NH_4^+, PO_4^{3} in the marine environment. Name these compounds and ions.

9. Studies have found active hydrothermal vents with water temperatures exceeding 350°C. These vents are called "black smokers" because the emissions contain sulfides that color them black (Figure 2). The sulfide mineralization occurs when very hot seawater circulates in the vents and leaches heavy metals and sulfur from rocks below the sea floor. After coming in contact with cooler seawater, the metals and sulfur precipitate, producing deposits containing ferric sulfide, cuprous sulfide, zinc sulfide, silver sulfate and calcium sulfate. Write the formulas for these compounds.

Figure 2 Black smoker



ACTIVITY 2

Marine Chemical Reactions

Purpose

To practice balancing chemical equations that describe marine reactions.

Procedure

Balance all equations in the problems below.

1. The formation of organic compounds in the ocean is an important process. This process uses carbon, nitrogen and phosphorus in a specific ratio called the Redfield ratio. Determine the ratio of atoms of C:N:P.

$CO_2 + NO_3^{1-} + PO_4^{3-} + H_2O \rightarrow C_{106}N_{16}PH_{108}O_{46} + O_2$

2. Scientists have determined ways to remove economically important metals from seawater. At Kure Beach, N.C., the first plant was built to extract bromine from seawater. (This plant is no longer in operation.) The reaction below occurs after the seawater is pumped into a plant. Chlorine is used to oxidize bromide into bromine gas.

$Cl_2 + NaBr \rightarrow Br_2\uparrow + NaCl$

3. The earliest recovery of bromine from seawater took place when the advent of leaded gasoline increased the demand for bromine. The following equation is another step in the process of extracting bromine from seawater. Bromine liberated in the reaction above diffuses into the surrounding air. The bromine-laden air passes into towers where it is absorbed by sodium carbonate. The products of this reaction are treated with sulfuric acid to liberate bromine.

$Br_2 + Na_2CO_3 \rightarrow NaBr + NaBrO_3 + CO_2$

4. This is the equation for photosynthesis in plants.

$CO_2 + H_2O \xrightarrow{light} C_6H_{12}O_6 + O_2$

5. The equation below is blue-green algae photosynthesis in bacteria and cyanobacteria. This process uses hydrogen sulfide instead of water as the hydrogen source.

$CO_2 + H_2S \xrightarrow{light} C_6H_{12}O_6 + S + H_2O$

6. The following equation is for chemosynthesis in bacteria. This process is similar to photosynthesis but uses hydrogen sulfide as an energy source instead of light. The discovery of hydrothermal vents gave this process ecological importance.

$CO_2 + O_2 + H_2S \rightarrow C_6H_{12}O_6 + S + H_2O$

7. Bacteria are important to marine sediments. In sediment communities oxygen is used rapidly. Organisms living there are adapted to low oxygen levels, and they break down organic compounds without using oxygen. The next two equations show ways that bacteria break down organic compounds without using oxygen.

$C_6H_{12}O_6 + H_2SO_4 \rightarrow H_2S + H_2O + CO_2$

$CH_2O + HNO_3 \rightarrow N_2 + H_2O + CO_2$

NOTE: CH_2O is the empirical formula for carbohydrates. It is the simplest form and makes balancing some equations easier.

8. The next five equations describe the weathering (breakdown) of rocks containing silicon. This weathering process takes place primarily on land through the erosion of rocks by rainfall. Silicon becomes dissolved in the water and enters rivers, then estuaries, and finally the ocean. Knowledge of these five equations is the result of silicon studies performed in estuaries.

SiO_2 (quartz) $+ H_2O \rightarrow H_4SiO_4$

$NaAlSi_3O_8$ (albite) $+ H_2CO_3 + H_2O \rightarrow Na^+ + HCO_3^- + H_4SiO_4 + Al_2Si_2O_5(OH)_4$ (kaolinite)

$KAlSi_3O_8$ (orthoclase) $+ H_2CO_3 + H_2O \rightarrow K^+ + HCO_3^- + H_4SiO_4 + KAl_3Si_3O_{10}(OH)_2$ (mica)

$KMg_3AlSi_3O_{10}(OH)_2$ (biotite) $+ H_2CO_3 + H_2O \rightarrow K^+ + Mg^{2+} + HCO_3^- + H_4SiO_4 + Al_2Si_2O_5(OH)_4$ (kaolinite)

$Al_2Si_2O_5(OH)_4$ (kaolinite) $+ H_2O \rightarrow H_4SiO_4 + Al_2O_3 \cdot H_2O$ (gibbsite)

9. The chemical cycles of almost every major element found in the earth's crust involves carbon dioxide. The following equations are reactions that are part of the cycling of calcium, magnesium, iron and iron silicates through the marine environment.

a) $CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$

b) $MgCO_3 + SiO_2 \rightarrow MgSiO_3 + CO_2$

c) $Fe_2O_3 + SiO_2 + CH_2O \rightarrow FeSiO_3 + H_2O + CO_2$

d) $Fe_2O_3 + CH_2O + CaSO_4 \rightarrow CaCO_3 + FeS + CO_2 + H_2O$

10. The next two reactions are part of element cycling but involve oxygen in the reaction instead of carbon dioxide.

a) $Fe_2S_3 + H_2O + O_2 \rightarrow Fe_2O_3 + H_2SO_4$

b) $FeSiO_3 + O_2 \rightarrow Fe_2O_3 + SiO_2$

ACTIVITY 3

Identification of Halide Ions

Purpose

To observe four chemical reactions between solutions of halide compounds and silver nitrate, and to use the results of those reactions to determine which halide ions are present in "unknown" solutions.

Background

The ocean is a practical example of elements existing as ions in water. Ions of elements in Group 1A, particularly sodium and potassium are found in seawater. All halogens, except for astatine, exist as ions in the ocean. The hot brines of the Red Sea contain chloride, bromide, sodium and potassium ions. Nitrogen is a micronutrient in the ocean and occurs in nitrate ions.

When salts dissolve in water they break into positive and negative ions. Negatively charged ions (other than polyatomic ions) have an "ide" ending on their names. Negative ions in the halogen group are collectively called halide ions. Chemical reactions can be used to determine the identity of ions in a solution.

Equipment/Materials

0.10 M sodium chloride
0.10 M sodium fluoride
0.10 M sodium iodide
0.10 M sodium bromide
0.10 M silver nitrate
notebook paper
glass plate
6 unknown halide ion solutions

CAUTION: Do not begin this lab until your teacher has given you safety instructions and cautions for each chemical. Wear eye and clothing protection. Silver nitrate temporarily stains human skin brown and decomposes when exposed to light.

Procedure

Section 1 / Reactions of Halide Compounds with Silver Nitrate

Place a well-cleaned glass plate on a sheet of notebook paper. On the notebook paper beside each of the four corners of the glass plate, write one of the halide compound formulas.

Put two drops of the appropriate halide solution on each labeled corner of the glass plate. Then add two drops of silver nitrate solution to each of the four solutions already on the plate.

Write your observations of the four reactions in a data table. This will be Table 1. Be sure to give it a title.

Section 2 / Identifying Halide Ions in Unknown Solutions

Now you are ready to determine which halide ion is present in unknown solutions. Thoroughly clean your glass plate. Add two drops of silver nitrate to two drops of unknown solution #1 on the plate. Write your observations of this reaction in a new data table. This will be Table 2.

Use your observations from Table 1 to determine which halide ion is present in unknown solution #1. You have four possibilities: chloride, fluoride, iodide or bromide. There will be only one halide ion in each unknown solution.

Once you have determined the halide ion present in unknown #1, record the answer (by using the symbol of the ion and a negative charge) in Table 2 beside your observation. (NOTE: Halide ions are not diatomic. Do not use a subscript beside the ion symbol.)

Repeat the procedure above until you have identified the halide ions in all six unknown solutions. Record the observation and identification data for all unknowns in Table 2.

Questions

1. Write balanced equations for the chemical changes (reactions) that occurred in section 1.

2. Write the names and formulas for the three water-insoluble silver compounds (precipitates) produced in section 1.

3. Write the name and formula for the one water-soluble silver compound produced in section 1.

4. Is silver nitrate soluble in water?

5. Is sodium nitrate soluble in water?

6. Sodium fluoride, sodium iodide, solium chloride and sodium bromide are all (soluble, insoluble) in water.

7. All compounds containing (silver, nitrate) are water soluble.

8. All compounds containing (sodium, silver) are water soluble.

9. All halide ions have a (negative, positive) charge.

10. What are the colors of the following compounds?

(a) silver chloride
(b) silver bromide
(c) silver iodide

11. Mention two sources of error in this experiment and ways to correct them.

12. I have a bottle of acid that has no label. It is hydrochloric or hydrofluoric acid. These two acids are water solutions. I added a few drops of silver nitrate to a small portion of the acid in question. A white precipitate formed. Now I know the identity of the acid. Is the acid hydrofluoric or hydrochloric?

13. How did I know the identity of the acid in the questions above? HINT: Acids break into ions when they are in water solution just as salts do.

14. What is the most abundant halide ion found in the ocean?

15. What are the two most abundant ions in the ocean?

ACTIVITY 4

Magnesium and its Compounds

Purpose

To produce and observe some compounds of magnesium.

Background

Magnesium (along with bromine, sodium chloride, natural gas, petroleum, sulfur and manganese nodules) is one of the substances that is currently being extracted from seawater. Magnesium is the third most abundant element in seawater and the eighth most abundant in the earth's crust. Zooplankton take up magnesium, particularly at greater depths. Magnesium is found in the hot brines of the Red Sea. The presence of magnesium sulfate affects the transmission of sound in the ocean.

Equipment/Materials

magnesium ribbon
crucible tongs
watch glass
phenolphthalein
test tube
Bunsen burner
hydrochloric acid (1.0 M)
Bunsen burner lighter
sodium hydroxide solution (1.0 M)
test tube rack
magnesium sulfate solution (sat'd)
test tube holder

CAUTION: Do not begin this lab until your teacher has given you lab safety instructions and cautions for each chemical. Wear eye and clothing protection.

Procedure

Answer the questions and follow the instructions below.

1. Describe two physical properties of a piece of magnesium.

Hold a 3-cm strip of magnesium with crucible tongs and ignite it with a Bunsen burner. (CAUTION: Do not look directly at magnesium while it is burning because of the emission of ultraviolet light.) Hold the magnesium above a clean watch glass. When the strip stops flaming, drop the burned piece on the watch glass. Keep this burned magnesium for later use.

2. Describe the state and color of the product of this reaction.

3. Write the balanced equation for the reaction above.

Moisten the magnesium oxide on the watch glass with a few drops of distilled water and add two drops of phenolphthalein.

4. What do you observe?

5. Is this solution acidic or basic?

6. Write the balanced equation for the reaction that has occurred. (Do not include phenolphthalein in your equation.)

Put 5 ml of dilute hydrochloric acid in a test tube and add a 3-cm length of magnesium ribbon. (Keep the test tube and contents for later use.)

7. Describe the reaction between magnesium and hydrochloric acid.

8. Write the balanced equation for the reaction in number 7.

Heat the test tube and contents (saved from above) gently with a very low flame. Move the test tube in and out of the flame slowly. Continue to heat gently until all the liquid evaporates.

9. Describe the residue left after the liquid evaporates.

10. Write the name and formula of the residue.

Place 3 cm of magnesium ribbon in a clean test tube with enough distilled water to cover the magnesium. Heat to boiling (use a test tube holder). Remove the test tube from the flame and observe the surface of the magnesium. CAUTION: Be careful not to burn yourself.

11. Was a gas formed in this reaction?

12. Add two drops of phenolphthalein to the test tube. What do you observe?

13. Is the solution acidic or basic?

14. Write a balanced equation for the reaction between magnesium and water. Do not include phenolphthalein in your equation.

In a test tube, combine 5 ml of magnesium sulfate and 5 ml of 1.0 M sodium hydroxide.

15. Describe what you observed after the two solutions were combined.

16. Write a balanced equation for this reaction. Be sure to show which product is insoluble in water (i.e. forms a precipitate).

ACTIVITY 5

Magnesium from the Sea

Purpose

To separate a magnesium compound from seawater and write an appropriate balanced chemical equation for the reaction.

Background

Magnesium (along with bromine, sodium chloride, natural gas, petroleum, sulfur and manganese nodules) is one of the substances that is currently being extracted from seawater. Magnesium is the third most abundant element in seawater and the eighth most abundant in the earth's crust. Zooplankton take up magnesium, particularly at greater depths. Magnesium is found in the hot brines of the Red Sea. The presence of magnesium sulfate affects the transmission of sound in the ocean.

Equipment

250-ml beaker
100-ml graduated cylinder
1.0 M NaOH (41 g/l)
5.0 g $MgSO_4$
distilled water
stirring rod
balance
goggles
apron
centrifuge
centrifuge tubes

Caution: Do not begin this lab until your teacher has given you lab safety instructions and cautions for each chemical. Wear eye and clothing protection.

Procedure

Mass out 5.0 grams of magnesium sulfate, $MgSO_4$. Place 100 ml of distilled water in a 250-ml beaker. Dissolve the 5.0 grams of $MgSO_4$ in the water, stirring as needed. (Some of the $MgSO_4$ may not dissolve.) This solution will represent seawater. Answer question 1.

Add 30 ml of 1M sodium hydroxide, NaOH, to the beaker of seawater. CAUTION: Sodium hydroxide is corrosive. Avoid skin contact. Rinse spills with plenty of water. Answer question 2.

Carefully follow the instructions provided by your instructor for using a centrifuge. Should a centrifuge tube break, it can cause serious injury.

The centrifuge must be balanced when you are using it. Add 8 ml of the solution just mixed to a centrifuge tube. Label your tube for easy identification. Place it in the centrifuge across from another student's tube or another tube filled with 8 ml of water for balance.

Centrifuge the tube for at least two minutes. Allow the centrifuge to stop slowly. Do not stop the spinning head with your hand. Remove your tube and answer questions 3 to 6.

Questions

1. Describe the appearance of the seawater you prepared.

2. Describe the seawater after the addition of the sodium hydroxide.

3. What did you observe after the solution was in the centrifuge?

4. Write a balanced equation for the reaction of magnesium sulfate and sodium hydroxide.

5. The magnesium was concentrated from the seawater by a technique known as precipitation. What is the name of the precipitate?

6. How do you think the magnesium could be separated from the hydroxide to yield pure magnesium metal?

ACTIVITY 6

Biogeochemical Zonation

Purpose

To illustrate the oxidizing agents at various depths in the ocean.

Background

Oxidation-reduction reactions involve the loss or gain of electrons from one atom, compound or ion to another. Better known as redox reactions, they include many naturally occurring reactions such as synthesis and decomposition that are important in maintaining life.

In photosynthesis, plants store chemical energy converted from solar energy. Other organisms eat plants to get this chemical energy. Chemically speaking, plants store energy in the bonds of the organic molecules they produce. This energy is released when the bonds are broken. This energy release, called cellular respiration, involves (among other reactions) the oxidation of carbon in organic molecules by an oxidizing agent.

In the mid-1970s, studies on respiration in marine sediments revealed distinct layers of microorganism communities. Each community uses a different oxidizing agent according to the efficiency with which it breaks bonds and its availability at different depths in the sediment.

This sequence of community layers is called biogeochemical zonation. "Bio" indicates the presence of living organisms that make the reaction go. The act of respiration involves chemical reactions; hence, the "chemical" part of the word. "Geo" refers to some mineral formation that occurs as a byproduct of these reactions.

In the top sediment layer, O_2 is the primary oxidizing agent. The use of different oxidizing agents at different depths results in different products being formed in each zone. This affects the chemistry of neighboring layers and the sediments as a whole.

On a global scale, oceans cover about 75 percent of the earth's surface, and sediments line a large percentage of the oceans' bottom. The chemistry of sediments has a large influence on the fate of important elements and related processes.

Materials

5 transparencies
1 large candy bar
1 small piece of candy
1 stick of chewing gum
1 small rock
tape

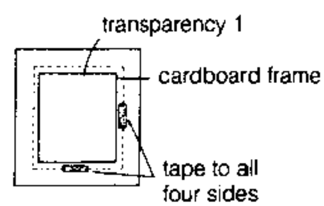
Procedure One

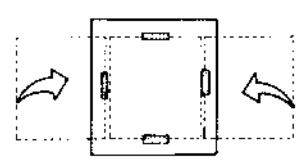
There are five sheets in this package that are intended to be xeroxed onto overhead transparency sheets. Transparency 1 is the base transparency. Tape it to a cardboard frame on all four sides.

Tape each of the remaining transparencies, 2 through 5, to a different side of the frame. Put them in a clockwise order.

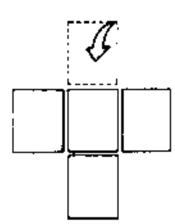
Use only one overlay at a time. After the base transparency is introduced, transparency 2 may be folded onto it. When finished with 2, return it to its original position and fold over 3. Continue this procedure.

Transparencies on cardboard frame





Tape remaining transparencies to frame in clockwise order.



Fold one transparency at a time over base transparency.

Transparency 1

This transparency provides a sectional view of the earth's surface that shows three major regions: atmosphere, water and sediment. These three regions have different properties (i.e. density, chemical composition, opacity). Think about how these differences will affect the movement of different sized objects, living and nonliving. How are animals adapted to move through each region? How would the properties of each region affect a steel ball's vertical movement? How would dissolved oxygen differ in each region?

Transparency 2

This transparency represents a schematic grouping of the major actors in photosynthesis and decomposition.

Microorganisms are very small (several microns in length) organisms that may found on land or in water. There are many kinds. Some make their own food; others decompose dead things.

Phytoplankton is derived from "phyto" meaning plant. Plankton means wanderer. They are microscopic plants that float or are suspended in the water. Phytoplankton are found near the water's surface because they need sunlight for photosynthesis. They make their own food.

Zooplankton is derived from "zoo" meaning animal. They are microscopic animals that float or are suspended in the water. Zooplankton can exist in deeper water because they do not photosynthesize. They live where they can find food—other zooplankton and sometimes dead organisms. They also eat phytoplankton.

Larger organisms, such as fish, eat phytoplankton, zooplankton or each other. Fish inhabit a greater range because they can move to find food.

Transparency 3

This transparency illustrates a very simple ocean food chain. Zooplankton may consume phytoplankton, microorganisms or other zooplankton. Fish may consume phytoplankton, zooplankton or other fish. Marine microorganisms may consume one another, other dead organisms or small dissolved molecules. Microorganisms are a vital part of the decay process. They reduce organic matter back to nitrates and phosphates.

Transparency 4

Waste products and dead organisms drift through the water to the sediment. As they sink or collect in the sediment, they are consumed by other organisms or decomposed by microorganisms. The matter that is not eaten is buried in the sediments.

Transparency 5

This transparency illustrates various redox reactions taking place in the water column and sediments. These reactions represent forms of respiration taking place. The equations show generic reactants and products. Many intermediate reactions are not shown. It is not unusual for reactions to stop at some midpoint rather than produce the completion products shown. This could be due to slow reaction, presence of inhibitors or competing reactions for same reactants.

If oxygen is unavailable and NO_3^- is available in the nitrate reduction and oxidation zones, animals, plants and organisms that use NO_3^- will dominate respiration. If NO_3^- and SO_4^{2-} are both present, NO_3^- will still dominate because it is thermodynamically more efficient. The transport of elements, ions and compounds is important in making reactions happen in different zones.

Notice that the reactions shown are not balanced and the number of organic molecules decreases with depth. The organic molecule quantities tend to decrease with depth because of continuous decomposition.

Procedure Two

The following is a simple student activity. It will illustrate how organisms use the oxidizing agents available to them at the level of the ocean in which they live.

Give the first student in a row in the classrom a tray on which you have placed a large candy bar, a smaller piece of candy, a stick of chewing gum and a small rock.

Tell the first student to take any item on the tray. Usually he or she will take the large candy bar.

The next student in the row is told to take any of the three items left on the tray. This student will likely take the smaller piece of candy. The third student will take the stick of gum, leaving the rock for the fourth student.

Students clearly see that organisms use (take) what is available to them. If several choices are available, organisms take the most desirable. Thus if several oxidizing agents are available in a sediment region, the most thermodynamically desirable one will be used.

Questions

Transparency 1

1. Name at least three forces that transport objects in each of three regions:

   (a) atmosphere
   (b) water
   (c) sediments

2. What force works in all three regions: atmosphere, water and sediments?

3. If the element silicon comes primarily from rocks found on land, how does it end up dissolved in the ocean?

4. Trace the pathway of a silicon atom as it starts in the sands of the Sahara Desert and ends up dissolved in the eastern Atlantic Ocean.

Transparency 2

The ocean, on average, is 3,800 meters deep; the photosynthetic zone is 100 to 200 meters deep.

1. Why do you think phytoplankton live in the photosynthetic layer of the ocean?

2. Why do you think zooplankton live in the photosynthetic layer of the ocean?

Transparency 3

Living organisms affect the fate of certain elements and compounds. Phytoplankton get their carbon from CO_2 and convert it to food (organic molecules) through photosynthesis.

1. Where do zooplankton get their carbon? How do fish satisfy their carbon needs?

2. When a fish eats zooplankton, what happens to the elements and compounds of the zooplankton?

Transparency 4

Elements and compounds are distributed throughout the ocean by living organisms that eat or filter materials containing compounds and elements. Upon death and decay of the organism, these chemicals are redistributed.

1. In what form does carbon exist in living organisms?

2. How does a carbon atom go from a CO_2 gas molecule in the atmosphere to:

   (a) be dissolved in the surface layer of the ocean?
   (b) a solid state at the surface layer of the ocean?
   (c) a solid at the bottom of the ocean?

Transparency 5

The redox reactions represent respiration modes of decomposition.

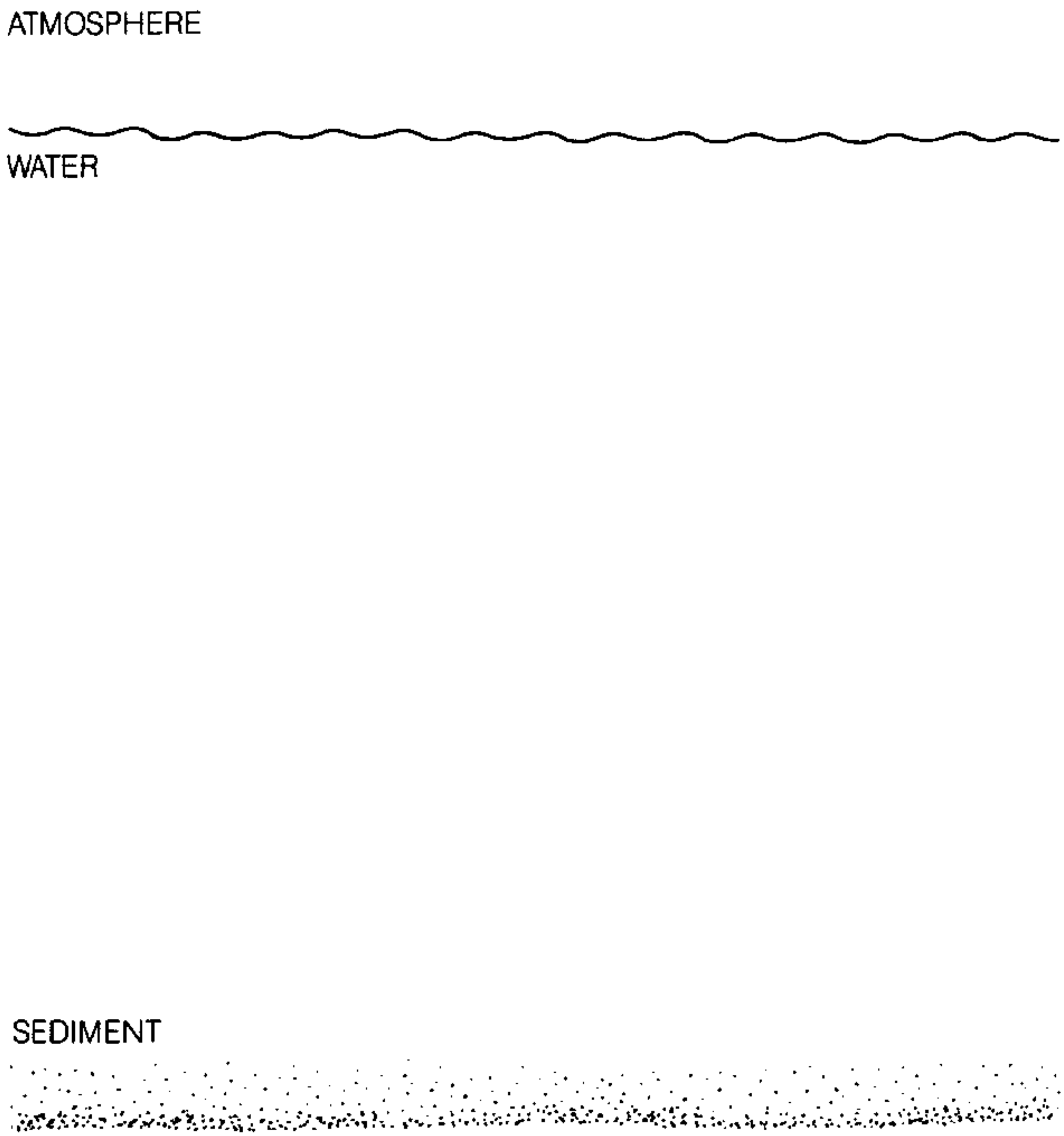
1. In photosynthesis, organic molecules are made. Notice that deeper in the ocean there is less organic matter. How could you explain such a decrease?

2. Just because O_2 is used as an oxidizing agent at some depth, doesn't mean that other oxidizing agents are not present. They may even be used, but their use is not significant. What might take place if all the O_2 in an area were used up?

3. What would happen to dead matter if all the oxidizing agents were removed or used up? (This takes place when lots of organic matter is drained into a lake or pond. Organisms eat the organic matter, using up all the oxygen. Fish die because they need oxygen, resulting in more organic matter to eat and more consumption of oxidizing agents.)

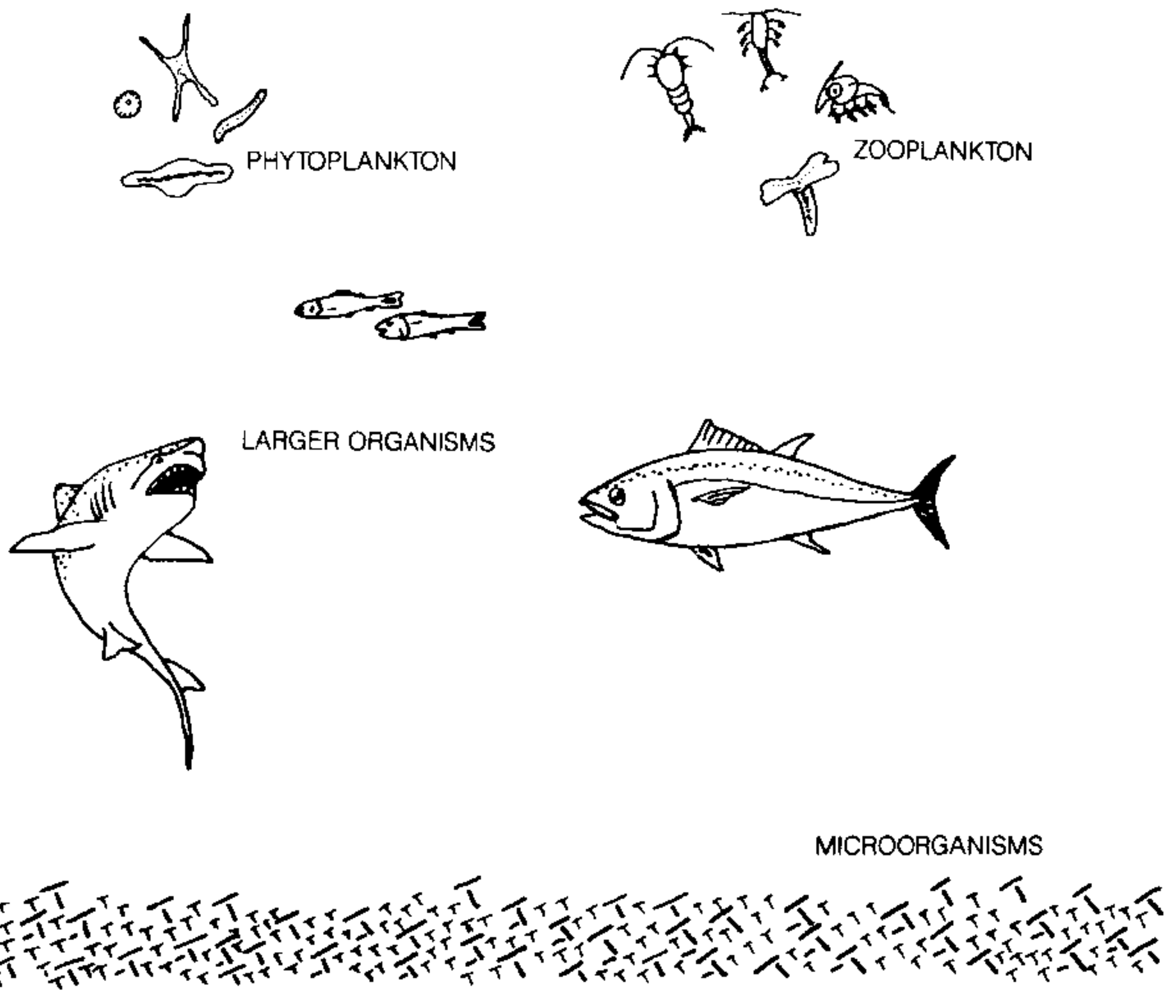
Transparency 1

Somewhere in the ocean...



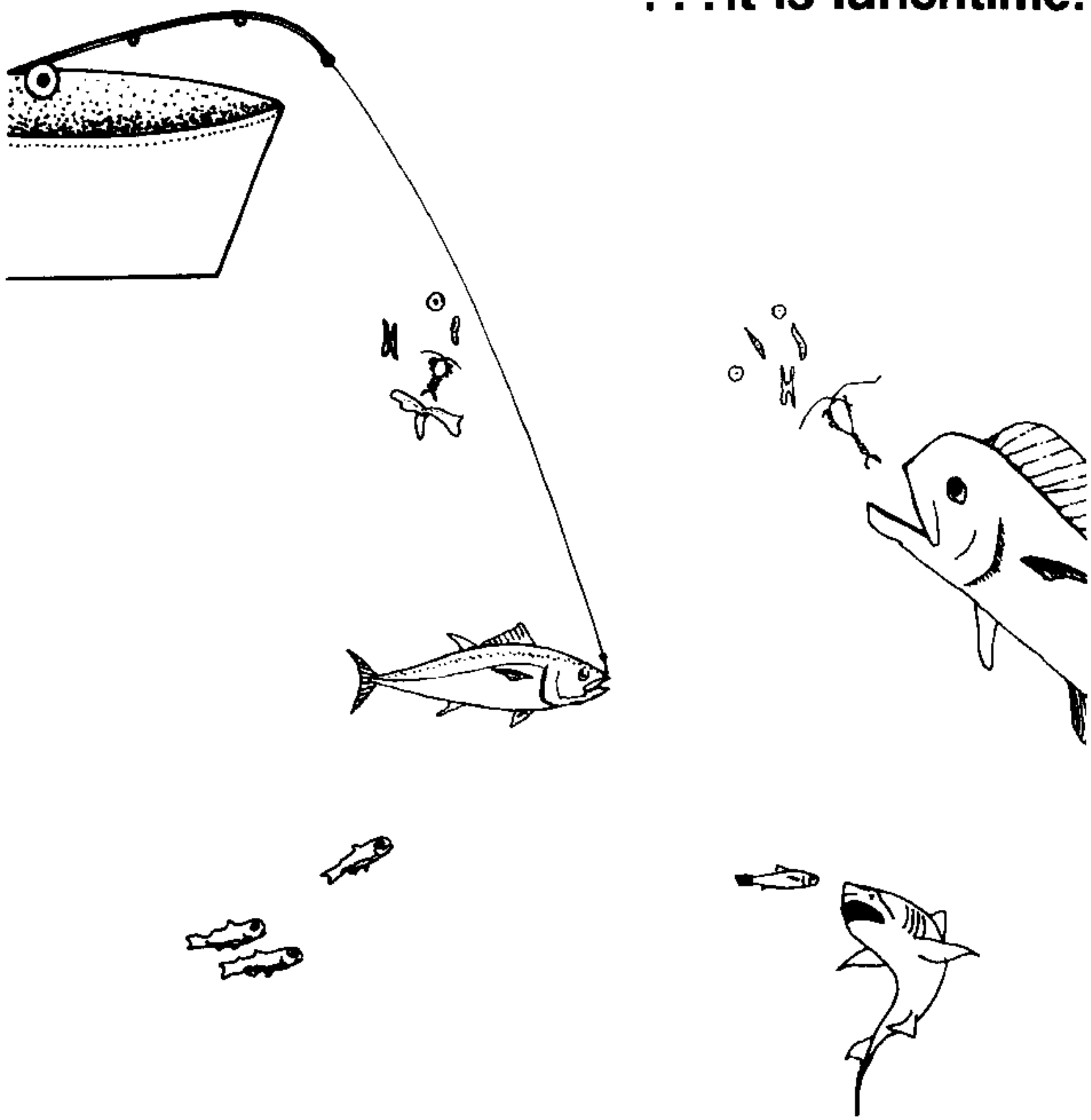
Transparency 2

. . . live all kinds of organisms . . .



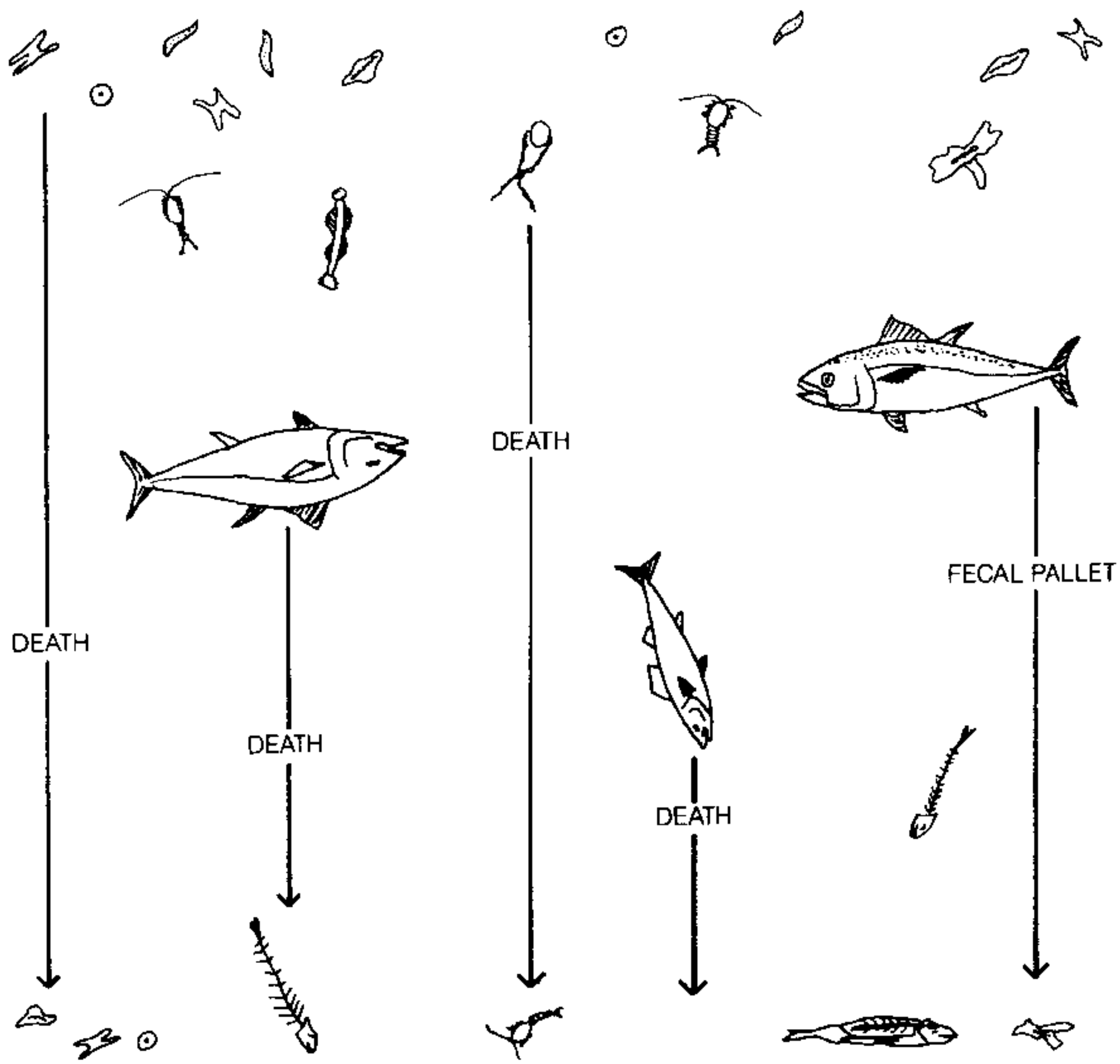
Transparency 3

. . . it is lunchtime!



Transparency 4

there's death and decay. . .



Transparency 5

chemistry happens.

PHOTOSYNTHESIS

$CO_2 + H_2O \xrightarrow[\text{FROM REACTION}]{\text{ENERGY ADDED}} 7C_6H_{12}O_6 + O_2$

RESPIRATION

OXIDATION $7C_6H_{12}O_6 + O \xrightarrow[\text{FROM REACTION}]{\text{ENERGY ADDED}} CO_2 + H_2O$

OXIDATION $6C_6H_{12}O_6 + O \xrightarrow[\text{FROM REACTION}]{\text{ENERGY ADDED}} CO_2 + H_2O$

OXIDATION $5C_6H_{12}O_6 + O \xrightarrow[\text{FROM REACTION}]{\text{ENERGY ADDED}} CO_2 + H_2O$

OXIDATION $4C_6H_{12}O_6 + O \xrightarrow[\text{FROM REACTION}]{\text{ENERGY ADDED}} CO_2 + H_2O$

NITRATE-REDUCTION $3C_6H_{12}O_6 + NO_3^- \longrightarrow CO_2 + H_2O + N_2$

IRON REDUCTION $2C_6H_{12}O_6 + FeO(OH) \longrightarrow CO_2 + H_2O + Fe^{+2}$

SULFATE REDUCTION $C_6H_{12}O_6 + SO_4^{=} \longrightarrow CO_2 + H_2O + S^{-2}$

Competency Factors/References

Competency Levels

Chemistry-Academic—

5.1 know how to write and use chemical formulas and equations;

6.1 know the concept of oxidation-reduction.

Chemistry-Applied/Technical—(see above).

Physical Science-Academic—

3.4 know that chemical reactions occur when two or more elements interact and form one or more new substances; and

3.5 know the processes of oxidation and reduction.

Competency Measures

Chemistry-Academic—

5.1.1 relate chemical names and formulas;

5.1.2 write the reactants and products of a chemical reaction in the form of an equation;

5.1.3 balance a chemical equation by inspection;

6.1.1 write the oxidation numbers for each element in a compound; and

6.1.2 identify and write the oxidation-reduction half reactions in a redox equation.

Chemistry-Applied/Technical—

5.1.1 relate chemical names and formulas;

5.1.2 write simple chemical reactions;

5.1.3 balance a simple chemical equation by inspection;

6.1.1 write the oxidation numbers for each element in a compound; and

6.1.2 identify oxidation-reduction equations.

Physical Science-Academic—

3.4.1 write chemical equations from word equations;

3.4.2 demonstrate knowledge of the law of conservation of mass by writing balanced equations; and

3.5.2 define chemical oxidation and reduction and illustrate the process using simple equations.

Physical Science-Applied/Technical—

3.4.4 write simple chemical equations.

References

Coker, R.E. 1949. *This Great and Wide Sea.* UNC Press, Chapel Hill. Chapters 6 and 7.

Davenport, J. 1982. *Environmental Simulation Experiments on Marine and Estuarine Animals: Advances in Marine Biology.* (J.H.S.Blaxter, ed.). Academic Press. 19:133–256.

Edmond, John. 1984. "The Geochemistry of Ridge Crest Hot Springs," *Oceanus.* 27:15–19.

Goldberg, Edward D. *The Sea.* John Wiley and Sons. New York. Vol. 5, Marine Chemistry, Parts III, IV, V.

Goldman, Joel C. 1979. "Chlorine in the Marine Environment," *Oceanus.* 22:36–43.

Heath, Ross. 1978. "Deep Sea Nodules," *Oceanus.* 21:60–68.

_______________, 1982. "Manganese Nodules: Unanswered Questions," *Oceanus.* 25:37–48.

Jannash, Holger W. 1984. "The Nutritional Basis for Life at Deep Sea Vents," *Oceanus.* 27:73–78.

MacIntyre. 1970. "Why is the Sea Salty?" *Scientific American.* Nov., 1970.

Miller and DiStefano. "Iron (II) Oxide," *Journal Of Chemical Education.* June, 1987.

Officer, Charles B. and John H. Ryther. 1981. "Swordfish and Mercury: A Case History," *Oceanus.* 24:34–41.

Riley and Chester. 1978. *Chemical Oceanography.* Academic Press. Vol. 7.

_______________ and Skirrow. 1975 and 1978. *Chemical Oceanography.* Academic Press. Vol. 1, 2, 4.

Spitzbergen, Judith M. 1980. *Seacoast Life.* UNC Press, Chapel Hill. p. 8.

Sverdrup, Johnson and Fleming. 1946. *The Oceans.* Prentice-Hall, Inc. p. 166.

Thurman, Harold V. 1983. *Essentials of Oceanography.* Merrill Publishing Company, Ohio.

Density Dynamics and Estuaries

Teacher Introduction

Estuaries are areas where river and ocean waters meet. In North Carolina, this occurs in sounds. In Pamlico Sound, ocean water moves through inlets to mix with waters from the Neuse and Pamlico rivers. The mouth of the Cape Fear River is also an estuary. Estuaries are biologically rich because available nutrients, marine grasses and fringing marshes provide food and shelter.

Chemically, the mixing of fresh and salt water is interesting. Salt water is denser than fresh water, and a density gradient occurs when the two waters meet. Vertically mixed and slightly stratified patterns of mixing are found in North Carolina's estuaries. Estuaries provide students with a concrete example of the importance of density and density gradients.

These activities are designed to give students practical experience with density and its calculation. Activities 1 through 3 are demonstrations that can be used to introduce density and specific gravity. An introduction to estuaries begins Activity 4. In this activity, students calculate density and compare the calculated values to known estuarine conditions. Activity 4 continues with biological examples of the effects of density changes on organisms. Review and test questions conclude this section.

Notes to the Teacher

1. To begin your discussion of density, students may find a demonstration helpful. See Activities 1 through 3.

2. Students should do a few density problems before beginning these activities.

3. A discussion of how the addition of salt to water increases density would also be helpful before students try these activities.

4. Students should use the correct number of significant figures in their calculations. Otherwise small variations in density may be missed.

5. The four estuarine density patterns presented are to be used as a comparison of density gradient possibilities. Students should not be expected to know these patterns, but they should be able to use them.

6. Figures 1 and 2 in Activity 4 can be used as overheads to help students with Activity 4 problems.

ACTIVITY 1

Salinity Stratification

Purpose

To demonstrate the layering effect of solutions that have different densities.

Equipment/Materials

3 100-ml graduated cylinders
sodium chloride
balance
stirring rod
food coloring
2 plastic squeeze bottles
four solutions:

Solution A (density = 1.148 g/ml): Combine 20 g NaCl with enough water to make 100 ml of solution.

Solution B (density = 1.071 g/ml): Dilute 50 ml of solution A to 100 ml.

Solution C (density = 1.034 g/ml): Dilute 50 ml of solution B to 100 ml.

Solution D (density = 1.000 g/ml): Use 30 ml of hot tap water.

Procedure

Use food coloring to make solution A yellow, solution B green, solution C red and solution D blue. Use three drops of coloring in each solution.

Put solution B in a plastic bottle. Gently squeeze approximately 30 ml of solution B into the graduated cylinder that already contains solution A. (Note: you may want to discard 20 ml of solution A before adding B so that the final layers have nearly equal volumes.) Let solution B trickle down the side of the graduated cylinder as you add it to solution A to minimize mixing of the two solutions.

In a similar manner, add approximately 30 ml of solution C on top of solution B. Finally, add solution D on top of solution C.

Questions

1. Why did the layers remain separated or stratified in the graduated cylinder?

2. What would have happened if you had changed the order of addition of the three solutions? Make a prediction and test it.

3. What will happen if the combination of solutions is stirred?

4. Estuaries are semi-enclosed coastal bodies of water in which seawater is diluted by fresh water from rivers. An estuary may contain water with different densities. Estuaries are named based on the extent of mixing of fresh and salt water. Name two ways in which nature could aid in the mixing of water in estuaries.

ACTIVITY 2

Salinity Predictions

Purpose

To predict the density of water in relation to salinity and to understand the layering in some estuaries and in the ocean.

Materials

small aquarium
food coloring (blue)
stiff piece of cardboard
box of salt
water

Procedure

Mix a gallon of tap water with one cup of salt. Have another gallon of water with no salt. Add enough food coloring to the saltless water to make it relatively dark (about 10 drops).

Place the cardboard in the middle of the aquarium. Make sure it fits tightly against the sides. At the same time slowly add the salt water to one side and the dyed water to the other. Let any water currents settle before lifting the cardboard. Lift the cardboard 5 to 7 cm, and observe the movement of the colored (non-salty) water near the bottom of the cardboard.

Lift the cardboard another 5 cm or so. Observe. Continue to lift in stages and enjoy what is happening. Once the cardboard is completely removed, notice the layering.

This can also be done with a gallon of cold water and a gallon of hot water (colored) to illustrate a thermocline in the ocean.

Questions

1. Which water is denser, the salt water or the fresh water?

2. Discuss what happened with the two volumes of water in the aquarium.

3. In estuaries, where would you expect to find the river water and where would you expect to find the ocean water?

4. If you were an oceanographer and took ocean samples from the surface to the bottom, where would you find the saltiest water?

ACTIVITY 3

Density and Buoyancy of the Ocean

Purpose

To demonstrate the difference between the densities of liquids.

Equipment/Materials

double-pan balance
2 1-gallon glass containers
tap water
1 can of diet soda*
2 cans of regular soda*
salt water (20 g NaCl/100 ml water)

*All sodas should be the same brand.

Procedure

Place one diet soda and one regular soda in two glass containers filled with tap water. The diet soda will float and the regular soda will sink.

Float a can of regular soda in salt water and another can of regular soda in fresh water. Observe what occurs.

Balance a double-pan balance. Put the regular soda on one pan and the diet soda on the other.

Lead students in a discussion of the different water densities in estuaries and the differences in the densities and buoyancies of ocean and fresh water.

Questions

1. How do you account for the difference in the densities of diet and regular soda?

2. In which environment does a soda float higher, salt water or fresh water?

ACTIVITY 4

Estuarine Stratification and Animal Adaptations

Purpose

To illustrate density through marine examples.

Background

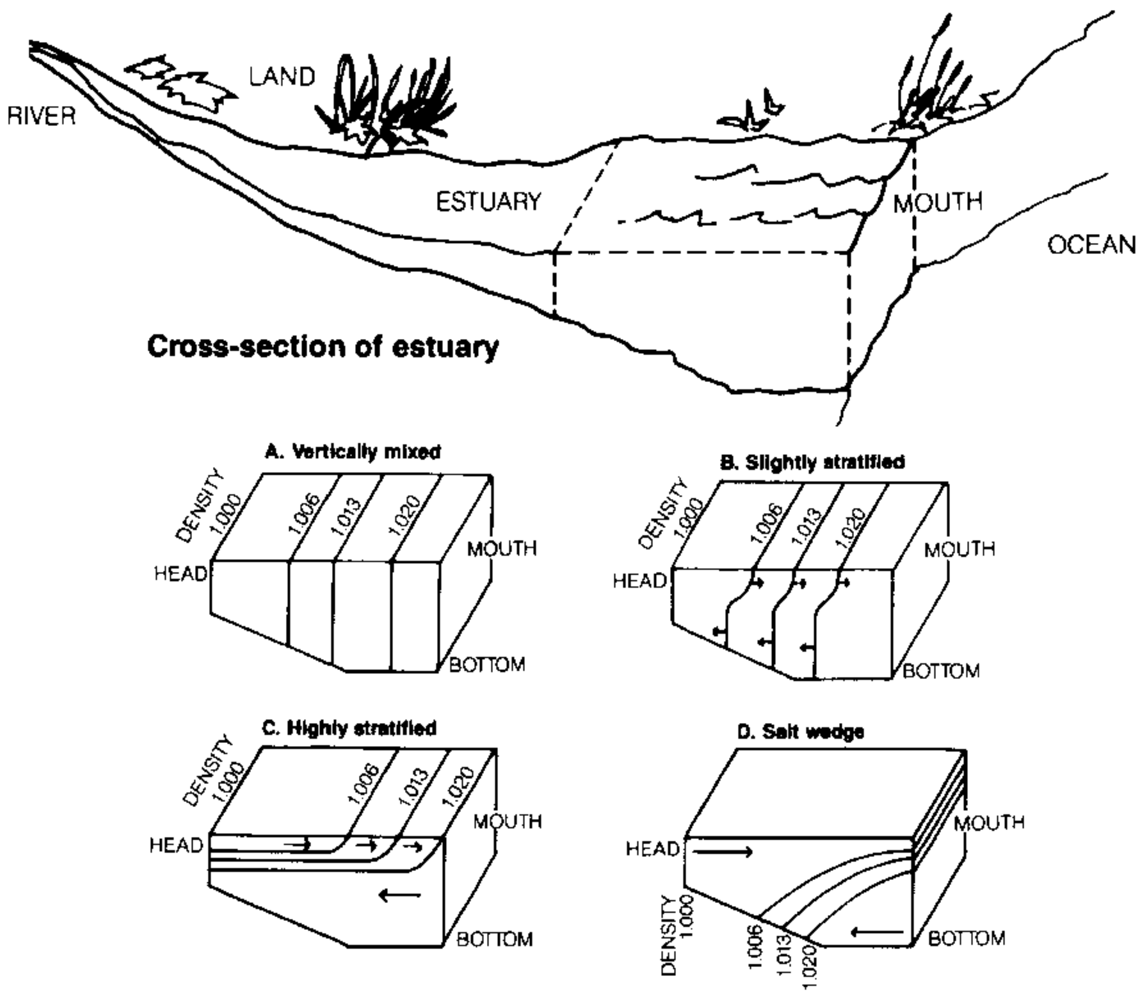
Estuaries are semi-enclosed coastal bodies of water within which seawater is diluted by fresh water from rivers. The density of fresh water is low (1.00). Ocean water with dissolved salts has a greater mass per volume and a greater density. Average seawater density is 1.034.

When ocean water meets river water, the lower density waters float over the heavier, denser water. Estuaries are often defined by the type of water mixing that occurs. This can vary from a highly stratified, or layered, estuary to one that is mixed and shows no stratification.

Estuarine scientists generally describe four types of mixing.

Vertically Mixed Estuary: The fresh and salt waters are completely mixed so there is a uniform density from surface to bottom (Figure 1). This is

Figure 1 Water densities at various locations in different types of estuaries



(ARROWS INDICATE THE DIRECTION OF WATER MOVEMENT) typical of shallow estuaries where winds keep the waters churned. However, density increases as you approach the ocean.

Slightly Stratified Estuary: The river water is not completely mixed within the estuary. The river water has a slightly stronger flow than the tidal ocean flow.

Highly Stratified Estuary: This occurs when a river empties directly into ocean, such as the Cape Fear River estuary. The river water and ocean water form separate layers. The density of the surface layers increases from nearly fresh at the head of the estuary to almost that of seawater at the mouth. Testing the water in one spot yields increasing density with depth.

Salt Wedge Estuary: The river water flows strongly over the ocean water. Ocean water is wedged against the bottom. This wedge moves in response to tidal flow and the velocity of the river flow.

The four patterns may appear in one estuary over time. Variations in mixing occur from changes in rainfall, wind direction and speed, and tidal cycle. For example, a rainy spring could increase river flow and produce estuaries with a salt wedge. Although most of North Carolina's sounds are vertically mixed estuaries, they may become stratified depending on the amount of rain runoff.

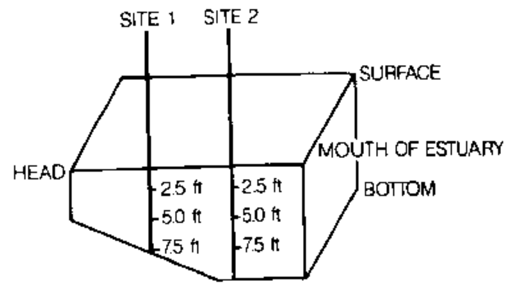
Questions

Estuarine Stratification

Calculate the density of the water (using the correct number of significant figures) at depths of 0, 2.5, 5.0 and 7.5 feet for each estuarine site. Figure 2 shows the two sites in the estuary where density data were taken. Figure 1 shows water densities at various locations in the different types of estuaries.

To determine the type of estuary described in a problem, superimpose Figure 2 over one of the estuaries in Figure 1 and hold the two pages up to the light. Roughly estimate the water densities for that estuary at sites 1 and 2 at the four depths marked on Figure 2. If the densities calculated in the problem correlate to the densities estimated from the two superimposed figures, you have identified the type of estuary. If the calculated and estimated densities do not match, repeat the superimposing process with a different estuary in Figure 1. Continue until you identify the estuary.

Figure 2 Sites where density data taken in estuary



Problem 1

Site 1

DEPTH	MASS	VOLUME	DENSITY
0 ft.	25.150 g	25.00 ml	______
2.5 ft.	35.210 g	35.00 ml	______
5.0 ft.	15.090 g	15.00 ml	______
7.5 ft.	45.270 g	45.00 ml	______

Site 2

DEPTH	MASS	VOLUME	DENSITY
0 ft.	10.160 g	10.00 ml	______
2.5 ft.	40.640 g	40.00 ml	______
5.0 ft.	30.480 g	30.00 ml	______
7.5 ft.	45.720 g	45.00 ml	______

This is a ______________________ estuary.

Problem 2

Site 1

DEPTH	MASS	VOLUME	DENSITY
0 ft.	20.020 g	20.00 ml	______
2.5 ft.	22.044 g	22.00 ml	______
5.0 ft.	30.120 g	30.00 ml	______
7.5 ft.	33.198 g	33.00 ml	______

Problem 2 (continued)

Site 2

DEPTH	MASS	VOLUME	DENSITY
0 ft.	40.081 g	40.00 ml	______
2.5 ft.	30.120 g	30.00 ml	______
5.0 ft.	35.525 g	35.00 ml	______
7.5 ft.	38.836 g	38.00 ml	______

This is a ______________________ estuary.

Problem 3

Specific gravity of the estuarine water was measured at sites 1 and 2. (Specific gravity of a liquid is the ratio of the density of the liquid to the density of water.)

Site 1

DEPTH	SPECIFIC GRAVITY	DENSITY
0 ft.	1.003	______
2.5 ft.	1.008	______
5.0 ft.	1.022	______
7.5 ft.	1.024	______

Site 2

DEPTH	SPECIFIC GRAVITY	DENSITY
0 ft.	1.010	______
2.5 ft.	1.013	______
5.0 ft.	1.022	______
7.5 ft.	1.024	______

This is a ______________________ estuary.

Animal Adaptations

Problem 4

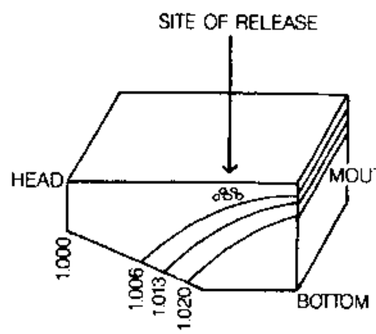
Many fish produce eggs of a specific density. This density affects the placement of the egg and thus larvae in the ocean or estuary. The eggs from different fish are collected and their densities are computed. The density of one set of eggs is 1.017. The eggs are released in a salt wedge estuary in the location indicated on Figure 3.

1. Where would the eggs be located after 1 hour? 2 days?

2. Why would the eggs be located in this region?

3. Are the eggs that are similar in density to the estuarine waters likely to move up the estuary into the river? Why?

Figure 3 Site of egg release in salt wedge estuary



Problem 5

Metridium is a common marine anemone. It is found in areas where the density of seawater is a constant value A.

In these areas with a density of A, the anemone is fully extended (as seen at 0 and 12 hours in Figure 4). An experiment to determine the effects of changing density on the *Metridium* obtained the results shown in Figure 4.

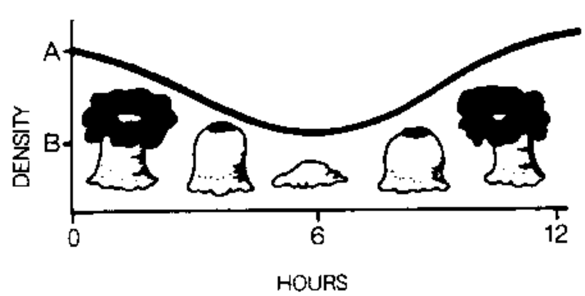
1. Determine the density of seawater at A and B.

SITE	MASS	VOLUME	DENSITY
A	28.784 g	28.00 ml	______
B	31.279 g	31.00 ml	______

Label Figure 4 with these densities.

2. Describe the behavior of the *Metridium* as the density of seawater changes.

Figure 4 Change in *Metridium* size over time



Problem 6

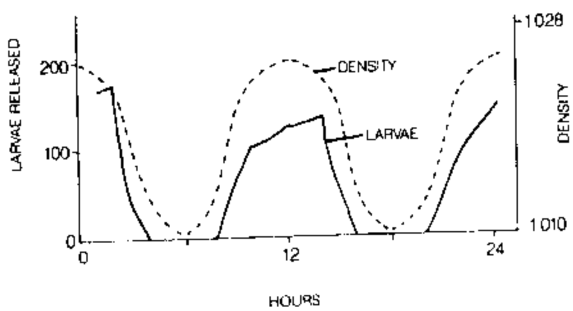
The barnacle, *Balanus balanoides*, is adapted to seawater with a density 1.028. Experiments were performed on the effects of density changes on the release of larvae by the barnacle. Figure 5 shows the results of experiments in which the number of larvae released were counted as density changed over time.

1. At what density does peak larval release occur?

2. At what density does the minimum larval release occur?

3. How does changing the density appear to affect larval release?

Figure 5 Barnacle larvae released over time



Test Questions

1. The greenhouse effect predicts that as we continue to burn fossil fuels, the amount of carbon dioxide in the atmosphere will increase, resulting in the atmosphere absorbing more heat and increasing the overall temperature on earth. This increase in temperature will bring about the melting of glaciers, providing more fresh water to the oceans. How will this affect the density of the ocean? How will this affect the density of estuaries?

2. The Northern Hemisphere has more land mass and less ocean than the Southern Hemisphere. If the Northern and Southern hemispheres receive the same amount of rainfall, will the ocean densities be the same for these two areas? If they differ, how? (Do not consider runoff from the land.)

3. The hermit crab, *Pagurus*, is not adapted for living in an estuarine environment. Figure 6 shows the crab's behavior when exposed to estuarine water. Describe the behavior seen. What might the behavior of the crabs be if placed in higher density salt water?

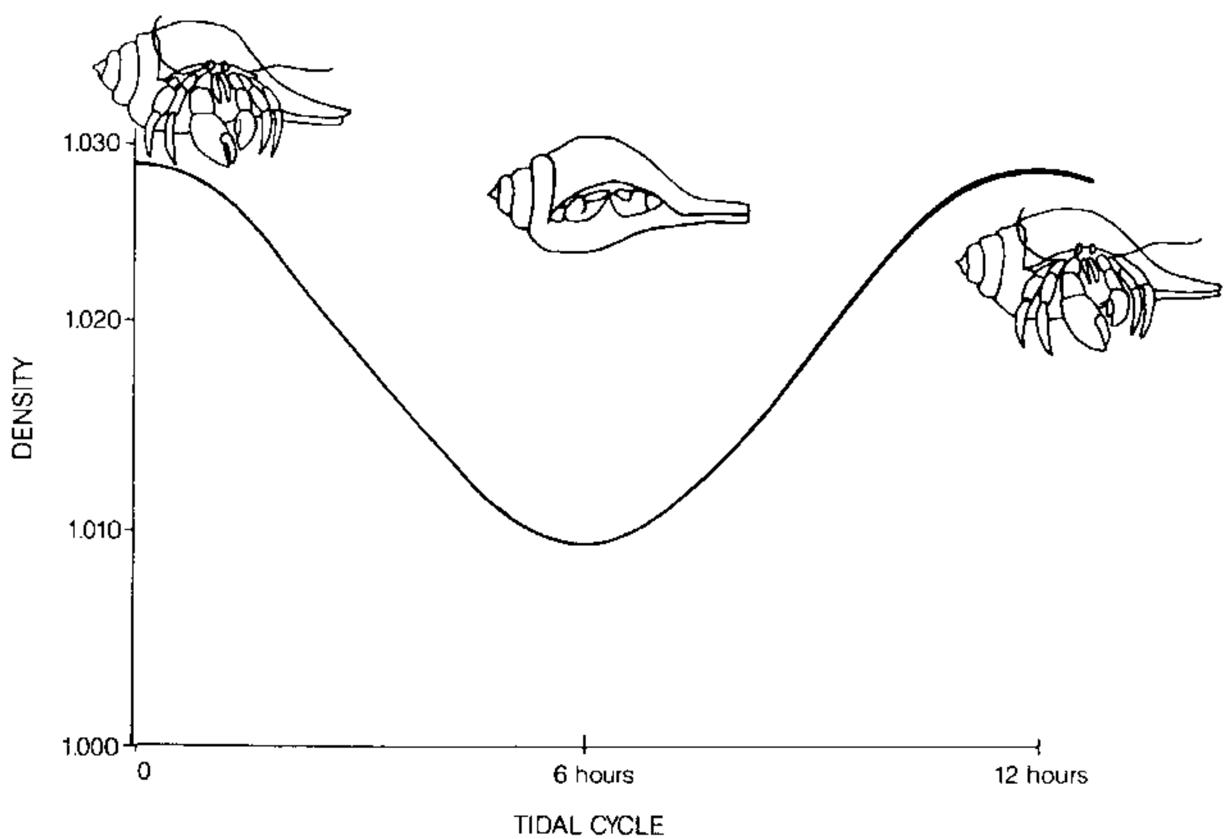
4. A scientist working on a research project in Bogue Sound measures water density at four depths (0 m, 2 m, 4 m, bottom). On the boat ride home, he mixes up the samples. When he returns to the lab, he processes the samples. He gets the following measurements:

	MASS	VOLUME	DENSITY	DEPTH
A	50.150 g	50.00 ml	______	______
B	35.910 g	35.00 ml	______	______
C	41.820 g	41.00 ml	______	______
D	48.432 g	48.00 ml	______	______

Calculate the densities for the five samples.

5. Based on your knowledge of density, list the correct depth for each sample in the table above. Using Figures 1 and 2 for site 1, what type of estuary is this?

Figure 6 Hermit crab behavior as density changes during tidal cycle



Competency Factors/References

Competency Indicators

Chemistry-academic/applied and technical—

1.2 know the properties of matter and energy.

Competency Measures

Chemistry-academic—

1.2.2 explain the concepts of density and specific gravity after performing density experiments.

Chemistry-applied/technical—

1.2.2 describe samples of matter in terms of mass, volume, density and physical state.

References

Coker, R.E. 1949. *This Great and Wide Sea*. UNC Press, Chapel Hill. Chapts. 6 and 7.

Davenport, J. 1982. "Environmental Simulation Experiments on Marine and Estuarine Animals," *Advances in Marine Biology*. (J.H.S. Blaxter, ed.). Academic Press. 19:133–256.

Gale, Judith A. 1989. *A Guide to Estuaries of the Albemarle-Pamlico Region, North Carolina*. Albemarle-Pamlico Estuarine Study, N.C. Dept. of Environment, Health and Natural Resources, Raleigh, N.C.

Goldberg, Edward D. *The Sea*. John Wiley and Sons, New York. Vol. 5, Marine Chemistry, Parts III, IV, V.

"Identification of a Substance Using Densities," Hered and Nebergall, *Basic Laboratory Studies in College Chemistry*. D.C. Heath and Company, Boston. (c. 1957)

Jones, Gail. 1989. *Project Estuary: N.C. National Estuarine Research Reserve System, A Curriculum Guide for Teachers*. N.C. Division of Coastal Management, Raleigh, N.C.

Levington, Jeffrey S. 1982. *Marine Ecology*. Prentice-Hall, Inc. New Jersey. Chapts. 1 and 17.

Mauldin, L. and D. Frankenberg. 1978. Unit 2: Seawater. *North Carolina Marine Education Manual*. UNC Sea Grant Publication UNC-SG-78-14-B.

Riley and Chester. 1978. *Chemical Oceanography*. Academic Press. New York. Vol. 7.

______________ and Skirrow. 1975. *Chemical Oceanography*. Academic Press. New York. Vols. 1, 2, 4.

Spitzbergen, Judith M. 1980. *Seacoast Life*. UNC Press, Chapel Hill. p. 8.

Thurman, Harold V. 1983. *Essentials of Oceanography*. Merrill Publishing Company, Ohio. Chapts. 6 and 12.

pH, Equilibrium and Ocean Buffering

Introduction

Discussion of acids, bases, pH and buffering can include consideration of the equilibrium between dissolved inorganic carbon species:

$CO_2\ (g) \rightarrow CO_2\ (aq)$

$CO_2(aq) + H_2O(1) \rightarrow H_2CO_3(aq)$

$H_2CO_3(aq) \rightarrow HCO_3^-(aq) + H^+(aq)$

$HCO_3^-(aq) \rightarrow CO_3^{2-}(aq) + H^+(aq)$

These equations provide a good illustration of acids, pH and buffering. The inorganic carbon species constitutes an important mechanism for buffering the pH of the ocean. Understanding the behavior of inorganic carbon in the ocean is important. It plays a role in the dissolution or preservation of the carbonate hard parts of many marine organisms that ultimately become limestone or other carbonate minerals. Recent attention to inorganic carbon in the ocean is related to the greenhouse effect. Scientists want to know how the increase in atmospheric CO_2 concentrations (from burning fossil fuels) affects oceanic pH or vice versa.

Oceans represent one of the most visible features on our planet. Covering approximately 71 percent of the earth's surface area, the oceans play an important role in the distribution of elements on the earth. Many reactions and processes that involve these elements take place in the oceans. Table 1 presents a brief description of the oceans' features.

Table 1.
General Features of the Oceans

The average ocean depth is approximately 3,800 meters (12,200 feet or 2.3 miles).

The deepest point is about 11,000 meters below sea level (the Philippine Trench and Marianas Trench in the Pacific).

The volume of all the oceans is approximately 317 million cubic miles or 1.33 billion cubic kilometers.

The average ocean temperature is 38.3°F (3.5°C). Temperatures range from 32°F (0°C) or less in the polar regions to 98.6°F (37°C) in the Persian Gulf.

Only about 0.33 percent of all the earth's water is fresh water for drinking and irrigation.

Table 2 lists the most abundant elements in seawater. Given the range in depths (that result in a range of pressure conditions) and temperatures, the quantities and types of elements present and its large surface area, it is not surprising that chemical processes occurring in the ocean have a significant influence upon living conditions on our planet.

Table 2.
Major Elements in Seawater

Element	metric tons/cubic kilometer
chlorine (Cl^-)	19,600,000
sodium (Na^+)	10,900,000
magnesium (Mg^{2+})	1,400,000
sulfur (S^{2-}, SO_4^{2-})	920,000
calcium (Ca^{2+})	420,000
potassium (K^+)	390,000
bromine (Br^-)	67,000
carbon (HCO_3^-, CO_3^{2-})	29,000
strontium (Sr^{2+})	8,300

Carbon, an important element to all living things, interacts in major processes that affect living conditions and the oceans' chemistry. The ocean is a natural, complex example of how acids and bases interact and of how certain compounds behave to buffer the pH level of the ocean. The main agents involved in these processes are carbon dioxide (CO_2), carbonic acid (H_2CO_3), bicarbonate ions (HCO_3^-) and carbonate ions (CO_3^{2-}). The main reactions involving these compounds and ions are depicted in Figure 1a below.

Figure 1a Carbon cycle

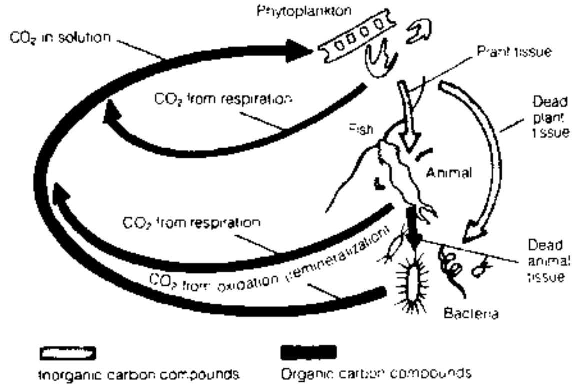


Figure 1b Inorganic carbon compound reactions in seawater

(1) $CO_2(g) \rightarrow CO_2(aq)$

(2a) $CO_2(aq) + H_2O(l) \rightarrow H_2CO_3(aq)$

(2b) $H_2O(l) + H_2CO_3(aq) \rightarrow HCO_3^-(aq) + H_3O^+(aq)$

(2) $CO_2(aq) + 2H_2O(l) \rightarrow HCO_3^-(aq) + H_3O^+(aq)$
(sum of 2a and 2b)

(3) $HCO_3^-(aq) + H_2O(l) \rightarrow CO_3^{2-}(aq) + H_3O^+(aq)$

ACTIVITY 1

Acids and Bases in the Ocean

Purpose

To identify acids and bases in the ocean environment and to interpret acid/base equations.

Questions

Identifying acids and bases (use equations in Figure 1b)

1. Which chemical equation(s) contains a Bronsted-Lowry acid? A Bronsted-Lowry base?

2. Identify the Bronsted-Lowry acid(s) and base(s) in each equation listed in answer 1 above.

3. Which of the following is an Arrhenius acid?

(a) HCO_3^- (b) CO_3^{2-} (c) CO_2

4. Why did you select your answer to number 3?

Identifying conjugate acids and bases

5. What are the conjugate acid-base pairs in each chemical equation you listed in number 1 above?

6. Which of the following represents a conjugate acid-base pair in chemical equation 3?

(a) CO_3^{2-} and H_2O (b) HCO_3^- and CO_3^{2-}
(c) H_2O and HCO_3^- (d) CO_3^{2-} and H_3O^+

Identifying the symbols in the chemical equations

7. What does $H_2O(l)$ symbolize?

8. How is $CO_2(g)$ different from $CO_2(aq)$?

Translating the symbolism of chemical equations

You have learned the meaning of the components of the chemical equation and certain acid-base expressions and how to identify them. Now test your understanding of what is represented or symbolized by a chemical equation as a whole.

9. What is happening to CO_2 in Figure 1b?

10. What is happening to the other compounds in Figure 1b?

11. What is H_3O^+ called?

12. Is bicarbonate ion (HCO_3^-) a Bronsted-Lowry acid, base, both or neither? Explain why, and include definition(s) of a Bronsted-Lowry acid and a Bronsted-Lowry base in your answer.

13. What are the reactants of equation 3 in Figure 1b as it is written? The products?

ACTIVITY 2

Inorganic Carbon Compound Reactions and Their Equilibrium Constants

Purpose

To identify the products and reactants in chemical equations, construct equilibrium constant expressions for given reactions, use tables to determine the value for equilibrium constants of inorganic carbon reactions, and calculate the concentrations of a product or reactant in a reaction. Students will use the equilibrium constant expressions and their values as determined from the given tables and other concentrations.

Background

For a given temperature and pressure, there is a definite relationship between the concentrations of the reactants and the products in a reaction when equilibrium is reached. This relationship is expressed by the equilibrium constant, represented by the letter K. Hence for the general reaction:

(1) $aA + bB = cC + dD$

where A and B are reactants and C and D are products, the equilibrium constant expression is:

(2) $K = \frac{[C]^c[D]^d}{[A]^a[B]^b}$

Students need to be reminded that pure liquids and solids are omitted from the right side of an equilibrium expression.

Questions

1. For reactions involving inorganic carbon compounds, fill in the blanks.

$CO_2(g) \rightarrow CO_2(aq)$

Reactants ________ Products ________ Equilibrium Constant Expression $K_1 =$ ________________

$CO_2(aq) + 2H_2O(l) \rightarrow HCO_3^-(aq) + H_3O^+(aq)$

Reactants ________ Products ________ Equilibrium Constant Expression $K_2 =$ ________________

$HCO_3^-(aq) + H_2O(l) \rightarrow CO_3^{2-}(aq) + H_3O^+(aq)$

Reactants ________ Products ________ Equilibrium Constant Expression $K_3 =$ ________________

Tables 3 and 4 provide values for K_2 and K_3, respectively, under different conditions of chlorinity and temperature. Chlorinity is a measure of the amount of salt dissolved in water. It is measured in parts per thousand, symbolized by ‰. (Similarly, percentages, which are parts per hundred, are represented by %).

Table 3.
Values for K_2* at Different Cl ‰ and Temperatures°(C)

Cl ‰	0	5	10	15	20	25	30	35
0	2.63	3.01	3.38	3.80	4.16	4.46	4.67	4.89
1	3.38	3.80	4.26	4.67	5.12	5.49	5.75	5.88
4	4.36	4.78	5.24	5.75	6.16	6.60	6.91	7.07
9	5.37	5.88	6.45	7.07	7.41	7.94	8.31	8.51
16	6.60	7.24	7.76	8.51	8.91	9.33	9.77	10.2
17	6.76	7.41	7.94	8.70	9.12	9.54	10.0	10.5
18	6.91	7.58	8.12	8.70	9.33	9.77	10.2	10.7
19	7.07	7.76	8.31	8.91	9.54	10.0	10.5	10.7
20	7.24	7.94	8.51	9.12	9.77	10.2	10.7	11.0
21	7.41	8.12	8.70	9.33	10.0	10.5	11.0	11.2
25	8.12	8.91	9.54	10.0	10.7	11.2	11.7	12.0
49	12.0	13.2	13.8	14.5	15.1	15.8	16.6	17.0

*These values should be multiplied by 1×10^{-7}.

Table 4.
Values for K_3 at Different Cl ‰ and Temperatures°(C)

Cl ‰	0	5	10	15	20	25	30	35
0	.240	.282	.324	.372	.417	.468	.513	.562
1	.871	1.02	1.17	1.35	1.55	1.74	1.95	.562
2	1.66	1.91	2.14	2.45	2.88	3.24	3.72	4.17
9	2.29	2.63	3.02	3.47	3.98	4.57	5.37	6.17
16	3.47	3.98	4.47	5.13	5.89	6.76	7.94	9.55
17	3.63	4.17	4.79	5.37	6.17	7.08	8.32	10.0
18	3.80	4.37	5.01	5.62	6.46	7.59	8.71	10.5
19	3.98	4.57	5.25	5.89	6.76	7.94	9.55	11.2
20	4.17	4.79	5.50	6.17	7.08	8.32	9.77	12.0
21	4.37	5.01	5.62	6.46	7.41	8.71	10.5	12.9
25	5.13	5.89	6.76	7.76	8.91	10.5	12.3	15.1
49	11.2	12.9	15.1	17.8	20.9	24.5	29.5	37.2

*These values should be multiplied by 1×10^{-10}.

2. Using Tables 3 and 4, find the expected values of K_2 and K_3 for the following oceanic conditions and fill in the blanks below.

Oceanic Conditions	K_2	K_3
Cl ‰ = 17 ‰, T = 5°C	________	________
Cl ‰ = 49 ‰, T = 35°C	________	________
Cl ‰ = 21 ‰, T = 20°C	________	________

You are ready to use the equilibrium constant expressions and the equilibrium constant values from Tables 3 and 4.

3. You collected samples of ocean water at different depths while on the research submarine *Alvin* (the vessel that explored the *Titanic* in 1986). You measured Cl ‰ and temperatures from the submarine; lab technicians measured $[HCO_3^-]$, $[CO_3^{2-}]$ and $[H_3O^+]$ from the *Atlantic II*, which transports *Alvin* to its dive sites. The technicians made several mistakes, so some of their data was not used. The collected data is represented in Table 5. Fill in the blanks.

Table 5.
Cruise Data

dpth(m)	Cl ‰	T(°C)	*a K_2	*b K_3	*1 HCO_3^-]	*2 $[CO_3^{2-}]$	*3 $[H_3O^+]$	*4 $[CO_2]$
0	21	30	________	________	2.04	3.98	3.98	________
100	20	25	________	________	3.40	________	5.01	1.67
200	18	20	________	________	5.72	5.86	6.31	________
300	17	20	________	________	8.51	5.25	10.0	________
400	16	10	________	________	13.5	________	________	21.6
500	16	10	________	________	13.3	________	________	21.9
750	16	10	________	________	14.0	6.53	12.6	________
1000	16	5	________	________	36.0	7.16	20.0	________

*1 Values are to be multiplied by 1×10^{-6}
*2 Values are to be multiplied by 1×10^{-7}
*3 Values are to be multiplied by 1×10^{-9}
*4 Values are to be multiplied by 1×10^{-8}
*a Values are to be multiplied by 1×10^{-7}
*b Values are to be multiplied by 1×10^{-10}

ACTIVITY 3

What is the pH?

Purpose

To work pH problems and to determine the pH of various aqueous solutions.

Background

The pH concept originated in 1909 with a Danish biochemist named Sorensen. The "p" in pH comes from "potenz," a German word for power. The "H" stands for hydrogen ions. The pH is a measure of the concentration of hydrogen (hydronium) ions in an aqueous solution. The formula, $pH = -\log [H^+]$, is used to calculate pH.

The pH scale, which generally ranges from 0 to 14, is used to indicate the acidity or basicity of a dilute (1 molar or less) water solution. Acidic solutions have a pH less than 7. Basic solutions have a pH greater than 7, and neutral solutions, a pH equal to 7. Citrus juices are acidic; pure water, neutral; and seawater, basic (Table 6).

The concentration of hydronium ion (H_3O^+) in aqueous solutions, often referred to as a hydrated proton, is important. These ions react with and affect many other elements, compounds and/or ions. The measure of $[H_3O^+]$ is so important that scientists have selected a convenient way to express it—pH. The pH is related to $[H_3O^+]$ by the following expression:

(1) $pH = -\log [H_3O^+]$

The pH of pure water is 7 ($[H_3O^+] = 1 \times 10^{-7}$ M).

Table 6.
The pH of Some Common Substances

Substance	pH
hydrochloric adic, HCl (0.1 M)	1.0
digestive juices in the stomach	2.0
lemon juice	2.3
vinegar	2.8
acetic acid, $HC_2H_3O_2$ (0.1 M)	2.9
carbonated drinks	3.0
grapefruit juice	3.1
orange juice	3.5
tomato juice	4.2
rainwater	6.2
milk	6.5
pure water	7.0
blood	7.4
seawater	8.1–8.3
sodium bicarbonate, $NaHCO_3$ (0.1 M)	8.4
milk of magnesia	11.1
ammonia water, NH_4OH (0.1 M)	11.1
sodium hydroxide, NaOH (0.1 M)	13.0

1. Using equation 1, calculate pH if:

a. $[H_3O^+] = 1.0 \times 10^{-4}$

b. $[H_3O^+] = 1.0 \times 10^{-14}$

c. $[H_3O^+] = 1.0 \times 10^{-7.1}$

d. $[H_3O^+] = 1.0 \times 10^{1.6}$

e. $[H_3O^+] = 3.56 \times 10^{-5}$

f. $[H_3O^+] = 2.91 \times 10^{-8}$

2. Using equation 1, calculate $[H_3O^+]$ if:

a. pH = 5

b. pH = 1

c. pH = 3.6

d. pH = 9.3

e. pH = 7.46

f. pH = 13.8

Equipment/Materials

stirring rod
drinking straw
wire
gauze
Bunsen burner
ring stand
2 rings
small test tube
100-ml beaker
two vials of pH paper*
one with even-numbered chart on the label
one with odd-numbered chart on the label
1 M lead (II) nitrate
1 M hydrochloric acid
0.8 M sodium bicarbonate
1 M acetic acid
0.1 M sodium carbonate
vinegar
shampoo
lemon juice
seawater**
household solutions

* The pH paper is identical in both vials. With two vials you will have access to both the even- and odd-numbered pH charts.

**Seawater (from the Pacific, Atlantic and the Gulf of Mexico) can be purchased. Seawater can also be simulated. There are two methods of achieving a solution with a pH near that of seawater (8.5). Prepare a 1.0 M solution of sodium bicarbonate (pH = 8.4). Or purchase powdered buffer formulations with a specific pH conveniently packaged in capsules. Dissolve the powder in distilled water. The seawater could be used to introduce the lab and show the correct use of pH paper. This would especially be desirable if you have to purchase seawater.

CAUTION: Do not begin this lab until your teacher has given you lab instructions and cautions for each chemical. Wear eye and clothing protection.

Procedure

When using pH paper to determine the pH of a solution, put one or two drops of the solution on the paper. This is easily done if the solutions are in dropper bottles. If they are not, dip a clean stirring rod in the solution to be tested and touch the rod to the pH paper. In either case, immediately compare the moistened pH paper to the odd- and even-numbered charts on the pH vials. Use a separate piece of pH paper for each solution. Discard the paper after use.

Step 1. The teacher will provide a list of solutions. Use pH paper to determine the pH of each of these solutions. Record the results in a data table. Remember that a data table must have a number and a title.

Step 2. Determine the pH of tap water and distilled water. Record this data in your data table.

Carbon dioxide can enter the ocean from the atmosphere. Water can hold higher concentrations of carbon dioxide than air, volume for volume. Dissolved carbon dioxide affects the pH of seawater. The saltier and colder the water, the more carbon dioxide it can dissolve.

Step 3. Put approximately 25 ml of distilled water (room temperature or colder) in a 100-ml beaker. Make sure the beaker is clean. Use a drinking straw to blow into the water for two minutes. Determine the pH of this water. Record it in your data table. (Instead of distilled water, students could use simulated seawater.)

Step 4. Set up the ring stand and rings so that heating can be done. One ring is to support the wire gauze and the other ring is situated so that it surrounds the beaker to prevent tipping. Gently boil the 25 ml of water from the step above for two minutes. Determine the pH of the boiled water. Record it in your data table. Do not let the water cool before taking the pH. Remember that the rings, beaker and water are very hot. Be careful.

Step 5. Determine the pH of the following solutions: lead (II) nitrate, vinegar, sodium carbonate, sodium bicarbonate, 1 M acetic acid, 1 M hydrochloric acid, shampoo, lemon juice and seawater. Record the results in your data table.

Step 6. In a small clean test tube, combine two drops of baking soda (sodium bicarbonate) and two drops of vinegar. Use data you have already collected to predict the pH of this combination of solutions. Write your prediction in the data table.

Step 7. Use a clean stirring rod to determine the actual pH of the combination of solutions above. Record this in your data table.

Questions

1. In step 3, what gas did you put into the water that could affect its pH?

2. In step 4, what gas (besides oxygen) was given off during the boiling process?

3. Mention one way that carbon dioxide enters the ocean.

4. Write the balanced equation for the reaction between carbon dioxide and water.

5. Why are the pHs different in steps 3 and 4?

6. What reasoning did you use to make a prediction in step 6?

7. Did your prediction in step 6 match the actual pH measured in step 7?

8. An acid reacts with a base to produce a _______ and water. This reaction is called _______.

9. What acid and base should be reacted to produce the salt, lead (II) nitrate?

10. What acid and base should be reacted to produce the salt, sodium carbonate?

11. Judging from the name of an acid-base reaction you would expect a salt solution to be neutral and have a pH of _______. However, not all salt solutions are neutral.

12. The ions of some salts undergo hydrolysis, and thus their water solutions are not neutral. Define hydrolysis.

13. What was the pH of the lead (II) nitrate solution? Does lead (II) nitrate hydrolyze?

14. What was the pH of the sodium carbonate solution? Does sodium carbonate hydrolyze?

15. Acetic acid is a (weak, strong) acid/electrolyte and does not completely ionize in water solution.

16. Hydrochloric acid is a (weak, strong) acid/electrolyte and ionizes 100 percent in water solution.

17. What was the pH of the 1 M acetic acid solution?

18. What was the pH of the 1 M hydrochloric acid?

19. Explain why acetic acid and hydrochloric acid have different pHs even though they are both 1 molar solutions.

20. Sodium bicarbonate (baking soda) forms a(n) (acidic, basic) solution.

21. Medicinally, how is a sodium bicarbonate solution used?

22. Hair can be damaged by combing or brushing immediately after it is washed. Wet hair is strongest and least vulnerable if it has a pH range of 4.0 to 5.0. Would the shampoo tested in this experiment be a good one to use to give your hair maximum wet strength?

23. If a shampoo has a pH that is too high, which household items from the list below could be used as a rinse after shampooing to reduce the pH nearer the acceptable level? You may choose more than one item.

Vinegar
Lemon juice
Sodium bicarbonate solution (baking soda)

24. Vinegar is used to preserve foods such as pickles because the (acidic, basic) nature of the vinegar inhibits the decomposition of tissues. Some lakes are as acidic as vinegar because of pollution and acid rain. Plants and animals have difficulty surviving in this type of environment.

25. What is the pH of seawater?

26. Use your answer above to explain why acid rain does not appreciably affect the ocean and its life forms.

27. The ocean is a buffer solution relative to acids because it has a large carbon dioxide content. Define buffer.

Competency Factors/References

Competency Indicators

Chemistry-academic—

7.3 know physical characteristics and chemical properties of solutions of acids, bases and salts; and

7.6 have a knowledge of acid-base equilibria and pH.

Chemistry-applied technical—

7.3 know physical characteristics and chemical properties of solutions.

Chemistry—

7.6 know about acids, bases and pH.

Competency Measures

Chemistry-academic—

7.3.2 determine experimentally the pH, the effect on litmus paper and other physical characteristics of acids, bases and salts;

7.3.3 explain the characteristics of solutions of acids, bases and salts in terms of interaction with water;

7.6.1 develop an understanding of pH and pOH as logarithmic expressions of concentrations of H_3O^+ and OH^- ions; and

7.6.2 calculate the pH of an acidic or basic solution given its concentration.

Chemistry-applied/technical—

7.3.1 (see 7.3.2 above);

7.3.2 (see 7.3.3 above);

7.6.1 draw a diagram of pH and pOH scales and give examples of everyday materials in the corresponding ranges; and

7.6.2 determine the pH of an acidic or basic solution given a pH meter or test kit.

Behavior of Gases in the Marine Environment

Introduction

Many students are familiar with the feeling of changing pressure against their ears when they dive into a pool. Some students are learning about pressure changes through scuba diving, an increasingly popular hobby. An understanding of the pressure changes are important for safety and a better understanding of pressure and volume interactions.

In addition, pressure problems have limited our exploration of the deep sea. Recently scientists have developed underwater stations, such as *Hydrolab*, and submersibles, such as *Alvin*, that allow researchers to work at greater depths for longer periods of time.

This section is designed to explain the gas laws through a practical example—scuba diving. Beginning with a discussion of pressure and its effects on the body may be helpful to students.

Notes to Teachers

1. All answers are based on using the correct number of significant digits for the final answer.

2. In Activity 3, you will notice that the percentage of gases making up air and the air in tanks is different. Air is 78 percent nitrogen, 21 percent oxygen, 0.03 percent carbon dioxide and small amounts of other gases. To make the problems easier, oxygen and nitrogen are assumed to be the only gases of importance in air and in dive tanks. All of the problems are based on using 21 percent oxygen and 79 percent nitrogen. (Nitrogen has increased by one percent over the normal percentage found in air. Nitrogen has incorporated the one percent occupied by the other gases.)

ACTIVITY 1

Seawater and Pressure

Purpose

To understand that with increasing water depth, there is increasing water pressure.

Background

As a scuba diver descends into deeper water, he feels the increased pressure. The water pressure pushes against the ear drums until the diver's ear equalizes or builds up the pressure inside equal to the external pressure. You experience the opposite effect when you drive up a mountain and have less pressure outside your ears.

Equipment/Materials

1 gallon milk carton
water
a nail or pick

Procedure

Look at the milk carton. If it were filled with water, where would you predict the greatest pressure would be? Near the top or bottom?

To test the hypothesis, punch three small holes in the sides of the carton—one near the bottom, middle and top. Put tape over the holes, and fill the carton with water. Remove the tape. What happens to the water? Try to measure the distance the water is pushed from the carton.

On a graph, plot the distance the pressure pushes the water stream versus the position of the hole from the bottom.

Questions

1. Why isn't the water pushed out at the same distance from all three holes?

2. What do you predict would happen to water coming out the bottom hole if you had a taller carton with more water?

3. What would happen to water coming out the bottom hole if you had a larger carton at the same height?

4. How does the distance the water streams out change as the water drains out of the container?

ACTIVITY 2

The Cartesian Diver

Purpose

To investigate how salinity and pressure affect density and how this affects objects floating in water.

Equipment/Materials

*2 plastic two-liter soda containers, 2 large test tubes (30 x 3.5 cm), 2 graduated cylinders (100 ml or larger) or 2 glass jars
2 identical medicine droppers (Cartesian Divers)
salt
teaspoon
plastic funnel

*If large test tubes, graduated cylinders or jars are used, two pieces of thin rubber (ballons) and two rubber bands are needed.

Procedure

Fill each of the selected containers almost full of water. Use the plastic funnel to add 4 to 8 teaspoons of salt to one of the containers. (Larger amounts of salt should be added to the larger containers.) Shake the container to help the salt dissolve.

Suspend a medicine dropper vertically in each of the containers. They can be suspended with a few drops of water in them.

If you are using the two-liter bottles, screw the caps on. If you are using any of the other containers, stretch a rubber ballon over the mouth of each container and secure it with a rubber band.

Press the sides of the two-liter bottle containing the fresh water. In the case of the other containers, press down on the rubber cover. What happens to the dropper?

Release the pressure on the bottle or rubber cover. What happens to the dropper?

What happens to the amount of water in the dropper/test tube as it submerges?

Now press on the sides or rubber cover of the saltwater container. Does the medicine dropper behave differently in the salty water?

Questions

1. Does the Cartesian Diver submerge easier in fresh or salt water?

2. Does the Cartesian Diver rise to the surface faster in fresh or salt water?

3. What makes the Cartesian Diver dive?

4. Why does the Cartesian Diver rise back to the surface of the water?

5. Discuss the relationship among density, salinity and pressure.

ACTIVITY 3

Scuba Diving and the Gas Laws

Purpose

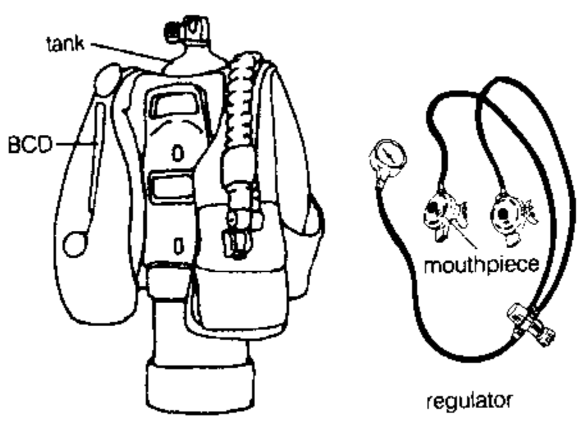
To introduce the gas laws in the context of scuba diving.

Background

People can explore the marine world by using a mask, snorkel and fins and holding their breath. Or they can prolong their exploration with the use of scuba (self-contained underwater breathing apparatus) equipment.

The self-contained breathing apparatus consists of a tank filled with compressed air, a regulator with a mouthpiece and a BCD (Buoyancy Control Device) (Figure 1).

Figure 1 Self-contained breathing apparatus



A regulator reduces the high pressure of the air in a scuba tank to a usable level and delivers air when needed by the diver. A BCD is mandatory equipment for all diving. It is an inflatable sack that increases buoyancy. It is used to provide surface support to rest, swim and maintain neutral buoyancy under water.

Other types of diving equipment are available but are less accessible to the general public.

Scuba diving has become a popular hobby for many people. It offers a wealth of information on diving physiology and the effects of gas exchange.

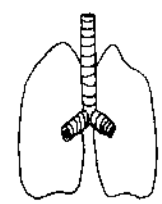
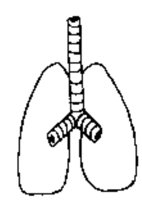
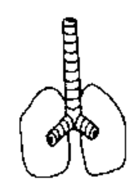
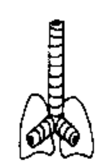
Introduction to Gas Laws

Boyle's Law

Boyle's law states that at a constant temperature, the volume of a gas will vary inversely with pressure, while the density of the gas varies directly with the pressure.

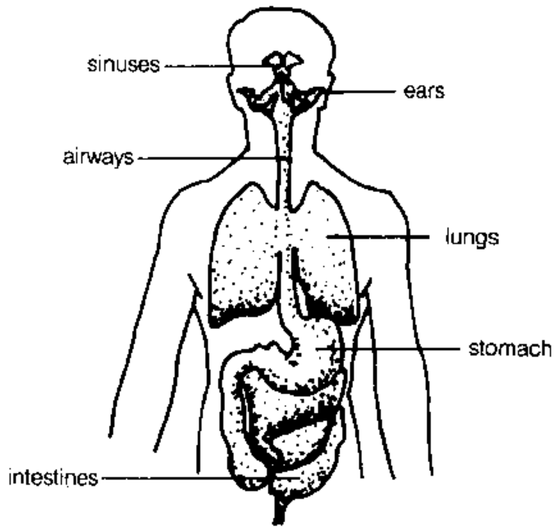
This means that as the pressure on a volume of gas doubles the gas is compressed to one-half its volume (see Figure 2). If the pressure triples then the volume is compressed to equal one-third of its original volume.

Figure 2 Boyle's law

Depth	Pressure on lungs	Volume of air	Density of air	Lungs of a diver holding breath
0 feet	1.0 atm	4.0 liters	1 kg/1	
33 feet	2.0 atm	2.0 liters (4/2)	2 kg/1	
66 feet	3.0 atm	4/3 liters	3 kg/1	
99 feet	4.0 atm	1.0 liter (4/4)	4 kg/1	

One of the first effects a diver feels is increasing pressure. As he descends, the pressure around him increases by 1 atmosphere for every 33 feet of descent in salt water (34 feet in fresh water) (Figure 2). The increasing pressure is not felt by bone and solid tissue but by air spaces (ears, lungs and sinuses) (Figure 3).

Figure 3 Air spaces in the body

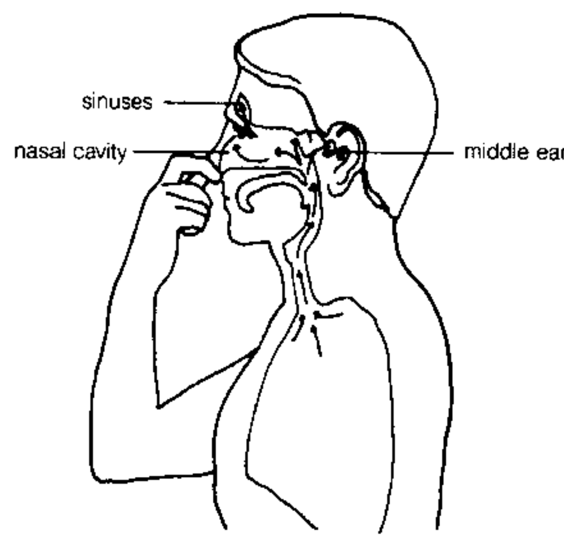


When a diver descends, the increase in pressure reduces the size of his air spaces (Figure 2) and compresses the air inside. A diver who holds his breath feels the increase in pressure (decrease in volume) as a squeezing in his lungs, sinuses and ears (Figure 4). As the pressure increases, the squeezing increases and becomes uncomfortable. Eventually the diver will stop his descent.

To relieve the pressure on the lungs, a diver breathes compressed air at a regular frequency. To relieve the pressure on ears and sinuses, a diver blocks his nose and attempts to exhale through it with his mouth closed. This forces air into the air spaces inside the ears and sinuses and relieves the squeeze. This technique is known as equalizing.

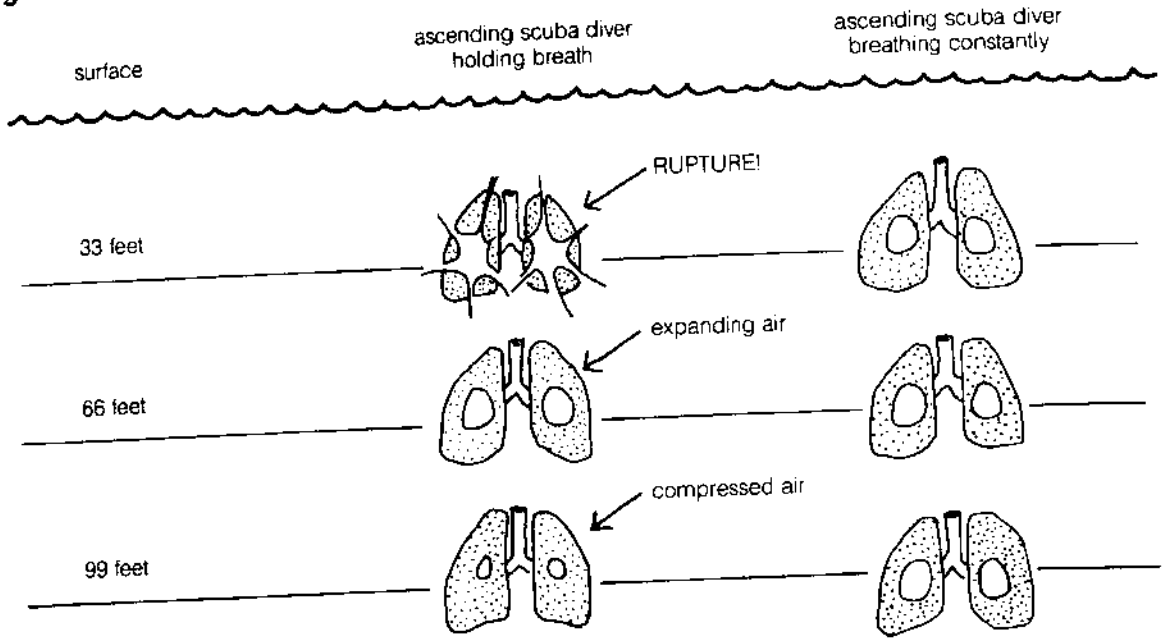
The process of equalizing returns the air spaces to their normal volume by equalizing the external water pressure and the pressure in the air spaces. As long as a diver breathes compressed air and equalizes the pressure in the air spaces, he will not feel the squeezing as he descends.

Figure 4 Technique to relieve pressure on the ear drum



A diver ascending experiences the opposite pressure-volume relationship. The pressure decreases and the volume increases. A diver not breathing on ascent will feel his lungs expand (Figure 5). A diver's lungs can only expand 15 to 30 percent of their original volume without bursting. Therefore, ascending without breathing may result in lung tissue bursting (Figure 5).

Figure 5 Lungs of ascending scuba diver



A smart diver breathes on ascent. Breathing results in equalizing the pressure inside the lungs and air spaces with the outside pressure so that the normal lung and air space volume is maintained (Figure 5).

As the pressure increases, the density of the gas increases directly. This means that if the pressure on a gas doubles, the density doubles. As the pressure of the gas increases, remember the volume decreases. This decrease in volume results in the gas molecules occupying a smaller space. This decrease in space occupied by a set number of gas molecules means that the density increases. An increase in the density of air makes it more difficult to breathe at deeper depths than at the surface.

Charles' Law

Charles' law states that if the pressure is kept constant, the volume of a gas will vary directly with temperature.

This means that as the temperature of a gas increases, the volume of space it occupies increases. This phenomenon is seen in a diver's compressed air tank. Filling the tank warms the air and causes it to occupy a greater volume. Under water, the cooler temperatures decrease the temperature of the gas in the tank and the gas decreases in volume.

Consequently, the tank will not have as much air in it as expected. This will shorten the dive time. To avoid this problem, dive shops place the tanks in cool water during filling so maximum air volume is achieved.

Dalton's Law

Dalton's law states that the total pressure exerted by a mixture of gases is equal to the sum of the pressures of each of the different gases making up the mixture—each gas acting as if it alone was present and occupied the total volume.

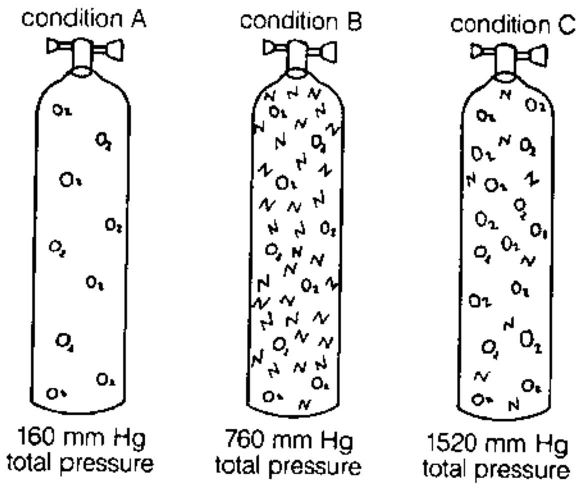
This law is illustrated in Figure 6, which shows air tanks filled under three different conditions.

Condition A

The tank contains only oxygen molecules at a low pressure. If the total pressure of the gas is 160 mm of Hg (mercury) and oxygen makes up 100 percent of the gas, what is the partial pressure of oxygen? (answer: 160 mm)

A diver's compressed air tank is never filled with pure oxygen because it is toxic. When using pure oxygen, the blood's hemoglobin becomes saturated with

Figure 6 Dalton's law



oxygen. This saturation turns off the reflexes controlling carbon dioxide exhalation and allows it to build up in the body. This results in nausea, vomiting, dizziness, tunnel vision, blackouts and grand mal seizures.

Condition B

Nitrogen has been added to the tank so that the total pressure, P_T, is 760 mm Hg (1 atm). No oxygen has escaped so the P_{O_2} is unchanged. What is the P_{N_2}?

$P_{Total} = P_{O_2} + P_{N_2}$
$760\text{ mm} = 160\text{ mm} + P_{N_2}$
$P_{N_2} = 600\text{ mm}$

What percentage of the total pressure is contributed by O_2? N_2?

$\%O_2 = P_{O_2} / P_{Total}$
$= (160\text{ mm}/760\text{ mm}) \times 100$
$= 21\%\ O_2$

$\%N_2 = P_{N_2}/P_{Total}$
$= (600\text{ mm}/760\text{ mm}) \times 100$
$= 79\%\ N_2$

These percentages are approximately the values found in the air we breathe. Other gases such as argon, neon and carbon dioxide are found in the atmosphere in very small quantities. Compressed air tanks are filled with these same percentages of oxygen and nitrogen.

Condition C

The tank's total pressure has doubled to 1,520 mm Hg (2 atm). The percentage of oxygen and nitrogen in the tanks has not changed. But more of both gases has been added to increase the pressure. What is the partial pressure of oxygen and nitrogen?

$P_{O_2} = P_{Total} \times \%O_2$
$= 1520\text{ mm} \times 0.21$
$= 320\text{ mm}$

$P_{N_2} = P_{Total} \times \%N_2$
$= 1{,}520 \times 0.79$
$= 1{,}200\text{ mm}$

The percent of each gas in the total gas mixture does not change. But as pressure increases, each of the partial pressures increase by the same amount. If you compare conditions B and C, you will see that the total pressure has doubled and so have each of the partial pressures.

Nitrogen Gas and Water Pressure—Nitrogen Narcosis

The air you inhale is a mixture of 78 percent nitrogen, 21 percent oxygen, 0.03 percent carbon dioxide and small amounts of other gases. The oxygen in the air you exhale decreases from 21 to 16 percent and the carbon dioxide increases from 0.03 to 5.6 percent. During exhalation, the body produces roughly the same amount of carbon dioxide as the oxygen taken in. Nitrogen remains the same.

At the surface, the pressure of air is one atm or 760 mm Hg. Nitrogen makes up 78 percent of the air with a partial pressure of about 600 mm Hg. As a diver experiences greater pressures, the partial pressure of nitrogen increases (the percentage of nitrogen in air remains the same with increasing pressure). At greater than 100 feet (4 atm), the increase in partial pressure causes nitrogen narcosis. At depths less than 100 feet, nitrogen is not used by the body and has no effects on it.

The symptoms of nitrogen narcosis are like those of intoxication. Divers act foolish, take off their masks, remove their mouth pieces and descend past safe limits. Several factors, including alcohol, a hangover, fatigue, excess carbon dioxide, inexperience and anxiety lower a diver's resistance to nitrogen narcosis. Nitrogen affects divers differently; any one diver may experience a variety of symptoms.

For divers working at depths greater than 100 feet, the compressed air mixture is changed. Nitrogen is removed and replaced with inert gases, usually helium. This removes the problem of nitrogen narcosis and allows the diver to work deeper. But helium is rare and costly. Usually only commercial and other professional divers descend to depths greater than 100 feet.

Henry's Law

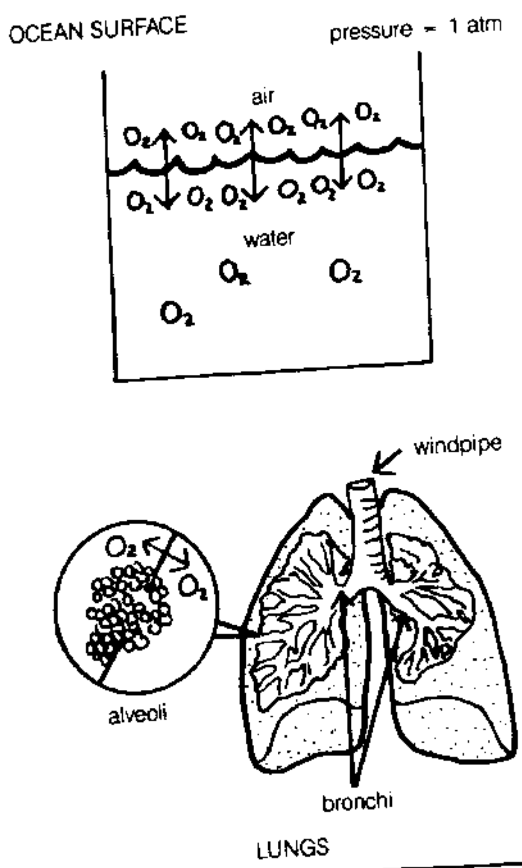
Henry's law states that the mass of a gas dissolved by a definite volume of liquid at a constant temperature is directly proportional to the pressure on that gas. The equation expressing the relationship between solubility and pressure is:

$$C_g = kP_g$$

Where:
C_g = solubility of gas in the solution phase
k = proportionality constant
P_g = pressure of gas over the solution

This means that a liquid will absorb a gas from within and outside itself (Figure 7). For example, the surface waters of the ocean are saturated with air at sea level pressure (1 atm). A human's blood is saturated with oxygen, nitrogen and other gases found in air at sea level pressure.

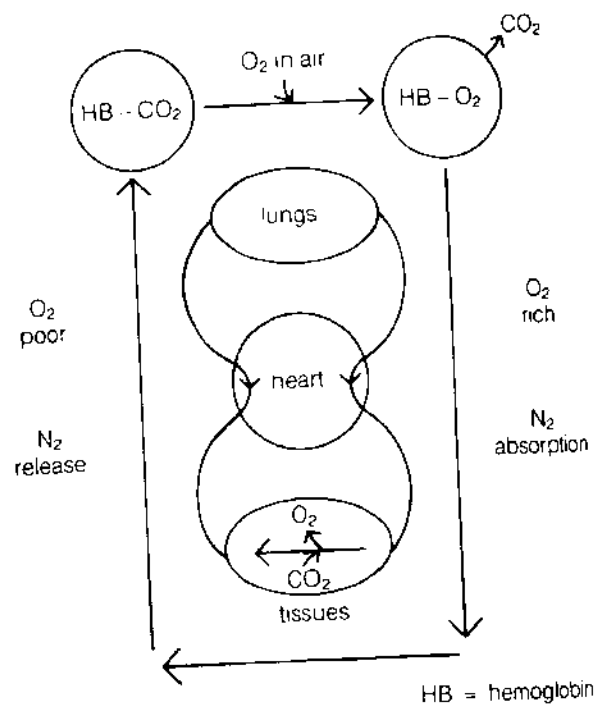
Figure 7 Henry's law



Nitrogen and Water Pressure—The Bends

Nitrogen, in air and compressed air, does not combine with blood like oxygen. As a diver descends, nitrogen goes into solution in the diver's blood and is carried to the tissues and fat. A diver's body tissues balance with the partial pressure of nitrogen for a particular depth in eight to 12 hours. The saturation of tissues by nitrogen increases with the length of the dive at a particular depth and pressure.

Figure 8 Oxygen extraction by air breathing animals



As a diver ascends, the partial pressure of nitrogen in the lungs decreases. Blood leaving the lungs at lower pressure has a lower nitrogen partial pressure and is circulated to body tissues. The tissues have a higher nitrogen partial pressure so nitrogen escapes from tissues into the blood. The blood returns to the lungs where nitrogen diffuses into the air exhaled (Figure 8). With each round of circulation, more nitrogen is removed. Nitrogen is eliminated from saturated tissues in 9 to 12 hours. This elimination process is known as decompression.

If decompression occurs too rapidly, the blood and tissues may receive too much dissolved gas to hold in solution. Because the load of gas cannot be carried to and eliminated from the lungs quickly enough, the gas liberates itself in the form of bubbles that appear in the blood and tissues. Therefore, a diver needs to observe certain "hold points" during his ascent. Stopping at certain points allows time for excess nitrogen to be removed from the bloodstream to the lungs.

The classic example of dissolved gas coming out of solution is a bottle of soda. No bubbles are visible when the cap is on because the liquid is under pressure and the bubbles are too small to be seen. Removing the cap reduces the pressure. The bubbles come out of solution. When the partial pressure of the carbon dioxide gas dissolved in the soda equals the partial pressure of the gas in the air surrounding the liquid, the soda does not bubble and is considered "flat."

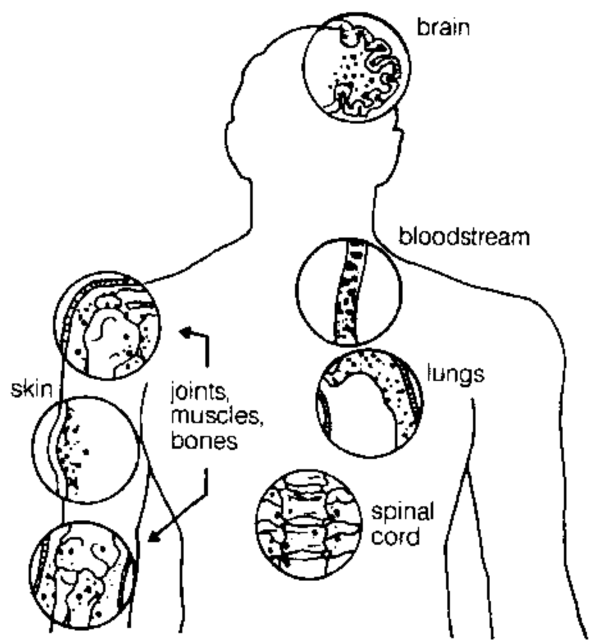
Nitrogen can form bubbles in the blood and tissues much like carbon dioxide bubbles in a soda. These bubbles move throughout the body and can: 1) lodge in constricted areas such as joints causing pain, 2) pinch off and damage nerves and 3) cause paralysis. This condition is known as decompression sickness, the bends or caisson disease.

Decompression sickness is certainly the most famous diving illness. It was discovered in the 19th century by laborers working in tunnels beneath rivers. To keep water out of working areas, the tunnels were pressurized. Many workers returning to ordinary atmospheric pressure at the end of the day developed pain in their joints. Some became paralyzed. The malady became known as caisson disease.

The disease remained a mystery until 1907 when J.S. Haldane developed "stage decompression." He found that decompression sickness could be avoided by bringing anyone who had been in a high-pressure environment to normal atmospheric pressure in gradual stages. This eliminated the formation of small bubbles of nitrogen in the blood and tissues.

Depending on where bubbles lodge in the body, the symptoms of decompression sickness may vary (Figure 9). In most cases, symptoms begin within an hour, but they make take longer (six or more hours). Other factors also increase a diver's chance of developing decompression sickness. Age, obesity, extreme fatigue, alcohol, old injuries, extreme hot or cold water, and dehydration can hinder blood circulation and prevent nitrogen from quickly entering and leaving the blood. Fat absorbs about five times more nitrogen

Figure 9 Areas affected by decompression sickness



than blood or other tissues. Consequently, nitrogen is not removed quickly from fat during decompression, making obesity a dangerous problem. Other factors to consider are the intake of certain drugs, metabolic stresses such as sleep loss, hypercoagulability (blood that readily coagulates), high altitude diving and work rate at depth.

The U.S. Navy has developed tables that tell divers the maximum number of minutes they can theoretically stay at certain depths and still avoid decompression sickness. But abiding by those limits does not guarantee safety. The U.S. Navy diving tables are based on evaluations of trained, healthy men. Sport divers range widely in physical condition and ability.

The only effective treatment of decompression sickness is immediate recompression in a hyperbaric chamber. Recompression increases the pressure around a diver (as if he were diving), reducing the size of the bubbles and forcing them back into solution. Then the pressure is slowly reduced to allow the diver to decompress gradually. At the first signs of the bends, a diver should not hesitate to seek treatment. Time is critical.

In North Carolina, the only recompression chamber is at Duke University in Durham. They have a facility for decompression sickness treatment. Duke University also sponsors a Diver Alert Network (DAN) that provides information to divers and physicians nationwide.

Questions

Boyle's Law

Hint: For every 33 feet of descent from the surface, the pressure increases by 1.0 atm. Surface pressure is 1.0 atm.

1. Holding his breath, a diver leaves the surface with 4.0 liters of gas in his lungs. What is his lung volume at a depth of 66 feet?

2. You are diving to a wreck at 132 feet. Using Boyle's law, determine the changes in pressure, volume and density with increasing depth.

Depth	Pressure	Volume	Density
(surface)	______	4.0 liters	1.0 kg/liter
33 ft.	2.0 atm	______	______
99 ft.	4.0 atm	______	______
132 ft.	______	______	______

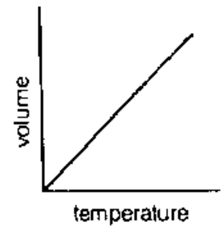
3. A diver is at 33 feet (2.0 atm of pressure) and the gas in his lungs occupies a volume of 1.0 liter. What volume would his lungs occupy at the surface? What volume at 99 feet?

4. You dive to a wreck off of the North Carolina coast. As you return to the surface (1.0 atm pressure), you forget to breathe (a big mistake). Will your lungs burst under the following situations? Use Boyle's law and show all work. Human lungs can only expand to four liters.

Site	Depth	Pressure	Volume of Lungs
A	66 ft	3.0 atm	3.0 liters
B	132 ft	5.0 atm	1.0 liter
C	99 ft	4.0 atm	0.50 liter
D	66 ft	3.0 atm	0.33 liter

Charles' Law

1. Examine the graph. Does the graph show a direct or an inverse relationship? Why?



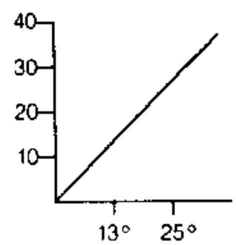
2. On a hot summer day you take your air tank to a dive shop to be filled. You then have to run a couple of errands, so you place the tank in the trunk of your car. The tank was filled at 20°C and your car trunk is 31°C.

a) What will happen to the temperature of the gas molecules in the tank?

b) What will the gas at 31°C do in the tank?

c) If the tank is filled to its maximum capacity, what do you think might happen to this tank in your trunk?

3. Using the graph below, answer the following questions.



a) What volume corresponds to a temperature of 25°C? 13°C?

b) If you were filling a tank for a diver, which temperature, 25°C or 13°C, would allow you to add the maximum amount of gas? Why?

Dalton's Law

1. The total pressure in an air tank is 810 mm Hg.

a) If the pressure of oxygen is 150 mm Hg, what is the partial pressure of nitrogen in the tank? (Assume oxygen and nitrogen are the only gases in the tank.)

b) What percentage of the gas in the tank is oxygen? Nitrogen?

c) Is this the composition you breathe normally?

2. What is the partial pressure of oxygen in compressed air from a scuba tank breathed at 132 ft? (in mm Hg and atm). Use the percent oxygen from the introduction.

3. In deep diving, divers breathe gas mixtures of helium and oxygen. The partial pressure of oxygen must be maintained at 160 mm Hg or slightly greater to avoid toxicity. In a helium-oxygen mixture breathed at 500 feet, what percentage of oxygen will result in an oxygen partial pressure of 210 mm Hg?

Henry's Law

1. Draw a graph that shows the relationship between pressure and the amount of gas dissolved in a liquid.

2. At which of the following depths would a diver have a higher partial pressure of nitrogen in his blood: 33 ft. or 132 ft. Why?

Test Questions

1. A diver descends to a wreck at 80 ft. He stays there too long and realizes that he is out of air. He swims to the surface quickly.

a) If the diver holds his breath during the ascent, how will this affect his lungs? Which gas law explains this?

b) At the surface, the diver feels pain in his joints. He suspects that he has the bends. Why might he have developed the bends? (Apply the appropriate gas laws in your answer.) How might he get rid of the pain?

2. Define each gas law.

a) Boyle's
b) Charles'
c) Dalton's
d) Henry's

3. Name the gas law that applies to each of the following conditions and explain how it applies.

a) Lungs burst
b) Nitrogen narcosis
c) Squeeze
d) Decompression sickness

4. Draw graphically the relationship that applies for each of the following gas laws.

a) Boyle's
b) Charles'
c) Henry's

5. What are the partial pressures of nitrogen and oxygen in the lungs at 0 ft? Do these change with increasing depth during a dive? Explain.

6. Rapid ascent rates may contribute to the cause of decompression sickness. True or false.

7. Helium causes decompression sickness in much the same way that nitrogen does. True or false.

8. What is the P_{N_2} of air breathed at 99 feet under water? (in atm and mm Hg)

9. Air pressure is (higher, lower) at the top of a tall building than it is at ground level.

10. Why are water pressure changes so much greater than air pressure changes with a change in depth?

11. For every 10 meters (33 feet) of water depth, divers experience an additional __________ atmosphere(s) of pressure.

12. Name three body areas where divers notice pressure the most.

13. How does scuba gear keep the diver from experiencing pressure in the body cavities?

14. Name three problems that air in the bloodstream can cause?

15. During a dive, gases entering the lungs are absorbed to a (greater, lesser) extent into the bloodstream than when the diver is on land.

16. As the diver ascends, gases dissolved in the bloodstream do not stay dissolved. They become bubbles in the blood. Name three problems that gas bubbles can cause for the diver?

17. The formation of gas bubbles in the bloodstream is called ______________________________.

18. What is the purpose of hold points during a diver's ascent to the surface?

19. A gas is (more, less soluble) in a hot liquid than it is in a cold liquid.

ACTIVITY 4

Underwater Research Facilities: *Hydrolab*

Purpose

To teach about saturation diving in underwater facilities.

Background

The number of people involved in diving activities has increased steadily. This increase is found in scientific, recreational and commercial diving. Because of this heightened interest, there is a need for equipment and procedures that would allow a diver to operate with greater flexibility, safety and effectiveness and for longer periods of time. Although significant achievements are being made towards working at greater depths, particularly by offshore industries, much work is still confined to waters less than 300 feet deep.

Pioneering work in the 1930s indicated that saturation diving might be feasible and provide divers the extended time and depth needed. Under saturation conditions, divers spend 24 to 36 hours under depth-pressure to become saturated with an inert breathing gas (probably helium). Once a diver is saturated, the required time for decompression is the same regardless of how long the diver stays below.

Researchers developed underwater research labs where divers become saturated and work for days to weeks at greater than normal pressures. *Hydrolab* in the Bahamas is one such facility. At *Hydrolab*, divers are saturated at 50 feet, allowing dives to greater depths to occur more easily.

The length of a dive usually proves to be the greatest limiting factor for scientists. But working out of *Hydrolab*, divers can work longer at their research sites and are able to obtain new air tanks without having to endure long surface intervals between dives. A surface interval is the time required at the surface between dives to gradually rid the body of nitrogen. The greater the time spent at the surface between dives, up to 12 hours, the longer the next dive can be.

Hydrolab is a manned habitat operated at ambient or surface pressure. Located at 50 feet, the lab saturates divers at this depth. Three to four divers live in *Hydrolab* for up to 14 days. *Hydrolab* is an 8-by-16 foot cylindrical chamber with a 3-by-10 foot submarine dry transfer tunnel. The habitat contains two bunks, lights, a communications radio, toilets, windows, tables and a shower. Divers use a lockout dry tunnel where water meets air of the same pressure to access the lab.

Divers using this facility undergo extensive training. On the first day, they are delivered to an area above the lab. They dive to the lab, set up and begin their work. Within 12 hours, they are saturated and have adjusted to the change in pressure. For the next week to 14 days, the divers work in shifts to perform their experiments. The boat returns daily to bring meals and compressed air tanks and to check on the divers.

On the last day, the divers close the tunnel and start decompression. The process takes about 14 hours. When decompression is complete, divers suit up and return to the surface. Then they return to the land station for at least 24 hours to guard against any post decompression problems.

The lab allows scientists to perform experiments that would be too difficult or impossible for divers working from the surface. Scientists use the lab to study marine biology, geology, chemistry, physics, ocean dumping, resource development and ocean technology.

Questions

1. What gas laws apply to the definition of saturation diving?

2. If a diver does not go through a complete decompression sequence what may occur? Why?

3. What is a surface interval?

4. What is the ambient pressure at *Hydrolab*? (approximate)

5. What two factors does *Hydrolab* extend for research divers?

6. Are divers using *Hydrolab* likely to develop nitrogen narcosis? Why?

7. How long does it take a diver to saturate at a new depth? How long does it take to return to surface pressure saturation?

ACTIVITY 5

Dramatic Pressure Changes

Purpose

To determine the moisture content of popcorn kernels and to observe how moisture and pressure relate to the popcorn's ability to pop.

Background

Dramatic pressure changes occur with increasing water depth in the ocean. The pressure increase of one atmosphere for every 33 feet (10 meters) of depth is a very important factor to be considered by scientific, recreational or commercial divers. Groupers, fish that are accustomed to high pressures deep in the ocean, explode when brought to the ocean's suface. Their air bladders protrude through their mouths and their eyes often pop out.

A single kernel of popcorn can provide some interesting pressure chemistry. A popcorn kernel is made of starch, protein, fat, minerals and water. The water is critical to the popping. When popcorn is heated, the water inside the kernel becomes steam and the internal pressure increases to as much as 9 atmospheres. When the hull can no longer withstand the pressure difference between the steam inside and the air outside, the kernel pops.

Equipment/Materials

normal popcorn
oven-heated popcorn
125-ml Erlenmeyer flask
aluminum foil
Bunsen burner
ring stand and ring
wire gauze
ruler
permanent felt marking pen
balance
10-ml graduated cylinder
heat-resistant gloves or flask tongs
100-ml graduated cylinder

Procedure

Moisture Content

Using aluminum foil, fashion a lid for a 125-ml Erlenmeyer flask. Determine the mass of the empty flask and lid. Record it in a data table. Remember that a data table should have a number and a title. Be sure to put units on the data.

Using the 10-ml graduated cylinder, measure the volume occupied by 20 kernels of unpopped normal popcorn. Record your findings in your data table.

Put the 20 kernels of unpopped corn in the Erlenmeyer flask and determine the mass of the flask, popcorn and the foil lid. Record this information.

Using subtraction, determine the mass of the 20 kernels of unpopped corn. Record this data.

Make sure the foil lid fits snugly over the mouth of the flask. With a pencil or a pen, make a few small holes in the foil.

Heat the flask over the Bunsen burner to pop the corn. Be sure to use wire gauze between the flask and the burner. Let the flask sit undisturbed until the kernels start to change color. Then use flask tongs or heat-resistant gloves to hold the flask. Shake the flask over the burner until all kernels pop.

Remove the flask from the heat and carefully remove the foil. CAUTION! Do not get burned by the steam! Let the flask stand for a few minutes to cool.

When the system is cool, determine the mass of the flask, lid and popped corn. Record this information.

Ability to Pop

Mark a kernel of oven-heated popcorn with a felt marker and place it in a 125-ml Erlenmeyer flask along with a normal kernel. Cover the flask tightly with a foil lid. Heat the flask as instructed before. Watch the two kernels to determine which pops first and which produces the fluffiest popcorn. Record these observations.

Measure in millimeters the longest side of each of the two popped kernels. Record this information.

Questions

1. Why is the mass in popped corn less than the mass in the unpopped corn (i.e., what has left the system)?

2. What is the mass of the water lost by the system? Show mathematically how you arrived at this answer.

3. What was the percentage of water in the unpopped kernels? Show mathematically how you arrived at this answer.

4. The ratio of the volume of the popped corn to the volume of the unpopped corn is called expansion volume. The popcorn industry uses expansion volume as a test of quality. Orville Redenbacher claims his gourmet popping corn has an expansion volume of 40 to 1. What is the expansion volume (expansion ratio) for the popcorn used in this experiment? Show mathematically how you arrived at this answer.

5. What substance is present in a larger amount in the normal kernel as compared with the oven-heated kernel? In which kernel was the internal pressure greater before popping?

6. Which kernel produces more desirable popcorn, the normal or the oven-heated?

7. Reread the lab introduction and answer the following questions: Would popcorn pop faster on Pike's Peak or in Durham? Why?

8. Prepare a graph of expansion volume (dependent variable with no units) as a function of the percentage of water (independent variable with % units). Use data from the whole class.

Remember: Label the axes of the graph and show the units where appropriate. Protect the points on your graph with circles, squares or triangles. Make the graph cover as much of the piece of graph paper as possible. Draw a best-fit line on your graph. Give the graph a number and a title.

9. A data table must accompany the graph. Give the table a title. The columns in your data table must have titles and units where appropriate. The column titles should be: Expansion Volume, Percentage Water (%) and Source of Data. The Source of Data column should contain the first names of the lab partnership from whom the data was obtained.

NOTE: Do not put units on data in a data table if the units are already specified in the column headings.

10. At what depth in the ocean would the pressure be equivalent to the pressure inside a popcorn kernel just before it pops (9 atmospheres)? Give your answer in feet and meters. Ignore significant figures.

ACTIVITY 6

Sea Squeeze

Purpose

To relate the change in the volume of a gas to a change in pressure on the gas (Boyle's law).

Background

Ships at sea often bag and weight garbage, then dump it overboard.*

Occasionally garbage containing Styrofoam cups escapes from the bags. The high pressures at great depths in the ocean compress the air in the cups, squeezing them into miniatures. This basic idea of the changing volume of a gas with a change in pressure on the gas can be illustrated using a marshmallow and a vacuum pump. In this case, air will be expanding instead of being compressed.

*An international treaty called MARPOL-Annex V, passed as an act by the U.S. Congress in 1988, bans all dumping by commercial vessels in territorial waters of the high seas. U.S. military vessels are exempt until 1994.

Equipment/Materials

vacuum pump
bell jar
marshmallows (fresh)

Procedure

Place a fresh marshmallow in a bell jar and reduce the pressure in the jar by using a vacuum pump. The marshmallow is whipped and contains air bubbles. As the external pressure is reduced, the air bubbles in the marshmallow will expand. The marshmallow looks like a monster coming alive as it grows.

As pressure returns to normal, the marshmallow shrinks. If the vacuum pump is left on too long, the air bubbles in the marshmallow will burst. When the pressure returns to normal, the marshmallow will shrivel. Then students can see an airless marshmallow.

An interesting extension of this demonstration is to combine several marshmallows into an artistic creation. For instance, you could make a snowman.

Questions

1. How are pressure and volume related, inversely or directly?

2. Write a mathematical equation that relates pressure and volume.

3. Use Boyle's law to relate the marshmallow exercise to a diver's lungs.

ACTIVITY 7

Diver's Lung

Purpose

To relate the change in the volume of a gas to a change in pressure on the gas (Boyle's law).

Background

The first effect divers feel when descending into the ocean is a "squeeze" on their lungs because of the increasing ambient pressure. Breathing compressed air will equalize the pressure inside and outside the lungs and relieve the squeeze.

An ascending diver experiences the opposite pressure-volume effect. Divers not breathing on ascent feel their lungs expand. A diver's lungs can only expand 15 to 30 percent of their original volume without bursting. Smart divers breathe on ascent so that external and internal pressure is equalized and the normal lung and air space volume is maintained. This pressure-volume relationship can be illustrated by using a ballon and a vacuum pump.

Equipment/Materials

vacuum pump
bell jar
balloons

Procedure

Put a small amount of air in a balloon. Tie it off so no air escapes. Place the balloon in bell jar. Reduce the pressure by using a vacuum pump. As the pressure reduces, the balloon expands because the pressure inside is greater than external pressure. As the pressure returns to normal the balloon shrinks.

To make this demonstration a little more interesting, a message or drawing could be put on the outside of the balloon. The message/drawing should be small so that it is hardly noticeable until after the balloon expands.

Questions

1. How are pressure and volume related, inversely or directly?

2. Write a mathematical equation that relates pressure and volume.

3. Use Boyle's law to explain the changes in a diver's lungs as he descends or ascends in the ocean.

ACTIVITY 8

Pressure Versus Volume Experiment

Purpose

To illustrate the relationship between the pressure and volume of a gas (Boyles' law).

Equipment/Materials

4,000-ml graduated cylinder
50-ml buret
smaller graduated cylinders
metric ruler

Procedure

Fill the 4,000-ml graduated cylinder to its top graduation with tap water. Let the water sit until it has reached room temperature. (The cylinder could be filled the night before the lab.)

Close the stopcock on the buret. Use a small graduated cylinder to add approximately 8 to 10 ml of tap water to the buret.

Put your finger over the open end of the buret; invert the buret; and lower it into the water in the 4,000-ml graduated cylinder. Remove your finger.

Raise or lower the buret until the water level inside the buret coincides with the water level in the graduated cylinder. At this point, is the pressure being exerted on the air in the buret greater than, less than, or equal to atmospheric pressure? (Answer: equal)

While holding the buret so the water levels inside and outside the buret coincide, read the volume of water in the buret.* Be sure to read the graduations on the buret to two decimal places. Remember to read the volume at eye level. Record this volume in a data table.

Move the buret down into the graduated cylinder until the water level inside the buret coincides with the 3,500-ml mark on the cylinder. Read the volume of water inside the buret.* Record this volume in your data table.

Has the water level inside the buret risen or fallen? (Answer: risen) Why did this water level change occur? (Answer: Pressure on the air in the buret is greater and the air takes up less volume.)

While holding the buret's water level at the 3,500-ml mark, use a metric ruler to measure the distance between the water level in the graduated cylinder and the water level in the buret.* Take your measurement in centimeters, and read the ruler to two decimal places. Record this measurement in your data table in a "Height of Water" column.

Move the buret down again so that the water level coincides with the 3,000-ml mark on the graduated cylinder. Read the water volume in the buret,* and record it in your data table. Before moving the buret from the 3,000-ml mark, use the metric ruler to measure the distance between the water level in the graduated cylinder and the water level in the buret. Record this measurement.

Continue this process of moving down 500 ml, measuring, and recording until you can go no further down in the graduated cylinder.

*Add the necessary volume to each reading to account for the water that is filling the unmarked part of the buret.

Questions

1. How can you determine the total volume of your buret?

2. What is the total volume of your buret? (It will not be 50 ml.) Record as many significant figures as your measuring device will give.

3. Calculate the volume of air in the buret at each data point by subtracting the volume of water from the total volume of the buret. Record the answers to your calculations in the "Volume of Air" column in your data table. Show your calculations.

4. State Boyle's law.

5. Write the mathematical statement of Boyle's law that shows two different pressures and volumes of the same gas.

6. Assume that the first volume of air in your data table was measured at room pressure. Use a barometer to determine the atmospheric pressure in the classroom. Record this pressure in the "Pressure on Air" column in your data table.

7. Use Boyle's law to calculate the pressures related to the other air volumes and record them in your data table. Show your calculations. Do not forget to use units.

8. Based on the data in your data table, how are the pressure and volume of a gas related, directly or inversely?

9. Using your data, make a proper graph of volume versus pressure.

10. Based on the water height and pressure data, how much does the pressure exerted by the water change for each centimeter of water height? HINT: Get an average of the $\Delta P/\Delta h$ calculations. Show your calculations.

11. In fresh water, pressure changes 1.00 atmosphere for every 34 feet of water height. Convert this to atmospheres/centimeter. Show your mathematical work.

12. Using the results in questions 10 and 11, calculate your percent error for change of pressure with depth of water. Show your mathematical work.

13. What other substance (in the gaseous state) was introduced into or increased in the air trapped in the buret because of the procedure used in this experiment.

14. Give two sources of error in this experiment.

15. How is the water we used in this experiment different from seawater?

16. If a diver is 50 feet down in fresh water, would he experience more or less pressure than if he were 50 feet down in ocean water? Why?

17. Imagine a diver descending into the ocean. What will happen to the volume of his lungs and the air inside? Why?

18. What could happen to a diver's lungs as he ascends if he does not exhale while rising?

19. Today scuba gear is commonly used for diving in the ocean. What words are represented by each letter in the acronym scuba?

Competency Factors/References

Competency Indicators

Chemistry-Academic—

5.4 know how to make calculations for the prediction of the behavior of gases.

Chemistry-Applied/Technical—

5.4 know how to make calculations for the predictions of the behavior of gases.

Physical Science-Academic—

3.6 know the basic characteristics of solutions.

Competency Measures

Chemistry-Academic—

5.4.1 describe the behavior of gas in terms of kinetic molecular theory; and

5.4.2 make calculations and laboratory verification of the relationships of pressure, volume and temperature.

Chemistry-Applied Technical—

5.4.1 make calculations and laboratory verifications of the relationships of pressure, volume and temperature; and

5.4.3 examine instruments and formulate methods of measuring pressures and volumes of gases.

Physical Science-Academic—

3.6.1 identify the various types of solutions: liquids, gases, solids.

References

"Balloon Pressure," *Chemmatters.* October 1985, p. 11.

Barsky, Steven M. 1982. "Diary of a Commercial Diver," *Skin Diver.* July. p. 19–22.

Bonaventura, Celia and Joseph, Irving Hooper, Todd Marshall. 1984. "Underwater Life Support Based on Immobilized Oxygen Carriers," *Applied Biochemistry and Biotechnology.* 9:65–80.

Bonk, James F. "Mixture of Gases Experiment," *Laboratory Manual for Chemistry: From Observations to Principles.* Contemporary Publishing Company, Raleigh, N.C.

"Build a Hot Air Balloon," *Chemmatters.* December 1983, p. 12.

Carrier, Rick and Barbara. 1973. *Dive.* Funk and Wagnalls Publisher, New York.

Clarke, Robert. 1973. *The Ocean World of Jacques Cousteau.* Robert Clarke-Publisher, Danbury Press, Volumes 10 ("Mammals in the Sea") and 12 ("Man Reenters the Sea").

"Gas Laws and Scuba Diving," *Chemmatters.* February, 1983, pp. 4–6.

Graver, Dennis. 1984. PADI Diver Manual. PADI Publishing. Santa Ana, California.

Hauser, Hillary. 1982. "The California Abalone Divers," *Skin Diver.* June. p. 32–38.

"How the Right Professor Charles Went Up in the Wrong Kind of Balloon," *Chemmatters.* December 1983, pp. 14–15.

Huguenin, John E., Richard A. Fralick. 1975. "Living under the Sea," *Sea Frontiers.* 21(2):95–103.

Jeppesen, 1981. *Sport Diver Manual.* Jeppesen Sanderson.

Lee, Owen. 1968. *The Skin Diver's Bible.* Doubleday and Company, New York.

Mauldin, L., Dirk Frankenberg. 1978. *North Carolina Marine Education Manual: Unit 2, Seawater.* UNC Sea Grant.

Miller, James W. 1976. "Vertical Excursions Breathing Air from Nitrogen-Oxygen or Air Saturation Exposures." U.S. Department of Commerce, NOAA.

"Reaction of a Metal with HCl," *Laboratory Manual for Chemistry Experimental Foundations,* Prentice-Hall, Inc., Englewood Cliffs, N.J., 1970.

Soule, Robert. 1968. *Undersea Frontiers.* Rand McNally and Company, New York.

Stenuit, Robert. 1966. *The Deepest Days.* Coward-McCann, Inc., New York.

Strauss, Richard H. 1976. *Diving Medicine.* Grune and Stratton, New York.

Stringer, Jack. 1983. "Euphoria at 200 ft," *Skin Diver.* February, p. 126–129.

"Students Develop Their Own Procedure," *Journal of Chemical Education.* August 1987, pp. 712–713.

Walker, Mort. 1977. *Sport Diving.* Henry Regenry Company. Chicago.

Chemistry Answers

Part 1/Chemical Reactions in the Marine Environment

Activity 1/Elements and Compounds in the Ocean

1. Silver, antimony, chromium, cobalt, rubidium, cesium, selenium, molybdenum

2. CuS, ZnS, HgS, Ag_2S, CdS, Bi_2S_3, PbS

3. Aluminum, lead, arsenic, manganese, beryllium, nickel, carbon, cobalt, silver, copper, zinc, niobium, cadmium, phosphorus, cerium, plutonium, chromium, scandium, iodine, zirconium, iron

4. Pb, Zn, Fe, Cd, Co, Cu, Ni, Mn, Sr, Ca, Mg

5. Chlorine, magnesium, bromine, strontium, sulfate, iron, silicon, manganese, sodium, zinc, calcium, copper, potassium, cobalt, nickel, lead

6. Chloride, bromide, sulfate, carbonate, bicarbonate or hydrogen carbonate, fluoride, boric acid, magnesium, calcium, strontium, potassium, sodium

7. Mn, Fe, Ni, Cu, Co

8. Carbon dioxide, nitrate ion, ammonia, ammonium ion, phosphate ion

9. Fe_2S_3, Cu_2S, ZnS, Ag_2SO_4, $CaSO_4$

Activity 2/Marine Chemical Reactions

1. $106CO_2 + 16NO_3^{1-} + PO_4^{3-} + 54H_2O \rightarrow C_{106}N_{16}PH_{108}O_{46} + 136O_2$

C:N:P = 106:16:1

2. $Cl_2 + 2NABr \rightarrow Br_2\uparrow + 2NaCl$

3. $3Br_2 + 3Na_2CO_3 \rightarrow 5NaBr + NaBrO_3 + 3CO_2$

4. $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

5. $6CO_2 + 12H_2S \rightarrow C_6H_{12}O_6 + 12S + 6H_2O$

6. $6CO_2 + O_2 + 14H_2S \rightarrow C_6H_{12}O_6 + 14S + 8H_2O$

7. $C_6H_{12}O_6 + 3H_2SO_4 \rightarrow 3H_2S + 6H_2O + 6CO_2$

$5CH_2O + 4HNO_3 \rightarrow 2N_2 + 7H_2O + 5CO_2$

8. $SiO_2 + 2H_2O \rightarrow H_4SiO_4$

$2NaAlSi_3O_8 + 2H_2CO_3 + 9H_2O \rightarrow 2Na^+ + 2HCO_3^- + 4H_4SiO_4 + Al_2Si_2O_5(OH)_4$

$3KAlSi_3O_8 + 2H_2CO_3 + 12H_2O \rightarrow 2K^+ + 2HCO_3^- + 6H_4SiO_4 + KAl_3Si_3O_{10}(OH)_2$

$2KMg_3AlSi_3O_{10}(OH)_2 + 14H_2CO_3 + H_2O \rightarrow 2K^+ + 6Mg^{2+} + 14HCO_3^- + 4H_4SiO_4 + Al_2Si_2O_5(OH)_4$

$Al_2Si_2O_5(OH)_4 + 5H_2O \rightarrow 2H_4SiO_4 + Al_2O_3 \cdot 3H_2O$

9. a) $CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$

b) $MgCO_3 + SiO_2 \rightarrow MgSiO_3 + CO_2$

c) $2Fe_2O_3 + 4SiO_2 + CH_2O \rightarrow 4FeSiO_3 + H_2O + CO_2$

d) $2Fe_2O_3 + 9CH_2O + 4CaSO_4 \rightarrow 4CaCO_3 + 4FeS + 5CO_2 + 9H_2O$

10. a) $Fe_2S_3 + 3H_2O + 6O_2 \rightarrow Fe_2O_3 + 3H_2SO_4$

b) $4FeSiO_3 + O_2 \rightarrow 2Fe_2O_3 + 4SiO_2$

Activity 3/Identification of Halide Ions

1. a. $NaCl + AgNO_3 \rightarrow AgCl\downarrow + NaNO_3$

b. $NaBr + AgNO_3 \rightarrow AgBr\downarrow + NaNO_3$

c. $NaI + AgNO_3 \rightarrow AgI\downarrow + NaNO_3$

d. $NaF + AgNO_3 \rightarrow$ No reaction

2. AgCl, silver chloride; AgBr, silver bromide; AgI, silver iodide

3. AgF, silver fluoride

4. yes

5. yes

6. soluble

7. nitrate

8. sodium

9. negative

10. a) white

b) off-white

c) yellowish

11. Improper cleaning of equipment. Poor observation/data recording techniques. Not carefully reading labels on solution bottles.

12. Hydrochloric

13. Because chloride ions in the presence of silver ions form a white precipitate, silver chloride, and fluoride ions in the presense of silver ions form no precipitate.

14. chloride

15. chloride and sodium

Activity 4/Magnesium and its Compounds

1. metal, solid, silvery, etc.

2. white powder

3. $2Mg + O_2 \rightarrow 2MgO$

4. solution becomes pink

5. basic

6. $MgO + H_2O \rightarrow Mg(OH)_2$

7. bubbling—a gas is formed

8. $Mg + 2HCl \rightarrow MgCl_2 + H_2\uparrow$

9. white powder

10. magnesium chloride, $MgCl_2$

11. yes

12. solution becomes pink

13. basic

14. $Mg + H_2O \rightarrow Mg(OH)_2 + H_2\uparrow$

15. a precipitate forms

16. $MgSO_4 + NaOH \rightarrow Na_2SO_4 + Mg(OH)_2\downarrow$

Activity 5/Magnesium from the Sea

1. clear, colorless solution

2. A cloudy, white, gelatinous precipitate formed.

3. The solution above the white precipitate was clear and colorless.

4. $MgSO_4 + 2NaOH \rightarrow Na_2SO_4 + Mg(OH)_2\downarrow$

5. magnesium hydroxide

6. Use an electric current (electrolysis).

Activity 6/Biogeochemical Zonation

Transparency 1

1. (a) atmosphere: air drafts, wind, diffusion, gravity, rain/precipitation, attachment to flying objects.

(b) water: currents, waves, diffusion, gravity, attachment to other moving things (sinking particles, swimmers).

(c) sediments: gravity, sedimentation (burial), diffusion, digging.

2. Gravity makes objects move toward the earth, whether these objects are in the atmosphere, water or sediments. However, gravity acting upon a stone in water is not the same as gravity acting upon a stone in the air or sediments.

3. The rock is eroded by wind and rain. Then it is swept into a river and eventually carried to the ocean where silicon may be leached to form dissolved ions. Leaching also may occur during runoff or in the river, with the resultant ion carried to the sea.

4. The wind carries sand across the Sahara until it reaches the Mediterranean where it drops into the sea. The sand floats to the bottom where the silicon is leached. The resultant ions are carried by current through the Straits of Gibraltar to the eastern Atlantic.

Transparency 2

1. They need light and CO_2 to make food.

2. The zooplankton feed on the phytoplankton.

Transparency 3

1. Zooplankton satisfy their need by eating phytoplankton, other zooplankton or decaying organic matter. Fish eat phytoplankton, zooplankton and other fish.

2. The decomposition process starts with the ingestion of the zooplankton. Through the digestive process, the zooplankton's cellular material is broken down into molecules the fish can use in their physiological functions. Excess and indigestible material collects in the digestive tract and is expelled as fecal material. Once the feces is released into the marine environment, it is consumed by other marine organisms and decomposed further. This decomposition process reduces the zooplankton's cellular structure to the less complex chemical elements and molecules.

Transparency 4

1. Carbon-containing molecules are the building blocks for living tissue. Through photosynthesis, carbon is changed from the atmospheric carbon dioxide molecule to a variety of saccharide (sugar) and protein forms that are used in the cellular construction and maintenance of living organisms.

2. (a) Carbon dioxide gas in the atmosphere diffuses into the water and is dissolved in the surface layers of the ocean. (b) The carbon dioxide gas dissolved in the ocean water is used by plants during photosynthesis to become carbon in living plant tissue at the ocean's surface. (c) The plant tissue containing carbon is eaten by an animal and is excreted as an ocean fecal pellet that sinks to the bottom. The plant tissue itself can be on the bottom if the depth is less than 200 meters.

Transparency 5

1. The matter is consumed by organisms that assimilate the nutrients into their own body or release them as new particles. Fewer particles are produced with depth because of continuous decomposition.

2. NO_3^- reduction would occur if NO_3^- is available; Fe reduction, if O_2 and NO_3^- are absent and iron (III) is available; SO_4^{2-} reduction, if O_2, NO_3^- and Fe (III) are absent and SO_4^{2-} is available.

3. The dead matter would not be broken down (decomposed) by organisms. It would probably sink and be buried over time. The absence of such oxidizers in our geologic past is believed to be what is responsible for large oil deposits.

Part 2/Density Dynamics and Estuaries

Activity 1/Salinity Stratification

1. Because of the different densities of the solutions and the care taken not to mix the solutions.

2. The solutions may have mixed depending on what order was chosen.

3. They will mix.

4. Waves, tides and rainfall.

Activity 2/Salinity Predications

1. salt

2. Denser salt water flows to the bottom.

3. Surface is river water; bottom is ocean water.

4. Closest to the bottom

Activity 3/Density and Buoyancy of the Ocean

1. The sugar makes the regular soda denser.

2. salt water

Activity 4/Estuarine Stratifications and Animal Adaptions

Problem 1

DEPTH	Site 2 DENSITY	Site 1 DENSITY
0 ft.	1.016 g/ml	1.006 g/ml
2.5 ft.	1.016 g/ml	1.006 g/ml
5.0 ft.	1.016 g/ml	1.006 g/ml
7.5 ft.	1.016 g/ml	1.006 g/ml

This is a vertically mixed estuary.

Problem 2

DEPTH	Site 2 DENSITY	Site 1 DENSITY
0 ft.	1.002 g/ml	1.001 g/ml
2.5 ft.	1.004 g/ml	1.002 g/ml
5.0 ft.	1.015 g/ml	1.004 g/ml
7.5 ft.	1.022 g/ml	1.006 g/ml

This is a salt wedge estuary.

Problem 3

DEPTH	Site 2 DENSITY	Site 1 DENSITY
0 ft.	1.010 g/ml	1.003 g/ml
2.5 ft.	1.013 g/ml	1.008 g/ml
5.0 ft.	1.022 g/ml	1.022 g/ml
7.5 ft.	1.024 g/ml	1.024 g/ml

This is a highly stratified estuary.

Problem 4

1. Between the 1.013 and 1.020 lines near the bottom; the same place.

2. Similar density

3. No. The water is of lower density.

Problem 5

1.

SITE	DENSITY
A	1.028 g/ml
B	1.009 g/ml

2. As the density decreases, the *Metridium* decreases in size. As the density increases, the *Metridium* returns to its original shape. The *Metridium* expels water from its body cavity reducing the tissue contact with the external medium when it encounters lower density seawater. This is a gradual change over the time period indicated.

Problem 6

1. High density

2. Low density

3. If density decreases, fewer larvae are released.

Test Question Answers

1. It will decrease. It will decrease.

2. No. Seawater in the Northern Hemisphere will be of a lower density.

3. A. As density decreases, the hermit crab hides in his shell (is not exposed).

B. As density increases, it moves around.

4. Density
1.003 g/ml
1.026 g/ml
1.020 g/ml
1.009 g/ml

5. Depth
0 m
bottom
4 m
2 m

Highly stratified.

Part 3/pH and Ocean Buffering

Activity 1/Acids and Bases

1. 2b and 3

2.

Equation	BL Acid	BL Base
2b	H_2CO_3	H_20
3	HCO_3^-	H_20

3. (a) HCO_3^-

4. Because HCO_3^- can donate a hydrogen ion.

5.

Equation	Conjugate Base	Conjugate Acid
2b	HCO_3^-	H_3O^+
3	CO_3^{2-}	H_3O^+

6. (b) HCO_3^- and CO_3^{2-}

7. The water is in the liquid state.

8. (g) means gaseous state
(aq) means dissolved in water

9. It is maintaining an equilibrium between the gaseous state in the earth's atmosphere and an aqueous state in the ocean.

(For example, carbon dioxide gas is traveling from the atmosphere to the water where it is dissolved. This reaction is tending toward equilibrium with respect to CO_2 gas and dissolved CO_2, which is coming out of solution [like bubbles in soda pop] and entering the atmosphere.)

10. They are also moving to equilibrium concentrations, which are based on the amount of the compounds and the buffering ability of the ocean.

11. Hydronium ion

12. Both, because it can function as a proton donor and a proton acceptor. A Bronsted-Lowry acid is a proton donor. A Bronsted-Lowry base is a proton acceptor.

13. Reactants; HCO_3^-, H_2O
Products; CO_3^{2-}, H_3O^+

Activity 2/Inorganic Carbon Compound Reactions and their Equilibrium Constants

1.

Reactants	Products	Equilibrium Constant Expression
$CO_2(g)$	$CO_2(aq)$	$K_1 = \frac{CO_2(aq)}{CO_2(g)}$
CO_2, H_2O	HCO_3^-, H_3O^+	$K_2 = \frac{[HCO_3^-][H_3O^+]}{[CO_2]}$
HCO_3^-, H_2O	CO_3^{2-}, H_3O^+	$K_3 = \frac{[H_3O^+][CO_3^{2-}]}{[HCO_3^-]}$

2.

K_2	K_3
7.41×10^{-7}	4.17×10^{-10}
17.0×10^{-7}	37.2×10^{-10}
10.0×10^{-7}	7.41×10^{-10}

3.

Table 5

K_2	K_3	HCO_3^-	CO_3^{2-}	H_3O^+	CO_2
11.0	10.5				.738
10.2	8.32		5.65		
9.33	6.46				3.87
9.12	6.17				9.33
7.76	4.47		4.87	12.4	
7.76	4.47		4.64	12.8	
7.76	4.47				22.7
7.24	3.98				99.4

Activity 3/What is pH?

1. a. 4.0
 b. 14
 c. 7.1
 d. 1.6
 e. 4.45
 f. 7.54

2. a. 1×10^{-5}
 b. 1×10^{-1}
 c. 2.5×10^{-4}
 d. 5.0×10^{-10}
 e. 3.47×10^{-8}
 f. 1.58×10^{-14}

Questions

1. CO_2

2. CO_2

3. From the atmosphere

4. $CO_2 + H_2O \rightarrow H_2CO_3$

5. Increasing dissolved CO_2 makes a solution more acidic.

6. (student answer)

7. (student answer)

8. salt, neutralization

9. HNO_3, $Pb(OH)_2$

10. H_2CO_3, NaOH

11. 7

12. The reaction of a salt with water to produce a slightly acidic or slightly basic solution.

13. (It will be acidic.) yes

14. (It will be basic.) yes

15. weak

16. strong

17. (student answer)

18. (student answer)

19. Hydrochloric acid furnishes more hydrogen (hydronium) ions in solution. pH is a measure of hydrogen ions in solution.

20. basic

21. to neutralize an "acid" stomach
to combat acidosis in heart attack victims

22. (student answer)

23. vinegar, lemon juice

24. acidity

25. (student answer)

26. Acids and bases neutralize each other.

27. A solution that resists a change in pH.

Part 4/The Behavior of Gases in the Marine Environment

Activity 1/Seawater and Pressure

1. Because of pressure differences, pressure is greatest on the bottom hole.

2. Water would stream out even farther because the pressure would be greater.

3. No difference

4. The distance is less because the pressure is decreasing.

Activity 2/The Cartesian Diver

1. fresh

2. salty

3. Pressure on the air in the dropper is increased. More water comes in. The dropper gets heavier and it sinks.

4. Releasing the pressure on the air in the dropper reverses the process described in #3.

5. Greater salinity makes the water denser, and it will support a greater mass. Thus the dropper must be denser to submerge in salt water than in fresh. That means greater pressure must be put on the air inside the dropper. This is why more pressure is required to cause the dropper to dive in salt water.

Activity 3/Scuba Diving and the Gas Laws

Boyle's Law

1. 66 feet = 3.0 atm pressure
$P_1V_1 = P_2V_2$
(1.0 atm) (4.0 liters) = (3.0 atm) V_2
V_2 = 1.31 liters

2.

Depth	Pressure	Volume	Density
surface	1.0 atm	4.0 liters	1.0 kg/liter
33 ft.	2.0 atm	2.0 liters	2.0 kg/liter
99 ft.	4.0 atm	1.0 liter	4.0 kg/liter
132 ft.	5.0 atm	0.80 liter	5.0 kg/liter

3. $P_1V_1 = P_2V_2$
surface: (2.0 atm)(1.0 liter) = (1.0 atm)V_2
V_2 = 2.0 liters

99 feet: (2.0 atm)(1.0 liter) = (4.0 atm) V_2
V_2 = 0.50 liter

4.

Site	Depth	V_2	Burst
A	66 ft.	9.0 liters	yes
B	132 ft.	5.0 liters	yes
C	99 ft.	2.0 liters	no
D	66 ft.	.99 liter	no

Charles' Law

1. As the temperature of the gas increases (at constant pressure), volume increases. This is a direct relationship.

2. a) It will increase.
b) The gas will expand.
c) It might explode.

3. a) 13°C = 1.5 liters 25°C = 3.0 liters
b) 13°C. The low temperature gas occupies less volume so more gas can be added to an air tank.

Dalton's Law

1. a. $P_{Total} = P_{O_2} + P_{N_2}$
810 = 150 mm + P_{N_2}
P_{N_2} = 660 mm Hg

b. $\%O_2 = (P_{O_2} / P_{Total}) \times 100$
$= (150\text{ mm}/810\text{ mm}) \times 100$
$= 19\%$

$\%N_2 = (P_{N_2} / P_{Total}) \times 100$
$= (660\text{ mm}/810\text{ mm}) \times 100$
$= 81\%$

c. Yes, very close.

2. 132 feet = 5.0 atm

$P_{O_2} = P_{Total} \times 21\%$
$= 5.0\text{ atm} \times .21$
$P_{O_2} = 1\text{ atm}$

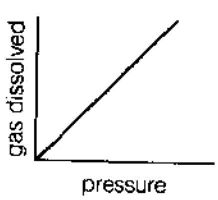
$5.0\text{ atm} \times 760\text{ mm Hg/atm} = 3{,}800\text{ mm Hg}$

$P_{O_2} = P_{Total} \times 0.21$
$= 3{,}800 \times 0.21$
$= 8.0 = 10^2\text{ mm Hg}$

3. 500 feet = 16.0 atm [1 atm at the surface plus 15.0 atm more (500.33 feet)]

$P_{Total} = (16.0\text{ atm} \times 760\text{ mm}) / 1\text{ atm} = 1{,}200\text{ mm Hg}$
$\%O_2 = (P_{O_2} / P_{Total}) \times 100$
$= (210\text{ mm} / 1{,}200\text{ mm}) \times 100$
$= 18\%\ O_2$

Henry's Law

1. 

2. At 132 feet, the increase in depth and in pressure results in increases in nitrogen dissolved.

Test Question Answers

1. a) If the diver holds his breath during ascent, he risks bursting his lungs. This is possible because as the pressure decreases in his lungs the volume of the gas increases (Boyle's law).

b) If the ascent is too quick because he panics, he may develop the bends. The decrease in pressure would force nitrogen from the tissues faster than it can be removed from the bloodstream. Nitrogen may have entered his bloodstream in the form of bubbles that lodged in his joints. This problem is explained by Henry's law. Using a recompression chamber should alleviate the pain. The diver will be fine if he remains calm, ascends slowly and exhales.

2. See lecture material.

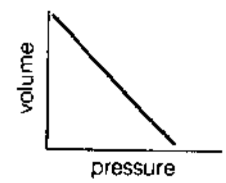
3. a) Boyle's law. If a diver holds his breath during ascent, the pressure decreases while the volume in his lungs increases. If the maximum expansion is exceeded, the lungs will burst.

b) Dalton's law. At depths greater than 100 feet the partial pressure of nitrogen increases to a level that produces nitrogen narcosis.

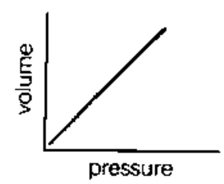
c) Boyle's law. As the pressure increases during a descent, the volume of the gas in the air spaces decreases and eventually produces a squeezing feeling.

d) Henry's law. Bubbles form in the bloodstream as nitrogen is released from tissues too quickly during a rapid ascent. As the pressure decreases on ascent, the amount of nitrogen that can remain in the tissues decreases, thus producing bubbles that bring about decompression sickness.

4. a) Boyle's Law



b) Charles' Law



c) Henry's Law

5. 160mm Hg of O_2 and 600mm Hg of N_2 (based on 21% oxygen and 79% nitrogen). Yes. The pressures change. But the percent of each gas in the air remains the same.

6. true

7. false

8. 4.0 atm at 99 feet
79% of air is N_2
$P_{N_2} = P_{Total} \times \%N_2$
$= 4.0 \text{ atm} \times 0.79$
$= 3.2 \text{ atm}$

4.0 atm = 3,040 mm Hg
$P_{N_2} = 3{,}040 \text{ mm Hg} \times 0.79$
$P_{N_2} = 2{,}400 \text{ mm Hg}$

9. lower

10. Water is denser than air.

11. 1.

12. lungs, middle ear and sinus cavities

13. Air tanks deliver air at the same pressure as the diver's surroundings.

14. loss of consciousness, brain damage, heart attacks.

15. greater

16. pain in the joints, nerve damage, paralysis

17. the bends, decompression sickness or caisson disease

18. Hold points allow dissolved nitrogen to escape.

19. less

Activity 4/Underwater Research Facilities: *Hydrolab*

1. Henry's, Dalton's and Boyle's laws

2. He may develop the bends during his ascent due to the nitrogen remaining in his tissues and fat.

3. A surface interval is the time required at the surface for a diver to gradually lose nitrogen.

4. 50 feet = 2.5 atm

5. depth and time

6. No. At *Hydrolab*, divers live and usually work at depths less than 100 feet. This means that partial pressure does not reach the level necessary to induce nitrogen narcosis.

7. It takes approximately 8 to 12 hours to become saturated at a new depth. It takes approximately the same time to return to surface pressure saturation.

Activity 5/Dramatic Pressure Change

1. water/moisture

2. student calculations

3. student calculations

4. student calculations

5. water/moisture in the normal kernel.

6. normal

7. Pike's Peak
The atmospheric/external pressure is less.

8. student graph

9. student data table

10. 264 ft. or 80 meters. The air above the ocean exerts one atmosphere of pressure.

Activity 6/Sea Squeeze

1. Pressure is inversely related to volume.

2. $P_1V_1 = P_2V_2$ or $PV = k$

3. As divers descend, the pressure increases and their lungs feel a "squeeze." As divers ascend, the pressure decreases and their lungs expand.

Activity 7/Diver's Lung

1. same as Activity 6

2. same as Activity 6

3. same as Activity 6

Activity 8/Pressure Versus Volume

1. Fill the buret with water and pour the water into a graduated cylinder through the top, not the tip, to avoid losing the water that fills the tip.

2. student answer

3. student answer

4 The volume of a gas is inversely related to the pressure exerted on the gas.

5 $P_1V_1 = P_2V_2$

6 student answer

7 student answer

8 inversely

9 student graph

10 student answer

11 $\frac{1.00\ \text{atm}}{34\ \text{ft.}} \cdot \frac{1\ \text{ft.}}{12\ \text{in.}} \cdot \frac{1\ \text{in.}}{2.54\ \text{cm}} = 9.6 \times 10^{-4}\ \text{atm/cm}$

12 student answer

13 water vapor

14 Not considering the pressure due to water vapor in the buret. Not reading the buret or metric ruler properly.

15. It is less dense because it did not contain any salt.

16. more—Salty water is more dense than fresh water.

17. It will decrease. Pressure is increasing as a diver descends.

18 They will expand and could burst.

19 self-contained underwater breathing apparatus

BIOLOGY

New Discoveries

Human beings have rocketed into space, walked on the moon and orbited the Earth. In short, we have turned science fiction into reality. Equally fascinating and challenging are the efforts to explore the "deep"—the vast oceans that cover 75 percent of the Earth's surface.

Biology is certainly the topic of the 1990s, with incredible and often troubling implications for humankind. But surely unraveling the mysteries of the ocean depths ranks as one of the most alluring subjects.

Recent discoveries have taken us to the forefront of exciting and unexpected frontiers: the discovery of new life forms, the unearthing of unusual geologic phenomena and the exploration of oceanic movements. This unit will introduce students to a few of these recent discoveries and discuss how they've altered our previous conceptions.

ACTIVITY 1

Putting "Goo" in its Place

Purpose

To compare old and new food web concepts for the open ocean.

Background

Plankton are living organisms (plants and animals) that drift passively in water. They cannot swim against a current. Plankton can be large like a jellyfish or very small like an amoeba (Figure 1). Marine biologists sample plankton by towing very fine mesh nets through the surface layers of the oceans (Figure 2).

When oceanographers collect plankton or fish larvae, the samples contain animals with hard outer skeletons (crustaceans such as copepods or phytoplankton such as diatoms) and unidentified "goo" (remains of animals destroyed by the net). Because the animals with skeletons are in good shape, biologists describe and study them. The goo is ignored.

Attention was focused on crustaceans and their importance in the oceanic food web. Plankton such as jellyfish were thought to be relatively scarce, unimportant and hard to sample. This view is changing.

In 1974, William Hamner and his colleagues tried a different method of sampling plankton. They put on scuba gear and floated in the water with jars, ready to

Figure 2 Plankton net

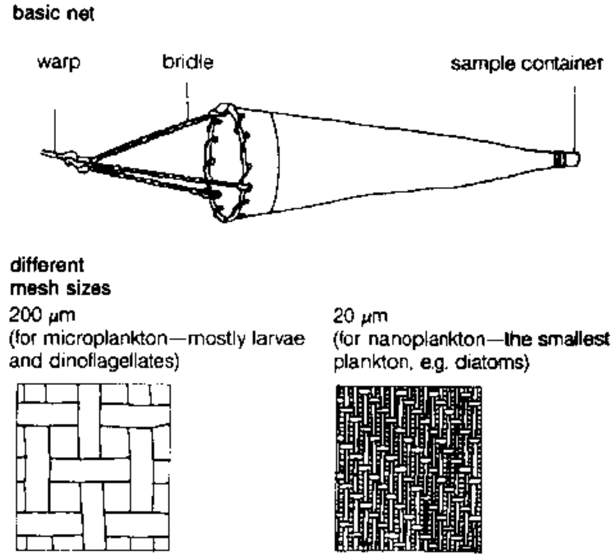
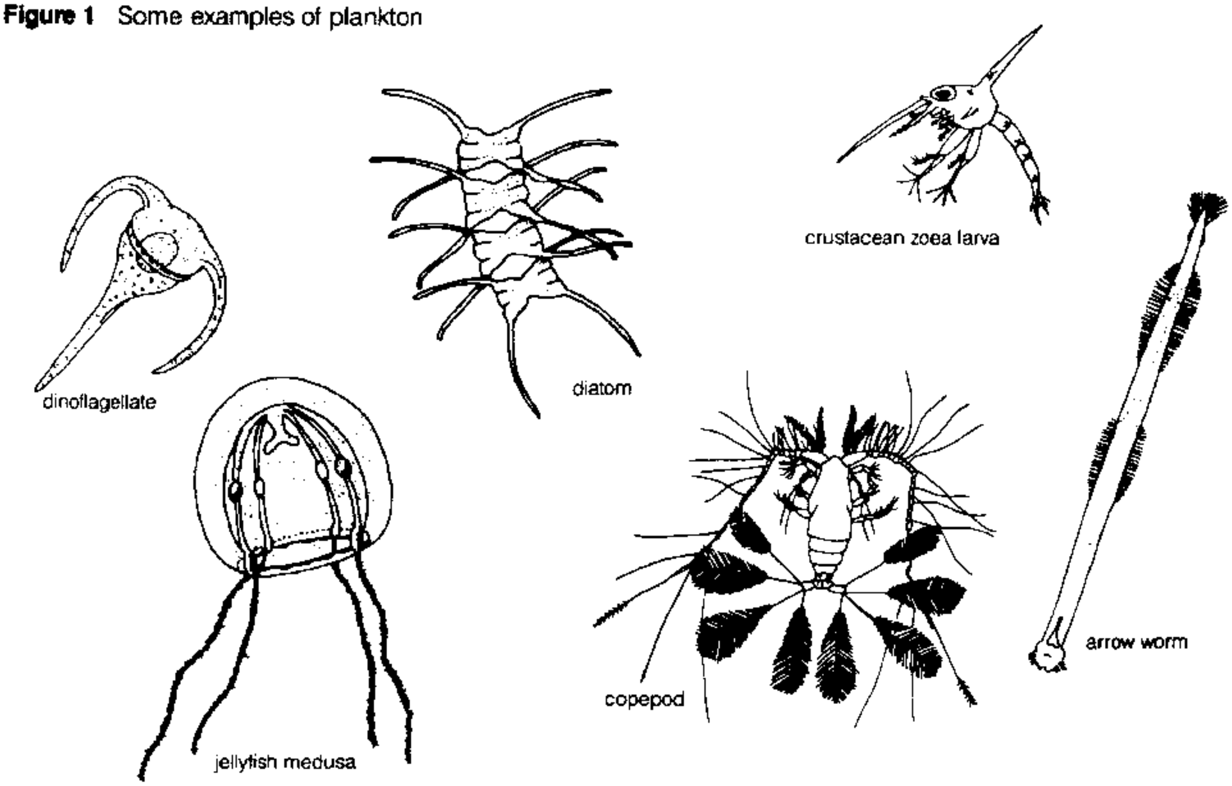


Figure 1 Some examples of plankton



observe and collect what they saw. They discovered that transparent, jellylike organisms were abundant—as numerous as the crustaceans.

These animals were behaving in ways never before seen. They were observed capturing tiny plankton that scientists had not included in the food chain.

These biologists changed the old idea of an ocean food web dominated by crustaceans to a more complex version involving a greater variety of organisms.

Gelatinous Plankton

Gelatinous zooplankton refers to the soft, transparent jellylike organisms that Hamner's group observed and collected. The term "blue-water plankton" is also used because the offshore water where they are abundant is deep and clear.

These animals come from four main phyla:
Cnidaria: the jellyfish
Ctenophora: ctenophores (comb jellies)
Mollusca: pteropods (sea butterflies)
Chordata: larvaceans, salps

Cnidarians (Figure 3) catch their prey with stinging tentacles. Ctenophores (Figure 4) swim with little rows of cilia that look like combs and catch prey with tentacles. Pteropods (Figure 5) are like floating snails. They use huge mucus nets to trap tiny plankton. Their nets work like fly paper. Larvaceans (Figure 6) look like little bent tadpoles. They build mucus houses with screens and filters to trap tiny plankton.

There are several strategies that ocean creatures use to keep from being seen and eaten in the open ocean. They can:

- be too small, therefore hard to find or not very filling (example: copepods);
- keep out of the light during the day by migrating down deeper and coming to the surface at night (example: euphausids);

Figure 3 Cnidarians

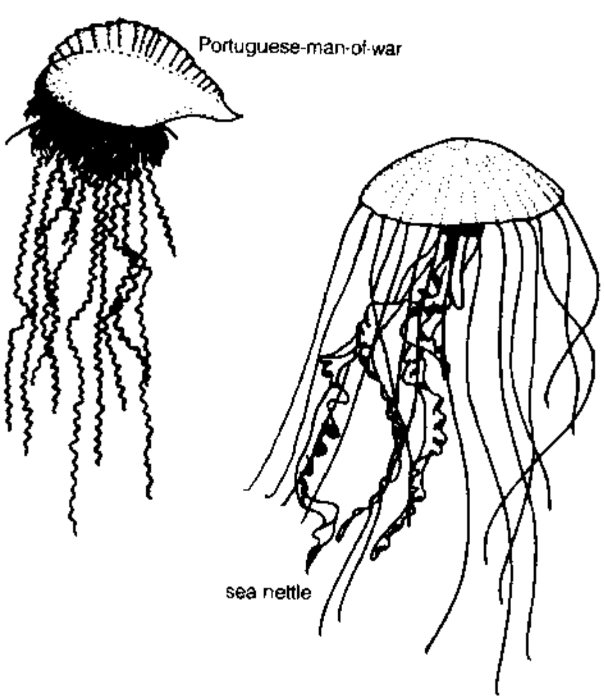


Figure 4 Ctenophores

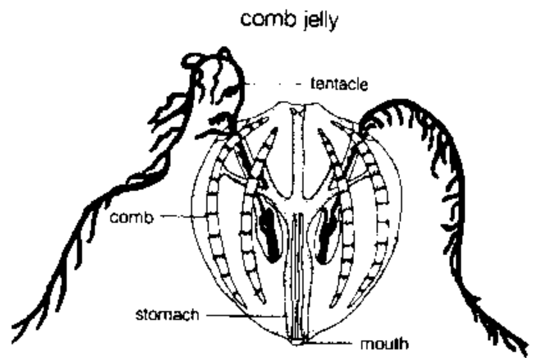


Figure 5 Mollusks

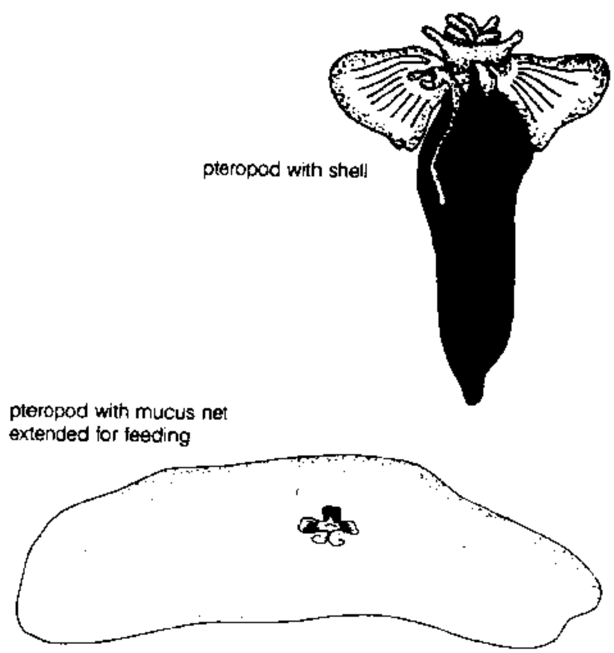
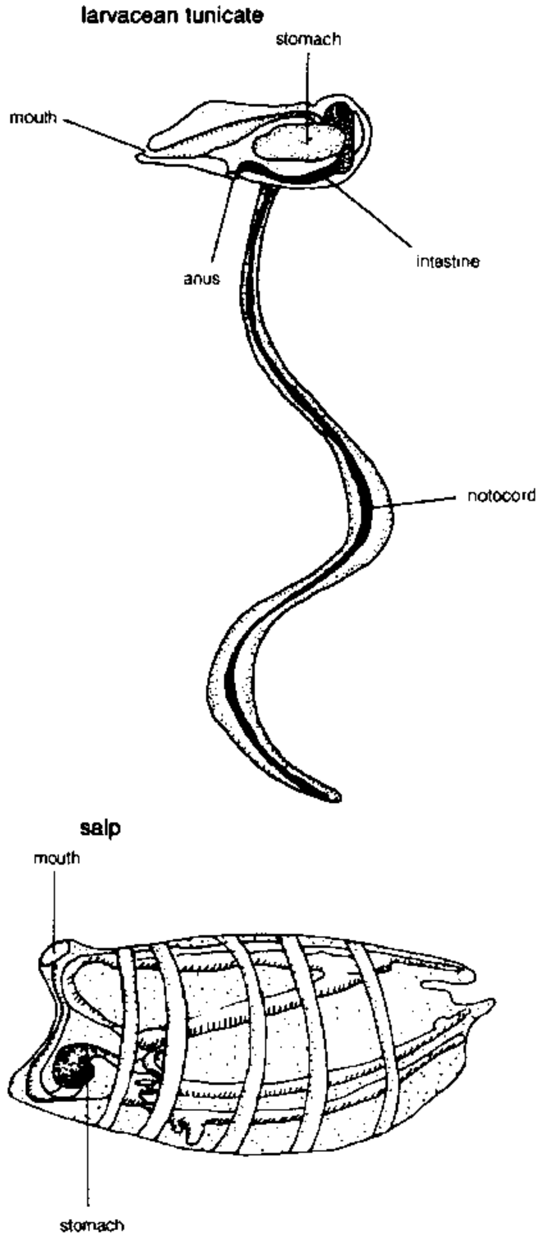


Figure 6 Chordates



- travel in large schools (example: herring);
- be large, fast and aggressive (example: sharks); or
- be large but invisible.

Blue-water gelatinous zooplankton make use of the fifth strategy. Their abundance (and the fact that we missed them for so long) proves that this is a successful strategy.

Food in the open ocean tends to be unevenly distributed and hard to find. To get as much food as possible, animals must try to do the following things:

- maximize their encounter rate with food;
- eat prey of different sizes; and/or
- use food no one else uses (less competition).

Gelatinous zooplankton have adopted these strategies and are efficient food gatherers. Jellyfish trail long tentacles (several feet) through the water. They can digest almost any size prey that is killed by the stinging tentacles.

Ctenophores use special cilia on their tentacles to slice up pieces of prey they catch. Pteropods spin a huge web of mucus to trap plankton that range from small "microplankton" to the tiniest "nannoplankton." Nannoplankton are not eaten by crustaceans because they slip through their appendages.

Larvaceans make a mucus house with filters and screens that catch the same wide range of plankton. Salps have an internal mucus net. Mucus feeding makes these creatures an important link in the food chain because they incorporate the abundant nannoplankton.

New Food Web

The abundance and behavior of gelatinous zooplankton changed the old food web outlined when crustaceans were considered the most abundant and significant (Figure 7). Adding the gelatinous plankton made the food web more complex (Figure 8).

"Marine Snow"

What happens to the discarded mucus nets, houses and dead bodies of these organisms? Some scientists believe that this gelatinous material creates a phenomenon known as marine snow. Marine snow can serve as little rafts for various tiny animals or as a food source. Often these aggregates can be fairly large mucus networks containing bacteria, fungi, phytoplankton, protozoa and small crustaceans. These packages make the ocean environment richer and able to support a greater diversity of life.

Figure 7 Old food web

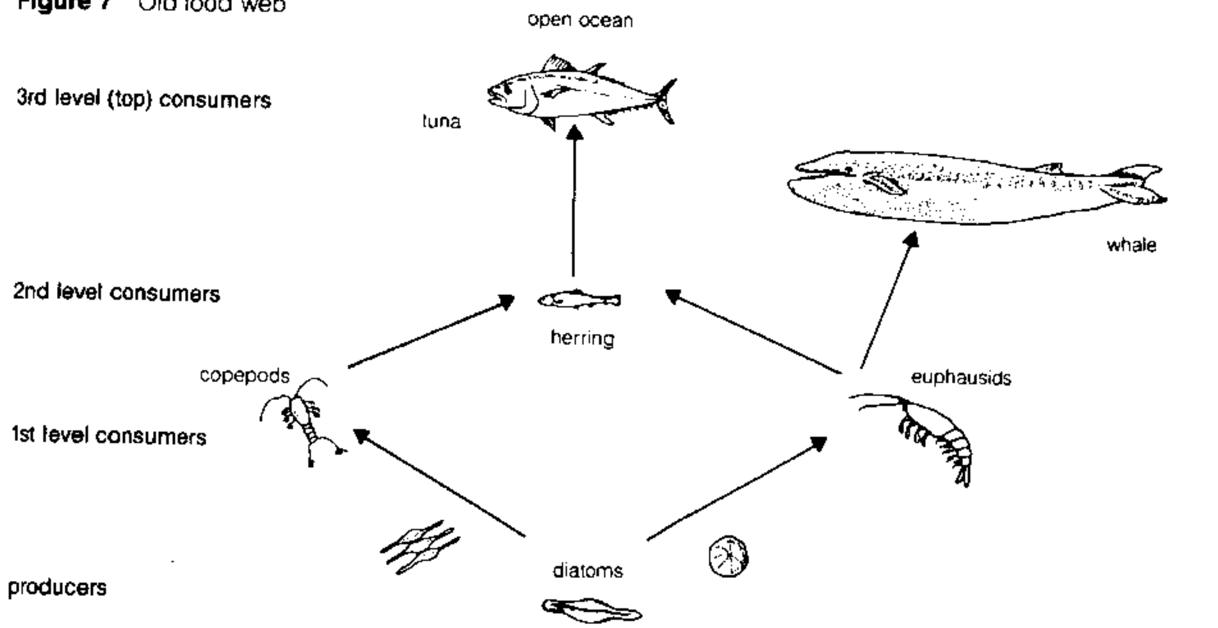
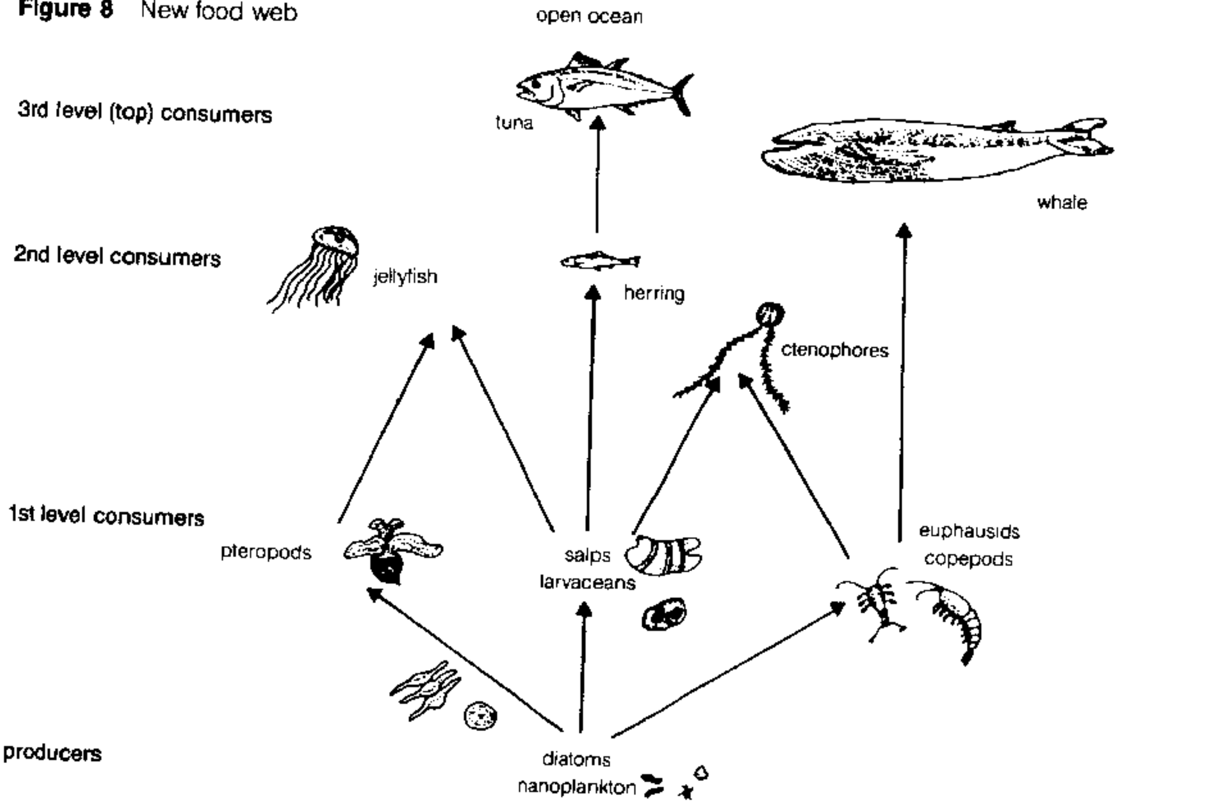


Figure 8 New food web



Introduction

Under the old method of ocean sampling, the only plankton not damaged beyond recognition by the net were those with a hard outer skeleton such as crustaceans. The most common crustaceans were tiny shrimp-like creatures called "copepods" and "euphausids." Because these were so prevalent, marine biologists assumed they were important in the ocean food web. They decided that what these crustaceans ate and what ate these crustaceans was also important. Here are the basic links in the food web they built:

- primary producers: diatoms (tiny plants with glass shells)
- primary consumers: copepods and euphausids
- secondary consumers: herrings and whales
- top-level consumers: tuna, marlin, sharks

Everything in this food web is easy to observe and catch with nets. And it is true that science depends on the accuracy of data collection and observation methods. Also, whether an idea is popular or not can make a difference. The word "paradigm" is used to describe an idea or a set of ideas that are accepted by nearly everyone. As new data is collected, scientific paradigms change. This is what happened to the open ocean food web.

The old paradigm was a simple food web made of only large animals or those with hard parts. The new paradigm uses the data collected by Hamner. It includes all the jellylike, transparent and delicate blue-water plankton. This had been ignored as "goo" in earlier plankton studies. The new food web includes:

- primary producers: nannoplankton and diatoms.
- primary consumers: pteropods, larvaceans, salps, copepods and euphausids.
- secondary consumers: jellyfish, ctenophores (comb jellies), herring and whales.
- top-level consumers: tuna, marlin and sharks.

This food web is more complete and contains a greater biomass than the old paradigm. It is important that the tiniest creatures, nannoplankton, were added as producers. This greatly increases the amount of solar energy being captured and sent through the food web. (Which creature is capable of catching nannoplankton?)

In this activity, groups will construct old style food webs and new style food webs to compare them.

Materials

wire, cut into different lengths
dental floss (or strong thread)
blank overhead transparencies
markers for transparencies
colored construction paper
hole punchers
scissors
tape

Procedure

Divide the class into two groups: Group A will construct a mobile depicting the old food web; Group B, a mobile illustrating the new paradigm.

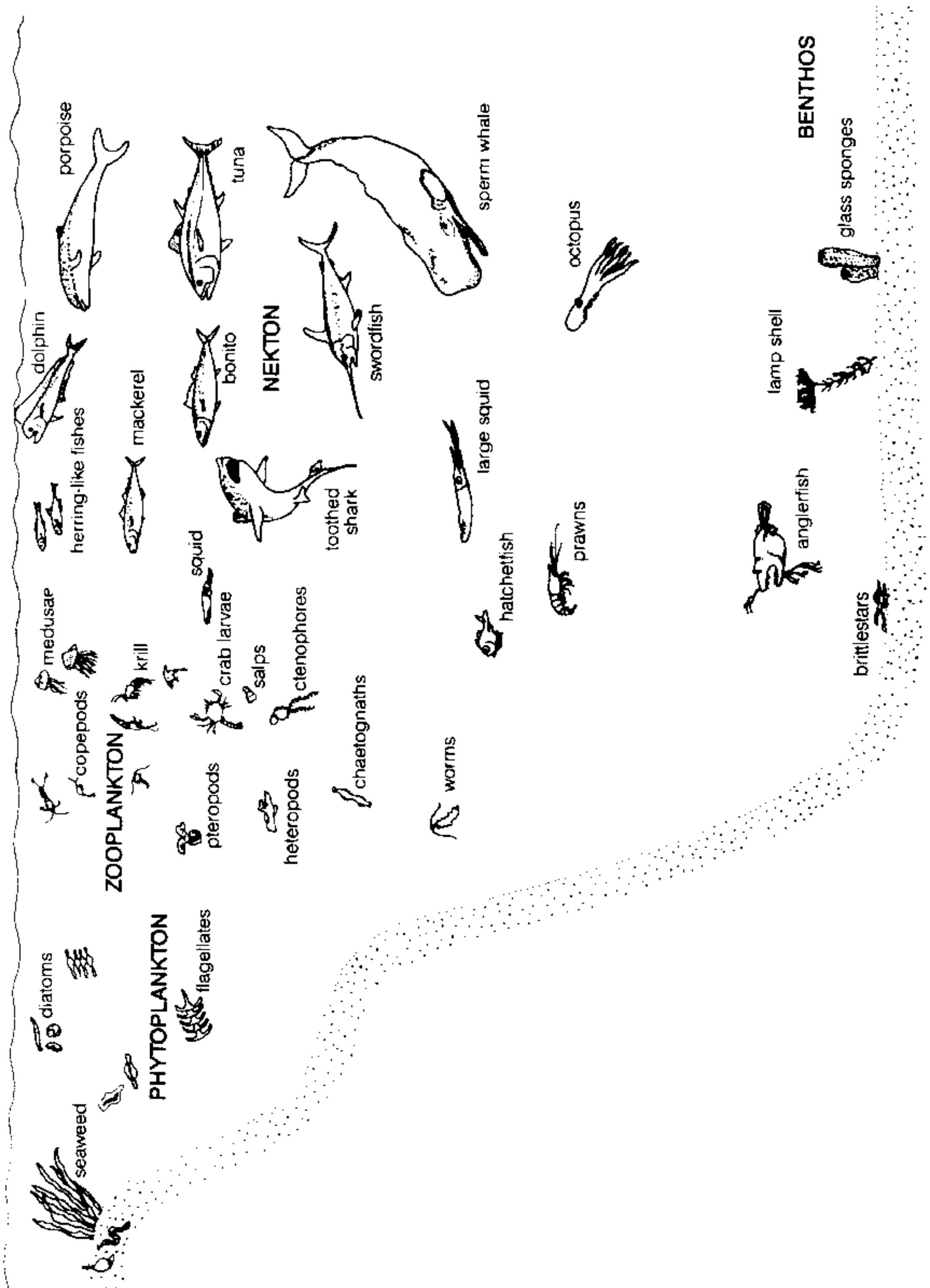
Each group should make a list of the animals they will need for their food web. Using various references provided by your teacher, search for pictures of the animals that you will include in your web. With the pictures as a guide, draw and cut out several of each kind of animal. Remember that as you go from primary producers to top-level consumers, the number of organisms would be fewer and fewer. (Example: You will need lots of diatoms, but only two or three tuna.)

Group A creatures should be cut out of construction paper. Group B should cut the delicate, transparent plankton out of overhead transparencies to make them as realistic as possible. Other creatures should be cut from construction paper.

Construct the mobile. The top of the mobile should be the top-level consumers. Make a large sign to attach to the top wire that will label your mobile as either the old paradigm or the new paradigm. Use only those organisms appropriate to your paradigm.

Each level of your mobile should contain organisms from the same trophic level. (Figure 9—Life in the Sea)

Figure 9 Life in the Sea



Questions

1. Marine biologists have always sampled plankton by:

a. Collecting it from water in jars.

b. Trapping it in nets towed from the ship.

c. Taking photographs of it floating in the water.

2. Gelatinous, blue-water plankton uses which strategy for survival in the open ocean:

a. moves fast, is large and aggressive.

b. is too small to be found easily.

c. travels in large schools.

d. is large but invisible.

3. Which of these organisms was considered important in the open ocean food web according to the old model?

a. copepods

b. pteropods

c. ctenophores

d. larvaceans

4. Which of the following statements is not true of science?

a. It is a set of theories, procedures and facts that can be used to develop new theories and collect new facts.

b. It discovers truths that are not disputed or changed once they have been accepted by scientists.

c. It is limited by time, society and technology.

d. It is constantly changing as new ways of finding facts are discovered and new theories are created.

5. Catching food with mucus is important because:

a. It changes the chemistry of the surrounding seawater.

b. It is easy to digest.

c. It is lightweight

d. It allows organisms to catch a wide size range of food.

6. Organisms that build houses out of mucus are called __________.

7. Dr. Hamner and his colleagues used __________ rather than towing nets to capture plankton.

8. A particular set of ideas or theories that nearly every scientist agrees on at one time is called a __________.

9. Jellyfish capture food with __________.

10. Diatoms and __________ are important primary producers.

Put the correct letter(s) in each blank. There may be more than one letter to each blank.

11. primary producers __________

12. primary consumers __________

13. secondary consumers __________

14. top consumers __________

a. larvaceans
b. salps
c. ctenophores
d. copepods
e. herring
f. jellyfish
g. tuna
h. whales
i. euphausids
j. diatoms

15. Explain how the invention of scuba affected our understanding of ocean plankton.

16. Give two reasons why the abundance and behavior of gelatinous zooplankton are important to the economy of the ocean.

ACTIVITY 2

Ocean Upwellings

Purpose

To see how the ecosystem concept applies to a discrete biological ocean system and to illustrate how distant events can have an impact on such a system.

Background

The ecosystem concept is important. It emphasizes the interactions between living things and their physical and chemical environment. An ecosystem is a unit of nature where organisms interact with the physical environment to create a flow of energy that defines nutritional structure, organism diversity and the exchange of materials between living and nonliving parts. But ecosystems with identifiable boundaries are rare.

Ecology texts usually use ponds or spaceships as ecosystem examples. Other systems overlap and make it difficult to perceive where one ecosystem ends and another begins. Unfortunately clear separation of units is not a common feature of the natural world. This is particularly true in ocean environments where gradual transitions from one type of natural system to another is encouraged by the constant movement of water. Consequently, ocean systems illustrate well the interconnection of natural systems and the potential impact perturbations have to areas great distances from their origin.

Coastal upwelling areas are as close to self-contained ecosystems as the ocean provides. These areas occur where offshore currents cause water from depths of about 200 meters to come to the surface.

This movement brings nutrients into the lighted surface layers and promotes biological productivity. The rate of primary production is five or more times higher than in surrounding waters. Also the relatively high nutrient concentrations allows growth of larger plants. Large plants are eaten by large herbivores. This leads to a short and efficient food chain between plants and animals that can be harvested by man.

In contrast, areas away from ocean upwellings generally have low levels of dissolved nutrients. Those that are available are rapidly taken up by photosynthesis (see Chemistry, Part 1). Plants able to compete effectively for nutrients at low concentration levels must have large surface to volume ratios, i.e. be small. Small plants can be harvested efficiently only by small herbivores. Therefore long food chains (five or more steps) separate small ocean plants from animals harvestable by man.

The result?

Almost 50 percent of the world's seafood is harvested from ocean upwelling areas. Yet, only 1 percent of the ocean has upwellings.

There are several types of upwelling: coastal, equatorial and topographic. Upwelling ecosystems are best illustrated by the coastal upwellings off the west coasts of North and South America. These systems illustrate the intimate relationship between physical conditions (wind and water movement), chemical conditions (nutrient-rich water moving to lighted surface layers; fecal and waste materials sinking to deeper layers) and biological productivity.

Tropical eastern Pacific upwellings are controlled by meteorological and oceanographic phenomena occurring over the entire Pacific Ocean basin. These phenomena, now termed El Niño or El Niño Southern Oscillation, are diagramed in the Figure 10.

In non-El Niño (normal) situations, surface air flows from areas of high pressure in the eastern Pacific to areas of low pressure in the western Pacific. This air flow augments easterly winds associated with the trade winds and blows surface water into the western Pacific where it piles up against the Asian continent.

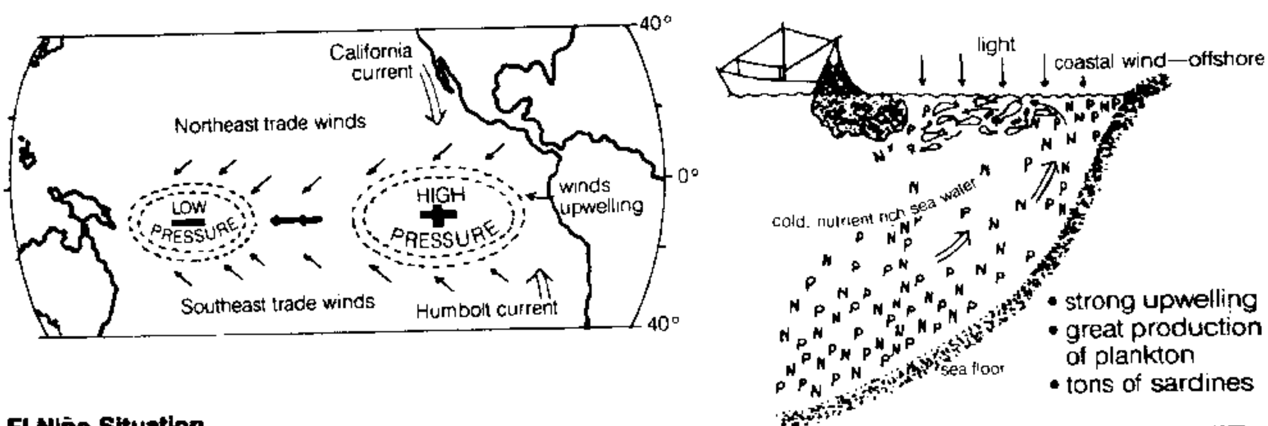
In El Niño situations, the high and low pressure systems become less intense and the flow of air between them decreases. This reduces the wind flow that holds water against Asia, and the water (or momentum derived from the potential energy of the pile) moves eastward across the Pacific. This shift of water or momentum (investigators disagree on which moves) causes warm, nutrient-poor water from the tropical Pacific to displace cold nutrient-rich water off Peru. This creates a sudden decrease in the nutrient supply and drastic changes in species composition and harvest potential. This change is termed El Niño (The Child) because it usually occurs around Christmas.

This sequence of events occurred with once-in-a-century intensity during the winter of 1982–1983. It caused droughts, floods, storms and food-production failures all across the tropical Pacific. It affected areas as far away as the Indian Ocean and U.S. Southeast. These events and the scientific analysis of their causes have been described in many popular journals—*National Geographic, Nature, Science* and *Oceanus*. Further readings are readily available for students.

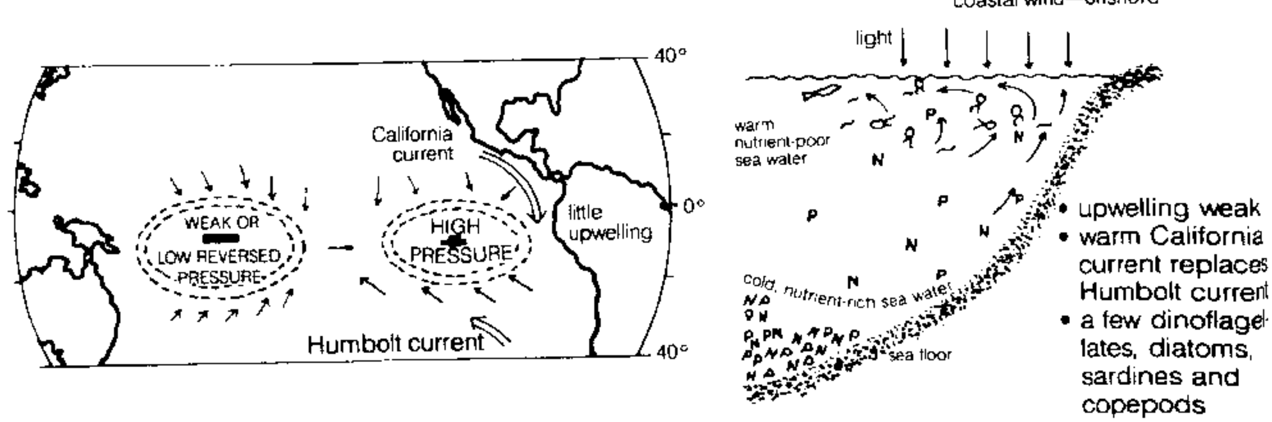
Figure 10 El Niño/non-El Niño Southern Oscillation

KEY
N = dissolved N
P = dissolved P

Non-El Niño Situation



El Niño Situation



Introduction

In an ecosystem, organisms interact with the environment so that materials are exchanged between living and nonliving components. The living components have specific composition and feeding relationships. It is easy to see how such a system exists in a lake or other habitat separated from neighboring ones. It is less easy to apply the ecosystem concept to habitats without sharp boundaries. This problem is particularly acute in the ocean where water movement and organism migrations constantly cross habitat boundaries.

Ocean scientists have recently investigated one type of ocean habitat to see how it fits the ecosystem concept. This research program focused on habitats characterized by upwellings. The research program, called Coastal Upwelling Ecosystem Analysis (CUEA), studied areas of upward moving water off Oregon, off western Africa and in the eastern Pacific off Peru. The scientists discovered these areas had common features and differed from nearby non-upwelling areas.

Scientists learned that upwelled water often had more than 10 times as great a concentration of dissolved nutrients as waters outside the upwelling zone. These nutrients interact with plants in the lighted surface layers and cause rates of photosynthesis about five times higher than those of other waters. In addition, the single-celled plants in upwellings areas are large (example: diatoms). Outside the upwellings, plants have smaller cells (example: dinoflagellates).

The food chain supported by these plants is also different. Inside the upwellings, large herbivorous animals (copepods) eat the diatoms and are, in turn, eaten by sardine-like fish harvested by fishermen. Outside the area, the small dinoflagellates are consumed by single-celled herbivores (protozoa). The herbivores are eaten by small animals that are eaten by slightly larger animals which are eaten by even larger animals. In these areas, an additional five or six steps are added to the food chain.

The ecological systems inside and outside the upwelling areas are different because the types of organisms and the feeding relationships of the systems are different. Consequently, scientists concluded that the ecosystem concept could apply to the system found in upwelled waters.

Procedure

1. List the biotic (living) factors of the upwelling system off the coast of Peru.

2. List the abiotic (nonliving) factors of the upwelling system off the coast of Peru.

3. Indicate organisms that are producers, first-order consumers, second-order consumers and decomposers in the food web of the upwelling system.

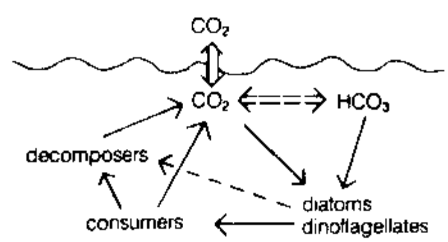
4. Look at the carbon and nitrogen cycles (Figure 11) and answer these questions. Keep in mind that both cycles have gases in the atmosphere that can dissolve in water.

a. What do dinoflagellates and diatoms use CO_2 for?

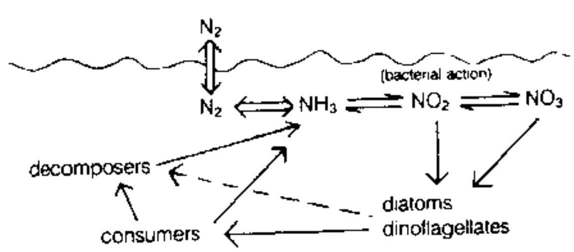
b. What do dinoflagellates and diatoms use NO_2 and NO_3 for?

Figure 11 Carbon and nitrogen cycles

Carbon cycle



Nitrogen Cycle



c. What would happen first to the CO_2 and NH_3 if diatoms and dinoflagellates died off?

d. What would happen over a long period of time?

e. What would happen first to the CO_2 and NH_3 if diatoms and dinoflagellates "bloomed?"

f. What would happen over a long period of time?

5. One of the economic products of Peru is guano (bird waste) from sea gulls defecating on the rocky islands offshore. Guano is used as fertilizer. Sea gulls mainly eat fish—sardines from the offshore upwelling. What would happen to the fertilizer industry during an El Niño?

For Further Study

The upwelling system off Peru was disrupted during the winter of 1982–83 by El Niño. This event caused the nutrient-rich waters off Peru to sink to depths from which they could not be brought up by upwelling. As a result, nutrient concentrations dropped to about 10 percent of their former levels. Large diatoms were replaced by small dinoflagellates; productivity declined; and the short food chain was replaced by a longer chain. This led to much smaller harvests of skipjack tuna and dolphin fish.

The features characteristic of an upwelling ecosystem disappeared and were replaced by features characteristic of non-upwelling areas. This change resulted in collapse of the Peruvian fishery for sardines and severe economic hardship for the fisherman.

El Niño caused other problems—droughts in Australia, Indonesia, Sri Lanka and India; floods in Peru, Chile and the United States; and severe winter storms on the coast of California. These events caused over $8 billion damage, killed hundreds of people and were part of a worldwide climate abnormality caused by the shifting of areas of high and low atmospheric pressure over the equatorial Pacific Ocean in 1982-83.

These events have been described in several popular magazines. Read one and write a brief report on the cause of the 1982–1983 El Niño. Include a section describing the impact of distant events on local ecosystems such as the upwelling ecosystem off Peru.

ACTIVITY 3

Life in Hydrothermal Vent Communities

Introduction

To demonstrate the need for scientists to keep their minds open to the possibility of modifying theories.

Background

In 1977, a startling discovery was made on the floor of the Pacific Ocean. An expedition from Woods Hole Oceanographic Institute was investigating sea-floor geology near the Galapagos Islands. Using a submersible, the researchers were exploring a rift region more than 2,500 meters below the surface. Unexpectedly, near a hydrothermal vent, the researchers observed an enormous concentration of organisms.

The discovery was a "new world." Although deep-sea life had been collected and observed for decades, nothing to equal the biological community near the vent had been imagined. Subsequent expeditions found comparable assemblages of life near other vents. These discoveries introduced marine biologists to dozens of new species of organisms, some with striking structural and physiological adaptations. But more importantly, the vent communities raised some intriguing questions for science.

Biologists told students that life on earth is dependent upon the energy supplied by the sun and converted during photosynthesis into a usable form. They did note that a few microorganisms could derive energy from simple chemicals. However, few imagined that whole communities could be based upon chemosynthesis. Yet, vent community food webs are completely dependent upon energy captured by bacteria from simple chemicals.

This exercise will focus on this major oceanographic discovery and on some questions it poses. The objectives are to explore some important assumptions about biological communities and to demonstrate how new information requires scientists to rethink their assumptions and theories.

Introduction

To begin this activity, ask students to list the problems associated with living in the depths of the ocean. Students will probably mention such issues as high pressure, low temperature, absence of light and low oxygen. With the exception of oxygen, the first three are limiting factors.

The most important is the absence of light. This eliminates the possibility of photosynthesis. So, how do deep-sea organisms obtain energy? It had been thought that they were dependent upon organic debris falling from surface waters. But this would supply only a limited quantity of food. Consequently, researchers believed this restricted the number of organisms living in the deep ocean.

But the discovery of hydrothermal vents changed many conceptions about the deep sea. *National Geographic* produced a film, *Dive to the Edge of Creation,* that explains hydrothermal vent explorations. If possible, show this film to your class. If not, ask students to read about the research findings from the references listed. The questions can be used with the film or the readings. The answers should stimulate discussion on the significance of the vent communities.

This exercise can be a basis for library research. Many interesting findings have resulted from the discovery of the vent communities—new species, unusual symbiotic relationships and remarkable physiological adaptations.

This unit reminds us of the need for scientists to keep their minds open to the possibility of modifying theories. The role of chemosynthesis in biological communities was given little attention before the discovery of the vent communities. A whole new field of biological study has now begun.

Film Source

North Carolina teachers can borrow *Dive to the Edge of Creation* through their county library from the N.C. Dept. of Cultural Resources, Division of State Library, Audiovisual Services Branch, 1811 North Blvd., Raleigh, N.C. 27635. The film number is BF 00364. Teachers can also order the film directly. Postage is paid by the state. The film can also be rented from Karol Media, 22 Riverview Drive, Wayne, N.J. 07470. Or call 202/628-9111.

Questions

After you have seen *Dive to the Edge of Creation* or read the articles assigned by your teacher, answer the following questions.

1. What is most surprising about the vent communities?

2. Which limiting factor of deep-sea life is most altered near vents?

3. Describe the food web of a vent community?

4. What special adaptations have been found in the animals of the vent community?

5. Why were such communities unexpected?

6. The discovery of these deep-sea communities has posed new questions for marine scientists. What are some of these questions?

ACTIVITY 4
Living Between Sand Grains

Purpose

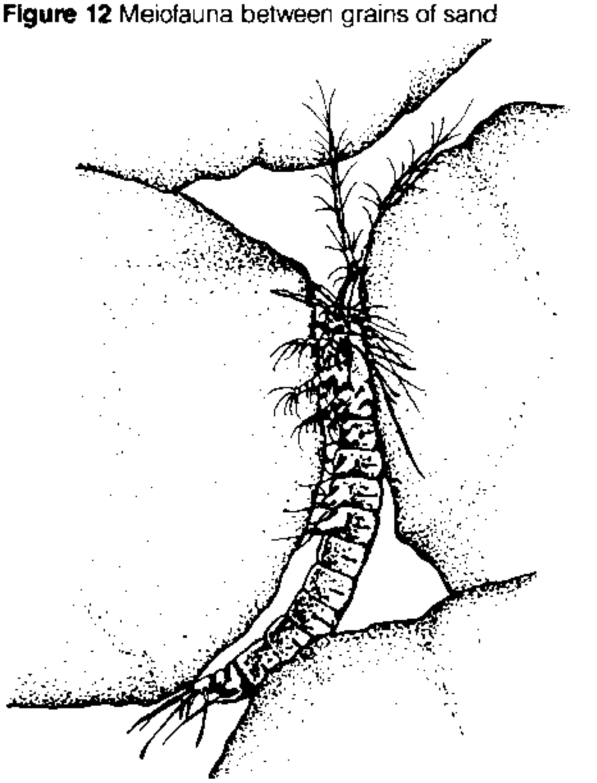
To observe the minute animals that live on and between sand grains in the marine environment.

Background

Marine ecosystems are often large—salt marshes, reefs, upwellings. But small ecosystems, called microcosms, are present within these larger systems. In this activity, consider the benthic animals that live buried in sediment—infauna. Now look even more closely. In sand or muddy sand, water is held between sand grains. This is called "interstitial water." In this water and attached to the sand grains is a very exciting tiny world—the world of the meiofauna (Figure 12).

Nearly every phylum in the animal kingdom is represented in the interstitial meiofauna. The main criteria is their size, between 63 microns and 500 microns. Worms, crustaceans, mollusks and cnidnaria have species that live attached to grains of sand. They use nearly every technique to feed—predation, filtering, scraping and grazing. They ingest tiny plants—such as diatoms and bacteria-rich organic material called detritus. In turn, they are preyed upon by larger animals in the sand, such as larger worms and crustaceans.

Figure 12 Meiofauna between grains of sand



Materials

For collecting meiofauna:

scraper, such as index card or piece of sheet metal
plastic storage bags or plastic buckets
hydrometer or salinity testing kit (obtain from aquarium/fish store or equipment supply company.) You want to get the specific gravity of seawater.

For the lab:

1 Erlenmeyer flask (250 ml or larger)
2 spoons
1 dissection scope
2 to 4 petri dishes
artificial seawater (obtain from aquarium/fish store)
$MgCl_2$ salts
filtering equipment* (obtain from equipment supply company. Order a geological sieve for 63 micron or make one.)

* To make an adequate sieve, you will need a material with holes about 63 microns. This is the size that geologists use to separate mud from sand. Some tight-weave nylon cloth or fine nylon stockings may work. Experiment with what you have available. Cut a ½-inch piece of 1½-inch PVC pipe. Using water soluble glue or a rubber band, attach the filtering sieve to the top of the pipe. You will pour the mixture of sediment and $MgCl_2$ through the sieve.

Procedure

At the coast

Choose a sandy or muddy sand environment such as an inlet, a sound-side beach or a tidal creek edge with low current or small waves. Collect at low tide when the intertidal sediment is being exposed.

Scrape some of the top layer—about 1 centimeter—into a plastic bag or bucket. Add some of the nearby water. Be sure to test the water for salinity or specific gravity. You'll need that information later. Your samples can be kept up to two days under cool conditions. Bring them back to the classroom.

In the classroom

Make up a solution of $MgCl_2$ and distilled water to the approximate specific gravity or salinity of the water at the sample site. Using a hydrometer is probably the easiest technique. You'll need about 1 liter of solution.

Make up a solution of artificial seawater to the same specific gravity or salinity as the sample.

Put 1 or 2 tablespoons of your sediment sample into the Erlenmeyer flask. Finish filling the flask with the $MgCl_2$ solution. Swirl gently. Cover the top of the flask and tip it back and forth several times to mix the solution thoroughly with the sediment. $MgCl_2$ relaxes the meiofauna so they release their hold on the sand grains and will be suspended in the liquid.

Let the sediment settle for a minute, then filter the liquid.

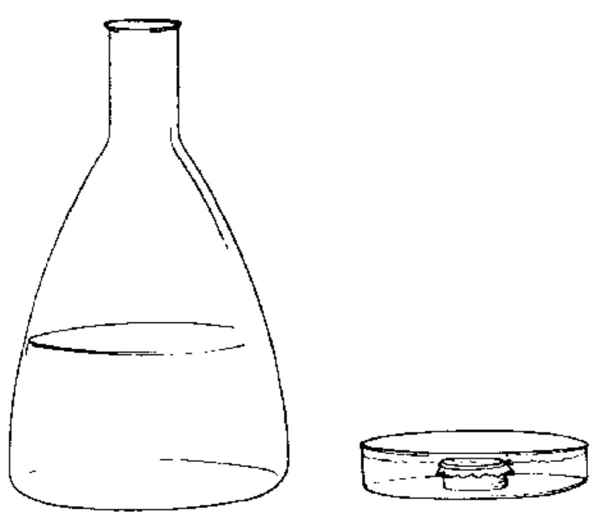
Place the filter* in the petri dish or wash the filter surface so the filtered particles will collect in the petri dish (Figure 13).

Add artificial seawater to cover the filter.

Observe the small animals in the petri dish. They will start to move slowly when back in a seawater environment.

Sketch the organisms, paying special attention to any attachment or feeding appendages.

Figure 13 Flask and petri dish with filter



How many different kinds of animals did you find? Could you identify their phyla? Which animals were most common? What do you think about each one's feeding habits based on their morphology?

Variations

Take sediment samples in different sites, different sediments, different salinities and different tidal cycles. Are there differences in the composition of the meiofauna?

Do not use $MgCl_2$ to relax the attached meiofauna. Now you will observe the organisms that live in the sand but do not attach to the grains. Are there differences?

Competency Factors/References

Competency Indicators

Biology/Academic—

1.1 know about the nature of science;

1.2 know the methods of science;

1.3 know the limitations of science;

7.3 know about the nature of ecosystems;

7.2 know about the nature of communities; and

7.3 know about the nature of ecosystems.

Biology/Technical-Applied—

7.2 and 7.3 same as above.

Competency Measures

Biology/Academic—

1.1.1 give examples of a science that exemplify it as a body of factual information, a set of theories and a set of procedures for finding facts and developing theories;

1.1.2 relate examples of scientific theories that have been disproved and scientific facts that have changed;

1.2.2 provide at least one example of each of the following: a scientific discovery based on many years of investigation and on result of an unplanned occurrence;

1.3.1 explain the limits of time, experience and society on scientific problem-solving;

1.3.2 describe several factors that have deterred scientists from finding solutions to some problems;

7.2.1 define community and explain the interactions of populations of a given biotic community;

7.3.1 identify the biotic and abiotic parts of a given ecosystem;

7.3.2 trace the energy flow and identify trophic levels within a given ecosystem; and

7.3.3 identify symbiotic interactions and predator-prey relationships within a given ecosystem.

Biology/Technical-Applied—

7.2.1 describe different kinds of communities;

7.2.4 describe the interactions of members of the biotic community when given a sample ecosystem; and

7.3.4 identify water, carbon and nitrogen cycles in a balanced ecosystem.

References

Alldredge, A.L. 1972. "Abandoned Larvacean Houses: A Unique Food Source in the Pelagic Environment," *Science*. 177:885–887.

Alldredge, A.L. 1976. "Discarded Appendicularian Houses as Sources of Food, Surface Habitats, and Particulate Organic Matter in Planktonic Environments," *Limnology and Oceanography*. 21:14–23.

Alldredge, A.L. 1976. "Appendicularians," *Scientific American*. July 1976:94–102.

Bainbridge, R. 1952. "Underwater Observations on the Swimming of Marine Zooplankton," *J. Mar. Biol. Assoc.* U.K. 31:107–112.

Ballard, Robert D. and J. Frederic Grassle. 1979. "Return to Oases of the Deep," *National Geographic*. 156(5):680–705.

Barber, Richard T. and Francisco P. Chavezs. 1983. "Biological Consequences of El Niño," *Science*. Vol. 222 (4629), pp. 1203–1210.

Biggs, D.C. 1977. "Field Studies of Siphonophores," *Marine Behavior and Physiology*. 4:261–274.

Biggs, D.C. 1977. "Respiration and Ammonium Excretion by Open Ocean Gelatinous Zooplankton," *Limnology and Oceanography*. 22:108–117

Bishop, J.W. 1969. "Comparative Feeding Rates in Tentaculate Ctenophores," *Ecology*. 49:996–997.

Canby, Thomas Y. 1984. "El Niños Ill Wind," *National Geographic*. Feb. Vol. 165(2), pp. 144–183.

Corliss, John B. and Robert D. Ballard. 1977. "Oasis of Life in the Cold Abyss," *National Geographic*. 152(4): 441–453.

"Deep-Sea Oasis," *Science News*. June 19, 1982; pp. 410–413.

"El Niño," *Oceanus*. 27(2):3–63.

Enright, J.T., et al. 1981. "Deep-Ocean Hydrothermal Vent Communities," *Nature*. 289:219–221.

Gilmer, R.W. 1972. "Free Floating Mucus Webs: A Novel Feeding Approach in the Open Ocean," *Science*. 176:1239–1240.

Grassle, J.F., et al. 1979. "Galapagos '79: Initial Findings of a Deep-Sea Biological Quest," *Oceanus*. 22:2–10.

Hamner, W.M. 1974. "Blue Water Plankton," *National Geographic Magazine.* 146:530–545.

Hamner, W.M. 1976. "Underwater Observations of Blue Water Plankton: Logistics Techniques and Safety Procedures for Divers at Sea," *Limnology and Oceanography.* 20:1045–1051.

Hamner, W.M. et. al. 1976. "Underwater Observations of Gelatinous Zooplankton: Sampling Problems, Feeding Biology and Behavior," *Limnology and Oceanography.* 20:907–917.

Harbison, G.R. and Madin, L.P. "Diving—A New View of Plankton Biology," *Oceanus.* 22:18–27.

Harbison, Madin and Swanberg. 1978. "On the Natural History and Distribution of Oceanic Ctenophores," *Deep Sea Research.* 25:233–256.

Higgins, Robert P. 1989. *Introduction to the Study of Meiofauna.* The Smithsonian Institute.

Jannasch, Holger W. "Chemosynthesis: The Nutritional Basis for Life at Deep-Sea Vents," *Oceanus.* Fall, 1984; pp. 73–78.

"Life Under Pressure: Vent Microbes Grow at 250°C or More," *Science News.* June 11, 1983; p. 372.

Lombardi, Julian and Edward E. Ruppert. 1982. "Functional Morphology of Locomotion in *Derocheilocaris typica* (Crustacea, Mystacocarida)," *Zoomorphology.* 100:1–10.

Lutz, Richard A. and Robert R. Hessler. 1983. "Life Without Sunlight: Biological Communities of Deep-Sea Hydrothermal Vents," *The Science Teacher.* 50(3):23–29.

Madin, L.P. 1974. "Field Observations on Feeding Behavior of Salps," *Marine Biology.* 25:143–148.

Mullin and Evans. 1974. "Use of a Deep Tank in Plankton Ecology," *Limnology and Oceanography.* 19:902–911.

Omari and Hamner. 1982. "Patchy Distribution of Zooplankton: Behavior, Population Assessment and Sampling Problems," *Marine Biology.* 72:93–200.

Philander, S.G.H. 1983. "El Niño—Southern Oscillation Phenomena," *Nature.* Vol. 302, pp. 295–301.

Pomeroy, L.R. 1974. "The Ocean's Food Web: A Changing Paradigm," *Bioscience.* 24:499–505.

Rasmussen, E.M. and John M. White. 1983. "Meteorological Aspects of the El Niño—Southern Oscillation," *Science.* Vol. 22 (4629), pp. 1195–1202.

"Predation," "Symbiosis I," "Symbiosis II," "Bony Fish" and "Sharks," *Oceans Alive.* 1990. Environmental Media, Chapel Hill, NC. (A series of 60, five-minute video programs designed to supplement life and physical science lessons.)

Riley, G.A. 1963. "Organic Aggregates in Seawater," *Limnology and Oceanography.* 8:372–381.

Swanberg, N. 1974. "Feeding Behavior of Beroe ovata," *Marine Biology.* 24:69–74.

"There's Life Among the Seeps, Too," *Science News.* December 15, 1984; p. 374.

Trent, J.D. et al. "In Situ Measurements on Macroscopic Aggregates in Monterey Bay, California," *Limnology and Oceanography.* 23:626–635.

"Vent Fish: Alvin's Unexpected Catch," *Science News.* December 12, 1981.

West, Susan. "Smokers, Red Worms and Deep Sea Plumbing," *Science News.* January 12, 1980, pp. 28–30.

Biochemistry

Biochemistry is at the root of all biological systems. But students often find the subject difficult and discouraging. The biochemistry of ocean systems is no less complex. But once students observe the tiny phytoplankton through microscopes, they begin to understand the vast numbers of these cells that would be necessary to provide the amount of oxygen and food that is generated through ocean processes. The continual interaction of photosynthesis and decomposition is a key to living systems and can be illustrated using the ocean environment. In this unit, students can experiment with these processes, using oxygen testing methods and paper chromatography—hands-on activities that bring biochemistry alive.

ACTIVITY 1
Photosynthesis and Decomposition

Purpose

To show the relationship between photosynthesis, decomposition and life in the ocean.

Background

Chemical reactions can be illustrated with numerous examples. The problem with simple reactions is that students see them as unrelated to real life. The processes by which the bodies of plants and animals are formed and disappear are reactions related to everyone's life and survival. This, coupled with an interest in the ocean, suggests that a discussion of photosynthesis and decomposition in the marine environment may intrigue physical and biological science students.

Photosynthesis and decomposition are useful examples of chemical reactions for beginning students because they can be made more complex and realistic by adding terms to the equation. How and why you would do that can be explained to students. But the drawback is that organic matter occurs in the reactions, and the chemical composition of this material is variable. Students seem not to be concerned about this problem. But the fact should be pointed out to avoid misunderstanding and future problems.

Whet students' interest with a discussion of the oceans' harvest, food chain and energy characteristics. A knowledge of photosynthesis can be combined with a modest exaggeration of the vertical separation between photosynthesis and decomposition to promote understanding of the oceans' food production for man. Use of oceanic photosynthesis and decomposition as a teaching tool for chemical reactions can accomplish several learning goals at one time.

The advantage of using marine photosynthesis and decomposition as examples of chemical reactions stems from the vertical separation of the processes. Since photosynthesis requires light and seawater absorbs light, photosynthesis can only occur near the ocean surface. Organic matter created by photosynthesis is usually more dense than seawater and sinks. Sinking takes it out of the photosynthesis zone into a zone where decomposition predominates. This vertical transport of organic matter has major implications for global geochemistry.

The downward transport of photosynthesized products also has implications for ocean chemistry and biology. In most oceans, the area below the photosynthesis zone has a reduced oxygen level (the oxygen-minimum zone). Here, decomposition reduces access to atmospheric oxygen, and light is too low to supply oxygen as a product of photosynthesis. These conditions lead to an increased concentration of dissolved plant nutrients. But these nutrients remain at depths where light is too low to support photosynthesis and spur the food chain.

Occasionally, the nutrient-rich water from this zone is pulled to the lighted surface layers and promotes photosynthesis. Areas where such movement occurs are ocean upwellings. They account for 50 percent of ocean seafood harvest even though they occupy only about 1 percent of the ocean area.

Famous fishing grounds are almost all upwelling areas—the Grand Banks off Nova Scotia, the ocean around Antarctica, the waters off Peru and Ecuador, and the equatorial tuna grounds. The physical processes that cause water to upwell in these areas is different in each, but the chemical, biological and commercial implications are the same. (See Part 1, Activity 2, Ocean Upwellings, for further information.)

These ocean characteristics can be used to provide an interesting context for the chemical reactions that describe the reversible reactions of photosynthesis and decomposition.

Introduction

Plants have the unique ability to convert the energy of sunlight into chemical energy. This reaction is called photosynthesis because chemicals (nutrients) are synthesized into plant material in the presence of light. Once plants have carried out this chemical reaction, people and other animals can use the chemical products for food, fiber and energy. During this use, further chemical reactions take place. These reactions are termed decomposition because the original composition of the chemical is destroyed in the process.

Photosynthesis occurs when nutrients containing carbon, nitrogen and phosphorus combine with the hydrogen and oxygen in water to produce solid organic matter and gaseous oxygen. The energy necessary to accomplish this process comes from sunlight that is trapped by the green chlorophyll pigments in the plant. This process occurs in every field, forest and body of water—wherever there are chlorophyll-containing organisms and the sun's energy is strong enough.

Once formed, organic matter can be used as food. This changes the chemical composition of the organic matter and may even result in its being decomposed into the basic chemical from which it was formed. Think about a wood fire. The energy that warms you is the sun's energy trapped by the process of photosynthesis and set free by the process of burning. Oxygen is needed to keep the fire going. The products of a wood fire are carbon dioxide and ashes that contain nitrogen and phosphorus.

Since these two reactions are each the reverse of the other, a single equation with the symbol $\rightarrow$ between reactants and products can be used to indicate both equations. This method of writing the chemical reaction should explain the nature of the energy used in photosynthesis and produced in decomposition. The energy differs depending on the direction in which the reversible reaction is proceeding.

Procedure

Answer the problems and questions in this section.

1. Write a word equation that describes the chemical reaction of photosynthesis and another for organic matter decomposition. Are these two equations related to one another? How?

2. A general chemical formula for organic matter is $C_{106}H_{180}O_{46}N_{16}P$ indicating that for every phosphorus atom there are 16 nitrogen atoms, 46 oxygen atoms, 180 hydrogen atoms and 106 carbon atoms combined together. When one phosphorus atom is synthesized into organic matter, 154 molecules of oxygen gas (O_2) are formed.

Here is an equation showing photosynthesis and decomposition. The right side is correct. You fill in the blanks to create a balanced equation.

_____ CO_2 + _____ NO_3^- + _____ PO_4^{3-} +

_____ H_2O + energy $\rightarrow C_{106}H_{180}O_{46}N_{16}P + 154O_2$

a. Which direction is photosynthesis?

b. Which direction is decomposition?

c. Which process uses the sun's energy?

d. Which process produces energy?

e. What is the energy produced used for?

f. Is any energy left? Is so, in what form?

The two chemical equations you have balanced symbolize chemical reactions that occur in nature. They can occur in a single plant cell (the decomposition equation is then called respiration) or they can occur in ecological systems. In the ocean, the ability of water to absorb light limits the process of photosynthesis to the upper layers. These layers are where most ocean organisms live. But decomposition occurs at all depths as organic matter from the surface sinks toward the sea floor.

Oxygen from the earth's atmosphere is absorbed into the ocean waters at their interface. Oxygen is also a product of photosynthesis that occurs in the upper ocean layers.

3. Knowing that the O_2 content in the ocean has two sources, would you expect dissolved oxygen concentrations to be higher or lower at the ocean floor than the O_2 content in the surface layers?

4. What about the concentrations of dissolved nitrate and phosphate in the surface layers compared to layers below?

5. If the concentration of one of the dissolved nutrients (CO_2, NO_3^- or PO_3^{4-}) is exhausted, what happens to the rate of photosynthesis?

6. What conditions of physical mixing of surface and deeper layers of water would you expect to find in ocean areas with the highest photosynthesis rates?

ACTIVITY 2

The Effect of Decay on O_2

Purpose

To investigate how oxygen concentration changes with decay.

Materials

3 quart jars
sliced vegetables
tap water
Lamott or Hach dissolved oxygen testing kits

Procedure

Label the jars 1 and 2.

Fill jar 1 with tap water and test the oxygen content using the dissolved oxygen testing kit. Record the results on the data sheet. Discard water. Refill one-half of jar 1 with sliced vegetables. Fill with tap water and cap. Jar 2 is the control jar. Fill the jar with tap water and cap.

Place the jars out of direct sunlight and extreme temperatures. Do not disturb the jars for three to five days.

After three to five days, measure the dissolved oxygen in jars 1 and 2. Make sure the water is poured very gently from each jar into the test kit. This is necessary to prevent atmospheric oxygen from entering the specimens.

Record the amount of oxygen in jars 1 and 2 on the data sheet. How does the oxygen content compare to the initial oxygen test?

Questions

1. What caused the difference, if any, in oxygen between fresh tap water and the water with vegetables (jar 1)?

2. What caused the difference, if any, in oxygen between fresh tap water and the tap water that sat for several days?

3. What caused the difference, if any, in oxygen between the water with vegetables and the tap water that sat for several days?

Data sheet

	DO ppm — Day 1	DO ppm — After 3 days	Change
Jar 1 tap water			
Jar 2 with vegetables			

ACTIVITY 3

Effects of Plants on O_2

Purpose

To investigate how plants affect the amount of oxygen in water.

Materials

pond algae or Elodea
2 jars of fresh tap water
Lamott or Hach dissolved oxygen testing kits

Procedure

Label two jars 1 and 2. Fill each jar three-fourths full with fresh tap water. Test each jar for the dissolved oxygen content using the dissolved oxygen testing kit. Record the results on a data sheet.

In jar 1, place a freshwater plant in the water, and place the jar in direct sunlight. Place jar 2 into direct sunlight as well. Make sure the lids are on both jars. After several days test the dissolved oxygen in both jars. Record your results.

Questions

1. What caused the difference, if any, in oxygen between the fresh tap water and the water with the freshwater plant?

2. What caused the difference, if any, in oxygen between the fresh tap water and the water that sat for several days?

3. What caused the difference, if any, in oxygen between the water with the freshwater plant and the water that sat for several days?

4. What is the purpose of jar 2, the control?

Data sheet

	DO ppm — Day 1	DO ppm — Day 2-4	Change
Jar 1 with plant			
Jar 2 tap water			

ACTIVITY 4

Temperature and O_2

Purpose

To investigate the effects of temperature on oxygen.

Materials

2 beakers
tap water
thermometer
heat source
Lamott or Hach dissolved oxygen test kits

Procedure

Fill each beaker three-fourths full of tap water. Measure the dissolved oxygen in both beakers using the dissolved oxygen testing kit. Record your results on a data sheet.

Heat the water in beaker 1 to 10°C above the present room temperature. Test for O_2. Record the results. Simultaneously retest for the dissolved oxygen content in beaker 2.

Increase the heat in beaker 1 by 20°C above room temperature, then 30°C above room temperature. Test the oxygen content after each increase. Also test the oxygen content in beaker 2 each time you test for dissolved O_2 in beaker 1. Record your results.

Graph your results.

Questions

1. What happens to the amount of O_2 as the water is heated? (What is the purpose of beaker 2?)

2. Apply what you have learned about dissolved oxygen to the situation described below.

A news report indicates that a fish kill of 100,000 menhaden occurred in the Neuse River in July. There has been an algae bloom on the river. Some people are blaming toxic chemicals for the kill; others think it could be due to natural causes. Relate your observations to this news story.

Data sheet

	DO ppm before heating	DO ppm 10° C increase	DO ppm 20° C increase	DO ppm 30° C increase
Beaker 1				
Beaker 2 (control)				

ACTIVITY 5

Determining Pigments in Marine Algae Using Paper Chromatography

Purpose

To observe different pigments in various marine algae, to compare these pigments to those in spinach and to become acquainted with a very useful biological and chemical technique.

Background

The term chromatography (Greek for "to write in color") was introduced in 1906 by a Russian botanist, Michael Tsvet. He used a column of calcium carbonate to separate the components of a petroleum ether chlorophyll extract and suggested that the method might be applicable to other chemical compounds. The process went unnoticed for 30 to 40 years. But in the last 50 years, it has become one of the most valuable tools of biology and chemistry.

In paper chromatography, the separation of the components of a mixture depends on their different affinities for a stationary phase (paper) and their different solubilities in a moving phase (liquid). The molecules that are very soluble in the moving phase and have little affinity for the paper will move faster and a greater distance than those having less affinity for the solvent and a greater affinity for the absorbent (paper).

In paper chromatography, the mixture to be separated is applied as a spot or a line. The chromatogram is developed by placing the bottom edge of the paper in the solvent and letting the solvent flow up the paper. The distance traveled by a particular compound under a specific set of conditions (temperature, solvent system, direction of flow, type of paper, etc.) is characteristic and may be used to identify it. The ratio of the distance traveled by a compound to that of the solvent front is known as the R value.

$$R = \frac{\text{distance from origin traveled by compound}}{\text{distance of solvent front from origin}}$$

Pigments are molecules that have color. They have color because they selectively absorb some wavelengths of light and reflect others. The wavelengths that they reflect are the ones that we see and identify as the color of the substance. Pigments are in plants and animals. They are used to attract mates and pollinators. Pigments can provide camouflage or warning indicators—both useful in avoiding predators.

In plants, several pigments are necessary for photosynthesis. These pigments absorb light energy from the sun and make it available for the splitting of the water molecule in the light reaction. Without these pigments, plants would be unable to produce the high energy carbohydrates (sugars) from carbon dioxide and water. Without this process, life as we know it could not exist.

The primary pigments are chlorophylls. There are a few different types of chlorophyll in addition to accessory pigments such as carotenoids (carotenes and xanthophylls). Carotenoids are yellowish pigments. They trap other wavelengths of sunlight and pass the energy along to the chlorophyll. Some carotenoids, known as carotenes, are made of carbon and hydrogen. Xanthophylls have oxygen in addition to carbon and hydrogen. Other carotenoids have uses other than as accessory pigments. They may be various colors of yellow, orange, red or brown—explaining the beauty of our autumns.

The three major groups of marine algae are distinguished by a variety of characteristics including the pigments that they have. Here is a table listing some of the differences.

Division	Photosynthetic Pigments
Chlorophyta (green algae)	Chlorophylls a and b, carotenoids
Phaeophyta (brown algae)	Chlorophylls a and c, carotenoids including fucoxanthin
Rhodophyta (red algae)	Chlorophyll a (Chlorophyll d in some), carotenoids and phycobilins

You can help your students observe these pigments through the technique of paper chromatography. It is advisable to have them also chromatograph spinach pigments for comparison. Spinach may be processed the same way as the algae and is entirely reliable. The algae works best when very fresh and when blotted dry before processing.

Teacher Materials

spinach (fresh)
marine algae*
acetone*
petroleum ether* (white vinegar can be substituted)

chromatography paper*
capillary tubes*
large test tubes with corks, spice jars or baby food jars
cheesecloth
mortar and pestle with fine sand
funnel
knife or scissors
flasks (these are handy to keep the chromatography test tubes in while the pigments are developing.)

* Algae: If you collect seaweed during a beach trip, keep it cool and in the dark until it can be frozen when you get home. Freezing helps break down the cells from which you will extract the pigments. If you order several months in advance, Carolina Biological Supply can provide some types of marine algae for culture. You can grow sufficient amounts in the classroom. You will need at least a handful of each type of algae.

* acetone: available from Carolina Biological Supply (order number 84-1481).

* petroleum ether: available from Carolina Biological Supply (order number 87-9540).

* chromatography paper: available from Carolina Biological Supply (order number 68-9105, 1.5 inches by 300 feet).

* capillary tubes: available from Carolina Biological Supply (order number 70-0702).

Note: These amounts will provide materials for several classes.

Teacher Procedure

Before class, the teacher should defrost the algae. Blot it dry with paper towels. Cut it up as finely as possible with a knife or scissors. Several tablespoons of finely chopped algae will be enough for a whole class. The better you chop it now, the better your results.

Put about two tablespoons of algae in a mortar. Add 5 ml or less of acetone. Thoroughly grind with the pestle. If you have good ventilation, you might let your students help with this. But don't let them lean over the mortar. You can add more acetone if needed. Your goal is a dark green or brown concentrated solution of about 5 ml.

When the acetone becomes colored (dark green to brown depending on the algae), pour the solution into a funnel lined with several layers of cheesecloth. The funnel should drain into a small glass vial. Squeeze the cloth to remove all the acetone and pigments. Wrap the vial in foil because the pigments absorb light energy. Without any chemicals to pass the energy on to, they will be broken down. Use this solution as soon as possible.

Student Information

When you observe a plant, it appears to have one color. In fact, you might say the plant has one pigment in it. But colors among terrestrial and marine plants are due to various concentrations and types of pigments combined in the cells.

These pigments range in color from red to orange to yellow to green. Most plants appear to be predominantly green because green chlorophyll pigments are the most predominant. In autumn, when the chlorophyll pigments break down in the leaves of deciduous trees, you can see the other pigments that are present.

Pigments have color because their molecules reflect the light waves of that color and absorb other light waves. For example, green chlorophylls reflect green light waves and absorb the other light waves (colors).

What is the purpose of these pigments? The chlorophyll molecule traps the energy from the sun for the plant cells to use in the formation of glucose (a molecule with high energy bonds). Several other pigments can absorb other colors of light waves and pass this energy on to the chlorophyll. These are called accessory pigments.

How does paper chromatography work? You will put a concentrated dot of pigment mixture on your chromatography paper. Then touch the bottom of your paper to a liquid solvent that will "crawl" up the paper. This solvent will pick up any pigments that dissolve in it. Some pigments will dissolve easily in the solvent. Other pigments will be held more tightly by the paper and will not easily dissolve in the solvent. Consequently, the pigments will travel at different speeds. When you remove the paper from the solvent and let it dry, the pigments will be fixed at the place on the paper that they had reached when you removed the paper.

You will probably find the following pigments:

chlorophyll a:	blue-green
chlorophyll b:	green (in green algae only)
chlorophyll c:	green (in brown algae only)
chlorophyll d:	green (in red algae only)
xanthophyll:	yellow to brown
carotene:	yellow-orange

Student Materials

spinach pigment extract (in acetone)
algae pigment extract (in acetone)
thumbtack
test tubes with corks
holder for test tube
petroleum ether/acetone mix (92 parts petroleum ether to 8 parts acetone. You can use white vinegar instead of petroleum ether.)

capillary tubes
pencil
strips of chromatography paper
hair dryer (cool setting only)

Procedure

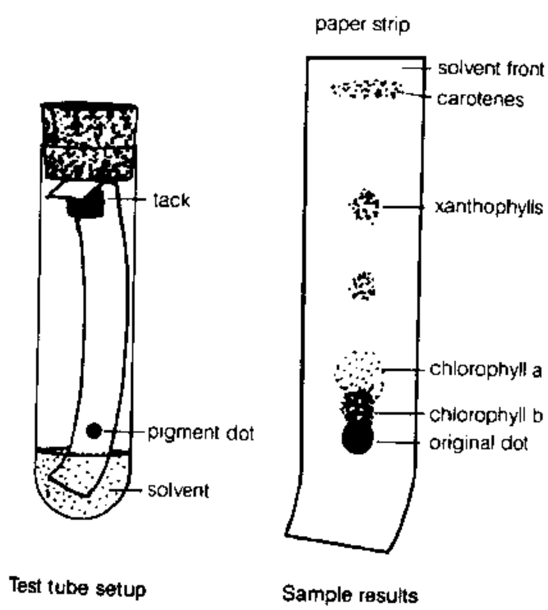
Put 6 to 7 millimeters petroleum-acetone or white vinegar-acetone mix in the bottom of your test tube.

Center a pencil dot about 2 cm from the bottom of your chromatography paper strip. Be careful to handle the paper by the edges only. Oily fingerprints will ruin it.

Dip a capillary tube in the pigment-acetone mixture and touch it to the pencil dot briefly. Blow until the acetone evaporates. Repeat often until the pigment dot gets dark green or brown. Be sure you let the paper dry between dots. You can use a hair dryer to speed the process, but only use the cold setting. Heat will destroy the pigments.

Tack the paper with the dot to the bottom of your cork. Drop the paper into the petroleum ether/acetone in your test tube and cover quickly. Be sure that your dot of pigment is not in the petroleum ether/acetone mix, and make sure that your paper strip is not touching the sides of the test tube. Do not move the setup while it is developing (Figure 1). You can place the test tube in a flask to keep it steady.

Figure 1 Test tube setup



Five to 10 minutes later or when the petroleum ether/acetone mix has traveled to the top of your paper, remove the strip and observe the pigments.

Repeat for other algae samples and the spinach sample.

NOTE: If you run all your samples for the same amount of time, you can compare and decide if the pigments are the same. Or, you can measure the distance each pigment traveled from the original dot and divide that by the distance that the solvent (petroleum ether/acetone) traveled from the dot. If you compare these numbers, they should be the same for identical pigments. This is called the R number.

$$R = \frac{\text{pigment distance from dot}}{\text{solvent distance from dot}}$$

The algae you use will determine the exact results. But in general, carotenes travel fastest and will be at the top of the paper. Below them are the xanthophylls. Next will be chlorophyll a, d or c, depending upon the algae used. Finally, you will find the slow moving chlorophyll b.

Questions

1. Algae are classified according to their pigments. The algae are assigned to phyla based on which pigments they have. According to your results, would you place the algae you tested in different phyla? Why or why not?

2. Describe the difference between the spinach pigments and the algae pigments.

3. Why do you think acetone is used to extract chlorophyll pigments instead of water?

4. Does the chromatogram provide information about the relative concentration of the pigments? Explain.

5. Which wavelength of light (color) is the least useful in providing energy for photosynthesis?

6. There are other pigments in algae and spinach that we did not separate. Do you know why we were not able to separate these pigments?

7. Why do you need to be careful not to let your dot of pigment touch the petroleum ether/acetone mixture in your test tube?

8. What is the function of the variety of pigments in the algae and the spinach?

Competency Factors/References

Competency Indicators

Physical Sciences—

3.4 know that chemical reactions occur when two or more elements interact and form one or more new substances.

Biological Science/Applied Technical—

2.4 understand the chemical processes of life.

Biology/Academic—

1.2 know the method of science; and

2.4 know chemical processes of life.

Competency Measures

Physical Sciences—

3.4.1 write chemical equations from word equations;

3.4.2 demonstrate knowledge of the law of conservation of mass by writing balanced equations; and

3.4.3 classify chemical reactions as one of the four basic types: synthesis, decomposition, single and double replacement.

Biological Science/Applied Technical—

2.4.6 explain the significant events in such cell processes as intracellular respiration, digestion, photosynthesis and protein synthesis; and

2.4.7 describe the effects of various environmental variables on respiration, digestion and/or photosynthesis.

Biology/Academic—

1.2.1 perform laboratory exercises that use process skills such as observing, hypothesizing, interpreting data and formulating conclusions; and

2.4.6 explain the significant events in such cell processes as intracellular respiration, digestion, photosynthesis and protein synthesis.

References

Arditti, Joseph and Arnold Dunn. 1969. *Experimental Plant Physiology—Experiments in Cellular and Plant Physiology.* Holt, Rinehart, Winston, Inc., Atlanta.

"Biological Sciences Curriculum Study," 1968. *Biological Science—Molecules to Man: Teacher's Edition.* Houghton Mifflin Company, Boston.

"Biological Sciences Curriculum Study," 1968. *Biological Science—Molecules to Man: Answer Key and Teacher's Guide to Laboratory Investigations.* Houghton Mifflin Company, Boston.

McCormack, Alan J., Arnold I. Miller and Robert Motzko. 1980. *Biology Laboratory Manual.* Scott, Foresman and Company, Dallas.

Seaweed Chromatography. National Aquarium Education Department, Baltimore.

Animal Adaptations

The ocean depths and shores provide homes to an array of creatures with a variety of shapes and sizes that adapt each creature to a different habitat, a different way of catching food and a different mode of protection.

The colorful and diverse sea life has caught the fancy of writers, poets and musicians. But in science, we look at the hows and whys of these adaptations. We examine the mathematics of speed in water and the complexities of the surface/volume relationships. And yet we remain full of wonder for the marvelous intricacy of the orgamisms and their suitability to their environments.

ACTIVITY 1

Plankton, Nekton and Benthos—Their Underwater Environment

Purpose

To investigate absorption as a nutritional technique in marine organisms.

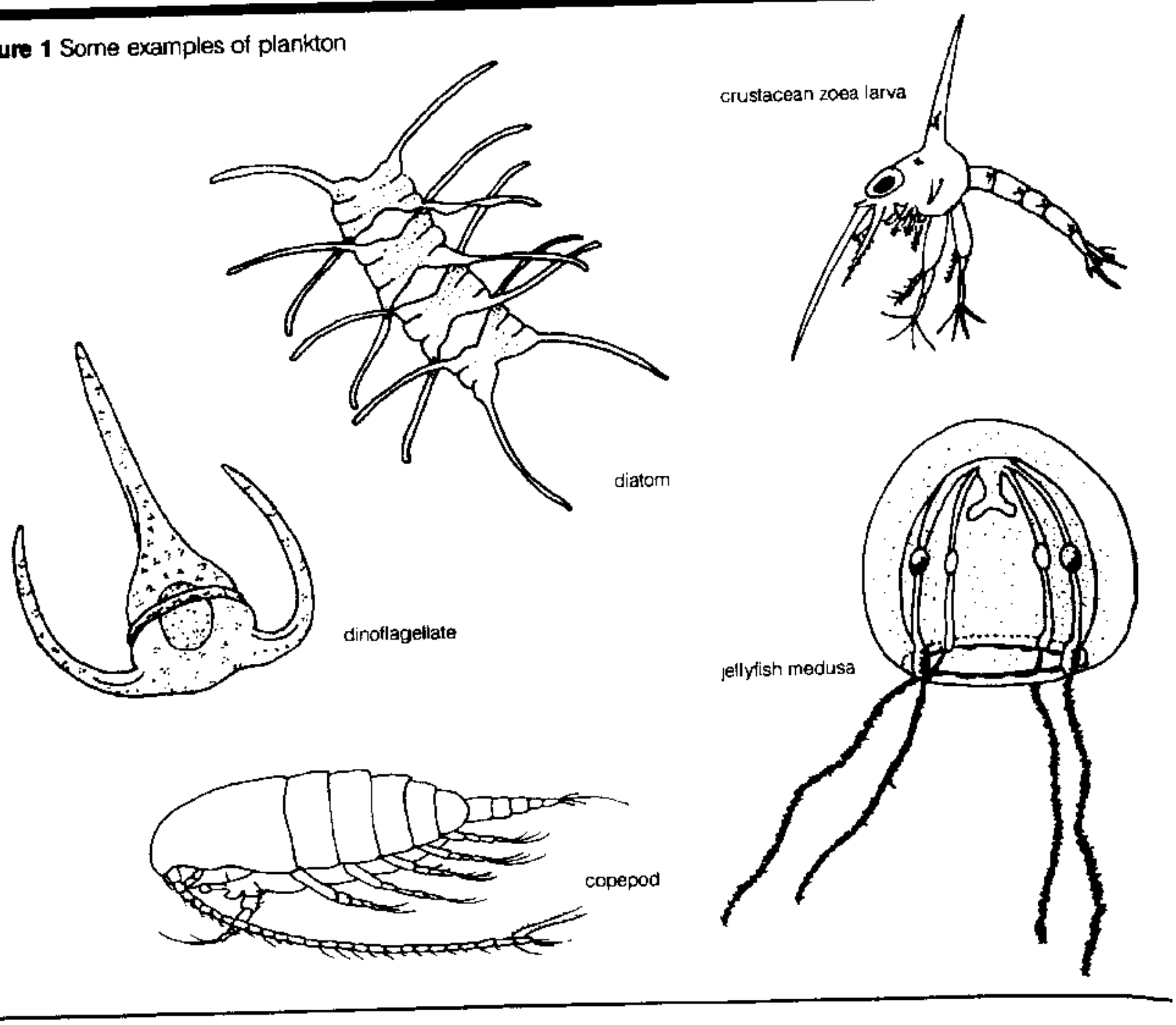
Background

Marine creatures come in different sizes and shapes, but all must adapt to flowing water. Before examining the principles of fluid flow and how it affects marine organisms, you should become familiar with fundamental aspects of life in the ocean.

The ocean can be divided roughly into three basic habitats: planktonic, nektonic and benthic.

Organisms that drift passively in water are called plankton. (See Figure 1. Copy and use as overhead transparency.) Many can swim but not strongly enough to go against currents and tides. Most plankton are very small (microscopic), but some can be large. For example, a jellyfish may be several feet in diameter; a diatom, only a few microns across. Plankton float in the surface layers of the ocean where light and food are relatively abundant. It is important that they do not sink into the deeper waters.

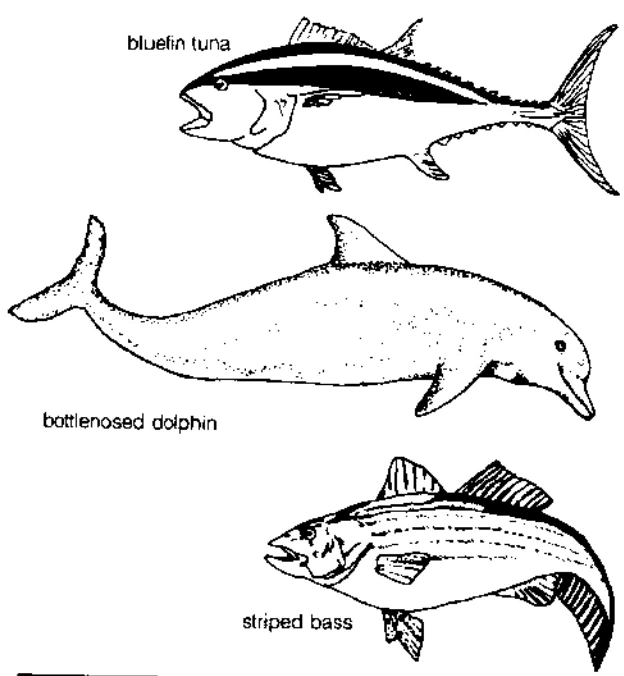
Figure 1 Some examples of plankton



Organisms that move independently of currents and are capable of long migrations are called "nekton" (Figure 2). These include fish, whales, sharks, squids and turtles. Nekton are usually large and built for rapid, efficient swimming. They must be able to locate and capture food.

Organisms that live along the ocean bottom are called "benthos" (Figure 3). Some crawl along the sea floor; some burrow into it; and some live permanently attached to it. Benthic animals depend on food falling from the waters above them or being transported in water flowing along the bottom. Examples of benthic animals are starfish, sea anemones, corals and clams.

Figure 2 Nekton



Animals that live in these habitats use three methods of feeding: absorbing, filtering and grabbing.

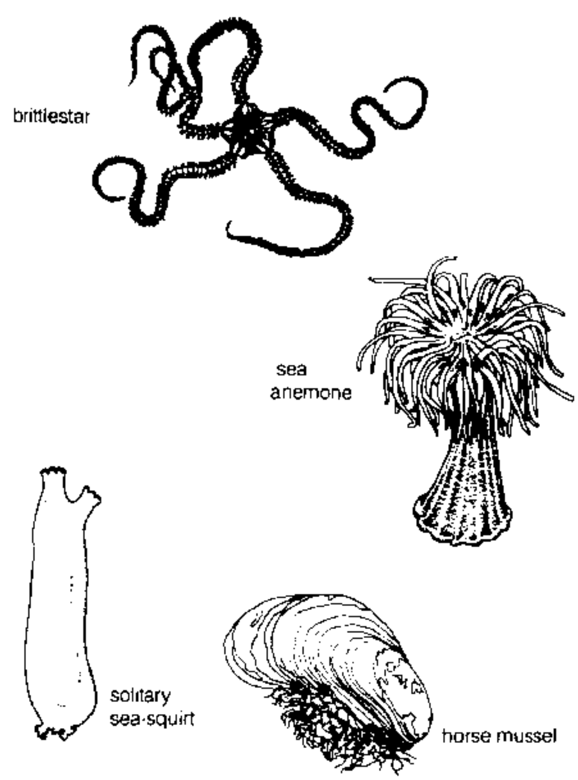
Absorbing is the most common method by which plankton obtain food. The one-celled creatures use simple diffusion and osmosis to draw nutrients from the seawater (example: diatoms).

Because seawater is often filled with plankton and other organic matter, many organisms filter their food from the water by pumping it over gills, mucus nets or other sieve-like structures (example: clams).

Grabbing is a familiar predation mechanism that occurs when one organism attacks and eats another organism. This is an active response rather than a passive one like filtering. The predator may have complex sensory organs to stalk its prey. It needs teeth, suckers or stingers to capture and eat it. Examples of animals that use this method are sharks, tuna and octopuses.

These three feeding methods and habitat affect, to a large degree, the size and shape of marine organisms.

Figure 3 Benthos



Basic principles of fluid flow

Because all marine life must cope with movement of water around them, it is important to understand some basic ways that scientists describe fluid flow. Here are some fundamentals.

All organisms live in a fluid, either liquid (water) or gas (air). When the fluid moves, it imposes forces on the organism that tend to carry the organism downstream. These forces are called drag. Underwater, drag does three things:

1. It helps organisms move downstream through a fluid (plankton and nekton).

2. It dislodges or breaks organisms that live attached to things (benthos).

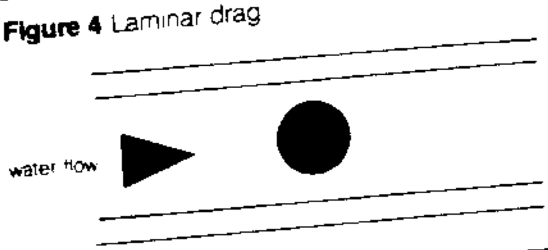
3. It slows down organisms trying to swim fast (nekton).

Most organisms in the sea depend on moving water to bring them food and oxygen. Therefore, many marine organisms reach a compromise between the benefits of moving water and the disadvantages of drag.

There are several types of drag.

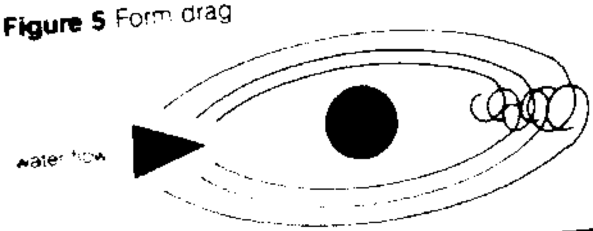
Laminar is a slow, smooth flow of water (Figure 4). No mixing occurs between layers of water. The drag is due to viscosity, which is the tendency of water molecules to stick together.

Figure 4 Laminar drag



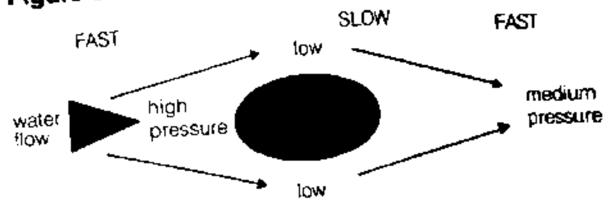
Form drag is a faster flow of water, and it causes a wake behind the organism (Figure 5). It also creates a boundary layer. This is a thin layer of slowly moving water next to a surface. It's caused by viscosity.

Figure 5 Form drag



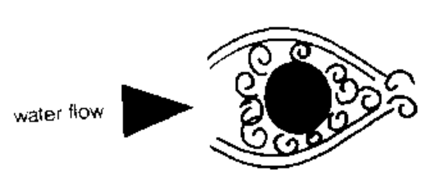
The wake you see in form drag is caused by a combination of the boundary layer and "the Bernoulli effect." This occurs when fluid flows around a round or oval object (Figure 6). It has to slow down to round the curve. When the fluid slows down, the pressure caused by moving water decreases. The change in pressure actually stops the water in the boundary layer, sometimes moving it backwards. This creates the wake at the back of the organism and a mixing of water layers.

Figure 6 The Bernoulli effect



Turbulent drag is a very fast flow of fluid (Figure 7). It causes the boundary layer to become turbulent.

Figure 7 Turbulent drag



"Reynold's number" describes the viscosity of water in relation to the size of an organism. A small organism has a low Reynold's number. That means the water seems thick (like butterscotch) when the organism is very small. A large organism has a high Reynold's number. To a large creature, water seems thin, like air.

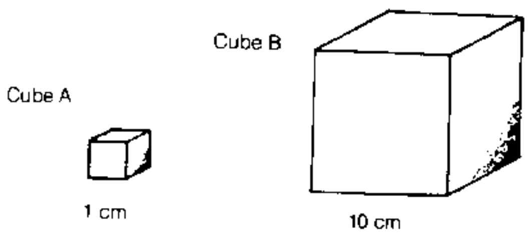
At low Reynold's numbers, drag due to skin friction is not significantly affected by the shape of the organism. But at high Reynold's numbers, any size, shape or orientation that reduces the size of the wake caused by the organism reduces drag.

Background

Plankton Size

Plankton come in a wide range of sizes, but a significant portion are very tiny, from one micron to one centimeter. One advantage of this is their small surface area to volume ratio. Most tiny one-celled plankton use absorption as a feeding method. This is handy because they don't need any special food gathering apparatus. But this method also restricts their size. For example, look at the two cubes in Figure 8.

Figure 8 Two cubes



Cube A is 1 centimeter on all sides. Determine its volume by multiplying

1 cm × 1 cm × 1 cm = ________ cm^3.

Determine its surface area by multiplying

1 cm × 1 cm = ________ cm^2 (area of 1 side)
1 cm^2 × 6 sides = ________ cm^2 (total surface area)

Now determine the surface area to volume ratio for this cube.

Surface Area: ________
Volume: ________

If Cube A were a planktonic animal, it would have six units of surface to absorb food. Yet it has only one unit of internal space to feed. With six times as much food gathering capacity as body to feed, this creature will never have difficulty feeding itself as long as food is abundant in the surrounding water.

Cube B is 10 centimeters on all sides. Determine its volume by multiplying

10 cm × 10 cm × 10 cm = ________ cm^3.

Determine its surface area by multiplying

10 cm × 10 cm = ________ cm^2 (area of 1 side)

100 cm^2 × 6 sides = ________ cm^2 (total surface area)

Write the surface area to volume ratio for this cube:

Surface Area: ________
Volume: ________

If Cube B were a planktonic animal, it would only have .6 units of surface through which to absorb food to feed one unit internal space. This organism would die of starvation.

This example shows that if an organism relies on absorption for food, it cannot be large. This explains why most plankton are so small.

Another reason has to do with sinking. Plankton survive best in the upper, lighted layers of the ocean. There, the sun's light is used for photosynthesis, and organic matter is formed. To sink below this area means almost certain death. But the plankton's small size slows sinking. To tiny plankton, the water is as thick as butterscotch. But to a large creature, the water is almost as thin as air.

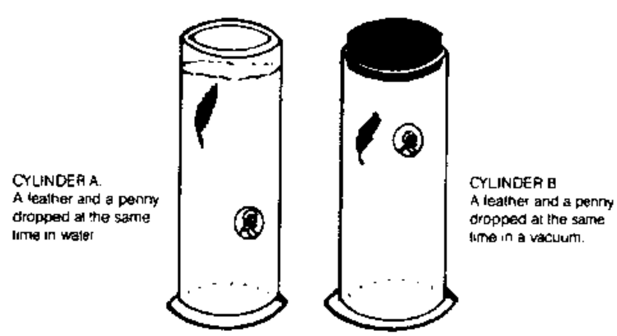
Plankton Shape

Shape can play a big role in an organism's rate of sinking. Notice the shape of some of the plankton in Figures 1 and 2. Note the long, feathery appendages and ornate spiny skeletons. By increasing surface area, plankton not only increase their food absorption but keep themselves from sinking too fast.

Examine Figure 9. In a liquid (or gas), if you drop a penny and a feather at the same time, the penny will fall faster. This is because a penny has less surface area for its volume. This makes it more dense and less resistant to sinking. However, the feather has more surface area than volume. It pushes on more liquid as it goes down, giving it more resistance to sinking.

In a vacuum where no liquid or gas is present, a penny and a feather would fall at the same rate. There is no substance to provide resistance.

Figure 9 Sinking objects



Nekton Size

If you were a scuba diver exploring the middle of the Atlantic Ocean, you would probably encounter several schools of large fish (tuna), and an occasional shark, whale or dolphin. What do all these animals have in common? They are all large and have basically the same shape.

Look at the Figure 5 and note the size of most nekton in comparison to plankton and benthos. Although the drawing is not to scale (plankton are actually much smaller), you can see that most nekton are large creatures. Size is a reflection of efficient food capturing.

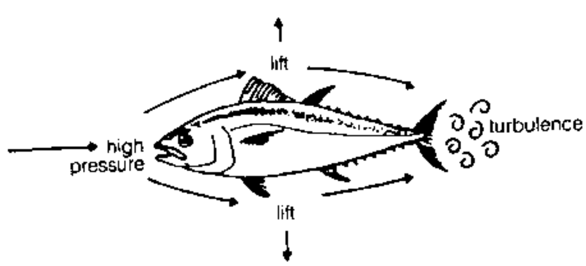
The upper middle layers of the ocean are rich in plankton and nekton. Blue whales, for example, are the largest animals on earth (up to 100 feet long). They survive by filtering small "krill" from the water. In one day, they eat several tons of krill simply by traveling through the right area.

Whales and large tuna migrate to areas where food is seasonally abundant. Sharks, however, are efficient predators and do not need to migrate. They can detect blood and vibrations from long distances, and their sharp teeth are almost impossible to escape. These abilities allow sharks to home in on prey in their vicinity.

Nekton Shape

Virtually every marine organism that spends most of its time swimming has a streamlined, fish shape. Fish-shaped creatures reduce drag by decreasing turbulence at the back and creating lift in the middle (Figure 10).

Figure 10 Nekton shape

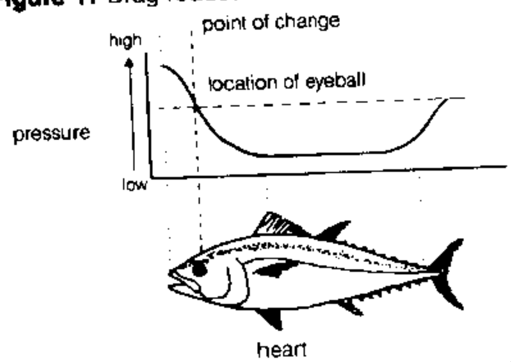


The speed of water as it flows around a fish slows in the middle as it goes over the hump. This reduces pressure, which creates a lift for the animal and allows it to swim even faster.

Sharks have rigid fins on either side (like airplane wings) and an asymmetrical tail. These shapes help with lift. Although sharks do not have an internal swim bladder to keep them buoyant like other fish, oil in the liver does assist in buoyancy.

This reduction of drag and increase of lift benefits fish in other ways. For example, the bluefish's eye is located at the exact point where high pressure turns to low (Figure 11). It experiences neutral pressure. Therefore, the eyeball is not flattened by high pressure or sucked out by low pressure.

Figure 11 Drag reduction

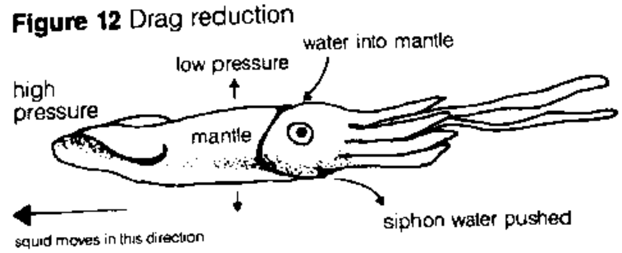


The heart also is located at a zone of minimum pressure so it can work more efficiently.

Another way that drag reduction and increased lift help nekton can be seen in squid. A squid swims by jet propulsion. It takes water into its expandable mantle and shoots it out a siphon. Think of a balloon when you let go of the opening. It travels very quickly around the room. You blow air into a balloon, but how does a squid fill its mantle with water? It's not muscular enough to do it on its own (Figure 12).

The low pressure in the middle allows the mantle to expand. The faster the squid swims, the lower the pressure and the more the mantle can hold. This enables the jet of water to become even more powerful and the squid to move even faster.

Figure 12 Drag reduction



Benthos Size

Organisms that live on the bottom of the ocean are often subject to strong currents and other water movement because the greatest concentration of benthic life is along the shore where breaking waves and storms cause rapid flow of water. The forces of moving water often determine the size and shape of benthic organisms.

Organisms that are attached to the substrate can be subjected to forces generated by water slowing down as it travels over them. If the creature is asymmetrically shaped, water will flow faster around one side than the other and tend to pull the organism toward the slow side.

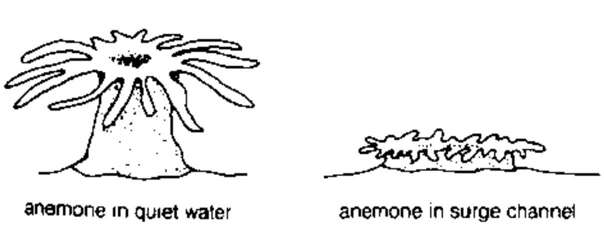
If the water slows down, speeds up or changes direction, it causes an acceleration reaction. This pushes the organism in the direction that the water is accelerating.

In constructing equations expressing the drag, lift and acceleration forces on an organism, you discover that the more volume and surface area an organism has, the stronger the forces. This explains why benthic organisms living in quiet, steady conditions are usually larger than those living in turbulent areas. The larger the creature, the more drag it must overcome.

Benthic Shape

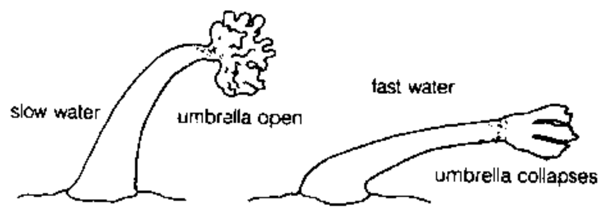
Like fish, benthic creatures can use shape to reduce drag and benefit from water flow. Sea anemones live permanently attached to the sea floor. In California, great green anemones live in surge channels where waves crash and water rushes in and out. These anemones feed on mussels, sea urchins and other organisms knocked down by waves. Yet they remain undamaged by taking advantage of the boundary layer. They contract their bodies into a 1-inch tall pancake (Figure 13). This keeps them in the slow-moving layer of water near the bottom and away from the harsh drag and turbulence above. In more protected habitats, great green anemones are usually 3 inches tall.

Figure 13 Green anemones



Anemones can also minimize drag by keeping most of their surface parallel to the flow. The fluffy anemone has an umbrella crown of tentacles it uses to filter feed. When water flows slowly, the tentacles lean at right angles so the anemone can filter the most water (Figure 14). In faster moving water, this could be a high drag situation. But the anemone can alter its shape for fast water. The crown collapses like an inside-out umbrella to make the surface parallel to the flow.

Figure 14 Fluffy anemones



Benthic marine organisms can also reduce the effects of drag by reducing "stress" (force per unit of surface area). The size and shape of an organism determines the amount of stress it will experience from a given amount of drag. Stress is the force that causes tissue to stretch or break.

The tall, narrow fluffy anemone actually experiences 45 times more stress than short, fat green anemones. The green anemone has fewer units of area to be affected by the drag force.

Procedure

In this activity, you will create your own organism. You will try to design a drag-proof, sink-proof or stress-proof marine creature.

Draw an imaginary marine organism that is built to avoid the disadvantages of living in a fluid and takes advantage of some of the benefits (such as the reduction of drag and the increase in lift). Label each part of your creature, and explain the good and bad points of its construction. Include a description of its habitat and feeding method, and don't forget the texture and strength, too.

If your teacher has planned it, use paper, staples, balloons, modeling clay, pencils or any other available materials to build your organism.

Worksheet

Draw and label your organism

Characteristics Advantages Disadvantages

1. Where does your organism live?

2. How does your organism move?

3. How and what does your organism eat?

4. How does your organism reproduce?

5. How big is your organism? Estimate surface/volume ratio.

6. What color is your organism? How does it protect itself?

7. Is your organism plankton, nekton or benthos? Explain.

Questions

1. Which of the following phrases describes nektonic animals?

a. very small, float in the surface layers of the ocean.

b. ultimately dependent on food from the water above.

c. live permanently attached to rocks.

d. large and built for rapid, efficient swimming.

2. Which of the following organisms do not use filtering as a feeding mechanism?

a. baleen whale

b. clam

c. tuna

d. oyster

3. Absorption, rate of sinking and surface area to volume ratios are important for:

a. plankton

b. nekton

c. sea anemones

d. benthos

4. When you drop a penny and a feather in a vacuum,

a. the penny falls more slowly

b. the feather falls more slowly

c. they fall at the same speed

d. the feather never falls

5. Whales, dolphins and fish have similar shapes because:

a. they are closely related

b. it keeps them from being seen by predators at the surface

c. it enables them to dive deeper

d. it reduces drag and takes advantage of the Bernoulli effect.

6. The larger the creature, the more ____________ it must overcome when it lives in a moving fluid.

7. When water flows over an object, there is a zone very close to the object where the water moves slowly. This is called the __________ ______________.

8. Water seems thin to:

a. plankton

b. nekton

c. benthos

9. The forces that tend to carry an organism downstream are called ________________________.

10. A cube has a side length of 5 centimeters. Calculate its surface area to volume ratio. Why would this cube not be successful as a member of the plankton?

11. Below is a drawing of two anemones. Describe the conditions surrounding each based on what you can see in their size and shape.

A. B.

12. Copepods are little shrimp-like animals that live in the plankton of the ocean. They eat tiny creatures in the surrounding water by using long, feathery projections. These copepods are small enough that water seems thick to them. Knowing what you know about water, do you think that copepods use their arms as filters or as scoops? Can they capture tiny things that would normally fit through the spaces in their arms? Explain your answer.

ACTIVITY 2

What Shapes Mean Speed

Purpose

To learn about how a fish swims, how it feeds and where it lives by looking at its body parts.

Procedure

Read the introduction for Activity 1.

Study the fish parts in Figure 15. Make an educated guess at speed value (1–3) for fish body parts in Figure 16. Test your estimates by adding part values on the drawings of the real fish.

Figure 15 Fish body parts

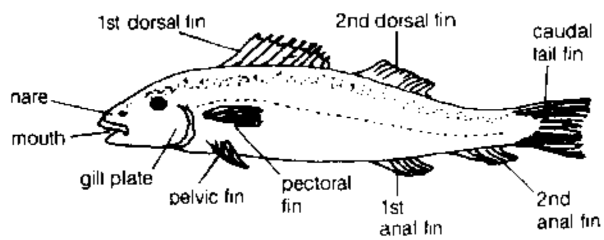
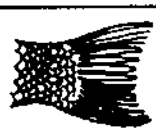
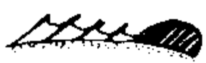
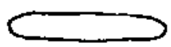
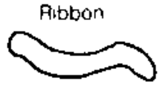
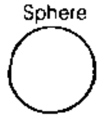
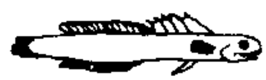
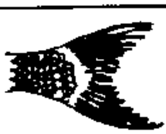
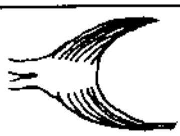
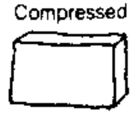
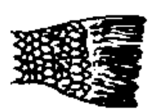


Figure 16 Speed values for fish body parts

Tail fin (a)	Middle fins (b,c)	Body shape (d)	Put it all together	Fast score
Guess and score Slow = 1 Medium = 2 Fast = 3	Guess and score Slow = 1 Medium = 2 Fast = 3	Guess and score Slow = 1 Medium = 2 Fast = 3	Use numbers from a, b, c, d to judge fish's speed	Total of a, b, c, d
	**Dorsal fin (b)** 	Rod 	 a___ b___ c___ d___	
		Ribbon 	 a___ b___ c___ d___	
		Sphere 	 a___ b___ c___ d___	
	**Pectoral fin (c)** 	Fusiform 	 a___ b___ c___ d___	
		Compressed 	 a___ b___ c___ d___	
		Flattened 	 a___ b___ c___ d___	

Competency Factors/References

Competency Indicators

Biology—

2.4.5 explain the special roles that water plays in living systems as solvent, transport medium and essential component;

4.1.1 support with examples, the principle that an organism's activity, size and habitat determine the nature of its morphology and internal systems; and

4.1.8 describe examples of systems in multicellular organisms that provide support and movement.

References

Alexander, R. McNeill, 1983. *Animal Mechanics, 2nd edition.* Blackwell Scientific Publications: Oxford, London.

Koehl, M.A.R., 1977. "Effects of Sea Anemones on the Flow Forces They Encounter," *J. Exp. Bio.* 69:87–105.

Koehl, M.A.R., 1982. "The Interaction of Moving Water and Sessile Organisms," *Sci. Amer.* 247(6), 124-134.

Vogel, S. and M. LaBarbera, 1978. "Simple Flow Tanks for Research and Teaching," *BioScience* 28:638–43.

Vogel, Steven, 1981. *Life in Moving Fluids: The Physical Biology of Flow.* Willard Grant Press, Boston, Mass.

Vogel, Steven, 1984. "Drag and Flexibility in Sessile Organisms," *American Zoologist* 24:37–44.

Vogel Steven, 1987. "Flow-Assisted Mantle Cavity Refilling in Jetting Squid." *Biol. Bull.* 172:61–68.

Wainwright, S.A., W.D. Biggs, J.D. Currey, J.M. Gosline, 1976. *Mechanical Design in Organisms.* John Wiley and Sons, N.Y.

Wainwright, S.A., and M.A.R. Koehl, 1976. "The Nature of Flow and the Reaction of Benthic Cnidaria to it," In *Coelenterate Behavior and Ecology.* G.O. Mackie Plenum Press, New York.

Geologic History and the Oceans

Organisms must adapt to their environment to survive. One of the most remarkable aspects of life is the efficient design of many animals and plants. Think about a shark, for example. Its keen senses and razor-sharp teeth make it such a successful predator that it has lived in the oceans for millions of years.

How do we know? Fossils. Fossils are the remains of organisms preserved in rocks and sediments. We know by studying fossils that the animals and plants on Earth have changed over millions of years. (The science of fossils is called paleontology.) This is one of the reasons that the theory of evolution was formed. The word "evolution" means change over time.

We said that organisms cannot survive unless they adapt to their environment. Therefore, if animals and plants have changed, so has the environment. In the past few decades, scientists have discovered evidence that the ocean has played a major role in worldwide environmental change.

Geologic Time/Dating Fossils

Marine invertebrates (animals with no backbone) are the most abundant type of fossil. They are so common that many geological periods are based on them. A geologic period is a unit of time when a particular group of organisms was prevalent. Paleontologists speak in terms of "geologic time," where events are thought of in thousands and millions of years.

Determining the age of the Earth and of fossils is not easy. Scientists have two different methods—correlative dating and radiometric dating.

In correlative dating, the paleontologist examines layers of rocks containing fossils and determines which ones are in the upper, middle and lowest layers. Those at the bottom were deposited first and are the oldest. The layer above is younger, and the upper layer is youngest. This method is useful but doesn't give an absolute date.

To get a more accurate date, scientists use radiometric dating. Unstable radioactive isotopes have known decay rates. These are expressed in "half-lives." For example, ten units of an isotope with a half life of 200 years will have decayed to five units between 1900 and the year 2100. By calculating the relative proportion of the radioactive element and its decay products found in a fossil (or in a rock next to the fossil), you can determine how long it has been since that fossil formed.

For example, uranium-235 decays to lead-207. A rock with more uranium-235 than lead-207 is younger than a rock with more lead-207 than uranium-235.

Radioactive isotopes don't occur in every rock. But by combining correlative dating with radioactive dating, a trustworthy age can be obtained.

The Marine Fossil Record

The first forms of life on Earth are believed to have lived in the sea since the earliest fossils are found in ocean sediments. And, you don't have to be a scuba diver to collect them. Fossils of marine organisms can be found in the middle of continents (far from any beach) and even on the tops of mountains. The distribution of the oceans certainly has changed since the Earth was formed. This environmental change may have had a big effect on the evolution of life.

Another interesting thing about marine fossils is the existence of periodic mass extinctions. Hundreds of species disappeared in a geologically short period of time.

There are many marine creatures that we don't see today as a result of these extinctions (Figure 1 and 2). These include rugose corals, hyolithids, trilobites and plesiosaurs. But there are some marine organisms that have been so evolutionarily successful that they have survived environmental changes since the Paleozoic era and are still with us today (Figure 3).

No one knows exactly why some animals become extinct and others survive, but there are lots of theories.

Figure 1 Extinct marine creatures

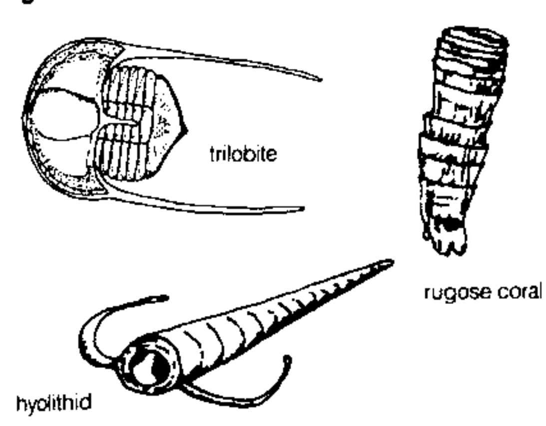


Figure 2 Extinct marine creatures

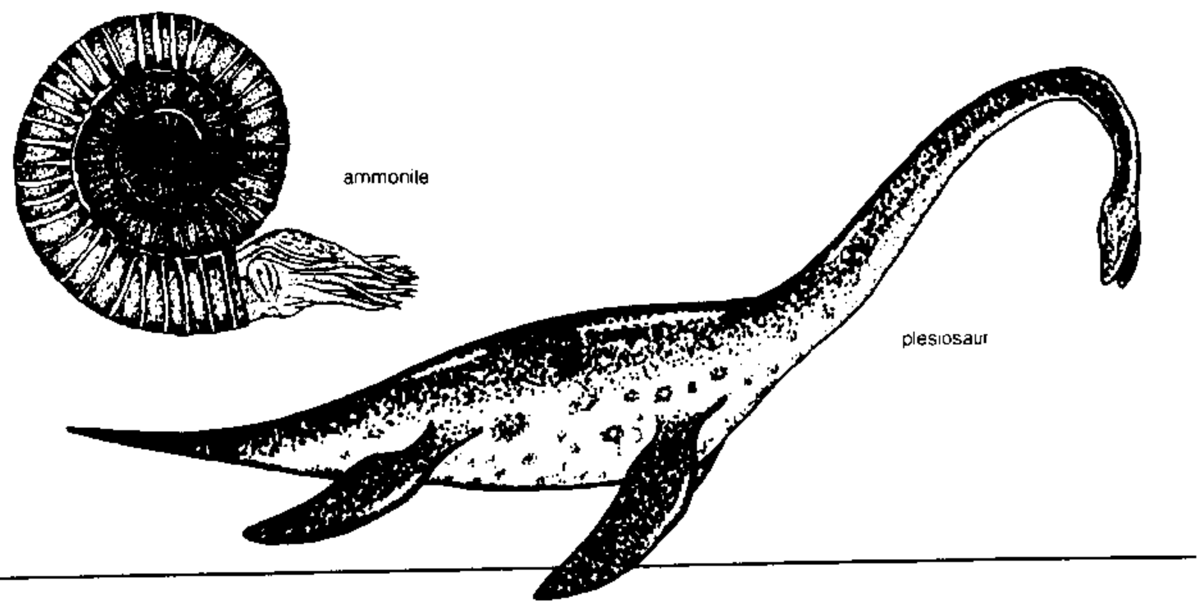
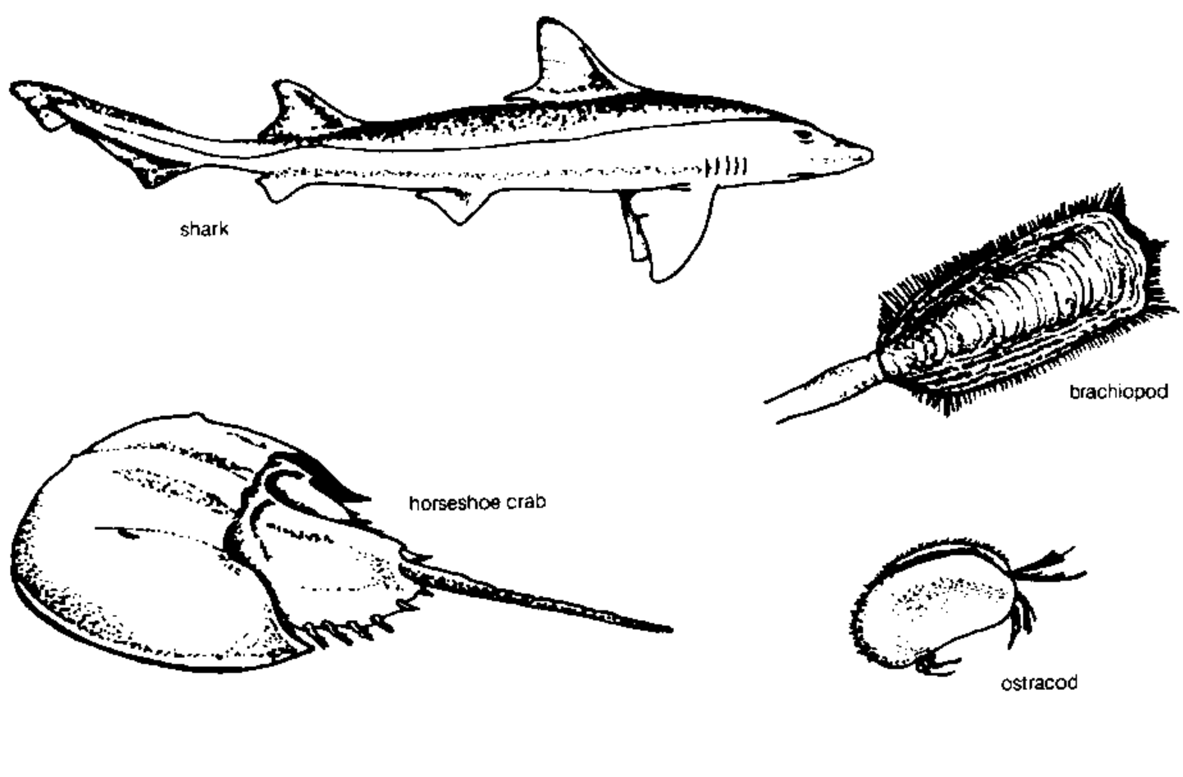


Figure 3 "Living fossils" in the sea—marine animals that have survived since the Paleozoic era



Changes in the Oceans

Theories about the causes of mass extinctions often center on the history of the seas. The occurrence of mass extinctions and the abundance of marine fossils on land are evidence that the oceans have undergone dramatic changes in their shape and geographical distribution. Scientists hypothesize that two major processes are responsible—plate tectonics and sea level changes.

Plate Tectonics

In the 1960s, scientists accepted the idea that the continents have moved since they were formed. As long as maps have existed, people have noticed that the edges of the continents fit together (especially South America and Africa). It was not until recently, however, that it was proved that continents do drift.

Scientists discovered ridges in the middle of the oceans through which hot, new crust seeps (Figure 4). At the edges of some ocean basins, there are deep trenches where old crust is destroyed. This means that the continents are riding "plates" that cover the Earth like a skin. New material is added to a plate at one end (ocean ridge) and destroyed at the other end (trench). This results in constant movement.

This process brought the continents together in the Mesozoic era and gradually pushed them apart. New oceans formed between them. Plate movement continues today, although it is not fast enough to notice. Geologists have used scientific technology to measure the Atlantic Ocean's growth, which is at the rate of approximately one inch a year.

Although this is not significant in our lifetimes, in geologic time such movement makes a big difference. The formation of new oceans changed the distribution of water and altered climate. This may have caused some extinctions.

Sea Level Changes

When you change the shape of a container (like an ocean basin), you change the level of the water in it. Think of the water level in a short, wide glass versus the same amount of water in a tall, narrow one.

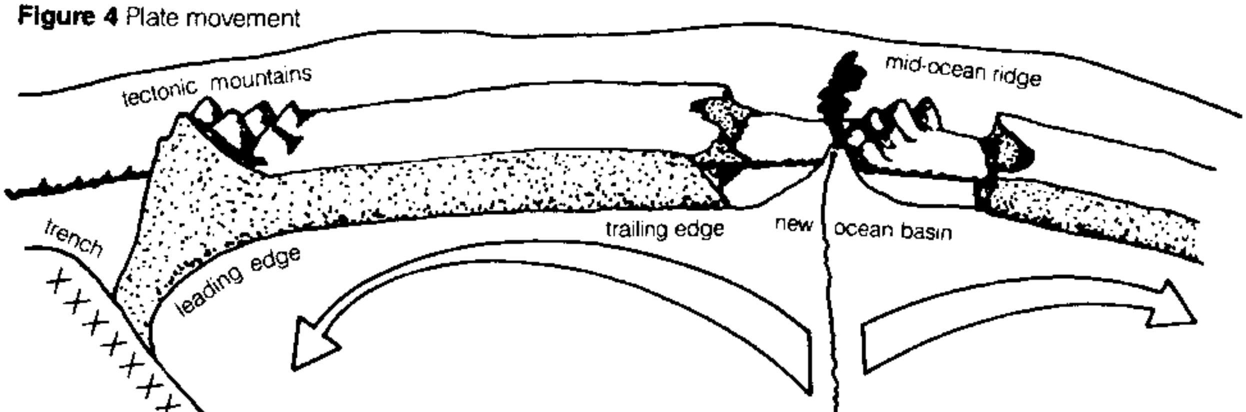
Scientists have plotted the changes in sea level as they correlate to warm and cold climates. The evidence shows that sea level has rarely been stable.

For much of the Earth's history, sea level has been higher than it is today. Then, the ocean covered most of the continents, creating large, shallow seas. The waters were warm, the depth and currents uniform, and the conditions stable. Many different, specialized types of creatures evolved in these oceans. The times of maximum diversity in the fossil record coincide with times of maximum flooding. When sea level dropped and new, deeper basins formed, the organisms that depended on the shallow seas lost their habitat and became extinct. It is possible that the movement of the continents and the changes in sea level have written the course of evolution in the sea.

There are many different theories about mass extinctions. Interestingly, the extinctions of marine fauna coincide with extinctions on land. Why? Some researchers believe that a key species, such as a small fish or algae, formed the base of the food chain for ocean and land animals.

Other scientists have focused on extraterrestrial reasons for mass extinctions. The presence in rocks of meteorite dust (a mineral called iridium) corresponds to times of extinctions. This suggests that asteroids hitting the earth may have caused huge dust clouds to block out the sun and rapidly alter the climate. Other researchers are looking at comets to explain the changes. It is unlikely we will ever know for sure what caused extinctions, but is important to try to understand so we can better predict the future.

Figure 4 Plate movement



ACTIVITY 1

Personal Time Line

Purpose

To develop an awareness of the amount of time involved in the evolution of life, to become aware of when complex organisms evolved in geologic time, to see how much evolutionary time is focused on ocean life and to become aware of the oceans as the birthplace of all living things.

Materials

scissors
colored pencils
paper
geologic time scale (textbook for information and data)

Figure 5 Fold a sheet of paper lengthwise three times

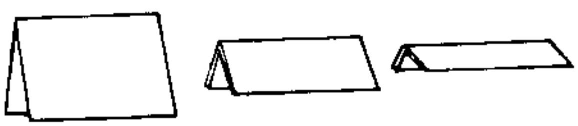


Figure 6 Draw a line in each crease as indicated

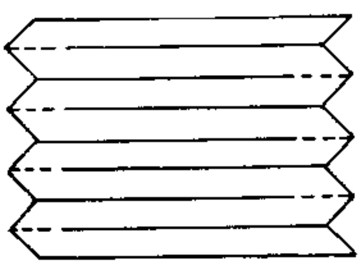
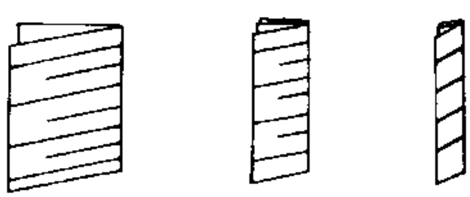


Figure 7 Fold the paper crosswise three times



Procedure

Fold a sheet of paper (8½ by 11 inches) in half lengthwise three times. When you unfold the sheet, the creases should make eight sections (Figure 5).

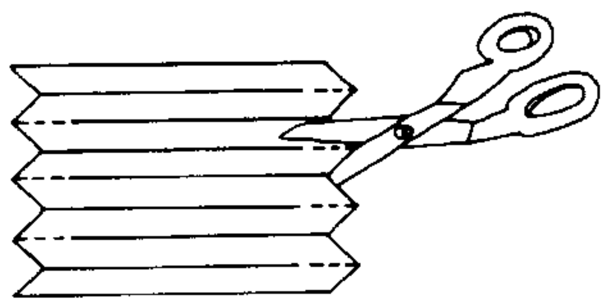
Draw lines like those indicated in Figure 6 at each crease. Fold the paper in half crosswise three times (Figure 7). Unfold and cut along the horizontal lines you drew earlier. Now unfold your time line, bending it over at the joints so that it will lay flat and straight (Figure 8).

Label your time scale. Each crease mark is equal to one million years. Mark the boundaries of the three eras Paleozoic, Mesozoic and Cenozoic. Use the geologic time scale in your textbook to determine the eras. With light-colored pencils, color each era a different color.

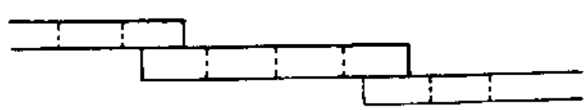
Label the periods (Pre-Cambrian, Cambrian, Ordovician, etc.). In each period, make small drawings of the organisms that were abundant then.

Put a star where there were mass extinctions. Be sure to notice where humans appear.

Figure 8 Unfold and cut along lines drawn earlier



Unfold time line, bending it over at joints so that it lays flat and straight



ACTIVITY 2

A Classroom Geologic Time Line

Purpose

To develop an awareness of the amount of time involved in the evolution of life, to become aware of when complex organisms evolved in geologic time, to see how much evolutionary time is focused on ocean life and to become aware of the oceans as the birthplace of all living things.

Materials

poster board
scissors
marking pens
masking tape or thumbtacks
meter sticks or tape measures
calculators

Procedure

Cut out large (30 cm wide by 15 cm long) arrows from the poster board.

Using the evolutionary time line from a textbook, prepare as many arrows as the number of significant events you want to portray. On each arrow put when the event occurred. For example, mark these firsts: cell formation, land plants, fish, air-breathing animals, insects, reptiles, birds, mammals, hominids, human beings and modern humans.

Now, measure the total periphery of your room. Take that number and divide by 5. If you assume that Earth is 5 billion years old, then ⅕ of the room's periphery will equal 1 billion years.

Now divide the length that equals 1 billion years by 10. That length will equal 100 million years.

Finally, divide the length that equals 100 million years by 100. You will have the length that equals 1 million years.

If the periphery of your room is 50 meters, then 1 million years will be 1 cm. If the periphery is 25 meters, then 1 million years will be .5 cm.

Now, agree on which corner to the room to start. Take your first arrow, marked "Earth is formed—5 billion years ago," and tape it in this corner.

Take the next arrow, marked "First cell formed—2.7 billion years ago," and put it the appropriate distance away from your first arrow according to your calculations.

Continue putting up arrows until you have represented all the major events in the evolution of living things.

Questions

1. What are the benefits and disadvantages of radiometric dating?

2. What are the most abundant types of fossils.

3. In which geologic period do we find humans?

4. Name three very ancient types of organisms that are still alive today.

5. What are three possible explanations for the mass extinctions that have occurred over geologic time?

6. How long had the Earth been in existence before the first living cell evolved?

7. When did plant life first appear on land?

8. How long did life exist in the oceans before life first appeared on land?

9. Why did life first evolve in the oceans?

10. How do you explain the vast increase in the diversity of life over time?

11. How did ocean life affect the ozone layer? How did this permit terrestrial life?

12. What is the theory of plate tectonics?

13. What does the word "evolution" actually mean?

14. How can the movement of the continents affect sea level?

15. Why might sea level changes have significantly affected the evolution of marine and terrestrial organisms?

16. Can you think of something that is going on today that might be causing many species of animals and plants to become extinct? Explain.

17. Why should organisms change over time rather than remain the same? What are they reacting to?

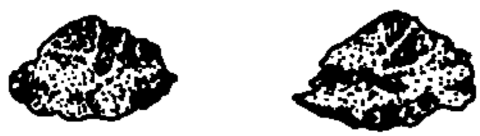
18. Let's say that uranium-236 decays to lead-205. Which of the rocks below is older (Figure 9)?

a. more uranium-236
less lead-205

b. more lead-205
less uranium-236

Explain your answer.

Figure 9 Two rocks



ACTIVITY 3

Fossil Lab

Purpose

To make careful observations, to become familiar with and recognize many different kinds of fossil formations and to interpret observations.

Teacher Background

Fossils are excellent teaching materials. Many students are already familiar with and enthusiastic about fossils. They are likely to bring contributions from home for use in the classroom. The incredible age of fossils generates amazement in students and teachers alike. But most important, fossils can be used to sharpen students' observation skills and to lead them to interpret and hypothesize.

Some of the easiest fossils to collect and the most inexpensive to obtain are marine fossils. In fact, the most likely place for a quick burial (before the body can be eaten or rotted away) is in the sea. There, sediments are always collecting in an anaerobic environment, explaining why 90 percent of all fossils are marine organisms. And, those organisms with hard shells are the most likely to leave fossil remains. Finding marine fossils far from today's oceans tells us a lot about the Earth's past.

Even ancient people were aware of fossils, wearing them as amulets and attributing supernatural powers to them. In the Middle Ages, fossils were thought to be vestiges of the "The Great Flood," remains from the trial and error of creation, temptations by Satan, or a trick of nature. Leonardo da Vinci was one of the first people to grasp the implications of fossil remains. But is was not until the early 1880s that paleontology, the study of fossils, became an established science.

There are several types of fossils:

- **Preservation** of complete organisms or parts of organisms in ice, amber or tar.

- **Molds**—an imprint of the actual organism, such as a shell, in mud or sediment. Molds can be of the inside or outside of the shell.

- **Trace fossils**—tracks such as the trail of a horseshoe crab in rock that was once sediment, former "homes" such as preserved mud burrows or tubes from worms, or the feeding traces of worms or other organisms.

- **Petrifactions**—replacement fossils, where the original material was dissolved and replaced with minerals.

- **Casts**—The inside of a bivalve, for example, may be filled with minerals that harden, leaving the shape of the shell on the outside.

- **Distillation**—carbon films left by a leaf or an animal. The film may wash away but the impression can be left behind in the rock.

Fossils can tell us many things about the Earth. We can tell the age of a stratum of earth by noting the fossils found in the material. Each geologic era has its characteristic flora and fauna. Thus we determine what kinds of environments existed in different areas of the Earth over time. We can determine the Earth's movements and the shifting of its layers.

In addition, we can use fossils to see how organisms have changed. This helps us understand the vast time involved in evolutionary changes and the interaction between organisms and their environment during evolution. Fossils are even used to locate coal seams and petroleum and gas deposits. Microfossils in deep borings can be indicators of carbon products.

In addition, fossils are valuable in what they don't tell us. Many organisms were not preserved as fossils. This provides the opportunity to gather available data and make interpretations based on incomplete evidence.

The following student activity is designed to provide the student with a "lab practical" environment. The students move around the classroom for 1½ to 2 minutes to observe each specimen and answer a question. The actual fossils and questions will be specifically determined by what the teacher and students have collected. In addition, the lab is best if a few fossils of land organisms (plant and animal) are used to provide for comparison and discussion.

It is suggested that a collection of fossils be obtained. These may be fossils already present at the school or ones from various private collections. Other sources are:

- Carolina Biological Supply—GEO 5299 is 15 fossils from the Texasgulf Inc. phosphate mine in Aurora. These are mounted on labeled cards and come with background information. The cost is $14.

There are other sets available. A larger one with bigger fossils from Aurora costs $46. In addition, there are individual fossils such as ammonites, crinoids and sand dollars.

• Texasgulf Inc. can be contacted directly. Write the Communications Coordinator, Texasgulf Inc., P.O. Box 48, Aurora, N.C. 27806.

• Also try museum stores (Discovery Place in Charlotte, The Museum of Life and Science in Durham, The N.C. State Museum of Natural Sciences in Raleigh, etc.), gem and mineral stores or science and hobby stores.

• Or collect your own. Educators at the N.C. Aquariums, the N.C. Maritime Museum or the N.C. State Museum of Natural Sciences could direct you to good fossiling areas.

Try to collect a variety of fossils that represent different geologic periods of formation.

Examples:

Brachiopods—These are bivalves. You can find the actual shells, imprints or casts. They are common in rocks of the Cambrian to Carboniferous ages.

Corals—The walls and partitions built by tiny soft-bodied creatures long ago decomposed are preserved.

Trilobites—These creatures had a head, segmented body and tail section. They roll up like a pill bug and are found in mudstones of the Cambrian to Silurian ages. They can be imprints or replacements.

Snails (Gastropods)—These are single-coiled shelled organisms.

Sea urchins—The spines are usually missing in fossils.

Ammonites (Cephalopods)—These are extinct now but were common from the Jurassic to Cretaceous ages. They are found as replacements or casts.

Various fish—These are usually imprints and a fine example of marine vertebrate fossils.

Whale bone—These are easy to find in North Carolina and are an excellent example of minerals replacing tissue but leaving the porous bony appearance.

Sharks' teeth—These are easy to find and can be used to illustrate how one part of an organism can be used to extrapolate other data.

Tube worm homes—These are harder to find but not impossible.

Insects encased in amber—These must be bought. They are expensive but nice to have.

Petrified wood—Carolina Biological Supply has some samples from the West for about $6.

Horse teeth, plant imprints, internal casts, sand with miniature fossils, fossil feces (coprolite), etc. can be collected.

Always include in your collection at least one example of something that is not a fossil. You can even let the students know there is an imposter. It will sensitize their observation powers. You might use a piece of pyrite (fool's gold), a dead beetle, a barite desert rose, uncut geode or a snake skin. Use your imagination.

Student Procedure

Around the room you will see 30 stations. Each station has one fossil and a question. Observe the fossil and answer the question. After about two minutes, you will be asked to shift to the next station. Repeat the process.

At the end of the lab, you will have time to return to any fossils you wish to observe longer. Answer these questions as best you can, remembering that sometimes even the experts disagree. Among the fossils will be some impostors. See if you can identify the materials that are not fossils.

Remember that fossils are by definition the actual remains or evidence of living organisms that lived in the past. They may be impressions, casts, parts of the organism or mineral replacements of bone or shell.

Teacher Procedure

Provide students with a sheet that has the questions for each station printed out next to the station number. Each student starts with the question that corresponds to his first lab station and continues from there in numerical order. This saves the student time and allows more time for observing and thinking. For some stations, students will need a dissecting microscope or magnifier.

Here are some sample questions for various fossils. The types of fossils at each station are in parentheses. Do not include these on the cards next to the fossils or on the handout. These are for your information only.

Sample Questions

1. (shark teeth)

Shark teeth are commonly found at the bottom of the ocean, but other parts of the shark are rarely found there. Suggest a reason for this.

2. (mold of a seashell)

What type of fossil is this and how was it formed? What environment would these animals have lived in?

3. (trilobite from Utah)

Was the animal that formed this fossil soft- or hard-bodied? Explain. What was the environment like 500 million years ago in Utah?

4. (petrified wood)

What does this sample have in common with wood? What does this sample have in common with rock?

5. (leaf film)

Fossil evidence suggests that much vegetation found in Canada today is similar to what was found 14,000 years ago in our area. Suggest an explanation for this.

6. (shellacked fish)

Is this a fossil? Why or why not?

7. (spider in amber)

How might this spider have been preserved so completely?

8. (ammonite cast/mold)

What kind of fossil is this? What kind of environment did this organism live in?

9. (fossil coral)

What is the common name of this fossilized organism? What used to live in the tiny holes?

10. (leg bone [femur] of large mammal)

Is this a fossil? Why or why not?

11. (shark's tooth)

Is this an example of actual remains or replaced remains? Explain.

12. (arrowheads)

What are these? Are they fossils? Why or why not?

13. (fossil fern [Pennsylvanian] and fossil coelenterate [Mississippian])

If the coelenterate fossil was found in a deeper stratum of rock in the same location as the fern fossil was found, which do you think was older? Why? What must have happened to the area over time?

14. (fish print [Wyoming])

How do you think this fossil was formed? I thought Wyoming was where "the deer and the antelope play." Why was this fossil found there?

15. (whale vertebra)

This is a fossil. What part of the anatomy of a large animal is it? This was an ocean-dwelling organism. Any guesses?

16. (gastropod)

Is this fossil a mold or a cast? Explain.

17. (piece of pyrite [fool's gold])

Is this a fossil? Why or why not?

18. (plant pod [pseudoivory] and fern film)

One of these is a fossil. Which one? Explain.

19. (Chesapeake Bay fossil scallop)

Fossils of this type are common. Was this organism more abundant than other species that lived at the same time? Why or why not?

20. (cast of a bivalve)

What kind of fossil formation is this? What kind of organism was it?

21. (sycamore leaf [carbon film])

What kingdom did this organism belong to? What was the environment like when and where this organism lived?

22. (petrified wood)

How many years ago did this organism first appear on Earth? Certain fuels are often associated with an abundance of these organisms. Cite two examples of these fuels.

23. (plaster cast of mastodon molar)

This is a plaster cast made from a fossil or part of a mastodon. What part of the mastodon is this?

24. (oreodont teeth [pig-like creature])

Was this animal a herbivore or carnivore? Explain.

25. (fossil long bone)

What is this a fossil of? Was the organism a vertebrate or an invertebrate? Explain.

26. (fern film and branch of another plant on same piece of rock)

Are the branch and leaves in this fossil from the same type of organism? Explain.

27. (two trilobite fossils in same rock)

How many fossil organisms are here? What kind of environment do you think they once lived in?

28. (tube worm homes)

What kind of organisms were these? What kind of environment do you think they once lived in?

29. (rock with many small molds of marine organisms)

There are fossils on both sides of this rock. Are they all from the same species? Explain.

30. (two samples of whale vertebrae [one is noticeably heavier])

Lift both of these fossils. Can you explain the difference in weight?

31. (marine vertebrae [small])

What do you think these pieces of marine skeleton are?

Competency Factors/References

Competency Indicator

Biology—

1.1 know about the nature of science;

1.2 know the methods of science; and

1.3 know the limitations of science.

Competency Measures

Biology/Academic—

1.1.3 give scientific evidence to support the theory of evolution;

1.2.1 perform laboratory exercises that use process skills such as observing, interpreting data and formulating conclusions; and

1.3.1 explain the limits of time, experience and society on scientific problem-solving when given an example of a problem facing past generations.

References

Brownlee, Shannon. "Cycles of Extinction," *Discover.* May 1984, pp. 22–24.

Carter, J.G., P.E. Gallagher, Enos Valone and T.J. Rossbach. 1988. *Fossil Collecting in North Carolina.* N.C. Department of Natural Resources and Community Development, Division of Land Resources, Geological Survey Section, Raleigh.

Gramwell, Martyn. 1983. *Understanding and Collecting Rocks and Fossils.* Usborne Publishing Ltd., London.

McCormack, Alan J., Arnold I. Miller and Robert Motzko. 1980. *Biology Laboratory Manual.* Scott, Foreman and Co., Glenview, Ill.

Rhodes, Frank H.T., Herbert Zim and Paul R. Shaffer. *Fossils, A Golden Guide.* Golden Press, New York, Western Publishing Co., Racine, Wis.

Spence, Lundie and Dirk Frankenburg. 1989. *North Carolina Marine Education Manual: Coastal Geology.* UNC Sea Grant, UNC-SG-78-14A, Raleigh, N.C.

Thompson, Ida. *Audubon Society Field Guide to North American Fossils.* Alfred A. Knopf, Inc., New York.

Wilbur, Amy. "A Dynamic Planet," *Science Digest.* March 1986, pp. 52–53.

Seashells and Scientific Names

Background

Seashells have always been admired and sought for their beauty, their variety and the mystery of their appearance on our shores. They exemplify art in nature—the exquisite delicacy and pattern that man can never truly duplicate. Because of their attraction, seashells are excellent for teaching classification. Students enjoy handling them and examining their differences and similarities.

Seashells are common and readily available. Most students have probably picked one up at some time. This set of materials should stimulate their interest in knowing the actual names of shells and demonstrate the importance and utility of a good classification system. Plus, students should emerge with a sound understanding of the phylum, Mollusca.

Teacher Notes

Students may want to use words such as clam or snail in their keys. Be sure to make it clear that this assumes prior knowledge on their part and shouldn't be used.

Remember, don't let your students look at the pictures in the field guide until they have decided on a possible identification. You want them to try to take each shell through the key at least once.

A Description of the Mollusk Phylum

Common features of all mollusks:

- soft-bodied
- body includes: a muscular foot or arms
a visceral mass (guts) and gills
a mantle
a shell
a trochophore larva

The Four Major Classes of Mollusks:

Class Polyplacophora: many shell bearers

- common name: chitons
- common features: eight internal shell plates; a radula, or row of teeth, for scraping algae off rocks

Chitons are slow, usually small, brownish creatures that live on rocks at the seashore. When disturbed, they clamp down powerfully and are difficult to pry off. In California, you can find cryptochitons as large as footballs.

Class Gastropoda: belly-foot

- also known as: univalves—one shell
- common names: snails, slugs, limpets, whelks, etc.
- common features: a radula for scraping algae off rocks; one coiled, external shell; well-developed head and eyes; an asymmetrical visceral mass

Gastropods live in a coiled shell. They move on a muscular foot that they can draw back into their shell when danger threatens. Some gastropods have lungs and can live on land. But most live underwater. Slugs are gastropods without shells. In the tropics, there are gastropods called cone shells that can shoot a poison dart lethal enough to kill a man.

Class Pelecypoda: hatchet-foot

- also known as: bivalves—two shells
- common names: clams, scallops, mussels, oysters, etc.
- common features: no radula, uses gills to filter food; two external shells attached by a hinge; no head, primitive eyes; two siphons: one pumps water in, the other out

Pelecypods move rapidly by digging with their muscular, hatchet-shaped foot. Almost all of them live buried in the sea floor. There are giant clams in the tropics, but they close their shells very slowly. Pelecypods are eaten all over the world, and some are harvested for pearls.

Class Cephalopoda: head-foot

- common names: squids, octopus, chambered nautilus
- common features: no radula, captures food with tentacles and arms; well-developed head and eyes; muscular foot has become arms and tentacles; uses ink as an escape mechanism

Cephalopods are some of the fastest moving and most intelligent animals in the ocean. An octopus has no shell, but it has a beak that it uses to bite and eat its prey. Squid have an internal shell called the gladius, or pen. The chambered nautilus has a beautiful external shell with internal chambers filled with gas to help them float and swim. Unlike gastropods, the nautilus is not coiled up into the shell. It lives only in the last chamber.

Believe-It-Or-Not Mollusk Facts

- There are over 100,000 species of mollusks. That makes it the second largest phylum on earth. Arthropoda, the phylum containing insects, has the most species.
- The radula and mantle are found in no other phylum.
- Slugs can crawl over the edge of a razor without being cut. This is because their foot is protected by special slime.
- Giant clams may be five feet long and weigh 500 pounds.
- Only one in 1,000 wild oysters contain a pearl.
- In 1860, a giant squid was found whose body, not including the arms, was 50 feet long and 20 feet in diameter. It was estimated to weight two tons.
- The Indians of New England used whelk shells for beads and clam shells for money. It was called "wampum."
- Until plastic was invented, many buttons were made of shell.

ACTIVITY 1

Designing a Dichotomous Key

Purpose

To teach students how to set up and use a dichotomous key.

Student Background

When you want to organize your record albums at home, you have to develop a system of classification. This system must be consistent, easy to use and based on important common characteristics. You could, for example, arrange your records according to the color of the cover. If you tried it this way, you would run into some problems. First, most album covers are many different colors. How are you going to decide which color to file the album under? And does the color of the cover really make a difference to you when you're looking for music to play? A better way might be to organize the albums according to the type of music: country, jazz, rock, etc.

Biologists need a system to organize living things. When you go to the zoo, you don't find birds on display with monkeys or snakes slithering around with lions. The animals are arranged in a particular way. When you open a biology book, the chapters on plants and animals are arranged in a certain order. That's because scientists use the Linnaean System of Classification. This system has seven categories: kingdom, phylum, class, order, family, genus and species.

Originally, organisms were classified and organized to make them easier to study and to simplify communication with scientists worldwide. It was an attempt to create order out of chaos and to develop an understanding of relationships.

With our understanding of evolution, genetics and biochemistry, many other characteristics are considered when placing an organism in a group with similar organisms. Several changes in the placement of organisms have occurred since researchers discovered new ways of assessing similarities, differences and relationships. Currently, the classification system represents evolutionary relationships and can give us information about the changes that have occurred over time. Classification is not a fixed absolute, but rather a dynamic system that can change with new knowledge or with the changes that occur in organisms over time.

You may have learned about Linnaeus's system before today. Even if you haven't, you've probably seen a product of it—the scientific name. Scientific names come from the last two categories: genus and species. *Homo sapiens* is made up of the genus name and species name of human beings. Lions are in the genus *Felis* and the species *leo*, so their scientific name is *Felis leo*. Notice how the name is written. The genus is capitalized; the species is not. The entire name should always be italicized or underlined. All organisms have scientific names.

Scientists called taxonomists put living things into a system of classification and give them names based on important characteristics. They place organisms into groups that have clear-cut similarities. Think about the class, mammals. You should be able to point out the important characteristics that all mammals share. And you should be able to point out why something like a toad is not a mammal.

Naming a creature is one thing, but figuring out what that name is when you're not a taxonomist requires a key. A key allows you to retrace the steps that a taxonomist took to classify an organism. It leads you through a series of choices until you get to a final choice that points to the scientific name of the organism you wanted to identify. Because there are at least two choices at every step, these devices are called dichotomous keys (di- means two, -chotomous means branched) (see Figure 1).

Materials/Equipment

an assortment of seashells (Use whatever shells are available, such as scallops, mussels, cockles, whelks, periwinkles, clams, oysters, limpets, moon snails or slipper shells.)
rulers
string
balance
hand lens

Procedure

Part 1

Your class should divide itself into groups of four. Each group should have a number. Your teacher will give each group a collection of different seashells plus some work sheets.

1. Separate your shells into two distinct groups. To do this, pick a characteristic that looks important. Look at the color, size and shape. Use a ruler and string, scale or hand lens to identify significant differences between the shells. You want to find one characteristic that will divide all your shells into two categories. (For example, shells with hinges and shells without hinges [typically snails]) NOTE: Be sure not to use words such as clam and snail. These words assume too much.

2. Separate each of your large categories into smaller ones, using dividing characteristics. (For example, hinge at center of top and hinge off to one side.) Remember you are dividing two already separate groups. Do not recombine any of the shells you divided in step 1.

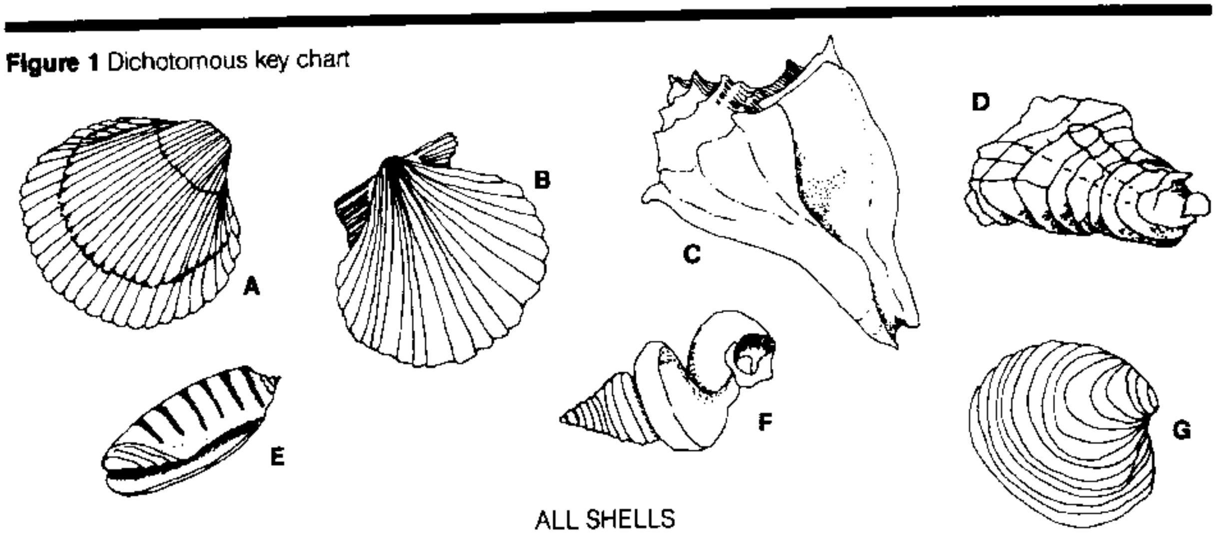
3. Once again, divide the shells in each remaining group. By now you may have categories with only one shell. When this happens, you are ready to name that shell. This could be its common name (coquina, disk clam) or a made-up name (George, Sue).

4. Any categories that still have more than one shell can be divided, named and listed. By now each shell should have its own category and name.

Your chart represents one form of a dichotomous key. At each step, there are two choices. You could have easily created a different form by making different choices. Therefore, taxonomic keys are reflections of individual choices that are arbitrary in nature.

When the class has completed their charts, switch charts and shells with another group. Using a stopwatch, your teacher will then time how long it takes for each group to correctly identify the shells using your chart. The group that is fastest has the best key. To be sure, switch again.

Figure 1 Dichotomous key chart



ALL SHELLS

- hinge
  - hinge center
    - ears extension — B — **Scallop**
    - no ears — A — **Cockle**
  - hinge off-center
    - even rounded shape — G — **Quahog Clam**
    - elongated irregular shape — D — **Oyster**
- no hinge
  - whorls connected — F — **Wormshell**
  - whorls not connected
    - wide cavity for animal, knobs — C — **Lightning Whelk**
    - narrow cavity for animal, no knobs — E — **Olive Shell**

ACTIVITY 2

Using a Dichotomous Key

Purpose

To teach students how to use a dichotomous key

Materials

an assortment of shells
copy of the dichotomous key chart (Figure 1)

Procedure

Divide students into groups of four or five. The teacher will give each student a collection of shells and a dichotomous key of seashells.

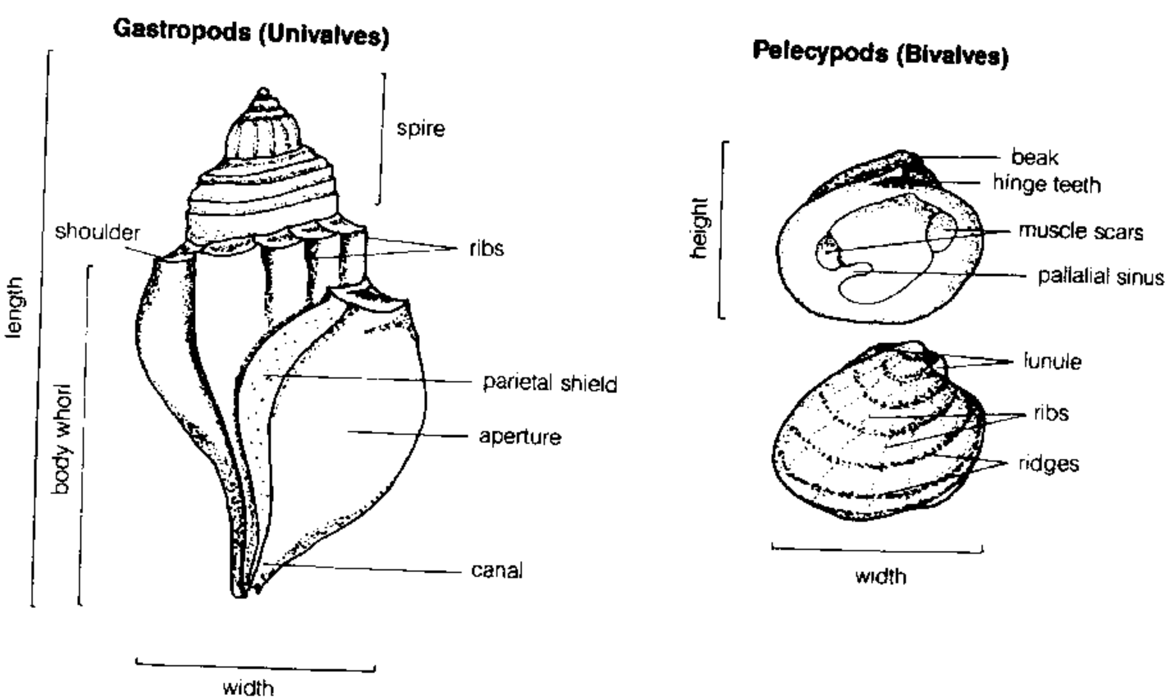
Examine the key and notice how it differs from the one you made in Part 1. It has no boxes, but the categories are arranged in sequence on each page. See how each number has at least two choices. Pick up one of your shells and try to work through the key until you get to its scientific name. Be sure to read all the choices before picking one that seems closest to your shell. When you select a description, follow the dotted line to see where you should go next.

If you're not sure about some of the words used in the choices, use the glossary and Figure 2. Occasionally, none of the choices seem right. In this case, either start over or pick a choice to see if it leads you to a description that sounds like your shell. You must be patient.

Once you reach a scientific name for your shell, check it by looking it up in a field guide with photographs or drawings. Your teacher will only allow you to check your shell when you have a possible name. And, it's not fair to leaf through the guide to find the right picture and then look for the name.

Try to properly identify all the shells given to your group. When you're finished, test each other on the common and scientific names. Next time you go to the beach, you'll be a real expert.

Figure 2 Parts of shells



Glossary

Aperture: in gastropods, the major opening of the shell.

Beaded: sculptured so as to resemble beads or strings of beads.

Beak: small tip of a pelecypod (bivalve) shell, near the hinge. Also called the "umbo."

Canal: in gastropods, a narrow notch or tubular extension of the aperture.

Crenulations: regular notches on the edge of a shell.

Height: see Figure 2.

Hinge: all the structures at the dorsal region of pelecypod (bivalve) shells that function in opening and closing the shells.

Length: see Figure 2.

Lunule: heart shaped area on the dorsal margin of pelecypods. (see Figure 2).

Pallial Sinus: an inward curve of a faint line on the inside of pelecypod shells.

Parietal Shield: a covering on the inner lip of a gastropod (see Figure 2).

Ribs: an external, raised structure on gastropods and pelecypods, running vertically (lengthwise) on bivalves and in all directions on univalves.

Ridges: an external, raised structure on pelecypods, running horizontally.

Spire: the upper whorls from the top of the shell to the body whorl.

Whorl: in spiral gastropods, one full turn of the shell. The body whorl is the whorl that occupies the largest area of the body (see Figure 2).

List of Common North Carolina Shells

These are the shells that can be found in the dichotomous key

Pelecypods:
Anadora ovalis Ark Shell
Anomia emphippium Atlantic Jingle Shell
Arca zebra Zebra Ark
Argopecten gibbus Calico Scallop
Argopecten irradians Atlantic Bay Scallop
Atrina serrata Pen Shell
Chione cancellata Dog Clam
Crassostrea virginica Eastern Oyster
Dinocardium robustum Great Heart Cockle
Divalinga quadrisulecata Cross-Hatched Lucine
Donax variabilis Coquina Clam
Dosinia discus Disk Shell
Macrocallista nimbosa Venus Sunray Clam
Mercenaria mercenaria Northern Quahog
Modiolus demissus Ribbed Mussel
Mytilus edulis Common Blue Mussel
Placopecten magellanicus Deep Sea Scallop
Pteria colymbus Wing Oyster
Spisula solidissima Surf Clam
Tagelus divisus False Razor Clam
Trachycardium egmontianum Prickly Cockle

Gastropods:
Busycon carica Knobbed Whelk
Busycon canaliculata Channeled Whelk
Busycon contrarium Lightning Whelk
Crepidula fornicata Slipper Shell
Cypraea cervus Atlantic Deer Cowrie
Diodora cayenensis Keyhole Limpet
Epitonium spp. Wentletrap
Fasciolaria hunteria Banded Tulip Shell
Ilyanassa obsoleta Mud Snail
Littorina irrorata Marsh Periwinkle
Nassarius vibex Mottled Dog Whelk
Oliva sayana Olive Shell
Phalium granulatum Scotch Bonnet
Polinices duplicatus Moon Snail
Sinum perspectivum Baby's Ear
Terebra dislocata Atlantic Augur Shell
Turbo castanea Chestnut Turban

Questions

1. Place the correct letters next to the following items. In some cases more than one letter may be right.

Polyplacophora = P
Gastropod = G
Pelecypoda = B (bivalve)
Cephalopoda = C

a) radula _______
b) pearls _______
c) ink _______
d) trochophore larva _______
e) tentacles _______
f) slugs _______
g) scallops _______
h) chiton _______
i) belly-foot _______
j) two siphons _______
k) internal shell(s) _______
l) hatchet-foot _______
m) no head _______
n) two shells _______
o) head-foot _______

2. Describe what you think is the best way to arrange books in your locker or on a shelf at home. Why do you prefer this way to any other?

3. What do we call the system that biologists use to arrange living things?

4. What do we call scientists who classify living things?

5. What is a dichotomous key?

6. What are the common features of all mollusks?

7. What are the four major classes of mollusks?

8. In which class is a snail? Describe the main features of this class.

9. In which class is a squid? What does the class name mean? Does a squid have a shell?

10. What kind of mollusks are in the class polyplacophora? Do they have a shell?

11. In which class would you find bivalves? How would you distinguish between a bivalve and a univalve? Make a list of the differences between the two.

12. What's different about the lifestyle of a snail and a clam?

13. How do you explain the fact that a chambered nautilus is not in the same class as a moon snail?

14. Describe two major differences between a scientific name and a common name.

15. What do clams eat?

16. Where are chitons found?

17. The Linnaeus Classification has seven divisions. In order, they are:

18. Name several ways in which humans use (or have used) mollusks.

19. Tell the scientific name and common name of one mollusk that you identified using the professional dichotomous key.

20. Why do you think it's alright for gastropods to move slowly? How do they protect themselves from danger if they can't run away?

21. Explain why you think it is important for scientists to have a way of organizing living things. Give at least three reasons. Then tell why it's important for you to know about this system.

Competency Factors/References

Competency Indicators

Biology—

3.4 know about the diversity of living things;

3.4.2 design a dichotomous key for a group of objects;

3.4.3 devise several classification systems based on similar characteristics;

4.2 know the major representatives of kingdoms of living things;

4.2.1 use a given classification system to find the organism's species name when given sufficient features of the organism;

4.2.2 describe the binomial system of nomenclature; and

4.2.4 state the advantage of a biological classification system.

References

Abbott, R. Tucker. 1974. *American Seashells: The Marine Mollusca of the Atlantic and Pacific Coasts of North America.* Van Nostrand Rheinold Co., New York.

Abbott, R. Tucker. 1972. *Kingdom of the Seashell.* Crown Publishers, New York.

Buchsbaum, Ralph. 1976. *Animals Without Backbones.* University of Chicago Press.

Granger, Charles R. 1983. "The Classification Conundrum." *Science Teacher.* December.

Morris, P. 1973. *A Field Guide to Shells of the Atlantic and Gulf Coasts and the West Indies.* Houghton Mifflin Company, Boston.

Koyama, Keith. 1974. "Understanding Biological Keys." *American Biology Teacher.* November.

Porter, Hugh J. and Tyler J. 1972. *Seashells Common to North Carolina.* UNC Sea Grant College Program, Raleigh, NC. UNC-SG-72-09.

Rehder, H.A. 1981. *The Audubon Society Field Guide to North American Seashells.* Alfred A. Knopf, New York.

Rhyne, Nancy. 1982. *Carolina Seashells.* Fast and McMillian.

Spitsbergen, Judith M. 1980. *Seacoast Life.* University of North Carolina Press, Chapel Hill, NC.

Verrill, Hyatt A. 1950. *Shell Collectors Handbook.* Putnam's, New York.

Zinn, Donald J. 1984. *Marine Mollusks of Cape Cod.* Cape Cod Museum of Natural History, Brewster, Mass.

Behavior of Ocean Creatures

Humans have always been interested in the behavior of the organisms that share this planet. Some interest is based on the need to use other organisms for food. But much curiosity comes from fascination with other living things and our desire to understand how they survive—how they meet the basic needs to eat, be safe and reproduce.

This interest is particularly focused on ocean creatures. How do they survive in a watery environment that poses such danger to humans? How do the tides, temperatures and levels of light affect their behavior? How do they internally balance their physiology to cope with their salty, aqueous environment?

This unit will introduce students to some behaviors that are unique to the marine environment. It may raise more questions that it answers. But that, after all, is one of the delights of science.

ACTIVITY 1

Biological Clocks

Purpose

To introduce students to two different biological clocks found in one organism.

Introduction

There is a season for everything
And a time for every purpose under the heaven.
A time to be born, and a time to die;
A time to plant and a time to reap. . .

The words of Ecclesiastes are familiar. They speak of the cycle of life. Although the writer was not a scientist, he understood the unrelenting rhythms of the earth. The cyclical patterns of physiological functions and of behavior in plants and animals have been established by research. In the last 30 years, the work in this field has expanded. We assume the patterns provide a survival advantage for the organisms. For some behaviors, it is clear how a cyclical activity is beneficial; for others, research continues to determine their value.

For terrestrial organisms, patterns are often tied to the movements of the sun. The annual migrations of birds are a good example. In addition, there are an array of circadian, or 24-hour, rhythms. The ocean provides a different environment with different demands.

John Palmer, a leading researcher in the field, defines biological clocks as the mechanisms that control rhythmic behaviors that persist in constant conditions. This definition distinguishes biological clocks from those behaviors that are cyclical but depend upon a recurring external stimulus. As we shall see the distinction is sometimes difficult to maintain.

Procedure

Use Figures 1 to 4 concerning the green crab. Either overhead transparencies or student copies can be made from the figures.

Figure 1 shows the level of activity of the crab. Have students describe the pattern. They should see that there is an increase in movement at 12-hour intervals; in addition, activity is greater during the night time. Can students suggest a reason for the 12-hour rhythm?

The green crab lives on sand and mud flats along the sea's edge. The crab's cyclical behavior can be explained by the return of high tide. If the graph is studied carefully, you can see that the peak of activity is actually a bit longer than 12 hours. High tide occurs every 12 hours and 25 minutes. Under natural conditions, the green crab forages during each high tide but is even more active during darkness.

Figure 2 shows the color change of the green crab. At night, the crab blanches; during daylight, it darkens. This color change is controlled by chromatophores in the crab's hypodermis. This rhythm is circadian. However, there is a slight tidal factor because they are darker at low tide. The green crab has two clocks—one related to tidal rhythms; the other, solar rhythms.

Both graphs are based on the behavior of crabs in a laboratory where it was continually dark with no tidal rhythm. In other words, the activity and color change continue without any environmental stimulus. This fulfills the definition of a biological clock. If you have made overhead transparencies, you can lay one graph over the other and see both rhythms together.

Figure 3 shows the migration of the diatom, *Hantzschia*, during a three-day period. This single-celled organism lives in the intertidal sands. Again ask students to describe the pattern of migration.

This photosynthetic organism migrates to the surface during daytime low tides. Other times, it lives about a millimeter below the sand's surface where it will not be carried away by the waves. This graph also results from data collected in a laboratory of constant darkness and no tidal rhythm.

The persistence of rhythms in the laboratory vary. However, within days or weeks most rhythms are curbed. Figure 4 illustrates what happens to the pattern of activity of the fiddler crab in the laboratory. Within six days, the activity level of the crab at low tide has deteriorated. Keep in mind that light, temperature and water-level conditions are held constant in the laboratory.

A series of experiments has been done to determine what is required to restore the crab's biological clock. By immersing the crabs in seawater or lowering the temperature without immersion, the crabs return to their former pattern. The immersion or temperature drop appears to reactivate the biological clock.

The major organism activities that function in conjunction with tidal rhythms are motor activity, respiratory ventilation, oxygen consumption and color change. All have adaptive significance in the anticipation of either high or low tide. Fiddler crabs retreat to their burrows before the tide comes in. Thus they avoid

Figure 1 Level of activity of crab throughout day

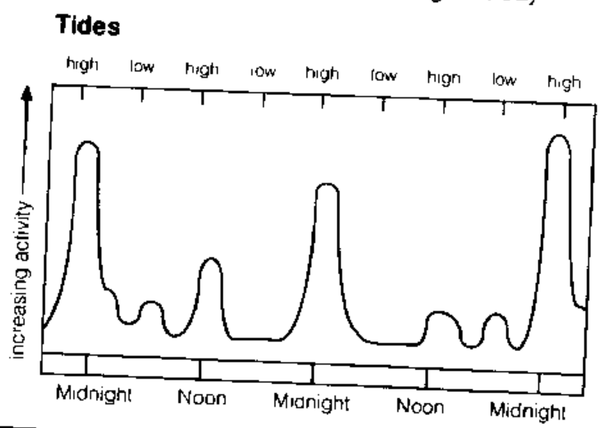


Figure 2 Color change of green crab throughout day

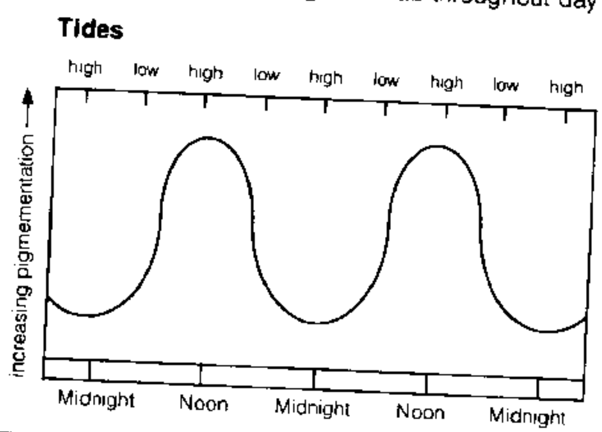


Figure 3 Migration of *Hantzschia* over three days

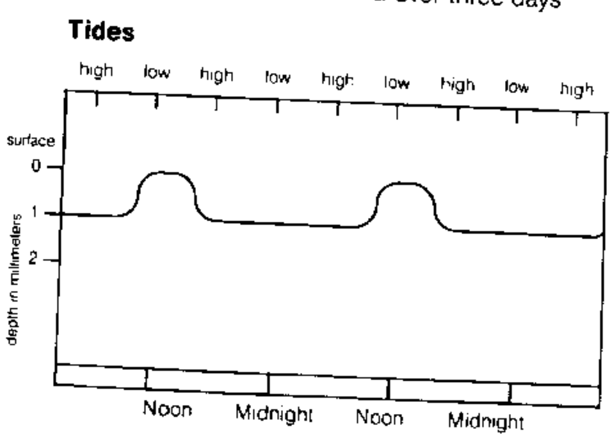
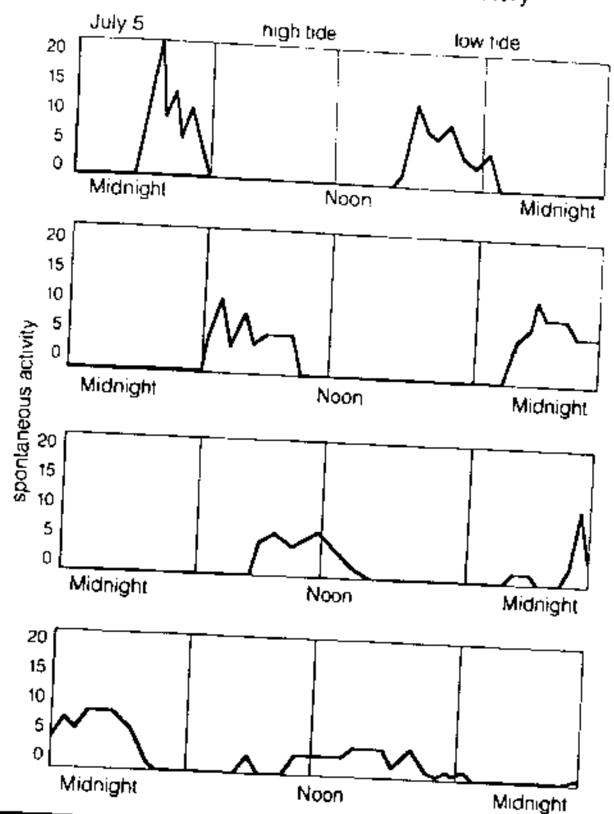


Figure 4 Fiddler crab activity in the laboratory



predators who arrive with the incoming tide. The beach isopod, *Eurnydice*, depends upon maintaining its place in the intertidal region. To accomplish this, it must avoid the swash of the waves and the pull of the receding tide. It anticipates the falling tide by burrowing below the surface.

Questions

Figure 1

1. When are the green crabs most active? (Describe in terms of light and dark as well as tides.)

2. Is tidal or solar rhythm most important?

Figure 2

3. When are green crabs darkest?

4. Which external stimulus seems most important? Solar or tidal rhythms?

5. If these graphs are of organisms kept in a lab that was continuously dark and had no tidal rhythm, what do you conclude about the control of the crabs' behavior?

Figure 3

6. What controls the migration of the diatom, *Hantzschia*? Tidal or solar rhythms or a combination of both?

7. What is the advantage of staying below the surface?

8. What is the advantage of coming to the surface at noon during low tide?

9. Again, this data was collected in a lab in constant darkness and no tidal rhythms. What do you conclude about the behavior?

Figure 4

10. In nature, what is the fiddler crab's pattern of activity?

11. Describe what happens to the fiddler crab's biological clock in lab conditions of constant light and temperature.

12. How can a fiddler crab's clock be restored?

13. Of what advantage is it to a fiddler crab to hide during high tide?

ACTIVITY 2

The Fiddler Crab Experiment

Purpose

To practice designing and performing experiments.

Teacher Background

Most current biology curricula include the development of an experiment—stating the hypothesis, making observations, collecting data, reporting results, using controls and drawing conclusions. Students are interested in animal behavior, and the fiddler crab's behavior lends itself to experimental design.

This activity can be used to simply develop an experimental plan or the experiments can actually be carried out.

The fiddler crab, *Uca*, is a small crustacean that burrows along the salt marshes, estuaries and shorelines from Cape Cod to Texas. They are scavengers, eating bacteria, small algae and decaying marsh plants. The male has one very large claw (either right or left); the females' claws are all about the same size. The small claws are used for eating. The male uses the large claw to attract females and to threaten off other males. The male waves the large claw much as a musician playing the fiddle. When the male fiddler loses a claw in a fight, a new one will grow. There are three common species: a sand fiddler, *U. pugilator;* a mud fiddler, *U. pugnax;* and a brackish-water fiddler, *U. minax*.

The fiddler crab can be collected along brackish water areas. Or, you can order freshwater fiddler crabs from Carolina Biological Supply (L607—12/$26.50. The food costs about $3 per bag.)

To house the crabs, you need a large, shallow aquarium. Put beach sand at one end, holding it in place with small rocks. Partially fill the aquarium with seawater (fresh water if you are using the Carolina Biological crabs). The sand needs to be deep enough that they can burrow and the water deep enough to crawl around in. They can eat dry or canned dog or cat food, fruits and vegetables. They are more active at higher temperatures but do fine at room temperature. They are not dangerous to handle if you avoid the male's large claw.

Characteristics to study are the fiddler crab's level of activity and the periodic color changes. Temperature, light and tides are possible triggers. Fiddlers are light brown with purple and dark brown marks. But periodically their biological clock causes them to become lighter or darker according to solar rhythms. They are lightest at noon and darkest at midnight. Their activity level seems to be controlled by tidal and solar rhythms. They are most active at low tide when they search for food. At high tide, the crabs return to their burrows to rest.

Teacher Procedure

Have students research the fiddler crab and then design various experiments to study their activity levels and color changes. Are these behaviors internally controlled, caused by external stimuli or perhaps due to a combination of both?

What is their native habitat? What would they need to be kept in a classroom? What characteristics lend themselves to an experiment?

Have students decide which characteristic they are going to investigate. Let them develop a hypothesis.

Ask students to design an experiment to test their hypothesis. They need to control for everything except one variable. They need to decide when and what they will record. For example, what will they call "activity?" They will determine what data to collect and how to quantify their data. And they need to decide on the length of time needed to carry out the experiment.

Have the students report their results in data charts and with graphs. Let the students analyze their data and draw conclusions. And allow students the opportunity to explore their sources of error, the quality of their experimental design and future investigations. You might let some students reinvestigate.

Student Procedure

In this activity, you will use your research and observations to identify a specific behavior in fiddler crabs to investigate.

Developing a Hypothesis

Develop a hypothesis that can be tested with an experiment. Use the following questions to form your hypothesis:

1. In your research and observations, what were the various behaviors that you identified in fiddler crabs?

2. Which behavior would you like to investigate further?

3. What are the possible factors that cause this behavior?

4. Which factor do you think is likely to be the cause?

Write your hypothesis, using one behavior and one factor that you can test. Remember your hypothesis must be a statement that can be tested with an experiment.

Designing an Experiment

Now you're ready to design an experiment that tests your hypothesis. Determine what you need to set up your experiment, what type of data you will collect and how long to run your experiment. Use the following questions to guide you in the development of your investigation:

1. What is the hypothesis that you are going to test?

2. What will your variable be?

3. What factors will you need to control?

4. Describe your experimental design. How many aquaria? How many crabs in each aquarium? What rocks, sand, water, light, etc. will you provide for each aquarium? How will each aquarium be treated differently?

5. What will you be observing? If you are observing an activity, how will you recognize the activity. Can you quantify the observation?

6. How often will you observe and for what duration? How long will the experiment continue?

Prepare a sheet with the following information:

a. Your hypothesis.

b. Your variable (what you change in testing).

c. The factors you need to control.

d. The experimental design. Diagrams are appropriate; be very complete. You need a list of equipment and materials required as well as the actual setup.

e. A description of the data that will be collected, including how often and for what length of time.

f. A sample data chart.

g. How long will you run the experiment?

Reporting and Analyzing the Data

Create graphs to display your data. Compare your data with your hypothesis and determine whether it was supported or not. Suggest improvements on the experimental design, and discuss sources of possible error. Use the following questions to direct your presentation of data and analysis of the results.

1. Using you data charts, create a graph or graphs to display your results. Place the dependent variable on the "y" axis.

2. Examine your graphs and data charts; compare them to your hypothesis. Does your data support your hypothesis?

3. Do you think your data is reliable? If not, why not?

4. Do you think that there is another variable that should be tested? What variable?

5. What are some sources of error in your experimental design and collection of data?

6. What conclusion can you draw concerning the behavior you identified and the variable you tested? Is the behavior controlled by internal or external stimulus or a combination of both?

7. Suggest what the next experiment might be for further investigations.

Prepare a sheet with the following information:

a. Hypothesis

b. Materials

c. Procedure/experimental design

d. Data/results/graphs

e. Conclusions

f. Sources of error

g. Suggestions for further investigation

ACTIVITY 3

Salinity Changes and Sea Animals

Purpose

To investigate how organisms adjust to dramatic changes in salinity to maintain internal balance.

Introduction

A major principle of biology states that life is dependent upon a maintaining of balance. The process of maintaining internal balance while adjusting to changing external conditions is know as homeostasis. Homeostasis occurs at all levels of biological organization—cells, organisms and ecosystems.

There are innumerable examples of homeostatic mechanisms that students can study to appreciate and understand this phenomenon. The next four activities focus on how organisms cope with a change in their environment that is potentially life threatening.

The open ocean is remarkably stable in many characteristics, including salinity. The salt concentration in most oceans areas is about 3.5% (35 parts per thousand). Variation is minimal, about .5%.

This is not true of coastal regions where fresh water enters. Fresh water with a salt content of less than 2% dilutes the seawater and reduces salinity. In many coastal regions, the variation in salinity can fluctuate between .5% and 3.5%.

Background

Introduce the exercise with a demonstration that shows the effects of a sharp difference in salinity between an organism (or tissue) and its environment. Place sticks of potato or carrot in salt water. After a short time, they will soften due to loss of water. Also place vegetable sticks in fresh water. They will harden.

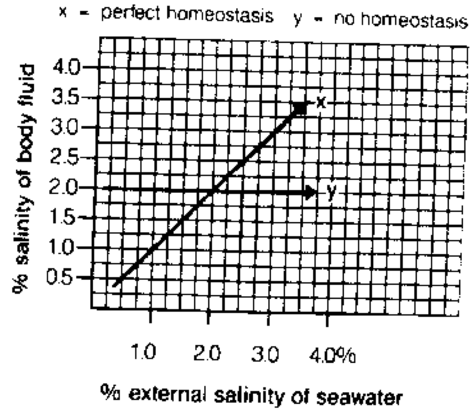
If this demonstration was done when diffusion and osmosis were taught, then a brief review may suffice. Be sure to teach the concept that the contractile vacuole rate of activity is affected by hypotonic or hypertonic solutions on a cellular level. It is essential that the students understand why a substantial diffusion of water into or out of an organism is so harmful.

The activity sheet presents a set of data to be graphed. The environmental salinity is plotted against the internal salinity of each organism. The graph (Figure 5) illustrates the changes in the salt concentration of the body fluids as the external salinity changes. It is easy to see from the graph that not all organisms adjust the same. The questions following the graph should be answered by the student before any discussion occurs. They are designed to encourage the student to analyze the data and arrive at a hypothesis or conclusion.

The three organisms are: A—*Australopilax tridentata*, a crab; B—*Gammarus duebeni*, an amphipod; and C—*Palaemonetes varians*, a shrimp. The crab and amphipod adjust their internal salinity as the external salinity varies, always keeping the blood salt concentration greater than seawater. In contrast, the shrimp does not significantly alter its internal salinity.

Figure 5 Changes in salt concentration of body fluids

x = perfect homeostasis y = no homeostasis



Questions

1. Describe the reaction of organism C to the change in external salinity. What must organism C do to react in such a way?

2. How are the reactions of organisms A and B similar? How are the reactions different?

3. Which is better: the adjustments of A and B or that of C?

ACTIVITY 4

The Sea Worm

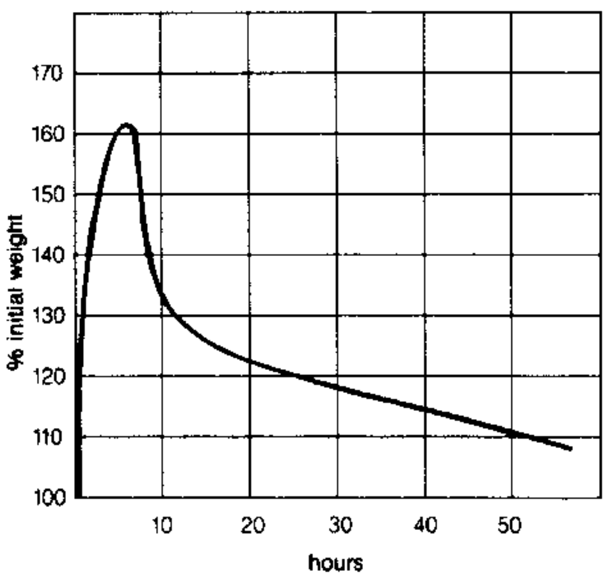
Purpose

To learn how a marine worm maintains a balance in its internal fluids and its environment.

Procedure

The graph below (Figure 6) shows what occurs when a sea worm, *Nereis diversicolor,* is placed in water of 1.0% salinity. It usually lives in seawater with a salinity of 3.5% salinity. Study the graph carefully, and answer the questions. Keep in mind what you learned about osmosis and diffusion as well as the ability of organisms to maintain homeostasis.

Figure 6 Change in body weight of *Nereis diversicolor*



Questions

1. What was the maximum gain in body weight?

2. What could account for this increase during the first five hours?

3. How can the gradual loss of weight be explained?

4. Is this an example of homeostasis? Explain.

5. Consider the pattern illustrated in the graph. *Nereis* inhabits coastal regions. Of what value to the organism is the ability shown here?

6. Far fewer organisms are adapted to live in coastal waters than in the open ocean. Suggest a reason for this based on what you have learned in this exercise.

7. For an organism to survive changes in salinity, what must the cells of this organism be able to do?

8. More highly evolved organisms are generally more capable of controlling osmosis than less evolved organisms. Why? As an illustration, compare the contractile vacuole of the amoeba versus the paramecium or the kidneys of higher animals.

9. Some organisms migrate from fresh water into the ocean or vice versa. Describe what these organisms can do to survive this passage.

ACTIVITY 5

Homeostasis on a Graph

Purpose

To investigate how some organisms adjust to changes in salinity.

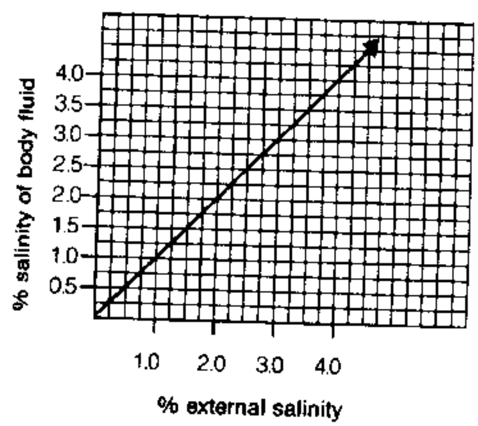
Procedure

Examine the chart below (Figure 7). In the first column are data representing changes in the salinity of water. In the other three columns are the data for the changes in the internal salinity of three different organisms. Plot the data on the graph below (Figure 8). The diagonal line represents a perfect balance between internal and external salinity. It is there only for reference.

Figure 7 Internal salinity change of three organisms

Environmental salinity	Organism A	Organism B	Organism C
1.0%	2.7	2.4	2.0
1.5%	2.9	2.5	2.0
2.0%	3.1	2.6	2.0
2.5%	3.2	2.9	2.1
3.0%	3.2	3.3	2.2
3.5%	3.4	3.8	2.2
4.0%	3.5	4.2	2.3

Figure 8 Changes in salinity



ACTIVITY 6

The Homeostatic Relationship Between Water Temperature and Respiration Rate in Marine Fish

Purpose

To determine what effect a change in water temperature has on the rate of respiration in fish.

Teacher Background

Fish are cold-blooded. Very high or very low temperatures can cause lethal enzyme damage, either by causing the cells to literally burn themselves up or by crystallizing the proteins.

Counting operculum (gill cover) movements is a way to calculate respiration rate in fish. Fish breathe by taking water in through the mouth and forcing it over the gills when the mouth closes. An oxygen-carbon dioxide exchange occurs. Then the operculum opens to allow the carbon dioxide-rich water to exit. The speed of oxygen intake is an indicator of the speed of cellular respiration. Complicating this process is the fact that the solubility of oxygen in water decreases as the temperature of the water increases. Less oxygen is available at higher temperatures.

This activity has been done using goldfish, guppies or other small, inexpensive freshwater fish. But it is adaptable to the use of marine fish. The value in using marine fish is that thermal pollution of our marine fisheries is a practical problem that could be discussed as a result of doing this lab.

Any fish that can be kept in a marine tank in your classroom can be used. Exotics are fine, but expensive. An excellent choice are is killifish (*Fundulus*). They live in estuarine tidal flat habitats.

Materials

For every two students provide:

1 killifish/goldfish
crushed ice
1 large beaker
hot water
1 thermometer
timer
plastic zip-lock bag (sandwich size)
1 sheet graph paper

Procedure

Put your fish in a plastic bag that is half filled with the marine water from the tank that held the fish. Put the bag in the beaker, which should be half full of tap water at room temperature.

Gently insert the thermometer in the plastic bag. Do not disturb the fish too much, and be careful not to break the plastic bag. Observe the movement of the operculum or gill cover of the fish. Notice how it opens and closes in rhythm with the opening and closing of the mouth. The fish takes water in through the mouth, then closes it, forcing the water over the gills. After the oxygen-carbon dioxide exchange, the operculum closes.

Count each time the operculum closes in one minute. Record the water temperature and the number of closings on your chart.

Slowly add ice to the water in the beaker until the temperature is 10 degrees below the original room temperature. After a few seconds, count the operculum closings for one minute and record your results on the chart.

Slowly add hot water to the water in the beaker until the temperature has increased by 5 degrees. Record the temperature and the number of operculum closings in one minute of observation. Before each count be sure to let the fish adjust for a few minutes.

Continue adding hot water to the beaker until the temperature has increased by another 5 degrees. Record the temperature and operculum closings in one minute. Continue the procedure until the temperature of the water in the beaker is 10 degrees above the original room temperature.

Return your fish to the marine tank by floating the plastic bag in the tank water to give the fish time to adjust before you gently pour it into the tank.

Record your data on a class chart. You will use class averages and your lab team data to prepare your graph of the relationship between temperature and respiration in marine fish.

On your graph, put the dependent variable (the operculum counts) on the y axis and the independent variable (the temperature) on the x axis. Be sure to use all of your graph paper to label the axes and to title your graph.

First plot the points for your lab team's results. Join these points with a line. Now plot the averages, and join these points with a different colored line.

Questions

1. What general statement can you make about water temperature and respiration rate in marine fish?

2. How did your team's results differ from other teams in the class?

3. How did your team's results differ from the average results?

4. What would you conclude about the effect of thermal pollution on the respiration rate of marine fish?

5. Name three or four other factors that you think might affect respiration rate in fish.

6. When the operculum movement rate in fish increases, what process is increasing in the cells of the fish? What does this tell us about the metabolism?

7. Why do you think that the fish responds the way it does to an increase in temperature?

8. An increase in water temperature means a decrease in dissolved oxygen. How does this affect your interpretation of the results?

9. How is this relationship between water temperature and fish respiration rate an example of homeostasis?

Competency Factors/References

Competency Indicators

Biology/Academic—

1.2 know the methods of science;

1.2.3 suggest at least one appropriate, controlled experiment for solving a problem;

1.2.4 explain the purposes a hypothesis serves in scientific problem-solving;

2.5 know that living things exist in a state of dynamic equilibrium;

4.1 have a general knowledge of anatomy and physiology of organisms;

5.1 know that all organisms' survival requires suitable responses to the external environment;

5.1.2 conduct an experiment to investigate the effect(s) of selected environmental variables on the behavior of a selected organism; and

5.5 know about biological rhythms.

Biology/Applied-Technical—

2.5 same as above.

Competency Measures

Biology/Academic—

2.5.1 define homeostasis as a self-regulating or steady state condition;

2.5.2. give examples of homeostatic mechanisms in plants and animals;

4.1.2 describe various transport systems used by multicellular organisms whose cells are too distant from the environment to obtain materials by diffusion;

4.1.4 give evidence that the feature all respiratory devices have in common is that they expose a moist membrane to the environment;

4.1.6 give examples of feedback control mechanisms;

5.1.2 conduct an experiment to investigate the effect of a selected environmental variable on the behavior of a selected organism; and

5.5.1 discuss the importance of internal clocks in organisms including humans.

Biology/Technical-Applied—

2.5.1 define, in simple terms, what is meant by homeostasis;

2.5.2 explain that individual cells must exist in a balanced condition with materials moving in and out of each cell;

5.5.1 discuss the importance of internal clocks in organisms including humans; and

5.5.3 name several environmental cues that govern biological rhythms.

References

Barnes, R.S.K. and J. Green, editors. 1972. "Physiological Problems for Animal Life in Estuaries," *The Estuarine Environment.* Applied Science Publishers, London.

Brady, John; editor. 1982. *Biological Timekeeping.* Cambridge University Press, Cambridge.

Brady, John. 1979. *Biological Clocks.* University Park Press, Baltimore.

Brown, F.A., Jr. 1963. "Biological Clocks," *Biological Science Curriculum Materials Pamphlet No. 2.* Lexington, Mass., D.C. Heath and Company.

Brown, Frank A., J. Woodland Hastings and John D. Palmer. 1970. *The Biological Clock.* Academic Press, New York.

Bunning, Erwin. 1967. *The Physiological Clock.* Springer-Verlag, New York.

Carolina Arthropods Manual. 1982. Carolina Biological Supply Company, Burlington, NC.

Creger, Joan G., Paul G. Jantzen and James L. Mariner. 1985. *Teacher's Resource Book for Biology.* Macmillan Publishing Co., New York, pp.127-150.

DeCoursey, P.J., editor. 1976. *Biological Rhythms in the Marine Environment.* University of South Carolina Press, Columbia.

Gosner, Kenneth L. 1978. *A Field Guide to the Atlantic Seashore.* Houghton Mifflin Company, Boston.

Jones, Gail. 1989. *Project Estuary.* NC Division of Coastal Management, Raleigh, NC.

Ketchum, Bostwick, editor. 1983. "Responses to Estuarine Stress," *Estuaries and Enclosed Seas.* Elsevier Scientific Publishing Co. New York.

Kinne, Otto, editor. 1975. "Mechanisms of Ion and Osmoregulation," *Marine Ecology, Volume II.* John Wiley and Sons, New York.

Langley, L.L. 1965. *Homeostasis.* Reinhold Publishing Co., New York.

Masterton, William L. and Emil J. Slowinski. 1977. *Chemical Principles.* W. B. Saunders Co., Philadelphia.

McLucky, Donald S. 1981. *The Estuarine Ecosystem.* John Wiley and Sons, New York.

Meinkoth, Norman A. 1981. *The Audubon Society Field Guide to North American Seashore Creatures.* Alfred A. Knopf, New York.

Nybakken, James. 1982. *Marine Biology—An Ecological Approach.* Harper and Row, New York.

Otto, James H., Albert Towle and Elizabeth H. Crider. 1965. *Biology Investigations.* Holt, Rinehart and Winston, Inc., New York.

Palmer, John D. 1976. *An Introduction to Biological Rhythms.* Academic Press, New York.

Palmer, John D. 1975. "Biological Clocks of the Tidal Zone," *Scientific American.* February.

Simon, Seymour. 1981. *The Secret Clocks.* Puffin Books.

Spitsbergen, Judith M. 1983. *Seacoast Life, An Ecological Guide to Natural Seashore Communities in North Carolina.* The University of North Carolina Press, Chapel Hill, NC.

Man and the Ocean

Introduction

Much as people have looked to the heavens and imagined flying with the birds, we have also looked to the oceans and imagined swimming with the whales and the dolphins.

This unit offers several student readings to learn about the new technologies that have allowed human beings to explore the oceans. Limited by lungs that require us to breathe air, we have spent generations devising methods for diving below the surface of the sea. Jules Verne wrote of cities beneath the sea. We have not yet achieved that goal, but other wonders he wrote about have come to fruition.

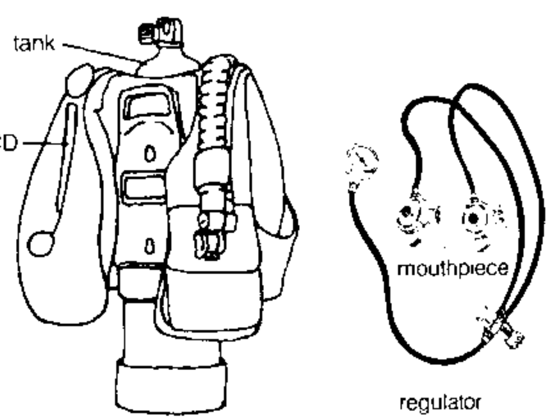
Students who envision careers at the forefront of discovery and at the edge of the unknown will be drawn to this unit.

Background

Students are familiar with the feeling of pressure changes against their ears when they dive into a pool or drive into the mountains. A hobby increasing in popularity is scuba diving. Students can become more familiar with gas exchange processes through discussions and reading about mammalian diving physiology.

People can explore the marine world by using a mask, snorkel and fins and holding their breath. Or they can prolong their exploration with the use of scuba (self-contained underwater breathing apparatus) equipment.

Figure 1 Self-contained breathing apparatus

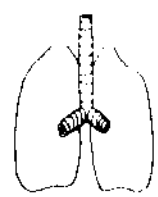
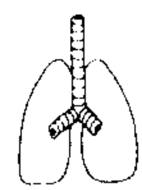
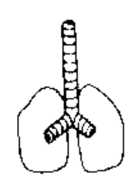
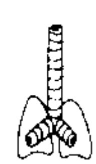


The self-contained breathing apparatus consists of a tank filled with compressed air, a regulator with a mouthpiece and a buoyancy control device (BCD - Figure 1).

A regulator reduces the high pressure of the air in a scuba tank to a usable level and delivers air when needed to the diver. A BCD is mandatory equipment for all diving. It is an inflatable sack that increases buoyancy. It is used to provide surface support to rest, swim and maintain neutral buoyancy under water.

Other types of diving equipment are available but are less accessible to the general public.

Figure 2 Boyle's law

Depth	Pressure on lungs	Volume of air	Density of air	Lungs of a diver holding breath
0 feet	1.0 atm	4.0 liters	1 kg/1	
33 feet	2.0 atm	2.0 liters (4/2)	2 kg/1	
66 feet	3.0 atm	4/3 liters	3 kg/1	
99 feet	4.0 atm	1.0 liter (4/4)	4 kg/1	

Scuba diving has become a popular hobby for many people. It offers a wealth of information on diving physiology and the effects of gas exchange.

One of the first effects a diver feels is increasing pressure. As he descends, the pressure around him increases by 1 atmosphere for every 33 feet of descent in salt water (34 feet in fresh water—Figure 2). The increasing pressure is not felt by bone and solid tissue but by air spaces (ears, lungs and sinuses—Figure 3).

When a diver descends, the increase in pressure reduces the size of his air spaces (Figure 2) and compresses the air inside (Boyle's Law). A diver who holds his breath feels the increase in pressure (decrease in volume) as a squeezing in his lungs, sinuses and ears (Figure 4). As the pressure increases, the squeezing increases and becomes uncomfortable. Eventually the diver will stop his descent.

To relieve the pressure on the lungs, a diver breathes compressed air at a regular frequency. To relieve the pressure on ears and sinuses, a diver blocks his nose and attempts to exhale through it with his mouth closed. This forces air into the air spaces inside the ears and sinuses and relieves the squeeze. This technique is known as equalizing.

The process of equalizing returns the air spaces to their normal volume by equalizing the external water pressure and the pressure in the air spaces. As long as a diver breathes compressed air and equalizes the pressure in the air spaces, he will not feel the squeezing as he descends.

Figure 3 Air spaces in the body

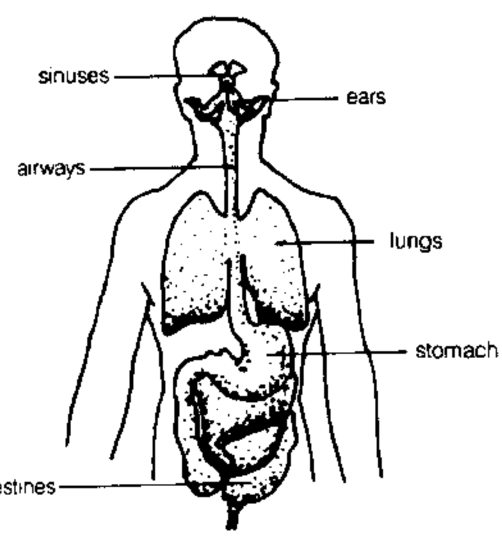
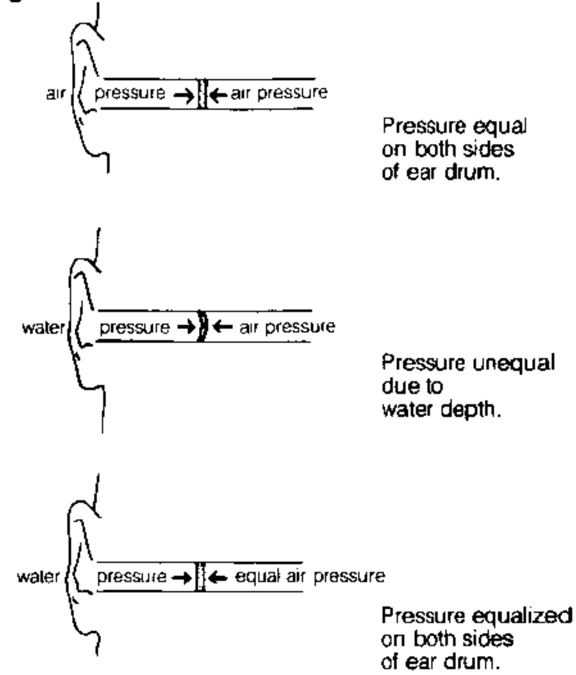


Figure 4 Pressure on the ear drum



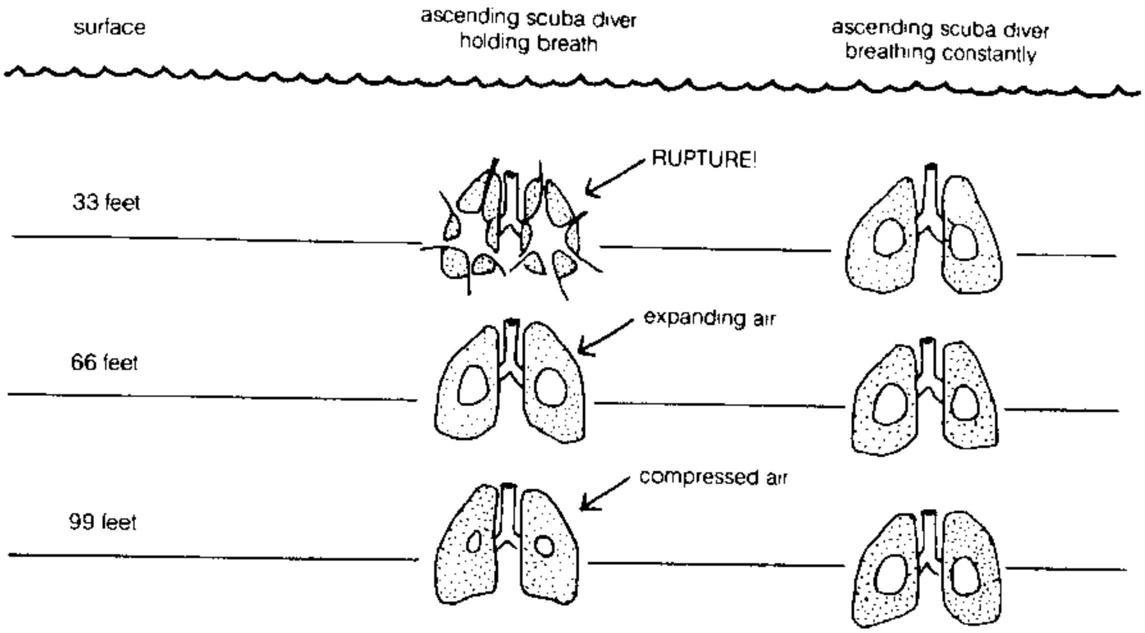
A diver ascending experiences the opposite pressure-volume relationship. Boyle's Law says that as pressure increases, volume decreases and as pressure decreases, volume increases. Therefore, as a diver ascends, the pressure decreases and the volume increases. A diver not breathing on ascent will feel his lungs expand (Figure 5). A diver's lungs can only expand 15 to 30 percent of their original volume without bursting. Therefore, ascending without breathing may result in lung tissue bursting (Figure 5).

A smart diver breathes on ascent. Breathing equalizes the pressure inside the lungs and air spaces with the outside pressure so that the normal lung and air space volume is maintained (Figure 5).

The air you breathe is a mixture of 78 percent nitrogen, 21 percent oxygen, 0.03 percent carbon dioxide and small amounts of other gases. The oxygen in the air you exhale decreases from 21 to 16 percent and the carbon dioxide increases from 0.03 to 5.6 percent. During exhalation, the body produces roughly the same amount of carbon dioxide as it has taken in oxygen. Nitrogen remains the same.

At depths less than 100 feet, nitrogen is not used by the body and has no effects on it. However, at

Figure 5 Lungs of ascending scuba diver



depths greater than 100 feet, the partial pressure of nitrogen increases to levels that can alter a diver's behavior in a condition known as nitrogen narcosis.

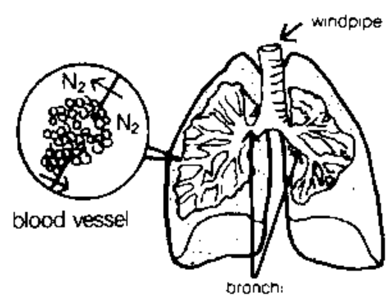
At the surface, the pressure of air is one atm (atmosphere) or 760 mm Hg. Nitrogen makes up 78 percent of the air with a partial pressure of about 600 mm Hg. As a diver experiences greater pressures, the partial pressure of nitrogen increases (Figure 6). According to Henry's Law, gases will enter into a liquid in proportion to the partial pressure of the gas. If you double the partial pressure of nitrogen, for example, the amount of nitrogen that can be dissolved in the blood and tissues of the body also doubles. At greater than 100 feet (4 atm), the increase in partial pressure causes nitrogen narcosis.

The symptoms of nitrogen narcosis are like those of intoxication. Divers act foolish, take off their masks, remove their mouthpieces and descend past safe limits. Several factors, including alcohol, a hangover, fatigue, excess carbon dioxide, inexperience and anxiety lower a diver's resistance to nitrogen narcosis. Nitrogen affects divers differently; any one diver may experience a variety of symptoms.

Nitrogen, in air and compressed air, does not combine with blood like oxygen. As a diver descends, nitrogen goes into solution in the diver's blood and is carried to the tissues and fat. A diver's body tissues balance with the partial pressure of nitrogen for a particular depth in eight to 12 hours. The saturation of tissues by nitrogen increases with the length of the dive at a particular depth and pressure.

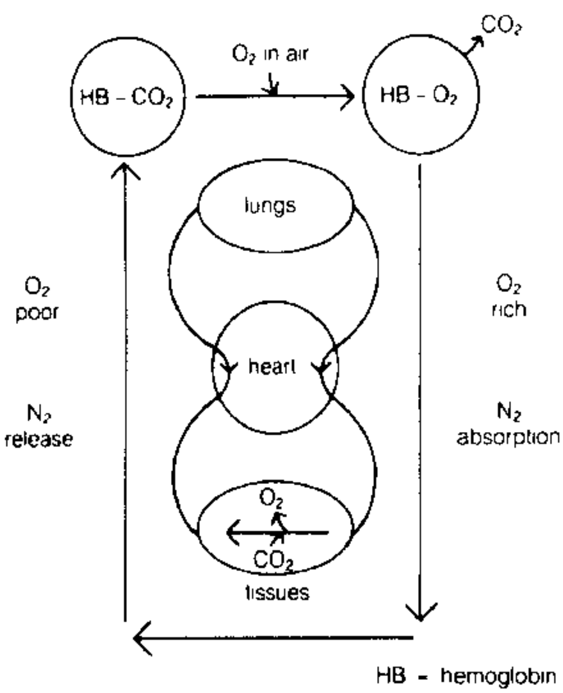
As a diver ascends, the partial pressure of nitrogen in the lungs decreases. Blood leaving the lungs at lower pressure has a lower nitrogen partial pressure and is circulated to body tissues. The tissues have a higher nitrogen partial pressure so nitrogen escapes from tissues into the blood. The blood returns to the lungs where nitrogen diffuses into the air exhaled (Figure 7). With each round of circulation, more nitro-

Figure 6 Nitrogen gas passing into blood



lungs under higher partial pressure

Figure 7 Oxygen extraction by air breathing animals



gen is removed. Nitrogen is eliminated from saturated tissues in 9 to 12 hours. This elimination process is known as decompression.

If decompression occurs too rapidly, the blood and tissues may receive too much dissolved gas to hold in solution. Because the load of gas can not be carried to and eliminated from the lungs quickly enough, the gas liberates itself in the form of bubbles that appear in the blood and tissues.

The classic example of dissolved gas coming out of solution is a bottle of soda. No bubbles are visible when the cap is on because the liquid is under pressure and the bubbles are too small to be seen. Removing the cap reduces the pressure. The bubbles come out of solution. When the partial pressure of the carbon dioxide gas dissolved in the soda equals the partial pressure of the gas in the air surrounding the liquid, the soda does not bubble and is considered "flat."

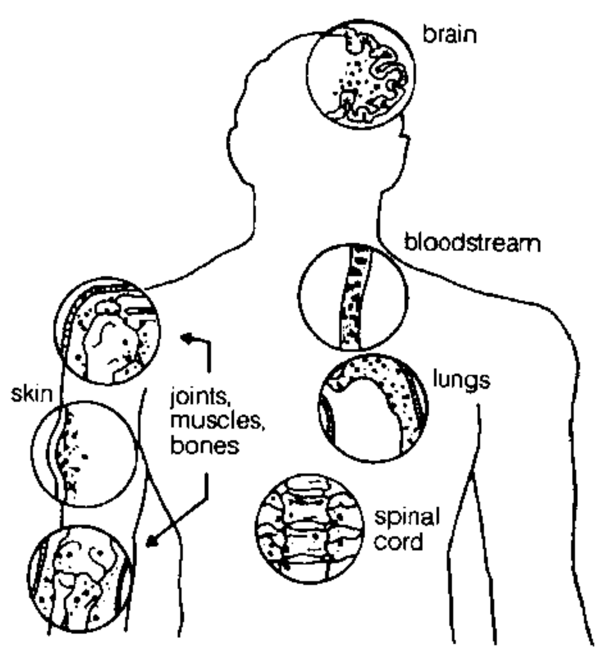
Nitrogen can bubble in the blood and tissues much like carbon dioxide bubbles in a soda. These bubbles move throughout the body and can: (1) lodge in constricted areas, such as joints, causing pain, (3) pinch off and damage nerves and (3) cause paralysis (Figure 8). This condition is known as decompression sickness, the bends or caisson disease.

Decompression sickness is certainly the most famous diving illness. It was discovered in the 19th century by laborers working in tunnels beneath rivers. To keep water out of working areas, the tunnels were pressurized. Many workers returning to ordinary atmospheric pressure at the end of the day developed pain in their joints. Some became paralyzed. The malady became known as caisson disease.

The disease remained a mystery until 1907 when J.S. Haldane developed "stage decompression." He found that decompression sickness could be avoided by bringing anyone who had been in a high-pressure environment to a normal atmospheric pressure in gradual stages. This eliminated the formation of small bubbles of nitrogen in the blood and tissues.

Depending on where bubbles lodge in the body, the symptoms of decompression sickness may vary. In most cases, symptoms begin within an hour, but they may take longer (six or more hours). Other factors also increase a diver's chance of developing decompression sickness. Age, obesity, extreme fatigue, alcohol,

Figure 8 Areas affected by decompression sickness



old injuries, extreme hot or cold water, and dehydration can hinder blood circulation and prevent nitrogen from quickly entering and leaving the blood. Fat absorbs about five times more nitrogen than blood or other tissues.

Consequently, nitrogen is not removed quickly from fat during decompression, making obesity a dangerous problem. Other factors to consider are the intake of certain drugs, metabolic stresses such as sleep loss, hypercoagulability (blood that readily coagulates), high altitude diving and work rate at depth.

The U.S. Navy has developed tables that tell divers the maximum number of minutes they can theoretically stay at certain depths and still avoid decompression sickness. But abiding by those limits does not guarantee safety. The U.S. Navy diving tables are based on evaluations of trained, healthy men. But sport divers range widely in physical condition and ability.

The only effective treatment of decompression sickness is immediate recompression in a hyperbaric chamber. Recompression increases the pressure around a diver (as if he were diving), reducing the size of the bubbles and forcing them back into solution. Then the pressure is slowly reduced to allow the diver to decompress gradually. At the first signs of the bends, do not hesitate to seek treatment. Time is critical.

In North Carolina, the only recompression chamber is at Duke University in Durham. They have equipment for treatment and research of decompression sickness. Duke University also sponsors a Diver Alert Network (DAN) that provides information to divers and physicians nationwide.

ACTIVITY 1

Understanding Diving Physiology

Purpose

To help students understand the effects of diving on the body.

Procedure

Either through a lecture or handouts, provide students with the information provided in the opening background. Then have them answer the following questions.

Questions

1. Divers experience the effects of increasing pressure in what parts of the body?

2. How does increasing pressure affect the lungs?

3. How does the ascent of a dive affect the lungs?

4. Describe why divers develop nitrogen narcosis.

5. What types of symptoms are seen with divers with nitrogen narcosis?

6. List three factors that lower a diver's resistance to nitrogen narcosis.

7. What are the bends? What causes them?

8. If the bends develop, what methods are available to alleviate the problem? How does this process work?

9. List four factors that reduce the validity of the No-Decompression Limits table.

ACTIVITY 2

The Hemosponge

Purpose

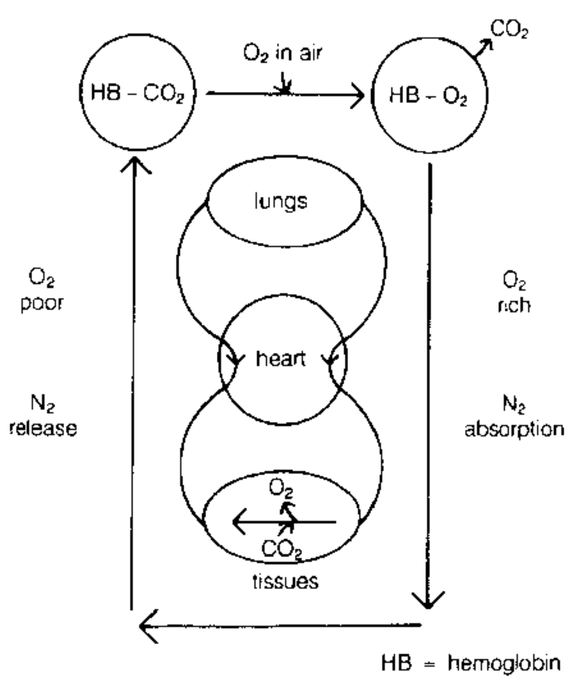
To help students understand the new scientific achievements in extracting oxygen from water.

Background

A hemosponge is a polymer capable of extracting oxygen from seawater. Polymers are long chains or branches of similar molecules linked together. The hemosponge was developed by Duke University biochemists, Joseph and Celia Bonaventura.

There are three mechanisms for oxygen transport. They are hemoglobin, hemerythrins and the hemocyanins. Hemoglobin is found in vertebrates; hemerythrin, in some polychaete worms; and hemocyanin, in horseshoe crabs. These metalloproteins bind oxygen at the interface between the organism and its environment, either at an air-lung interface or a water-gill interface. And they transfer that bound oxygen to the respiratory tissues. Figure 9 represents how oxygen is extracted from air by humans.

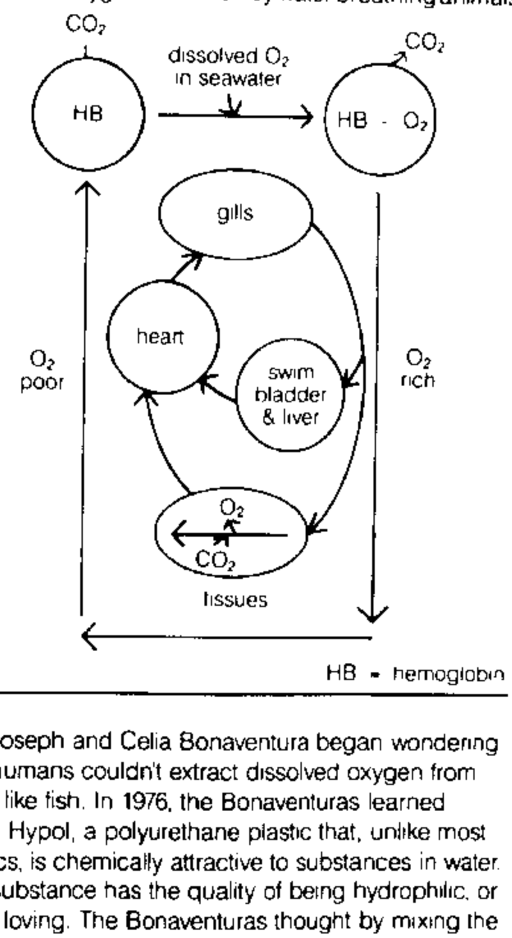
Figure 9 Oxygen extraction by air breathing animals



Being air breathers, humans must devise elaborate systems to provide breathable oxygen to go underwater for a prolonged time. But many organisms that have oxygen demands similar to humans live comfortably underwater. Porpoises and whales get oxygen by breathing air.

Other underwater animals breathe in water. Figure 10 shows how oxygen is extracted by water-breathing fish. An important distinction in water breathers is that the transfer of oxygen is a liquid-liquid one and does not involve gases.

Figure 10 Oxygen extraction by water breathing animals



Joseph and Celia Bonaventura began wondering why humans couldn't extract dissolved oxygen from water like fish. In 1976, the Bonaventuras learned about Hypol, a polyurethane plastic that, unlike most plastics, is chemically attractive to substances in water. This substance has the quality of being hydrophilic, or water loving. The Bonaventuras thought by mixing the polymer with hemoglobin, which is soluble in water, there might be a way to immobilize oxygen outside the bloodstream.

In November, the Bonaventuras obtained a sample of the polymer. Joseph Bonaventura drew a sample of his own blood, mixed it with a detergent and the polymer, which looked and flowed like honey. As he stirred, the mixture began to solidify into a rust-colored sponge-like material. The sponge had the ability to remove oxygen dissolved in water.

The honey-like plastic captured substances without interfering with the way they worked. When combined with the polymer, hemoglobin formed a sponge that when placed in water could take in oxygen like the gills of a fish. They called their discovery a hemosponge.

The hemosponge would also release the captured oxygen when the sponge was subjected to a slight electric charge or when washed with solutions low in oxygen. Figure 11 shows how hemoglobin could be used in an oxygen extraction process.

Figure 11 Oxygen extraction system

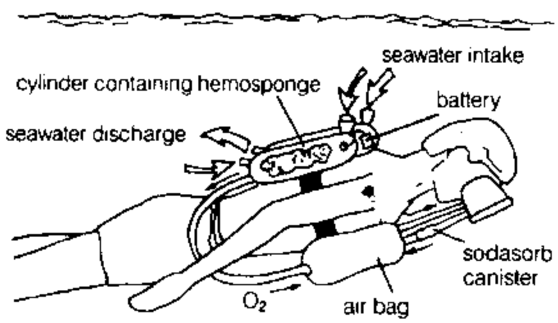
1. Fish hemoglobin is bound to the hemosponge (Hb = fish hemoglobin)
2. O_2 uptake — at neutral pH

   seawater w/O_2 + hemosponge–Hb → hemosponge–HbO_2
3. O_2 release — at low pH

   hemosponge–HbO_2 → hemosponge–Hb + O_2

In 1983, Duke University sold the hemosponge patent to the Aquanautics Corporation (for $1 million). The corporation is working on several uses for the hemosponge. An artificial gill was one proposed use. As an artificial gill, the hemosponge would extract oxygen from seawater and store it in a diver's tank (Figure 12).

Figure 12 Hemosponge as artificial gill in diver's tank



The hemosponge might also be used in submarines and submersibles. The prototype is expected to have two stages, loading and unloading. The Bonaventuras believe that if water were passed through a 3-by-10 foot canister of hemosponge, enough oxygen could be extracted from seawater for 150 people.

Another promising use of the hemosponge would be to extract oxygen for gasoline combustion in submarines and submersibles. Underwater vehicles use batteries as their power source. A typical internal combustion engine consumes eight times as much oxygen as fuel. Transporting the necessary volume of oxygen was not feasible. The hemosponge can solve this problem by extracting a supply of oxygen as the vehicle moves through the ocean.

The Bonaventuras are also investigating land uses for the hemosponge such as providing air supplies for miners, welders or medical equipment (oxygen tanks and portable dialysis machines). The hemosponge could be used in packaging to protect air-sensitive products such as beer and perfume. Or it could neutralize toxic fumes from mercury spills, treat nuclear effluent or produce rare enzymes and proteins. The Bonaventuras can research its possibilities for years.

Questions

1. How are the Bonaventuras able to remove oxygen from seawater?

2. List two possible developments that may come out of the discovery of the hemosponge.

3. Will the hemosponge help scuba divers? How?

4. What advantage will hemosponge diving offer over conventional scuba diving?

5. On what compound is the oxygen absorbed? What is this compound known for?

ACTIVITY 3

Helium Diving

Purpose

To learn about the history and scientific discoveries of deep diving.

Background

Greater diving depths were accomplished when it was discovered that helium mixed with oxygen did not cause nitrogen narcosis. Hydrogen, helium, argon, neon, xenon and krypton are inert gases present as traces in air.

Helium was found to be usable at depths greater than nitrogen. Helium is 4½ times less soluble in fatty tissue than nitrogen and makes a more effective breathing gas to accompany oxygen for deeper diving.

In 1937, Edgar End, a medical intern, successfully used helium to avoid nitrogen narcosis. The British Admiralty and the U.S. Navy Experimental Diving Unit had been unable to adapt helium for diving. But End developed a helium decompression schedule based on some original calculations.

End and diver, Max Gene Nohl, breathed a helium-oxygen mixture in an old recompression chamber. They found they could surface safely from depths of 100 feet. Then followed a series of successful open-water dives in Lake Michigan. In 1937, Nohl, using a self-contained suit, set a world record diving depth of 420 feet and surfaced without signs of decompression sickness.

After Nohl's dive, the Navy increased its interest. For the next 20 years, the Navy was the only user of helium-oxygen diving because they had the only available sources of helium.

With the development of offshore oil production, deep-water diving became a necessity, especially on the West Coast. Many companies hired local abalone divers to handle the diving jobs. However, when depths of 250 feet were reached, the compressed air equipment caused nearly prohibitive nitrogen narcosis. California abalone diver Dan Wilson decided that helium-oxygen was necessary. Using a Japanese abalone deep-sea diving dress and a special mask, Wilson made a helium dive to a depth of 420 feet.

During the 1960s, the demand for deep commercial diving accelerated rapidly, and new helium equipment was developed by commercial operators. Bell diving also came into vogue to deliver the commercial diver to the work site.

Questions

1. What gas was found to replace nitrogen and alleviate nitrogen narcosis?

2. Fat tissue absorbs how much less helium than nitrogen?

3. Who uses helium diving the most now? How does it help them?

4. How does replacing nitrogen with helium improve scuba diving?

5. Divers develop helium narcosis at the same depth as divers using nitrogen develop nitrogen narcosis. True or false?

ACTIVITY 4

Submersibles

Purpose

To learn about the development of deep sea submersibles.

Background

Submersibles were developed for work at great depths. Submersibles increased dive times where pressures were great and temperatures low. The components of most submersibles built today are the same.

The *Trieste I*, launched in 1953, holds the record for the world's deepest dive—35,800 feet to the bottom of the Mariana's Trench. The descent took 4 hours, 48 minutes. Scientists stayed on the bottom for 20 minutes and saw shrimp and other fish swimming above a diatomaceous ooze on the sea floor. Diatomaceous ooze is a deposit of dead diatoms in a very dense mat on the sea floor.

The *Alvin* launched in 1964 has a 12,000-foot depth maximum. Scientists aboard the *Alvin* made one of the most exciting marine discoveries this century—hydrothermal vents.

During a typical eight-hour dive, the *Alvin* provides working space for three observers (two scientists and a pilot). The interior space is so cramped with equipment, instruments and cameras that the three must sit crouched for the entire dive.

Four heavy steel pallets, two on each side, provide *Alvin* with the weight needed to descend slowly to the ocean floor. The submersible descends at a rate of 30 meters per minute.

Once *Alvin* is a few hundred meters below the water's surface, the ocean becomes pitch black. But the scientists can still see the thousands of organisms that inhabit these waters. They brilliantly luminesce in the dark sea.

Once near the bottom, the pilot engages *Alvin's* propulsion system to steer the submersible to the desired research spot. There it will remain for as long as five hours. During this time, scientists will conduct experiments, take samples and perform camera surveys. Time is precious because each dive costs more than $10,000.

The *Treiste I* and *Alvin* maintain an internal pressure equal to the surface pressure. This prevents divers from having to adjust to the changes in pressure and increases in nitrogen. They are able to carry out their experiments without worrying about developing the bends or nitrogen narcosis.

Alvin has no heat source so the temperature within the vessel slowly drops to match that of the cold seawater. Researchers must pack sweaters and wool socks to stay warm.

When the researchers finish, the pilot releases the four outside steel pallets to give the submersible the positive buoyancy needed to rise slowly to the surface. Once *Alvin* surfaces, it is picked up by a larger research vessel.

Procedure

Design a submersible. Explain its function (rescue, exploring hydrothermal vents, deep-sea mining), and show what appendages need to be engineered to accomplish these missions.

Questions

1. What are the benefits of diving in submersibles?

2. Why don't divers in submersibles develop nitrogen narcosis or the bends?

3. Name the submersible that dived to the bottom of the Mariana's Trench.

4. Are divers saturated at surface pressure or at the pressure of the depth of the dive in submersibles?

ACTIVITY 5

The *Hydrolab* Underwater Research Facility

Purpose

To learn about saturation diving.

Background

Recently, the number of people involved in diving activities has increased steadily. This increase is found in scientific, recreational and commercial diving. Because of this heightened interest, a need exists for equipment and procedures that would allow a diver to operate with greater flexibility, safety and effectiveness.

Although significant achievements have been made in deep-water diving, much work is performed in waters less than 300 feet deep. The need for extended diving times by scientists and working divers has also become apparent.

Research in the 1930s indicated that saturation diving might be feasible and might provide divers the extended time and greater depth needed. During saturation diving, a diver is exposed to an inert gas at a fixed high pressure long enough for all the body tissues to absorb all the gas they can. No additional gas can be dissolved in the tissues. Once a diver is saturated, the required time for decompression is the same regardless of how long the dive lasts.

Researchers have developed underwater research labs where divers become saturated and work for days to weeks at greater than normal pressures. *Hydrolab* in the Bahamas is one of these facilities. *Hydrolab* saturates divers at 50 feet, allowing dives to greater depths to occur more easily. From *Hydrolab*, divers can work longer at their research sites and can obtain new air tanks without having to surface for long periods to completely decompress.

Hydrolab is a manned habitat operated at either ambient or surface pressure. It is located at 50 feet, saturating divers at this depth. Three to four divers are able to live in *Hydrolab* for up to 14 days. *Hydrolab* is a 8-by-16 foot cylindrical chamber with a 3-by-10 foot submarine dry transfer tunnel.

The habitat contains two bunks, lights, a communications radio, toilets, seven windows, tables and a freshwater shower. It receives electricity, compressed air and fresh water from an unattached buoy. A lock-out dry tunnel where water meets air of the same pressure is used by divers to access the lab easily. Food is brought to divers daily in sealed bags.

Divers using *Hydrolab* undergo extensive diver training. On the day they begin at the lab, they are taken out in a small boat with all of their gear. They dive to the lab, set up and begin their work. Within 12 hours, they are saturated and have adjusted to the change in pressure. For the next week to 14 days, the divers work in shifts to carry out experiments. The boat returns each day, bringing meals and compressed air tanks.

On the last day, divers close the tunnel to *Hydrolab* and start the decompression process within the habitat. The process occurs over 13½ hours. When decompression is completed, divers suit up and return to the surface. Once topside, they return to a land station and remain there for at least 24 hours to guard against any post decompression problems.

Hydrolab allows scientists to perform many experiments that would otherwise be difficult or impossible for surface-working divers. Researchers use this lab to perform experiments in marine biology, geology, chemistry and physics. In recent years, studies of ocean dumping, resource development and ocean technology have been performed.

Procedure

Draw an underwater scene with a *Hydrolab* facility in operation. Be sure to show how many scientists would live there. Show inside arrangements and living quarters.

Questions

1. What is saturation diving?

2. If a diver does not go through a complete decompression sequence what may occur? Why?

3. What two benefits are there for divers who work out of the *Hydrolab*?

Competency Factors/References

Competency Indicators

Biology Academic and Applied/Technical—

6.3 have a general knowledge of human physiology.

Competency Measures

Biology Academic and Applied/Technical—

6.3.1 list the major functions of each organ composing the major body systems.

References

Barsky, Steven M. 1982. "Diary of a Commercial Diver," *Skin Diver.* July. p. 19–22.

Bonaventura, Celia and Joseph, Irving Hooper and Todd Marshall. 1984. "Underwater Life Support Based on Immobilized Oxygen Carriers," *Applied Biochemistry and Biotechnology.* 9:65–80.

Busby, R. Frank. 1976. *Manned Submersibles.* Office of Oceanography of the Navy.

Carrier, Rick and Barbara. 1973. "Dive." Funk and Wagnalls Publisher, New York.

Clarke, Robert. 1973. *The Ocean World of Jacques Cousteau.* Robert Clarke, Publisher, Danbury Press. Volumes 10 and 12.

Cush, Cathie. 1984. "Artificial Gill May Be Able To Replace Scuba," *Underwater USA.* August 1984, p. 9.

Graver, Dennis. 1984. *PADI Diver Manual.* PADI Publishing, Santa Ana, CA.

Hauser, Hillary. 1982. "The California Abalone Divers," *Skin Diver.* June, p. 32–38.

Hoban, Phoebe. 1984. "Breakthroughs-Sponge Power," *Omni.* September, p. 26 & 141.

Huguenin, John E. and Richard A. Fralick. 1975. "Living under the Sea," *Sea Frontiers.* 21(2), p. 95–103.

Jeppesen, 1981. *Sport Diver Manual.* Jeppesen Sanderson, Inc.

Kooyman, Gerald L. 1976. "Deep Divers of the Antarctic," *Natural Histo.y.* 85(3):36–45.

Lee, Owen. 1968. *The Skin Diver's Bible.* Doubleday and Company, New York.

Mauldin, L., Dirk Frankenberg. 1978. *N.C. Marine Education Manual—Seawater.* UNC Sea Grant, Raleigh, NC 27695.

Miller, James W. 1976. *Vertical Excursions Breathing Air from Nitrogen-Oxygen or Air Saturation Exposures.* U.S. Department of Commerce, NOAA.

Soule, Robert. 1968. *Undersea Frontiers.* Rand McNally and Company, New York.

Stenuit, Robert. 1966. *The Deepest Days.* Coward-McCann, Inc., New York.

Strauss, Richard H. 1976. *Diving Medicine.* Grune and Stratton, New York.

Stringer, Jack. 1983. "Euphoria at 200 ft.," *Skin Diver.* February, p. 126–129.

Sullivan, Walter. 1984. "Artificial Gills for People is Aim of New Device," *The New York Times.* July 10, 1984.

Walker, Mort. 1984. *Sport Diving.* Henry Regenry Company. Chicago.

Wolfe, M. 1983. "Hemosponge: A Breath of Fresh Air," *Science News.* December 31, p. 405.

Biology Answers

Part 1/New Discoveries Sea

Activity 1/Putting "Goo" in Its Place

1. b

2. d

3. a

4. b

5. d

6. Larvaceans

7. Scuba (and glass jars)

8. Paradigm

9. Stinging tentacles

10. Nannoplankton

11. j

12. a, b, d, i

13. c, e, f, h

14. g

15. Scuba allowed us to see the abundance, diversity and feeding methods of blue-water plankton.

16. They make the food web more complex, and they provide a link between nannoplankton and the rest of the organisms, etc.

Activity 2/Ocean Upwellings

1. The biotic factors of the upwelling ecosystem are: diatoms, copepods and sardines.

2. Abiotic factors of the upwelling ecosystem are: high and low pressure systems in tropical Pacific, movement of surface water across the Pacific, coastal winds, nitrogen and phosphorus, and sunlight (light).

3. Producer organisms: diatoms
First-order consumers: copepods
Second-order consumers: sardines
Decomposers: bacteria (not illustrated)—copepods and sardines also play a role in decomposing plant material

4. a. photosynthesis

b. protein synthesis/ATP and DNA synthesis

c. An increased concentration in the water of both chemicals would occur.

d. Eventually a new balance would occur after a decrease in heterotrophs (consumers).

e. A decrease in concentration would occur.

f. A bloom might cause pollution and deaths or an increase in heterotrophs. Eventually a new balance would be established.

5. The guano industry would also suffer economic hardship.

For Further Study: Answers would depend on the article read.

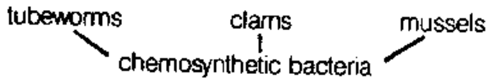
Activity 3/Life in Hydrothermal Vent Communities

1. This is an open-ended question. Accept any suggestions that are factually correct. This should provide an opportunity for discussion of the conditions necessary for life. Try to focus on the adaptive ability of organisms to this hostile environment.

2. Energy supply is the most limiting factor. Since there is no light at these depths, the available energy should severely limit the abundance of living things. Instead, we find a well-developed biological community. The key is the existence of chemosynthetic organisms at the base of the food web.

Students may also suggest that a higher temperature than normal is found at this depth. This is true. But as one moves away from the vent, the temperature drops sharply. In addition, low temperatures do not seem to limit organisms in other locations on the deep sea floor.

3. The specifics of the feeding relationships will be determined by future research. The following diagram shows what is known:



In addition, crabs and eelpout are scavengers, eating almost anything that is available.

4. The most noteworthy adaptation is the abundance of hemoglobin in large tubeworms and clams. The organisms' large size is possible because they concentrate oxygen in hemoglobin-rich tissues.

Another adaptation is the symbiotic relationship developed by the tubeworms, clams and mussels with the chemosynthetic bacteria. The relationship appears to be mutualistic. The bacteria supply food to the three hosts and the hosts concentrate the minerals the bacteria need to live.

5. It was thought that the absence of light precluded the development of a large community. Chemosynthesis had never been considered a basis for the abundance of large organisms.

6. This is also an open-ended question. However, some questions that are likely to be listed are: How do these oases of life come to be colonized? How stable are these communities in view of the limited number of species adapted to the stressful conditions? Hydrothermal vents are not permanent features, so what is the impact on the life history of the vent communities? What are the feeding relationships of the other members of the community? Are there practical applications of what has been discovered about this unusual ecosystem?

Activity 4/Living Between Sand Grains

Answers, observations, drawings and analysis will depend upon the organisms observed.

Part 2/Biochemistry

Activity 1/Photosynthesis and Decomposition

1. Nutrients (CO_2, NO_3^-, PO_4^{3-}) + water $\leftrightarrow$ organic matter + oxygen

Photosynthesis occurs when chemicals containing carbon, nitrogen and phosphorus combine with the hydrogen and oxygen in water and with the energy from sunlight to produce solid organic matter and gaseous oxygen. Decomposition is the oxidizing of organic matter back into simpler compounds.

In photosynthesis, the energy is that of sunlight trapped by chlorophyll and reacted with nutrients to form organic matter. In decomposition (or respiration), the energy liberated is in a chemical form that can provide energy for muscle contraction or other energy requiring biochemical processes.

2. $106\ CO_2 + 16\ NO_3^- + PO_4^{3-} + 9\ H_2O$ + energy $\leftrightarrow$ $C_{106}H_{180}O_{46}N_{16}P + 154\ O_2$

a. to the right

b. to the left

c. photosynthesis

d. decomposition (respiration)

e. life processes

f. yes; heat and molecular bonds

3. Oxygen would be lower in some lower layers—the O_2 minimum. It is not lower in all deep water because oxygen-rich water from high latitudes supplies the cold water that occurs deep in the ocean.

4. Nitrate and phosphate concentrations would be lower in the surface layers since they react in photosynthesis and are incorporated into organic matter.

5. If one nutrient is exhausted, the process of photosynthesis will slow down and stop. At this point, the composition of organic matter produced may have different chemical ratios than the ratio presented in this exercise. This is brought about by having smaller concentrations of the nutrient in limited supply.

6. Physical mixing between layers brings nutrients and light together to react in photosynthesis.

Activity 2/The Effects of Decay on O_2

1. The decomposition in jar 1 used O_2.

2. Temperature changes might cause differences; water holds less O_2.

3. The decomposition in jar 1 used up O_2.

Activity 3/Effects of Plants on O_2

1. There is more O_2 in Jar 1 because of photosynthesis.

2. Temperature changes might cause differences; water holds less O_2.

3. Photosynthesis caused the difference.

Activity 4/Temperature and O_2

1. As the water is heated, the amount of O_2 decreases.

2. When algae bloom, the ones that are lower die due to lack of light. Thus there is decomposition which releases heat. Water holds less O_2, and fewer fish can live.

Activity 5/Determining Pigments in Marine Algae Using Paper Chromatography

1. The answers to this depend on algae used and results.

2. Spinach will have bolder colors (more pigment) and will be similar to green algae (Ulva).

3. Chlorophyll and other pigments are soluble in acetone but not in water.

4. The darker the color on the chromatogram, the greater the concentration of pigment will be. However, this is a very qualitative observation.

5. Greens and to a lesser extent yellow, blue and orange are least useful in providing energy since these are the colors that are being reflected. The other light waves are being used for energy.

6. Other pigments are not soluble in acetone or petroleum ether.

7. The pigments might dissolve right into the solution.

8. The auxiliary pigments function to transfer energy to chlorophyll; this allows the utilization of more of the light energy.

Part 3/Animal Adaptations

Activity 1/Plankton, Nekton and Benthos—Their Underwater Environment

1. d

2. c

3. a

4. c

5. d

6. drag (forces)

7. boundary layer

8. low

9. drag

10. Surface area = 5cm × 6 sides = $150 cm^2$

Volume = 5cm × 5cm × 5cm = $125 cm^3$

$$\frac{150 = 6}{125 = 5}$$

There is only one unit of surface area for every 5 units of volume. This is not enough surface to feed the plankton.

11. Anemone A lives in a high turbulent area, such as a surge channel. The short, fat shape reduces the amount of surface exposed to drag and therefore stress. Anemone B lives in a quiet, stable environment. The tall, thin shape shows that this anemone doesn't experience a great deal of stress.

12. At a low Reynold's number, water is thick like butterscotch. Consequently, copepod arms act more like scoops than filters. They push parcels of water to their mouths. This makes them an even bigger part of the oceanic food chain.

Activity 2/What Shapes Mean Speed

Answers will vary.

Part 4/Geologic History and the Oceans

Activity 1/Personal Timeline

Check individual timelines.

Activity 2/A Classroom Geologic Timeline

1. The benefit of radiometric dating is that it is reasonably accurate. The disadvantage is that not all rock has a radioactive sample with a half-life that is in a useful range. Some rocks don't have any radioactive isotopes.

2. Marine invertebrate fossils are the most abundant.

3. We find humans in the Cenozoic era and the Quaternary period.

4. Glass sponges, sharks and horseshoe crabs are examples of very ancient organisms that are still alive today.

5. Possible explanations for mass extinctions include changes in the shape and geographical distribution of oceans, meteorites and comets.

6. The Earth was in existence for about 2 billion years before the first life appeared.

7. Blue-green algae appeared about 2.7 billion years ago, marine algae about 600 million years ago and the first land plants about 475 million years ago.

8. Life was in the oceans about 2 billion years before life appeared on land.

9. Since life is so dependent on water, beginning in the oceans meant that no special adaptations were necessary for obtaining and preserving water. Reproduction was simple in the watery environment, and maintaining shape was simple in the buoyant waters. The first cell was bathed in water and the necessary chemicals for life. It did not risk drying out.

10. As competition for space and food increased and the number of organisms increased, those with special adaptations that suited them for new environments had a survival advantage. This process continues as vacant niches are filled.

11. Ocean life contributed to an increase in the concentration of the ozone layer thus providing protection from radiation and making it possible for terrestrial life to safely evolve.

12. The theory of plate tectonics proposes that the continents are riding "plates" that cover the earth like a skin. New material is added to a plate at the ocean ridge end and destroyed at the trench end, resulting in constant movement.

13. The word "evolution" means change over time.

14. As the continents move, the shape of the ocean basins can change. If the shape of the basin changes, then the water level will change.

15. If oceans become deeper, organisms that depend on shallow seas will become extinct. They are not adapted to the deeper oceans. Shallow waters are warmer with more uniform water movements. If these factors change, then organisms adapted to them will die.

16. Extinction today might be occurring due to thermal or chemical pollution, loss of the ozone layer, loss of territory such as rain forests, overhunting or overharvesting, etc.

17. Organisms change over time because they are reacting to changes in the environment. Natural variations are selected by changing environments.

18. B is the oldest rock because more of the U-236 has decayed.

Activity 3/Fossil Lab

Answers vary depending on choice of lab fossils.

Part 5/Seashells and Scientific Names

Activity 1/Designing a Dichotomous Key

Answers will vary according to shells used.

Activity 2/Using a Dichotomous Key

1. a) G
   b) G
   c) B
   d) B
   e) C
   f) P,C
   g) P,G,B,C
   h) B
   i) C
   j) P,B
   k) G
   l) B
   m) B
   n) C
   o) P

2. Answers will vary with student. Possibilities include alphabetically, by type, etc.

3. The system is called the Linnaeus system of classification.

4. Taxonomists

5. It is a key used to identify organisms. It has at least two choices at every step.

6. The common features are: soft bodied, muscular foot or arms, visceral mass, mantle, shell, gills, trochophore larva.

7. The four major classes of mollusks are: polypacophora, gastropoda, pelecypoda, cephalopoda.

8. It is in the class gastropoda. This class has a radula, one-coiled shell, head and eyes, and an asymmetrical visceral mass.

9. It is in the class cephalopoda, which means "head-foot." Yes, it is internal.

10. Chitons. Yes, they have eight internal shell plates.

11. Pelecypoda. Bivalves have two shells, no radula, no head, primitive eyes and two siphons. Univalves have one shell, a radula and a well-developed head and eyes.

12. Snails crawl on the surface of rocks and scrape algae with their radula. Clams burrow into sand or mud and filter food from the water by pumping it through their siphons and gills.

13. A chambered nautilus is a cephalopod, not a gastropod. It has no radula and uses arms and tentacles to capture food. The shell is filled with hollow chambers. Snails have none of these characteristics.

14. Scientific names are always in Latin, do not change from place to place, are based on the Linnaeus system of classification, are made from the genus and species name, and are always underlined. Common names are in any language, can be different from place to place, are based on local culture and are not underlined or capitalized.

15. Clams filter seawater to eat plankton.

16. Chitons are found stuck to rocks in the sea.

17. The seven divisions are: kingdom, phylum, class, order, family, genus and species.

18. Humans use mollusks for money, jewelry, food, buttons, decorations and pearls.

19. Answer varies by student.

20. Their food doesn't move so that they don't have to be quick to catch it. They can pull their bodies all the way into their shell for protection.

21. Organization of living things is important so that people can communicate intelligently about them. The organization helps explain relationships and evolution of the organisms. In addition, a good system makes identification much easier.

Part 6/Behavior of Ocean Creatures

Activity 1/Biological Clocks

1. Green crabs are most active during a combination of high tide and darkness.

2. Solar rhythm is the most important factor.

3. Green crabs are darkest at noon.

4. Solar rhythm is the most important factor.

5. The green crabs' behavior is internally/genetically controlled.

6. Solar rhythms control the migration of the diatom, *Hantzschia*.

7. Staying below the surface keeps *Hantzschia* from being carried away by waves.

8. Coming to the surface at noon allows the organism to take advantage of light for photosynthesis.

9. Again, the behavior of *Hantzschia* is internally/genetically controlled.

10. During high tide, fiddler crabs are quiet in their burrows; during low tide, fiddler crabs emerge to look for food.

11. In conditions of constant light and temperature, the rhythm periods lengthen and no longer correspond to the tidal rhythms.

12. Immersing the crabs in seawater or lowering their temperature can restore their environmental clock.

13. Hiding during high tide allows the fiddler crab to avoid predators.

Activity 2/The Fiddler Crab Experiment

Answers depend on students.

Activity 3/Salinity Changes and Sea Animals

1. The body fluids in organism C remain unchanged as the external salinity changes. Since salt tends to diffuse into organism C when the salinity of the environment goes above 2%, the organism must do one of the two things: prevent the salt from entering or excrete salt at a rate to maintain a constant internal concentration.

2. Organisms A and B have an increase in internal salinity as the salinity of the environment increases. Organism A eventually reaches a point where its internal body fluids are in balance with the external salinity. Organism B always maintains an internal salinity less than the environment.

3. It is difficult to say which situation is more efficient or adaptable. The important thing is the organism survives. Whether it does so by tolerating higher external salinities or by altering its internal salinity is not crucial. Both ways solve the problem of a changing environment.

Activity 4/The Sea Worm

1. The maximum weight gain was 60 percent above its initial weight.

2. The weight gain is due to the diffusion of water into the worm. This occurs because the concentration of water is less inside the worm than it is outside. According to the principles of diffusion, molecules will tend to move from an area of greater concentration to an area of lesser concentration.

3. The weight loss can be explained by active transport. The worm begins to excrete the water that entered during the first five to six hours.

4. This is an example of homeostasis. After a time, the worm begins to restore the balance of salt in its body fluids. It is interesting that it does not seek to maintain this balance immediately.

5. An organism that lives in coastal regions is subjected to frequent changes in salinity due to runoff from the land and the effects of the tides. Active transport requires the expenditure of energy. The sea worm has developed an intriguing physiological adaptation. Rather than expending energy for a temporary change in salinity, it simply tolerates a period of imbalance in its internal body fluids. However, if the higher environmental salinity persists, then it begins to lower the water content of its fluids by excretion. This is useful and efficient for an organism that is subjected to frequent changes in environmental salinity.

6. To survive in coastal waters an organism must evolve mechanisms for tolerating or adjusting to frequent changes in salinity. Most marine organisms have not developed this ability. Therefore, they cannot inhabit coastal regions. The salinity of the open ocean is fairly constant. Consequently, the ability to cope with changes is not found in most marine organisms.

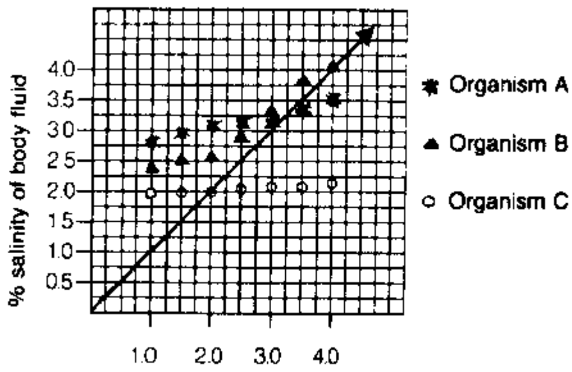
7. The cells must tolerate the changes in salinity. One way to do this is by actively transporting the diffusing salt molecules outward.

8. With the development of specialized tissues and organs, more highly evolved organisms can regulate processes that simpler organisms do not.

9. Organisms such as salmon and eels are migratory fish. To cope with the change in salinity from a freshwater river or lake to the open ocean, these organisms must tolerate internal changes or counter the changes with regulatory processes.

Activity 5/Homeostasis on a Graph

Figure 8 Changes in salinity



Activity 6/The Homeostatic Relationship Between Water Temperature and Respiration Rate in Marine Fish

1. Generally, the higher the temperature, the faster the respiration rate.

2. It varies.

3. It varies.

4. Thermal pollution is likely to increase the rate of respiration in fish.

5. Other factors that might affect respiration rate are: activity level of fish, depth of water, health, light and amount of oxygen dissolved in the water.

6. Breathing is increasing (the passing of water over the gills); this suggests that the metabolic rate may be increasing due to increased intake of oxygen. However, it is possible that the fish is simply increasing breathing because the oxygen level in the water is decreasing.

7. Answers may vary.

8. The student should answer that the fish respiration rate increased to maintain a constant oxygen supply to the tissues.

9. The fish has to adapt (breathe faster) when the water temperature increases to maintain a stable internal environment (i.e. a constant level of oxygen).

Part 7/Man Under the Ocean's Surface

Activity 1/Understanding Diving Physiology

1. A diver feels the effects of increasing pressure in the lungs, sinuses and ears.

2. Increasing pressure (external) reduces the size of the lung air spaces.

3. The air in the lungs expands.

4. Divers can get nitrogen narcosis at great depths because the partial pressure of nitrogen is greater at higher pressures and therefore enters the tissue fluid in greater amounts.

5. The symptoms of nitrogen narcosis are similar to intoxication—acting silly, irrational and in an unsafe manner.

6. A hangover, fatigue, alcohol, excess carbon dioxide, inexperience and anxiety can lower a diver's resistance to nitrogen narcosis.

7. Ascending quickly from great depths can cause the bends; too many of the gases in the tissues and blood come out of solution and form gas bubbles that get in the joints and cause pain.

8. Recompression in a hyperbaric chamber with subsequent slow decompression can be used to treat the bends.

9. Obesity, sleep loss, certain drugs, hypercoagulability, high altitude diving and work rate at the specific depth can reduce the validity of the No-Decompression Limits Table.

Activity 2/The Hemosponge

1. The Bonaventuras are able to remove oxygen from seawater with the hemosponge, which is a mixture of polyurethane plastic and hemoglobin. The hemoglobin maintains its ability to pick up oxygen and is able to remove oxygen from seawater.

2. The hemosponge could modify diving equipment and the method used to supply air for submarines and submersibles.

3. Yes. It is believed that a tank that will filter seawater and remove oxygen will replace the compressed air system used in scuba diving.

4. It will allow divers to dive for longer periods of time without fear of running out of air.

5. Hemoglobin absorbs the oxygen. It is known for its ability to bind oxygen at the interface between the organism and his environment, either at the air-lung interface or the water-gill interface.

Activity 3/Helium Diving

1. Helium

2. Four and a half times

3. Commercial divers use the helium system the most. It allows them to dive at greater depths without developing nitrogen narcosis.

4. It allows greater diving depths.

5. False

Activity 4/Submersibles

1. Depth and time

2. The internal pressure of the submersible remains equal to surface pressure so there will be no problem with nitrogen narcosis or the bends.

3. The *Trieste I*

4. Divers in submersibles are at surface pressures. This system offers the ability to dive to the bottom of the ocean floor without developing the bends or nitrogen narcosis.

Activity 5/The *Hydrolab* Underwater Research Facility

1. During saturation diving, a diver is exposed to an inert gas at a fixed high pressure long enough for all the body tissues to absorb all the gas they can. No additional gas can be dissolved in the tissues.

2. He may develop the bends. An incomplete decompression will leave nitrogen bubbles in the diver's tissues at a higher level than the partial pressure at the surface. When he ascends, if it is not slow enough, he risks developing the bends.

3. Time and depth

PHYSICS

Ocean Motion

Introduction

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

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

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

Teacher Background

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

Vocabulary

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

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

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

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

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

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

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

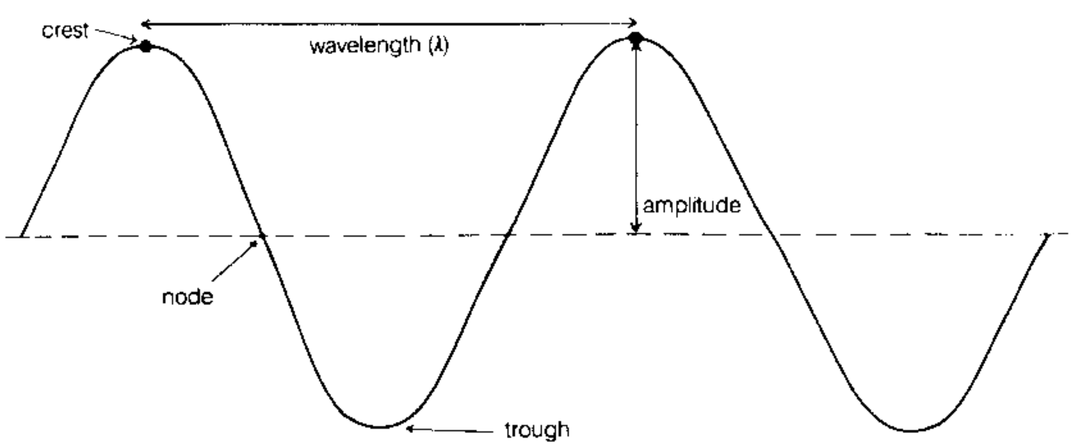
Diffraction—The bending and redistribution of the energy of a wave as it moves past an obstacle.

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

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

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

Figure 1 Transverse wave



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

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

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

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

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

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

Sound—A type of pressure wave.

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

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

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

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

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

ACTIVITY 1

Student Waves

Purpose

To simulate the flow of energy in a wave.

Background

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

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

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

Procedure

Longitudinal progressive wave

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

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

Transverse progressive wave

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

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

Transverse waves only occur in solid materials such as earth.

Questions

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

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

ACTIVITY 2

Water Waves

Purpose

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

Materials

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

Procedure

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

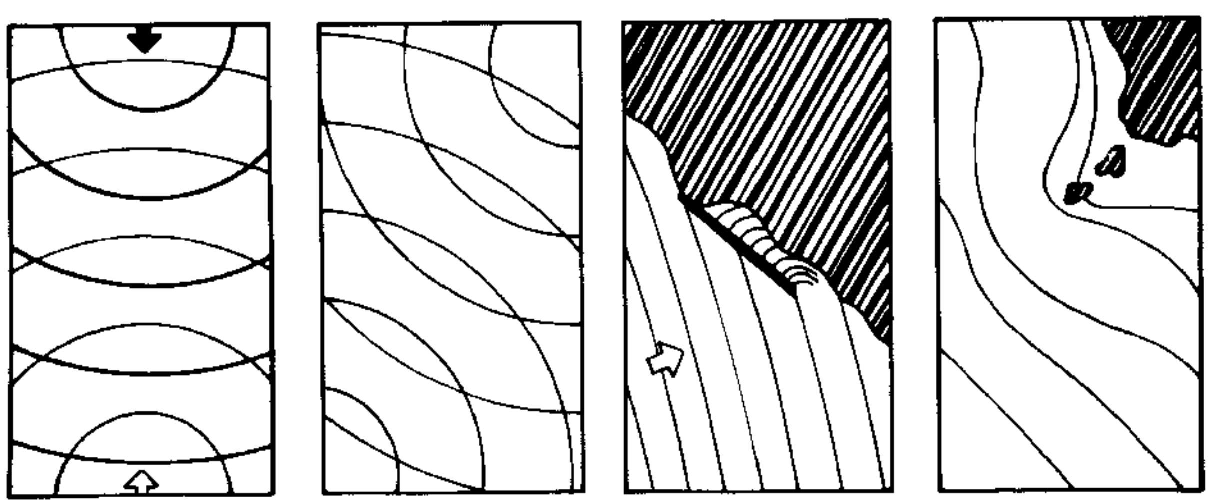
Notice how the waves reflect off of the sides of the tank (Figure 2a). Can you see how the incident or incoming waves interfere with the reflected waves (Figure 2b)? It occurs quickly so you will need to look carefully. The waves appear to move right through each other.

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

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

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

Figure 2 Wave activity



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

Student Questions

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

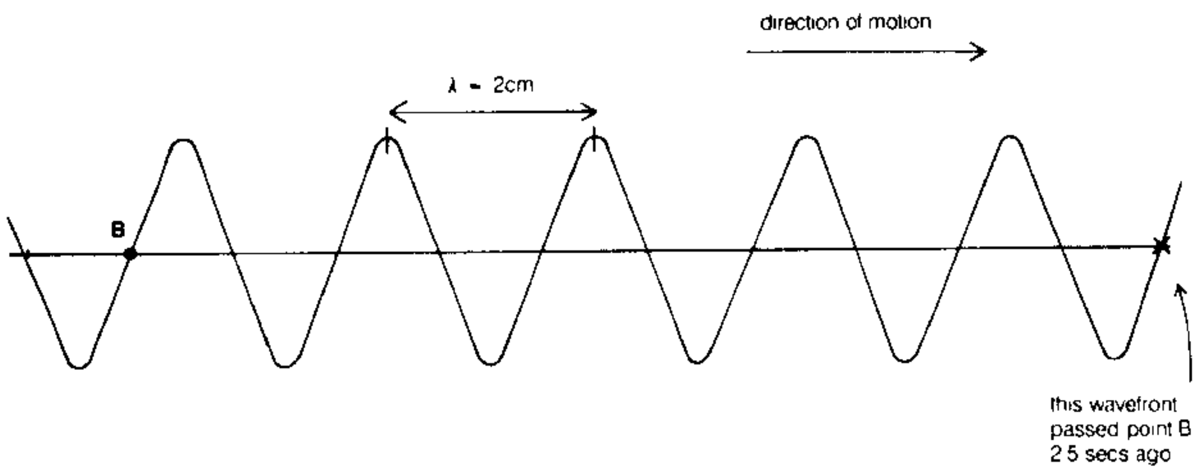
1. How many waves will pass point B (or any point) each second? This is the frequency of the waves in units of waves per second or Hertz.

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

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

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

Figure 3 Waves passing fixed point B in 2.5 seconds.



ACTIVITY 3

Record-Setting Water Waves

Introduction

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

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

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

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

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

Procedure

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

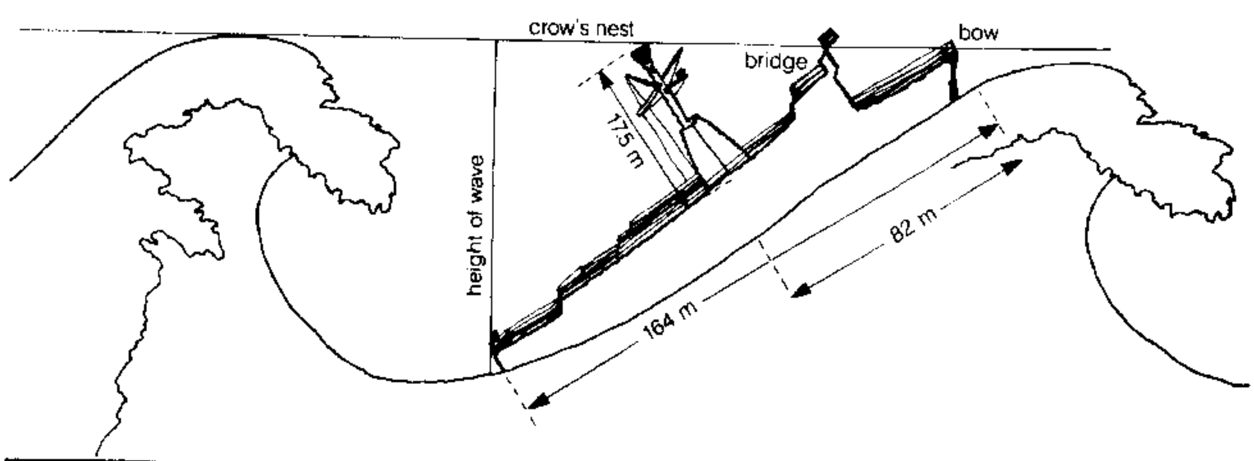
a. What is the length (λ) of the wave? [Use this formula: $\lambda(m) = 1.56\ P^2(sec)$.]

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

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

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

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



ACTIVITY 4

Snap the Whip

Purpose

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

Materials

20 feet of rope
3 students

Procedure

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

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

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

Questions

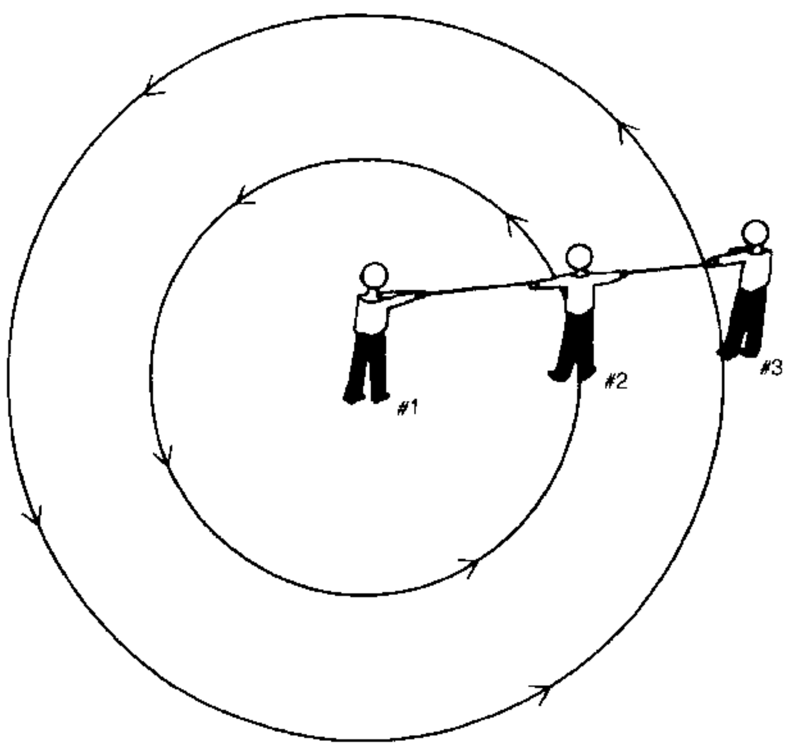
1. Who had to walk the fastest—Student One, Two or Three?

2. Who covered the greatest linear distance?

3. Who covered the greatest angular distance in degrees?

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

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



ACTIVITY 5
The Coriolis Effect

Purpose

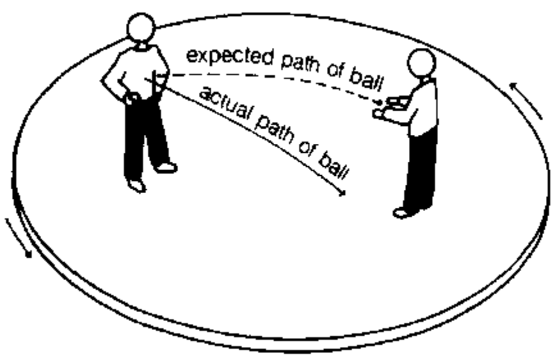
To investigate how objects are deflected in a rotating frame of reference.

Introduction

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

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

Figure 6 The Coriolis effect



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

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

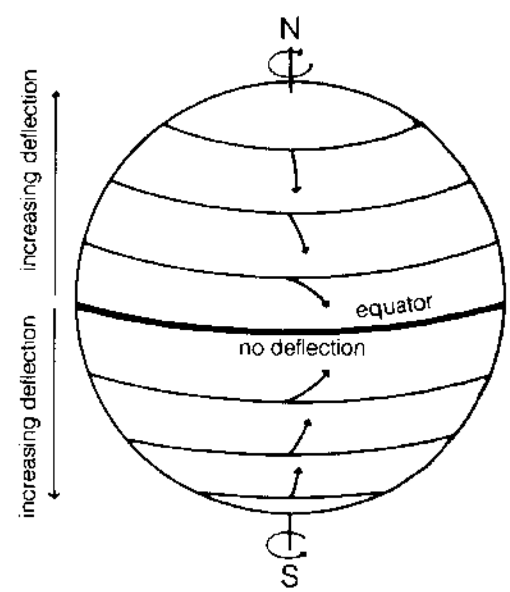
The car is kept on the highway by the friction of the tires, and the driver makes minor adjustments in directions. Therefore, we consider the car to be moving in a stationary frame of reference. Objects not in contact with the Earth, such as missiles and spacecraft, are not affected by the Coriolis force.

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

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

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

Figure 7 The Coriolis force



Materials

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

Procedure

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

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

1. What path does the ball follow?

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

2. Describe the ball's motion.

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

Rotate the demonstrator in a clockwise direction.

4. What happened?

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

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

6. What happens?

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

7. What happens?

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

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

ACTIVITY 6

Archimedes' Principle—The Tip of the Iceberg

Purpose

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

Introduction

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

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

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

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

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

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

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

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

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

Materials

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

Procedure

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

The density of an object is its mass per unit volume. The density of ice is 0.92 g/cm^3. The density of fresh water is 1.00 g/cm^3. The density of salt water (35 ‰) is 1.03 g/cm^3.

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

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

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

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

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

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

4. Repeat Step 3 for salt water.

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

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

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

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

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

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

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

Percentage Below Surface (fresh water) ____________

Percentage Below Surface (salt water) ____________

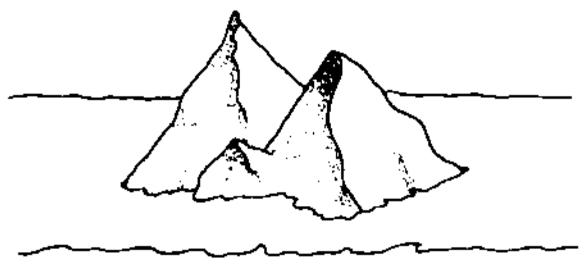
9. Compare your measured values with those you predicted earlier.

Use percent difference:

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

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

Figure 8 Iceberg



Competency Factors/References

Competency Indicators

Physics/Academic—

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

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

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

5.1 know the general properties of wave phenomena; and

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

References

Duxbury, Alyn C. and Alison B. Duxbury. 1989. *An Introduction to the World's Oceans (2nd edition).* William C. Brown Publishers, Dubuque, Iowa.

Guinness Book of World Records. 1986. Sterling Publishing Co., NY.

Giancoli, Douglas C. 1985. *Physics (2nd edition).* Prentice-Hall, Inc., Englewood Cliffs, NJ.

Gross, M. Grant. 1982. *Oceanography: A View of the Earth (2nd edition).* Prentice-Hall, Inc., Englewood Cliffs, NJ.

Halliday,David and Robert Resnick. 1981. *Fundamentals of Physics.* John Wiley and Sons.

Ingmanson, Dale E. and William J. Wallace. 1985. *Oceanography: An Introduction (3rd edition).* Wadsworth Publishing Company, Belmont, California.

Pilkey, Orrin H. Jr., William J. Neal and Orrin H. Pilkey, Sr., *From Currituck to Calabash.* North Carolina Science and Technology Resource Center.

Serway, Raymond A. 1982. *Physics: For Scientists and Engineers.* Saunders College Publishing.

Symon, Keith R. 1971. *Mechanics (3rd edition).* Addison-Wesley Publishing Company, Inc., Reading, Massachusetts.

The World Almanac and Book of Facts. Newspaper Enterprise Association.

Sound

Introduction

The search for fossil fuels involves sound. Knowing how sound waves work helps scientists develop tools to locate fossil fuels. This exploration can take place over land, on the continental shelf or in deeper waters over the continental slope.

The entire industrial world depends on a supply of energy. Currently, that need is met primarily by fossil fuels. As these fuels have become difficult to locate (and hence more valuable), the search for them has moved to a variety of locations.

Students should understand that sonar is used by the energy companies to map the ocean floor and help locate sites for drilling. Seismic equipment towed along the ocean floor is used to map the layers of rock and find geologic structures that may contain fossil fuels such as gas and oil.

ACTIVITY 1

Sonar—Using the Speed of Sound

Purpose

In this activity, students will perform an experiment to determine the speed of sound in air. They will also gain an understanding of how sonar works.

Background

Sound waves travel through many materials. The velocity of the waves depends on the material through which they are traveling. Specifically, the density and the elastic modulus of the material affect the speed of the waves. As you might expect, the speed of sound through steel railroad track is greater than the speed of sound waves through water, and the speed through water is greater than the speed through air. The greater elastic modulus of steel more than makes up for its greater density compared to water.

Knowing the speed of sound through materials allows us to use sound waves to determine distances. The system used for finding distances in water is called sonar, short for sound navigation ranging. This system is used to find the depth of the ocean at various locations (map the ocean floor) and to locate objects underwater.

Sonar was invented in the 1920s by August Hayes. By bouncing sound waves off of objects, he found you could measure distance. The system is similar to those used by bats and porpoises to navigate.

But before sonar can be used, the speed of sound waves must be known. The following experiment illustrates how the speed of sound waves can be found.

Materials

two metal objects (1 kg weights work well)
a meter stick or tape measure
a watch or clock with a second hand

Procedure

Find a large flat wall either indoors or outdoors. A school hallway with no side corridors works indoors or a gymnasium wall does fine outdoors. You will be bouncing (reflecting) sound waves off the wall to determine the speed of sound.

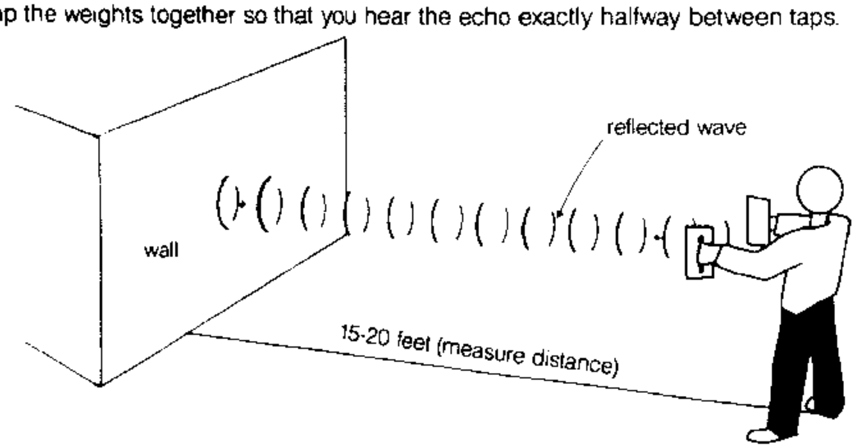
Position yourself 100 meters away from the wall. Measure the distance to make sure it is accurate.

Tap the two weights together and listen for the echo. You will need to be very quiet to hear.

Once you have produced a suitable echo, tap the weights together at a steady rate so that you hear the echo exactly halfway between taps. This will take a little practice (Figure 1).

Now that you have the rhythm of the experiment, you need to count how many taps you make in 10 seconds. Don't count the echoes. Repeat the experiment two more times. Record your results in a data table like the one on the next page.

Figure 1 Tap the weights together so that you hear the echo exactly halfway between taps.



Data Table: Velocity of Sound Determined by Reflection.

Trial	Time (s)	# of Taps	Time per tap	½ time per tap	Dist. (m)	Velocity (m/s)
1	10					
2	10					
3	10					

AVG: ____________

% Error = [(AVG. - Reference) / Reference] × 100]
% Error =

The speed of sound can be determined by using this equation: velocity = distance ÷ time. The distance that the sound wave traveled was twice the distance from you to the wall (round trip). The time it took was one half the time between taps.

Compute the speed of sound for the three trials and compare your results with a reference value for the speed of sound in air.

Reference Table for Velocity of Sound in Different Media

Material (at 20°C)	Speed of Sound (m/s)
Air*	343
Helium	1005
Water	1440
Sea Water**	1560
Hard Wood	4000 (approx.)
Steel	5000 (approx.)

*The speed of sound in air will increase approximately 0.6 m/s for each increase of 1°C.

**The speed of sound in seawater depends on salinity, temperature and pressure. An increase in depth of 1,000 meters will increase the velocity by approximately 18 m/s. Every 1 percent increase in salinity increases the velocity by 1.5 m/s. Each 1°C rise in temperature increases the velocity by 4 m/s.

Questions

1. How much time would elapse between a sonar system's "ping" on the surface and the return of the echo if the depth of the ocean was 750 meters?

2. How much time would elapse between a sonar system's "ping" on the surface and the return of the echo if the depth of a lake is 450 meters?

3. How deep would the Atlantic Ocean be beneath your ship if the time between your sonar's ping and the return of the echo was consistently 4.5 seconds?

4. How far away would you estimate a bolt of lightning struck the earth if you heard the thunder eight seconds after you saw the lightning?

5. What is the minimum time it would take an autofocus camera using a sonic ranging device to determine the distance to an object that is 40 feet from the camera?

Competency Factors/References

Competency Indicators

Physics/Academic—

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

1.1.1 solve algebraic equations utilizing mathematical formulas and expressions;

1.4 know of recent advances, career potentials and current societal issues in physics;

2.4 know how to quantify work, power and mechanical energy;

2.4.4 calculate the potential and kinetic energy of a body at rest and in motion;

5.1 understand the general properties of wave phenomena;

5.1.2 describe types of wave phenomena and modes of propogation;

5.2 know how to investigate and describe sound in a quantified manner;

5.2.2 make calculations relating velocity, wavelength, frequency and period of sound waves; and

5.2.4 calculate and verify the time for an echo return.

References

Guinness Book of World Records. 1986. Sterling Publishing Co. NY.

Giancoli, D. 1985. *Physics, 2nd edition.* Prentice Hall, Inc.

The World Almanac and Book of Facts. Newspaper Enterprise Assoc.

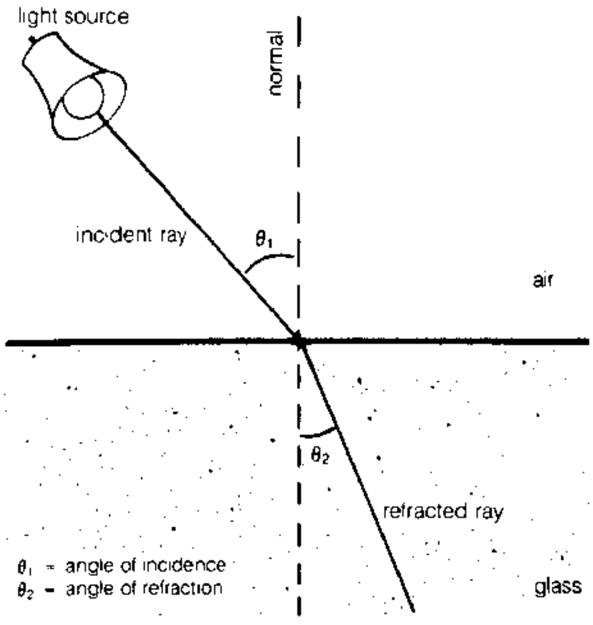
Light in the Sea

Introduction

In Figure 1, a beam of light strikes a glass surface at an angle. At the interface between the glass and the air, part of the beam is reflected and part enters the glass. Notice that the light entering the glass bends at an angle. This bending is called refraction, and it occurs whenever light crosses—at an angle—the boundary between two media of different densities.

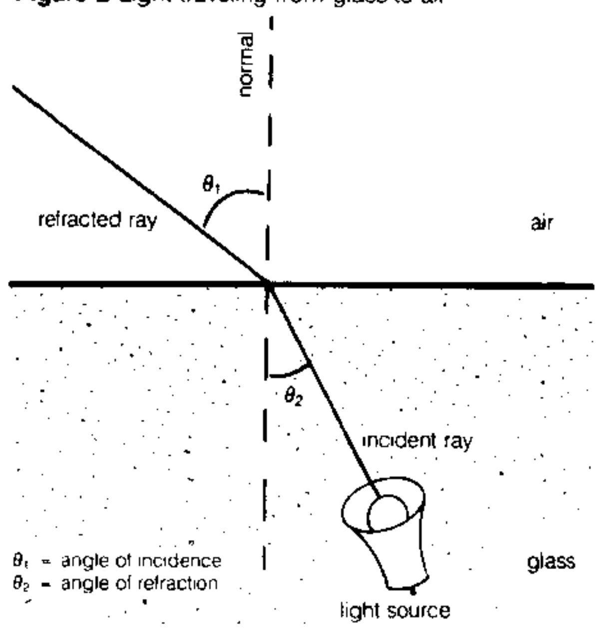
In Figure 1, light is traveling from a medium of low density to one of high density (air to glass). As the light enters the glass, it slows down and refracts toward normal. As n_2 (index of refraction) in second medium increases, the angle θ_2 (as measured from the normal) decreases.

Figure 1 Light traveling from air to glass



In Figure 2, the opposite occurs. As the light moves from a high density medium to one of low density (glass to air), it speeds up and refracts away from normal. If n_2 decreases, then the angle θ_2 increases.

Figure 2 Light traveling from glass to air



Willebrord Snell (1591-1626) is credited with the discovery of the relationships involved in refraction. He found that the change in velocity is analytically related to the angles formed at the boundary and the properties of the media through which the light is traveling.

That is,

$$\frac{V_2}{V_1} = \frac{\sin\theta_2}{\sin\theta_1} = \text{constant}$$

V_1 = velocity of light in first medium
V_2 = velocity of light in second medium

The constant is a dimensionless number called the index of refraction and is represented by the letter "n." From the above equation, we get the widely used form of Snell's Law:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2.$$

n_1 = index of refraction in first medium
n_2 = index of refraction in second medium
θ_2 = angle of incidence
θ_2 = angle of refraction

This is the equation you will use to solve the problems in the following activities.

ACTIVITY 1

Bending Light

Purpose

To draw the path a light ray follows as it travels through fresh water and salt water. You will then measure the angles formed and determine the index of refraction for fresh water and salt water.

Materials

glass or plexiglass rectangular box
straight pins
cardboard
white paper
protractor with straight edge
salt water (50 grams of table salt to 1 liter of water)

Procedure

Secure a piece of paper to the cardboard and set it down on a table. Place the glass box on the center of the paper. Trace the outline of the box. Remove the box from the paper.

Find the midpoint on the back of the outline and mark its position (next to the line, not on it) (Figure 3). Label this point B.

Draw a dotted line through Point B that is perpendicular to the outline of the box. This represents the normal to the back face of the box.

Draw another line, two centimeters in length, that extends out from Point B at a 45-degree angle. Label the point at the end of this line "A" and the angle.

Figure 3 Trace outline of box on paper

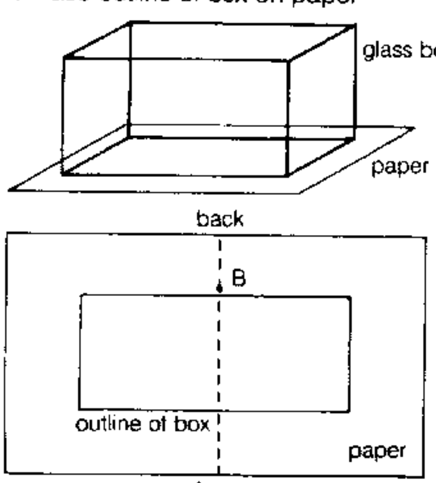
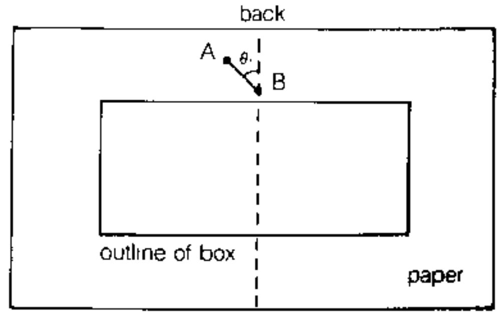


Figure 4 Stick straight pins into paper at Points A and B.



Stick a straight pin into the paper at Point A and another one at Point B (Figure 4). Fill the glass box with fresh water and place it back onto the paper inside the outline.

From the front of the glass box, position yourself so that your line of sight is just above the table top. You should have a clear view of the pins on the other side. Move left or right until the pins at Points A and B appear evenly aligned. (You may close one eye, but do not tilt your head.)

Once aligned, mark a third point, "C," on the front side as close to the glass box as possible. Stick a straight pin into the paper at Point C. All three pins should appear to be aligned.

Carefully remove the glass box from the paper. Draw a line from Point B to Point C. Label the angle this line makes with the normal, "θ_2" (Figure 5).

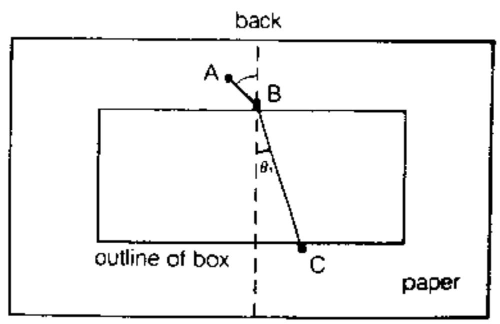
Measure the angle with a protractor.

Using Snell's Law, calculate the index of refraction for fresh water.

Fill the glass box with salt water and place it back over the outline. Repeat the steps above. Label your new point of alignment, "D," and the new angle, "θ_2'."

Calculate the index of refraction for salt water.

Figure 5 Draw a line from Point B to Point C.



Questions

1. The accepted value for the index of refraction in fresh water is 1.33. How does your measured value compare with the accepted value? Express your answer in terms of percent error.

$$\% \text{ Error} = \frac{\text{Difference between measured \& accepted values}}{\text{accepted value}} \times 100\%$$

% Error = ______%

2. Why is there no single accepted value for the index of refraction of seawater?

3. In the experiment, we did not take into account what happens to the light as it passes through the glass. In terms of speed and direction, how does the light behave as it travels from the air to the glass? From the glass to the water? From the water to the glass? And, finally, from the glass to the air again?

ACTIVITY 2

Now You Don't See It, Now You Do

Purpose

To observe the difference in refraction for air, fresh water and salt water and relate those observations to practical applications.

Materials

soup bowl
penny
saltwater solution (50 grams of table salt to 1 liter of fresh water)

Procedure

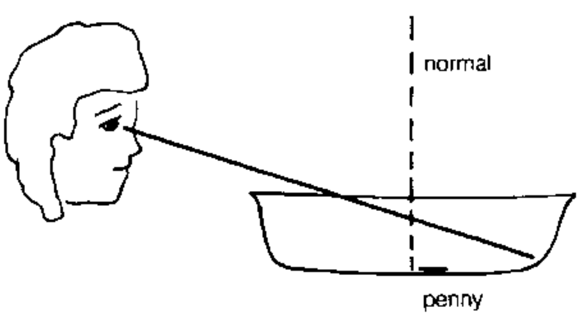
Place a penny in center of a bowl. Hold the bowl straight out from your chest at arm's length. The penny should not be visible.

Mark a spot on the wall or blackboard to indicate the level to which you raised the bowl. Return the bowl to this height for each procedure.

Add ¼ cup of water to the bowl, making sure the penny stays in the center. Again, hold the bowl at arm's length. Do you see the penny? If not, begin adding as many tablespoons of water as necessary to make the penny visible. How many additional tablespoons did it require?

Repeat the procedure using salt water. How many tablespoons of salt water did it require?

Figure 6 Light ray traveling through air in bowl



Questions

1. Which medium—air, fresh water or salt water—has the highest index of refraction? Explain.

2. In this experiment, light rays reflect off the penny and travel toward the observer's eyes. Figure 6 shows a light ray traveling through air. Draw the light rays for Figure 7 and Figure 8. (Remember: the light ray bends as it breaks the surface of the water, not when it reaches the top of the bowl.)

Figure 7 Penny in fresh water

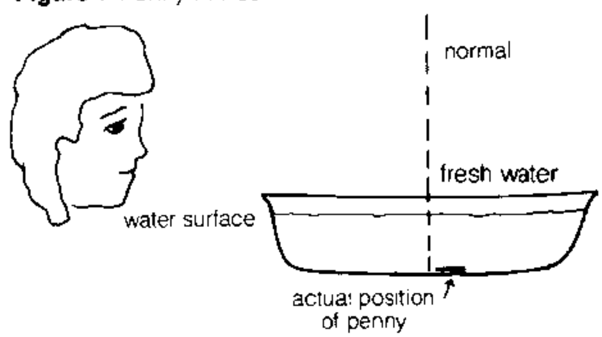
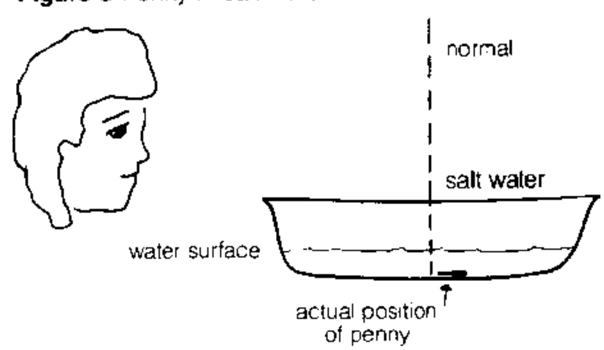


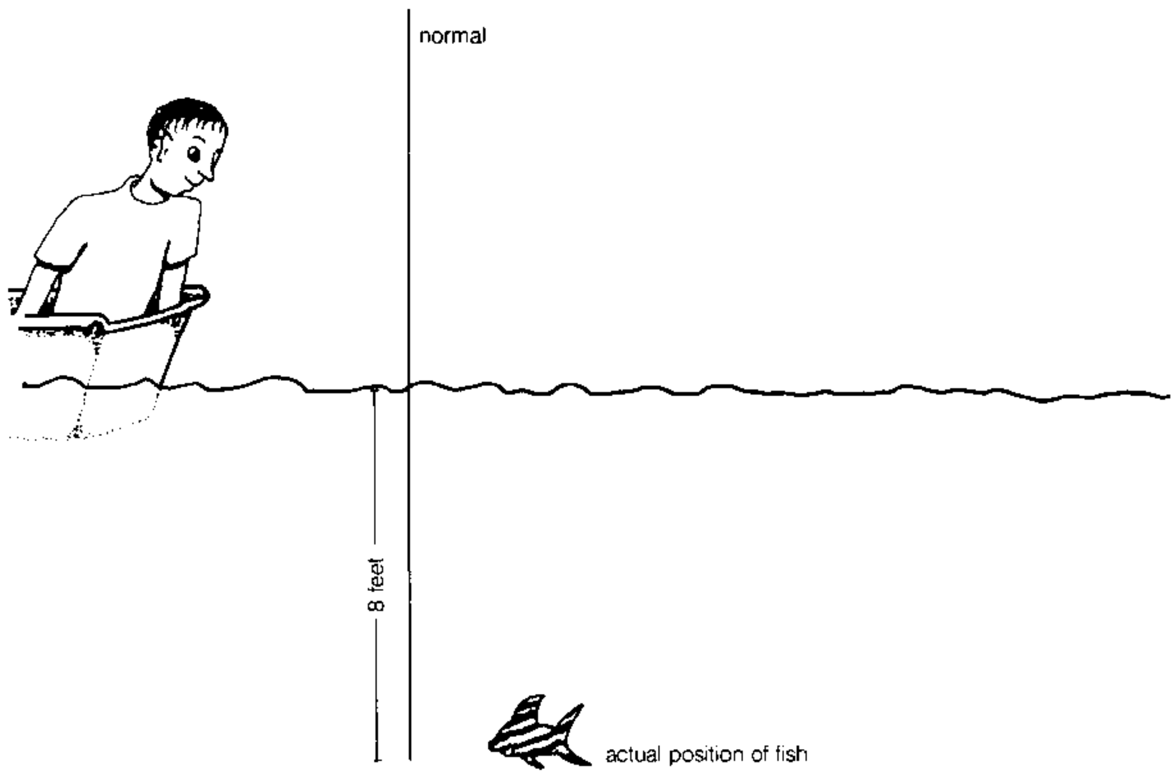
Figure 8 Penny in salt water



3. A tropical fish collector was rowing along the shore when he spotted a rare fish he wanted. The fish was swimming 8 feet below the surface of the water. Given that the angle of refraction (as the light travels from the fish to the collector's eyes) is 40 degrees, draw a ray diagram on Figure 9 below. Show the real and apparent positions of the fish.

To calculate the apparent position, first use Snell's Law to determine the angle of incidence. Then use the given angle of refraction (40 degrees) and the angle of incidence you calculated above. Hint: You will need to use basic trigonometry to solve this problem, i.e., relationships between angles.

Figure 9 Fish 8 feet below water surface



ACTIVITY 3

Absorption and Scattering

Purpose

To observe the effects of scattering and absorption on light waves in water.

Background

Many songs and stories suggest the ocean is blue. In fact, the ocean appears to be a variety of colors and hues, depending on your point of observation. From the beach, the ocean seems green or even gray. Water around a coral reef is a brilliant aquamarine, and a sunset casts a fiery red glare on the ocean's surface.

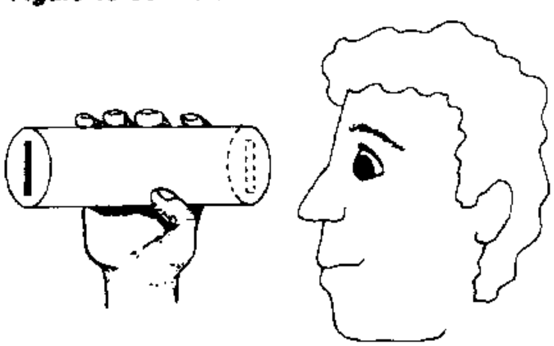
These changes in colors are related to reflection, absorption and scattering of light waves, which also affect the depth of solar light penetration, photosynthesis and the temperature of surface water.

Particles in the water, as well as plant life and animal life, absorb or scatter light as it enters the ocean. Thus, white light is separated into distinct colors. Some of these colors are absorbed, some scattered and others reflected back to the surface, creating the variations in the color of the ocean.

Materials

2 to 3 clear glass containers
flashlight
toilet paper roll
cardboard
2 to 3 pipettes or eyedroppers
milk
mud

Figure 10 Collimator



Procedure

To intensify the light source, make a collimator (Figure 10). Take your toilet paper roll and cut two pieces of cardboard into circles for end pieces Cut a vertical slit ⅛ inch wide in each of the circular ends. Glue the ends to the toilet paper roll, aligning the vertical slits.

Fill the glass containers with water. Shine the light through the containers. (Note: Place the collimator between the flashlight and the glass container. It will focus the light into a more concentrated beam.) Because tapwater contains little particulate matter, not much light will be scattered or absorbed.

Add one to two drops of milk to the container and stir well. Shine the light through the container.

Look at the water in the container from the top or from a side perpendicular to the beam of light. (You should see blue.)

Look at the water in the container from the side opposite the flashlight. (You should see red.)

Place additional glass containers behind the first to accentuate the redness.

Repeat the above procedure using mud.

Questions

1. In the above activity, what is the color of the water if you observe it from the top or side?

2. When you added mud to the glass, what is the color of water from the top, looking down and at the sides?

3. What appears to cause the color of the water? What general statement might you make about what is in the ocean water when it is blue? Green?

Competency Factors/References

Competency Indicators

Physics/Academic—

5.3 know how to investigate and describe light in a quantified manner

References

Dittman, Richard and Glenn Schmieg. 1979. *Physics in Everyday Life.* McGraw-Hill Book Company.

Ford, Kenneth W. 1973. *Classical and Modern Physics (Volumes 1 and 2).* John Wiley & Sons, Inc.

Gartenhaus, Solomon. 1977. *Physics, Basic Principles.* Holt, Rinehart and Winston.

Giancoli, Douglas C. 1985. *Physics (2nd edition),* Prentice-Hall, Inc., Englewood Cliffs, NJ.

Halliday, David and Robert Resnick. 1981. *Fundamentals of Physics (2nd edition).* John Wiley and Sons, Inc.

"Light in the Sea," *Oceans Alive.* 1990. Environmental Media, Chapel Hill, NC. (A series of 60, five-minute video programs designed to supplement life and physical science lessons.)

Project Physics. 1975. Holt, Rinehart and Winston.

Serway, Raymond A. 1982. *Physics: For Scientists and Engineers.* Saunders College Publishing.

von Baeyer, Hans C. 1984. *Rainbows, Snowflakes and Quarks.* McGraw-Hill Book Company.

Walker, Jearl. 1975. *The Flying Circus of Physics.* John Wiley and Sons, Inc.

Young, Hugh D. 1975. *Fundamentals of Waves, Optics and Modern Physics.* McGraw-Hill Book Company.

Answers

Part 1/Ocean Motion

Activity 1/Student Waves

1. Orbital waves occur in surface waters because they move in circular paths. Longitudinal waves are associated with sound. Transverse waves occur in solid materials and are associated with earthquakes.

2. An underwater earthquake tranfers a tremendous amount of energy, generating waves with large amplitudes and low frequencies [which is the equal to long periods (T)]. The power of the wave is generated from the speed.

Total Energy (TE) = PE(H) + KE (C^2)
H = height of wave; C^2 = square of the speed.
KE is very high because c is 480 to 500 mph. When waves shoal (or reach shallow water close to shore), c decreases, KE decreases, PE increases, H increases. As the wave slows in speed, the height of the wave increases—TE is the same. Finally the wave breaks according to the formula $H/L > 1/7$. H/L is a measure of wave steepness. (H = height; L = wavelength). A seismic wave becomes a wall of water perhaps 50 feet high traveling as fast as 30 mph. This is a powerful force.

Activity 2/Water Waves

1. 5 waves/2.5 sec = 2 waves/sec which is 2 HZ.

2. If 2 waves pass in 1 sec, and each wave is 2 cm long, then the distance = 4 cm

3. Celerity = 4 cm/ 1 sec = 4 cm/sec

4. Celerity = f times λ
2/sec times 2 cm = 4 cm/sec

$$\frac{5 \text{ waves}}{2.5 \text{ sec}} \times \frac{2 \text{ cm}}{\text{wave}} = \frac{10 \text{ cm}}{2.5 \text{ sec}} = 4 \text{ cm/sec}$$

Activity 3/Record-Setting Water Waves

1. a. Then λ (wavelength) = 323 m or just under 2 lengths of the ship.

b. Therefore, if the ship is placed as shown, the stern will be nearly at the bottom of the trough, and bow at the crest. The observer will look along the line of sight and line up the crow's nest with the top of the following wave. This enabled him to determine the sides and angles of the triangle using trigonmetry.
$\tan \theta = 17.5/82 = 0.213$
which means $\theta = \tan^{-1}(0.213) = 12°$

Now to find the wave height, $\sin(12°) = H/164$ m
or, $H = 164(0.209) = 34$ m.

2. PE = mgh = (9800 N/m^3) × (299,354 m^3) × (7.6 m)
PE = 2.2×10^{10} joules or 6,200 kilowatt-hrs of energy

It should be explained that the rise and fall of tides is influenced by the arrangement of land masses in a particular area and by the relative positions of the moon, Earth and sun. The French have built a working tidal power station along their Atlantic coast.

3. Amount of water mass is 1000 kg/mm^3 × 2.7 × $10^8 m^3$ = 2.7×10^{11} kg

Kinetic energy = $mv^2/2 = 5.7 \times 10^9$ joules

Since this amount of mass is being moved each second, the power of the current is 5.7×10^9 watts.

Activity 4/Snap the Whip

1. Student Three

2. Student Three

3. All the same. They each covered 360 degress when they completed one circle.

4. Plot the positions of the students on one axis, e.g. 0, 10 and 20 feet, and the distance that they traveled on the other axis.

$C_0 = 0$
$C_2 = 2\pi(10) = 62.83$ ft
$C_3 = 2\pi(20) = 125.66$ feet

Activity 5/The Coriolis Effect

1. Straight line

2. It curves to the left.

3. Answers will vary (prediction).

4. It curves to the right.

5. Answers will vary.

6. It curves to the left.

7. It curves to the right.

8. Southern Hemisphere; Northern Hemisphere

9. The ball followed a straight-line path while the surface moved.

Activity 6/Archimedes' Principle—The Tip of the Iceberg

1. $B = m_w g$	B = buoyant force
since $m_W = \rho_W V_W$	m_W = mass of water displaced
then $B = \rho_W V_w g$	ρ_w = density of water
	V_w = volume of water displaced
2. $\vec{W} = m_i g$	$\vec{W}$ = weight of iceberg
since $m_i = \rho_i V_i$	m_i = mass of iceberg
then $\vec{W} = \rho_i V_i g$	ρ_i = density of ice V_w = volume of iceberg

3. $B = \vec{W}$ (iceberg in equilibrum)

$\rho_w V_w g = \rho_i V_i g$

$\frac{V_w}{V_i} = \frac{\rho_i}{\rho_w} = \frac{0.92}{1.00} = 92$ percent below the surface

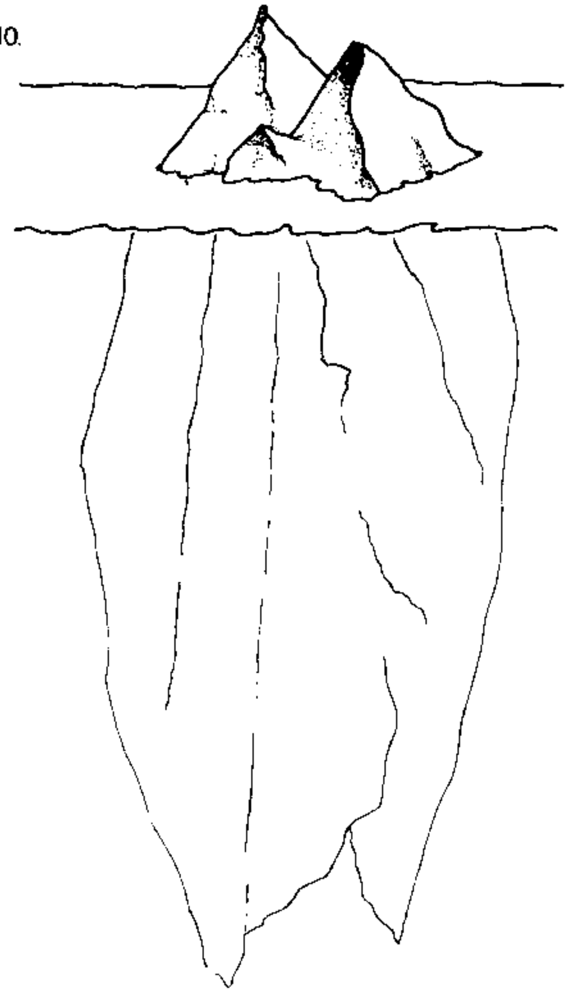
Therefore only 8 percent of the iceberg is exposed.

4. For salt water:

$\frac{V_{sw}I}{V_i} = \frac{\rho_i}{\rho_{sw}} = \frac{0.92}{1.03} = 89$ percent below the surface

Therefore 11 percent of the iceberg is exposed.

10.



Part 2/Sound

Activity 1/Sonar—Using the Speed of Sound

1. Approximately ½ second

2. Approximately ⅓ second

3. 7,020 meters

4. 2,744 meters

Part 3/Light in the Sea

Activity 1/Bending Light

1. Answers will vary.

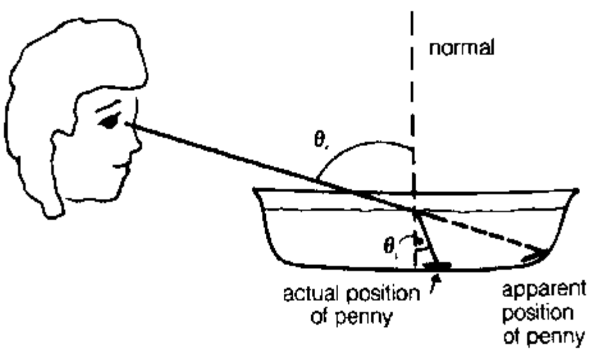
2. The density of seawater varies from one ocean to the next according to the degree of salinity.

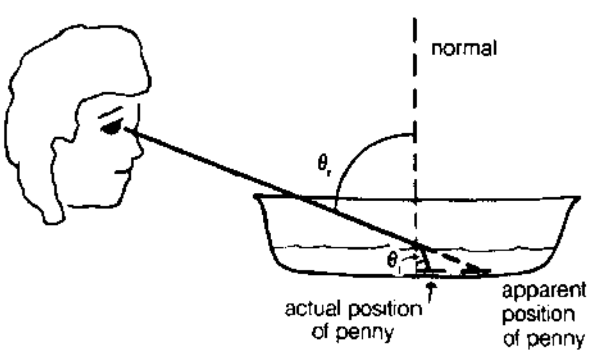
3. Light slows down and refracts toward the normal.
Light speeds up and refracts away from the normal.
Light slows down and refracts toward the normal.
Light speeds up and refracts away from the normal.

Activity 2/Now You Don't See It, Now You Do

1. Salt water because it is denser and therefore bends light more.

2. Figure 7 and 8





3. Angle of incidence

$$\frac{\sin \theta i}{\sin \theta r} = \frac{n_2}{n_1}$$

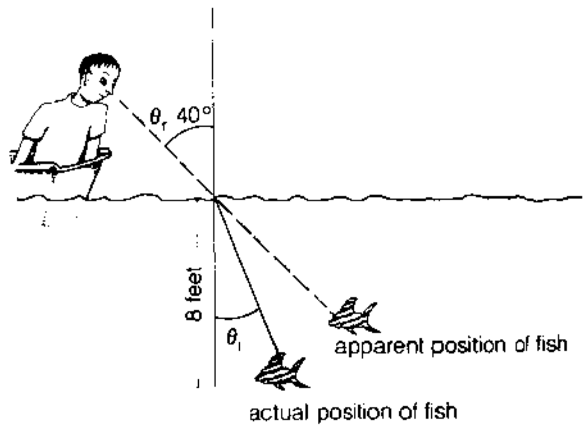
where $\theta_r = 40$ degrees
$n_1 = 1.33$ (salt water)
$n_2 = 1.00$ (air)

$$\sin \theta i = \frac{n_2}{n_1} \sin \theta_r$$

$$= \frac{1}{1.33} (\sin 40 \text{ degrees})$$

$$= 0.48$$

$\theta_i = \sin^{-1} (0.48) = 28.7°$

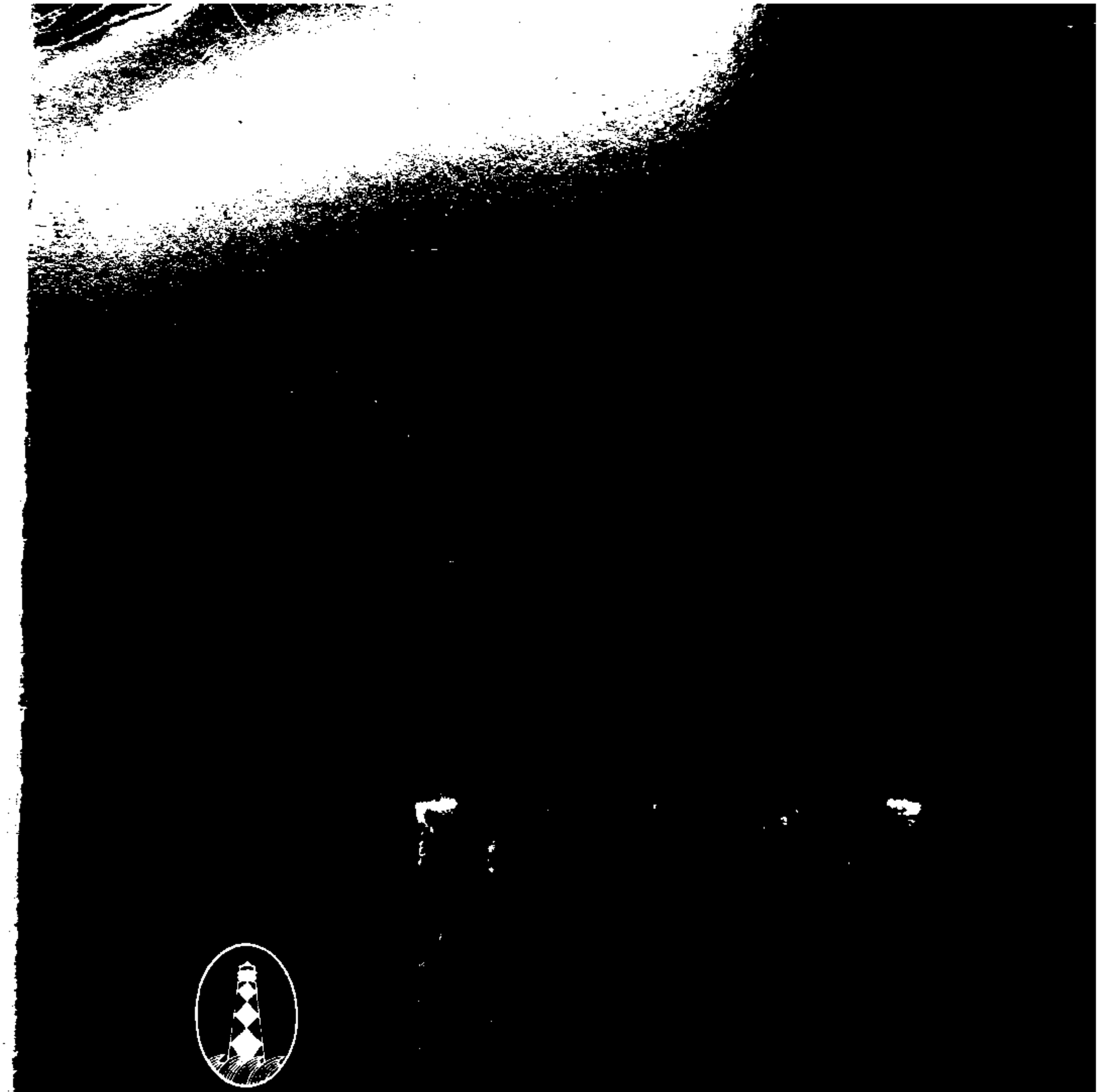


Activity 3/Absorption and Scattering

1. Blue

2. Brownish. After it settles, it gets lighter.

3. The particles in it affect the color. It has phytoplankton with chlorophyll or mud sediment.



$10

This work was sponsored by the Office of Sea Grant, NOAA, U.S. Department of Commerce under Grant No. NA86AA-D-SG046 and the state of North Carolina through the University of North Carolina. The U.S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright that may appear hereon.

For a copy of this book, write UNC Sea Grant College Program, Box 8605, North Carolina State University, Raleigh, NC 27695-8605

UNC Sea Grant Publication UNC-SG-90-01