DOCUMENT RESUME

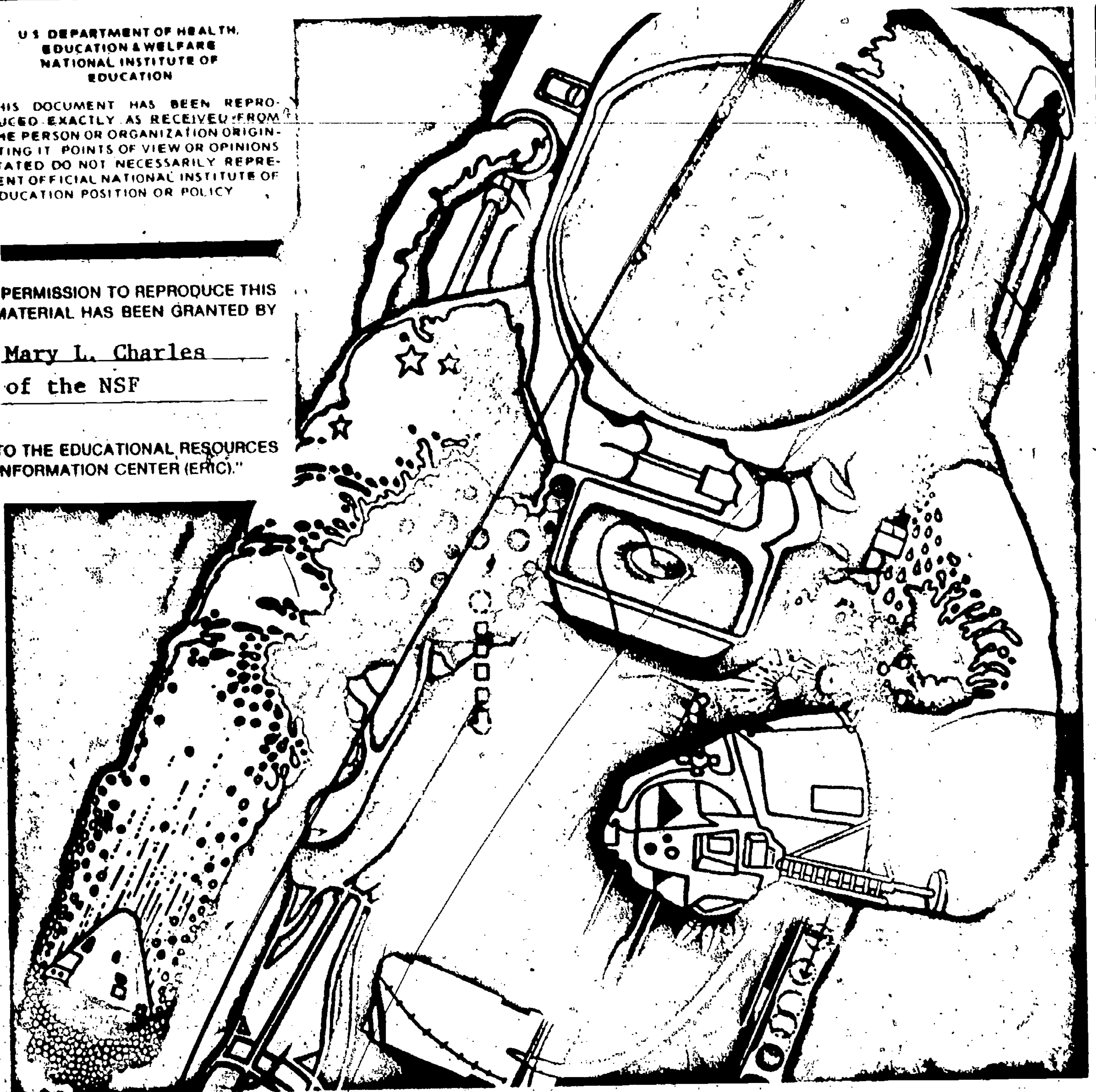
ED 190 376	SE 031 320
AUTHOR	Bonar, John R., Ed.: Hathway, James A., Ed.
TITLE	Probing the Natural World, Level III, Student Gui[illegible]: What's Up? Intermediate Science Curriculum Study.
INSTITUTION	Florida State Univ., Tallahassee. Dept. of Science Education.
SPONS AGENCY	National Science Foundation, Washington, D.C.: Office of Education (DHEW), Washington, D.C.
PUB DATE	72
NOTE	157p.: For related documents, see SE 031 300-330, ED 035 559-560, ED 049 032, and ED 052 940. Contains photographs and colored and shaded drawings and print which may not reproduce well.

EDRS PRICE	MF01/PC07 Plus Postage.
DESCRIPTORS	Grade 9: *Individualized Instruction: Instructional Materials: Junior High Schools: *Laboratory Manuals: Laboratory Procedures: *Physics: *Science Activities: Science Course Improvement Projects: Science Education: Secondary Education: Secondary School Science: *Space Sciences
IDENTIFIERS	*Intermediate Science Curriculum Study

ABSTRACT

This is the student's text of one unit of the Intermediate Science Curriculum Study (ISCS) for level III students (grade 9). The chapters contain basic information about rockets, space, and principles of physics, as well as activities related to the subject and optional excursions. A section of introductory notes to the student discusses how the class will be organized. Illustrations accompany all instructions and the students are encouraged to select the proper equipment based on the illustrations. (SA)

What's Up?



Probing the Natural World/3

2

INTERMEDIATE
SCIENCE
CURRICULUM
STUDY

THIS BOOK IS THE PROPERTY OF:

STATE ____________
PROVINCE ____________
COUNTY ____________
PARISH ____________
SCHOOL DISTRICT ____________
OTHER ____________

Book No. ________
Enter information in spaces to the left as instructed

ISSUED TO	Year Used	CONDITION	
		ISSUED	RETURNED

PUPILS to whom this textbook is issued must not write on any page or mark any part of it in any way, consumable textbooks excepted.

1. Teachers should see that the pupil's name is clearly written in ink in the spaces above in every book issued.
2. The following terms should be used in recording the condition of the book: New; Good; Fair; Poor; Bad.

INTERMEDIATE SCIENCE CURRICULUM STUDY

What's Up?

Probing the Natural World / Level III

SILVER BURDETT
GENERAL LEARNING CORPORATION
Morristown, New Jersey · Park Ridge, Ill. · Palo Alto · Dallas · Atlanta

ISCS PROGRAM

LEVEL I	**Probing the Natural World** / Volume 1 / with Teacher's Edition **Student Record Book** / Volume 1 / with Teacher's Edition **Master Set of Equipment** / Volume 1 **Test Resource Booklet**
LEVEL II	**Probing the Natural World** / Volume 2 / with Teacher's Edition **Record Book** / Volume 2 / with Teacher's Edition **Master Set of Equipment** / Volume 2 **Test Resource Booklet**
LEVEL III	**Why You're You** / with Teacher's Edition Record Book / with Teacher's Edition / **Master Set of Equipment** **Environmental Science** / with Teacher's Edition Record Book / with Teacher's Edition / **Master Set of Equipment** **Investigating Variation** / with Teacher's Edition Record Book / with Teacher's Edition / **Master Set of Equipment** **In Orbit** / with Teacher's Edition Record Book / with Teacher's Edition / **Master Set of Equipment** **What's Up?** / with Teacher's Edition Record Book / with Teacher's Edition / **Master Set of Equipment** **Crusty Problems** / with Teacher's Edition Record Book / with Teacher's Edition / **Master Set of Equipment** **Winds and Weather** / with Teacher's Edition Record Book / with Teacher's Edition / **Master Set of Equipment** **Well-Being** / with Teacher's Edition Record Book / with Teacher's Edition / **Master Set of Equipment**

ACKNOWLEDGMENTS

The work presented or reported herein was performed pursuant to a Contract with the U. S. Office of Education, Department of Health, Education, and Welfare. It was supported, also, by the National Science Foundation. However, the opinions expressed herein do not necessarily reflect the position or policy of the U. S. Office of Education or the National Science Foundation, and no official endorsement by either agency should be inferred.

ISCS STAFF

David D. Redfield, *Co-Director*
William R. Snyder, *Co-Director*
Ernest Burkman, *Steering Committee Chairman*

*Laura M. Bell, *Artist*
*John R. Bonar, *Editor*
Drennen A. Browne, *Artist*
*Harold L. Buell, *Administration*
Robert L. Cocanougher, *Art Director*
*Betsy Conlon Balzano, *Evaluation*
Stewart P. Darrow, *Field Trial-Teacher Education*
George O. Dawson, *Teacher Education*
James A. Hathway, *Editor*
*John S. Hutchinson, *Field Trial Teacher Education*
*Sally Diana Kaicher, *Art Director*
*Jane Larsen, *Art Director*
Adrian D. Lovell, *Administration*
*Audley C. McDonald, *Administration*
*W. T. Myers, *Administration*
Lynn H. Rogers, *Artist*
Stephen C. Smith, *Artist*
Lois S. Wilson, *Assistant Editor*

ISCS ADVISORY COMMITTEE

J. Myron Atkin, *University of Illinois*
Betsy Conlon Balzano, *State University of New York at Brockport*
Werner A. Baum, *University of Rhode Island*
Herman Branson, *Lincoln University*
*Martha Duncan Camp, *The Florida State University*
Clifton B. Clark, *University of North Carolina at Greensboro*
Steve Edwards, *The Florida State University*
Robert M. Gagné, *The Florida State University*
Edward Haenisch, *Wabash College*
*Michael Kasha, *The Florida State University*
Russell P. Kropp, *The Florida State University*
J. Stanley Marshall, *The Florida State University*
William V. Mayer, *University of Colorado*
Herman Parker, *University of Virginia*
Craig Sipe, *State University of New York at Albany*
*Harry Sisler, *University of Florida*
Clifford Swartz, *State University of New York at Stony Brook*
Claude A. Welch, *Macalester College*
Gates Willard, *Manhasset Junior High School, Manhasset, N.Y.*
Herbert Zim, *Science Writer, Tavernier, Florida*

* *Former member*

MATERIALS DEVELOPMENT CONTRIBUTORS

This list includes writing-conference participants and others who made significant contributions to the materials, including text and art for the experimental editions.

Janet Anderson, *Nyack, N.Y.* Gerald R. Bakker, *Earlham College.* Frank Balzano, *F.S.U.* Harald N. Bliss, *Mayville State College.* Olaf A. Boedtker, *Oregon State Univ.* Calvin E. Bohn, *F.S.U.* Earl Brakken, *Two Harbors, Minn.* Bobby R. Brown, *F.S.U.* Robert J. Callahan, Jr. *(deceased).* Brian W. Carss, *University of Illinois.* Lois H. Case, *Lombard, Ill.* Clifton B. Clark, *University of North Carolina at Greensboro.* Sara P. Craig, *F.S.U.* John D. Cunningham, *Keene State College.* David H. Dasenbrock, *F.S.U.* Doris Dasenbrock, *F.S.U.* Jeff C. Davis, *University of South Florida.* Alan D. Dawson, *Dearborn Public Schools, Mich.* George O. Dawson, *F.S.U.* Gerrit H. DeBoer, *F.S.U.* Howard E. DeCamp, *Glenn Ellyn, Ill.* James V. DeRose, *Newtown Square, Pa.* William A. Deskin, *Cornell College.* William K. Easley, *Northeast Louisiana State College.* Donald C. Edinger, *University of Arizona.* Camillo Fano, *University of Chicago Laboratory School.* Ronald A. Fisher, *Maquoketa, Iowa.* Edwin H. Flemming, *F.U.S.* Paul K. Flood, *F.S.U.* Harper W. Frantz, *Pasadena City College (Emeritus).* Earl Friesen, *San Francisco State College.* Bob Galati, *Fullerton, Calif.* J. David Gavenda, *The University of Texas.* Charles A. Gilman, *Winchester, N.H.* Robert J. Goll, *Jacksonville University.* Ralph H. Granger, Jr., *Walpole, N.H.* H. Winter Griffith, *F.S.U.* William Gunn, *Miami, Florida.* John Hart, *Xavier University.* John R. Hassard, *Georgia State University.* J. Dudley Herron, *Purdue University.* Father Francis Heyden, S.J., *Georgetown University.* Leonard Himes, *Sarasota, Florida.* Evelyn M. Hurlburt, *Montgomery Junior College.* John R. Jablonski, *Boston University.* Bert M. Johnson, *Eastern Michigan University.* Roger S. Jones, *University of Minnesota.* Leonard A. Kalal, *Colorado School of Mines.* Theodore M. Kellogg, *University of Rhode Island.* Elizabeth A. Kendzior, *University of Illinois.* F. J. King, *F.S.U.* David Klasson, *Millville, Calif.* Ken Kramer, *Wright State University.* Willian H. Long, *F.S.U.* Robert Lepper, *California State College.* Harold G. Liebherr, *Milwaukee, Wis.* William D. Larson, *College of St. Thomas.* Mable M. Lund, *Beaverton, Oregon.* H. D. Luttrell, *North Texas State University.* Maxwell Maddock, *F.S.U.* Solomon Malinsky, *Sarasota, Florida.* Eloise A. Mann, *Sarasota, Florida.* Harleen W. McAda, *University of California at Santa Barbara.* Auley A. McAuley, *Michigan State University.* E. Wesley McNair, *F.S.U.* Marilyn Miklos, *F.S.U.* Floyd V. Monaghan, *Michigan State University.* Rufus F. Morton, *Westport, Conn.* Tamson Myer, *F.S.U.* Gerald Neufeld, *F.S.U.* James Okey, *University of California.* Lawrence E. Oliver, *F.S.U.* Larry O'Rear, *Alice, Texas.* Herman Parker, *University of Virginia.* Harry A. Pearson, *Western Australia.* James E. Perham, *Randolph-Macon Woman's College.* Darrell G. Phillips, *University of Iowa.* Howard Pierce, *F.S.U.* David Poché, *F.S.U.* Charles O. Pollard, *Georgia Institute of Technology.* Glenn F. Powers, *Northeast Louisiana State College.* Ernest Gene Preston, *Louisville, Ky.* Edward Ramey, *F.S.U.* Earl R. Rich, *University of Miami.* John Schaff, *Syracuse University.* Carroll A. Scott, *Williamsburg, Iowa.* Earle S. Scott, *Ripon College.* Thomas R. Spalding, *F.S.U.* Michael E. Stuart, *University of Texas.* Sister Agnes Joseph Sun, *Marygrove College.* Clifford Swartz, *State University of New York.* Thomas Teates, *F.S.U.* Bill W. Tillery, *University of Wyoming.* Ronald Townsend, *University of Iowa.* Mordecai Treblow, *Bloomsburg State College.* Henry J. Triezenberg, *National Union of Christian Schools.* Paul A. Vestal, *Rollins College.* Robert L. Vickery, *Western Australia.* Frederick B. Voight, *F.S.U.* Claude A. Welch, *Macalester College.* Paul Westmeyer, *F.S.U.* Earl Williams, *University of Tampa.* G. R. Wilson, Jr., *University of South Alabama.* Harry K. Wong, *Atherton, California.* Charles M. Woolheater, *F.S.U.* Jay A. Young, *King's College.* Victor J. Young, *Queensborough Community College.*

The genesis of some of the ISCS material stems from a summer writing conference in 1964. The participants were:

Frances Abbott, *Miami-Dade Junior College.* Ronald Atwood, *University of Kentucky.* George Assousa, *Carnegie Institute.* Colin H. Barrow, *University of West Indies.* Peggy Bamzel, *F.S.U.* Robert Binger (deceased). Donald Bucklin, *University of Wisconsin.* Martha Duncan Camp, *F.S.U.* Roy Campbell, *Broward County Board of Public Instruction, Fla.* Bruce E. Cleare, *Tallahassee Junior College.* Ann-cile Hall, *Pensacola, Florida.* Charles Holcolmb, *Mississippi State College.* Robert Kemman, *Mt. Prospect, Ill.* Gregory O'Berry, *Coral Gables, Florida.* Elra Palmer, *Baltimore.* James Van Pierce, *Indiana University Southeast.* Guenter Schwarz, *F.S.U.* James E. Smeland, *F.S.U.* C. Richard Tillis, *Pine Jog Nature Center, Florida.* Peggy Wiegand, *Emory University.* Elizabeth Woodward, *Augusta College.* John Woolever, *Sarasota, Florida.*

Foreword

A pupil's experiences between the ages of 11 and 16 probably shape his ultimate view of science and of the natural world. During these years most youngsters become more adept at thinking conceptually. Since concepts are at the heart of science, this is the age at which most students first gain the ability to study science in a really organized way. Here, too, the commitment for or against science as an interest or a vocation is often made.

Paradoxically, the students at this critical age have been the ones least affected by the recent effort to produce new science instructional materials. Despite a number of commendable efforts to improve the situation, the middle years stand today as a comparatively weak link in science education between the rapidly changing elementary curriculum and the recently revitalized high school science courses. This volume and its accompanying materials represent one attempt to provide a sound approach to instruction for this relatively uncharted level.

At the outset the organizers of the ISCS Project decided that it would be shortsighted and unwise to try to fill the gap in middle school science education by simply writing another textbook. We chose instead to challenge some of the most firmly established concepts about how to teach and just what science material can and should be taught to adolescents. The ISCS staff have tended to mistrust what authorities believe about schools, teachers, children, and teaching until we have had the chance to test these assumptions in actual classrooms with real children. As conflicts have arisen, our policy has been to rely more upon what we saw happening in the schools than upon what authorities said could or would happen. It is largely because of this policy that the ISCS materials represent a substantial departure from the norm.

The primary difference between the ISCS program and more conventional approaches is the fact that it allows each student to travel at his own pace, and it permits the scope and sequence of instruction to vary with his interests, abilities, and background. The ISCS writers have systematically tried to give the student more of a role in deciding what he should study next and how soon he should study it. When the materials are used as intended, the ISCS teacher serves more as a "task easer" than a "task master." It is his job to help the student answer the questions that arise from his own study rather than to try to anticipate and package what the student needs to know.

There is nothing radically new in the ISCS approach to instruction. Outstanding teachers from Socrates to Mark Hopkins have stressed the need to personalize education. ISCS has tried to do something more than pay lip service to this goal. ISCS' major contribution has been to design a system whereby an average teacher, operating under normal constraints, in an ordinary classroom with ordinary children, can indeed give maximum attention to each student's progress.

The development of the ISCS material has been a group effort from the outset. It began in 1962, when outstanding educators met to decide what might be done to improve middle-grade science teaching. The recommendations of these conferences were converted into a tentative plan for a set of instructional materials by a small group of Florida State University faculty members. Small-scale writing sessions conducted on the Florida State campus during 1964 and 1965 resulted in pilot curriculum materials that were tested in selected Florida schools during the 1965–66 school year. All this preliminary work was supported by funds generously provided by The Florida State University.

In June of 1966, financial support was provided by the United States Office of Education, and the preliminary effort was formalized into the ISCS Project. Later, the National Science Foundation made several additional grants in support of the ISCS effort.

The first draft of these materials was produced in 1968, during a summer writing conference. The conferees were scientists, science educators, and junior high school teachers drawn from all over the United States. The original materials have been revised three times prior to their publication in this volume. More than 150 writers have contributed to the materials, and more than 180,000 children, in 46 states, have been involved in their field testing.

We sincerely hope that the teachers and students who will use this material will find that the great amount of time, money, and effort that has gone into its development has been worthwhile.

Tallahassee, Florida
February 1972

The Directors
INTERMEDIATE SCIENCE CURRICULUM STUDY

Contents

Notes to the Student

The word *science* means a lot of things. All of the meanings are "right," but none are complete. *Science* is many things and is hard to describe in a few words.

We wrote this book to help you understand what science is and what scientists do. We have chosen to show you these things instead of describing them with words. The book describes a series of things for you to do and think about. We hope that what you do will help you learn a good deal about nature and that you will get a feel for how scientists tackle problems.

How is this book different from other textbooks?

This book is probably not like your other textbooks. To make any sense out of it, you must work with objects and substances. You should do the things described, think about them, and then answer any questions asked. Be sure you answer each question as you come to it.

The questions in the book are very important. They are asked for three reasons:

1. To help you to think through what you see and do.
2. To let you know whether or not you understand what you've done.
3. To give you a record of what you have done so that you can use it for review.

How will your class be organized?

Your science class will probably be quite different from your other classes. This book will let you start work with less help than usual from your teacher. You should begin each day's work where you left off the day before. Any equipment and supplies needed will be waiting for you.

Your teacher will not read to you or tell you the things that you are to learn. Instead, he will help you and your classmates individually.

Try to work ahead on your own. If you have trouble, first try to solve the problem for yourself. Don't ask your teacher for help until you really need it. Do not expect him to give you the answers to the questions in the book. Your teacher will try to help you find where and how you went wrong, but he will not do your work for you.

After a few days, some of your classmates will be ahead of you and others will not be as far along. This is the way the course is supposed to work. Remember, though, that there will be no prizes for finishing first. Work at whatever speed is best for you. *But be sure you understand what you have done before moving on.*

Excursions are mentioned at several places. These special activities are found at the back of the book. You may stop and do any excursion that looks interesting or any that you feel will help you. (Some excursions will help you do some of the activities in this book.) Sometimes, your teacher may ask you to do an excursion.

What am I expected to learn?

During the year, you will work very much as a scientist does. You should learn a lot of worthwhile information. More important, we hope that you will learn how to ask and answer questions about nature. *Keep in mind that learning how to find answers to questions is just as valuable as learning the answers themselves.*

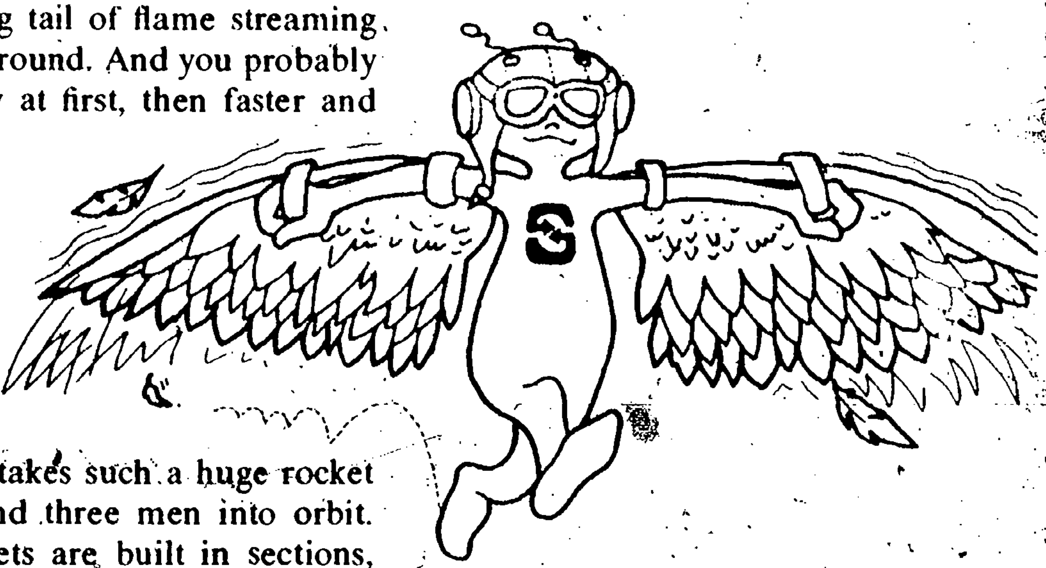
Keep the big picture in mind, too. Each chapter builds on ideas already dealt with. These ideas add up to some of the simple but powerful concepts that are so important in science. If you are given a Student Record Book, do all your writing in it. *Do not write in this book.* Use your Record Book for making graphs, tables, and diagrams, too.

From time to time you may notice that your classmates have not always given the same answers that you did. This is no cause for worry. There are many right answers to some of the questions. And in some cases you may not be able to answer the questions. As a matter of fact, no one knows the answers to some of them. This may seem disappointing to you at first, but you will soon realize that there is much that science does not know. In this course, you will learn some of the things we don't know as well as what is known. Good luck!

Up, Up, and Away

Chapter 1

Most Americans have watched on television as rockets are launched into space from Cape Kennedy. You may have been fortunate enough to have been there yourself—seeing, hearing, and feeling the blast-off. Whether viewing it in person or on TV, you saw the long tail of flame streaming out behind the rocket as it left the ground. And you probably noticed that the rocket rose slowly at first, then faster and faster. Do you know why?



Maybe you've wondered why it takes such a huge rocket to get a rather small spacecraft and three men into orbit. You probably know that the rockets are built in sections, called *stages*. One stage after another is discarded as the rocket pushes the spacecraft into orbit. Do you know why? Perhaps you've heard that a rocket engine works better out in space than it does in the earth's atmosphere. Is this really true?

To find the answers to questions such as those, you need some firsthand experience. First, you will launch a rocket to see what it takes to get it up. You and two other students will make up a launch team. Your team of three students should get the following equipment:

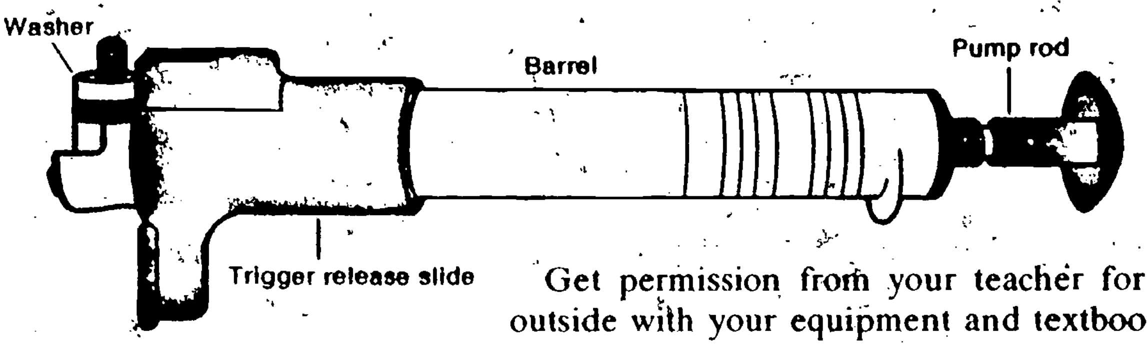
1 plastic water rocket, with pump and filler funnel
1 5-liter bucket, half full of water
1 100-ml calibrated beaker
1 meterstick

1

Before launching the rocket, read the following operating instructions carefully. Also, look back at them from time to time to be sure you are observing them. The rocket is breakable and should be handled carefully.

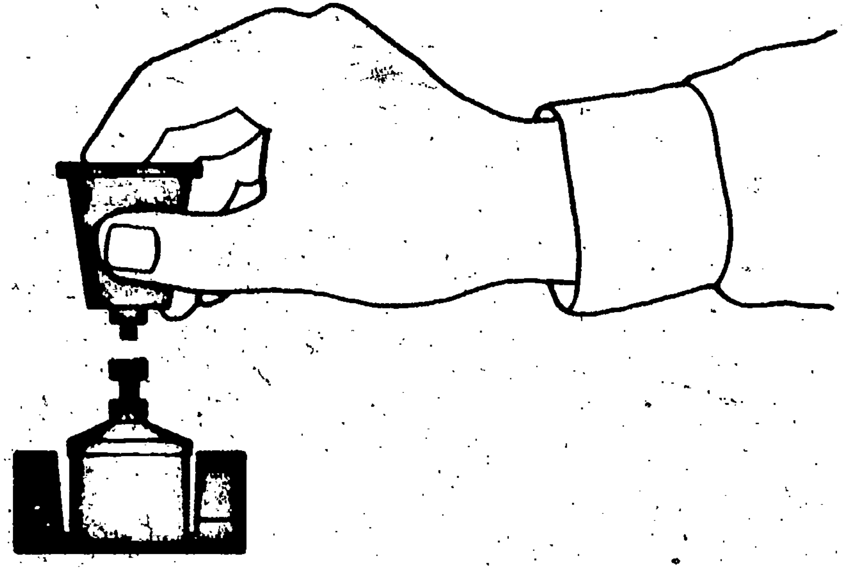
1. Use clean water in the rocket.
2. Keep all parts free of dirt and sand.
3. Apply oil or grease occasionally to the trigger release slide, barrel, and washer.
4. Keep the pump rod oiled with any fine machine oil.
5. Use cold water in the rocket. (Hot water could ruin the rocket.)
6. Avoid pumping more than 20 strokes into the rocket.

Figure 1-1

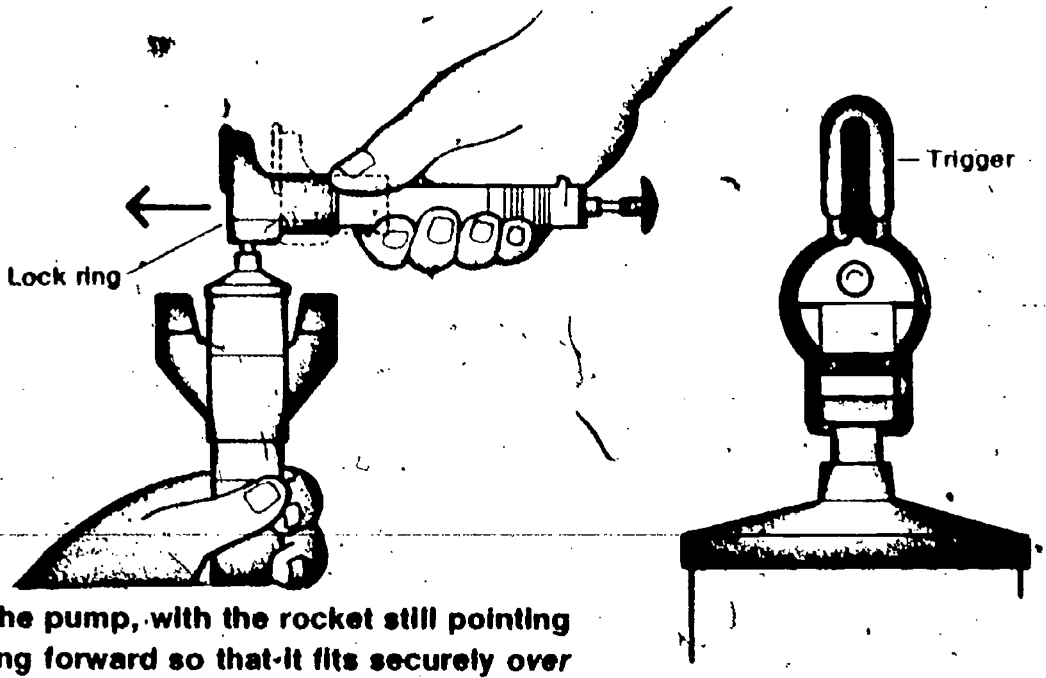


Get permission from your teacher for your team to go outside with your equipment and textbook.

Safety Note *You will need to go to a clear area away from buildings, trees, and wires. Try to find a spot about 100 feet from trees and structures.* **Do not point the rocket at people or windows, and don't lean over it yourself.**

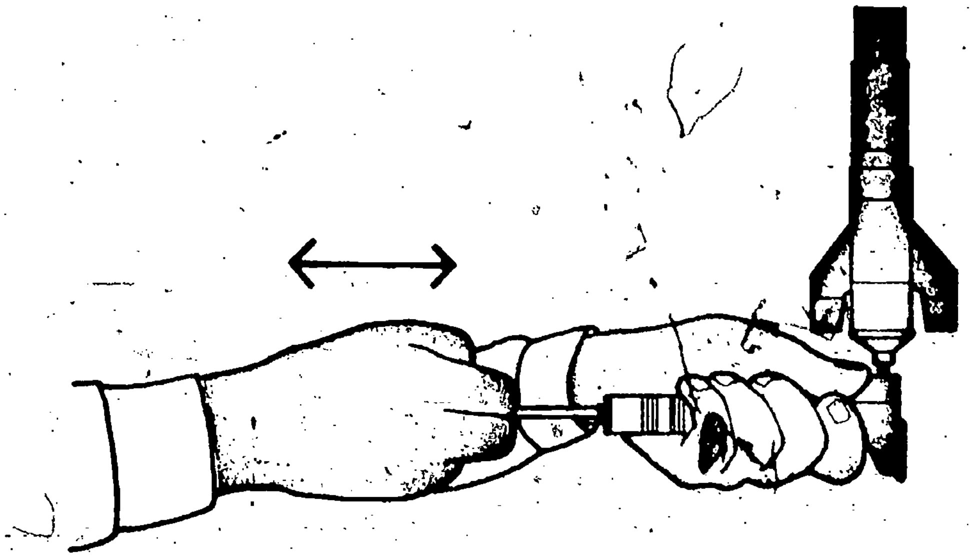


ACTIVITY 1-1. Insert the funnel. Pour in 50 ml of tap water, bringing the level to point A on the diagram. Remove the funnel.

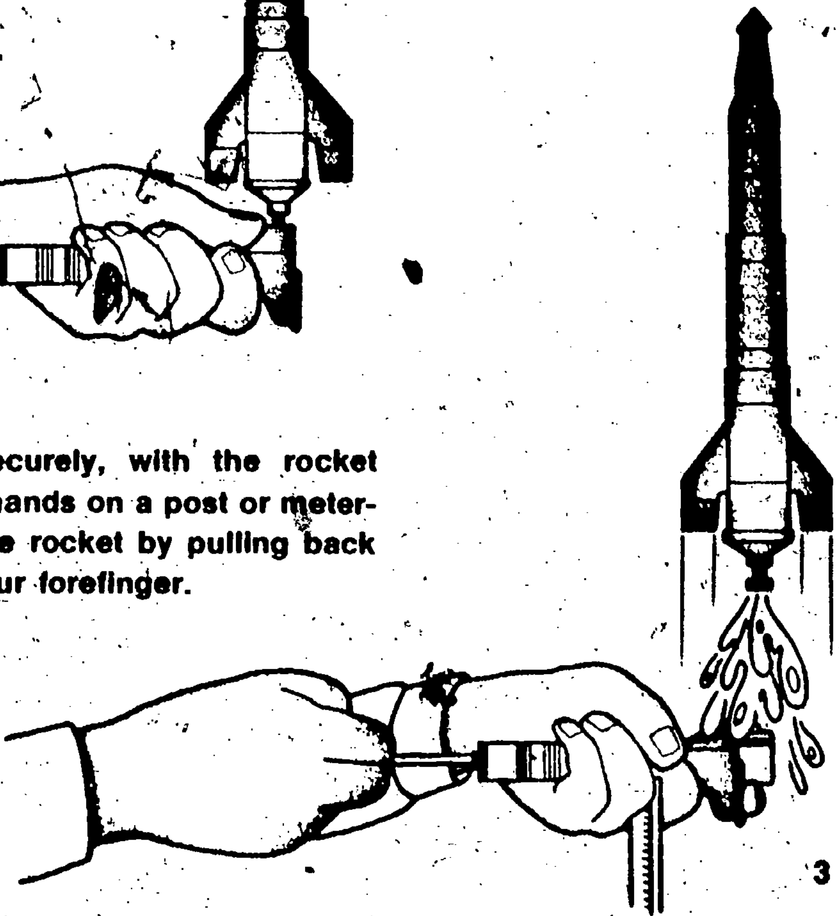


ACTIVITY 1-2. Attach the pump, with the rocket still pointing down. Push the lock ring forward so that it fits securely *over* the flanged end of the rocket, not just around it.

ACTIVITY 1-3. Turn the rocket skyward. Pump exactly 15 strokes. Ask the other team members to stand back.



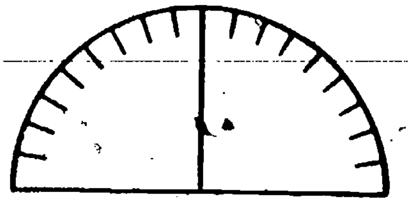
ACTIVITY 1-4. Hold the pump securely, with the rocket pointing straight up. Support your hands on a post or meterstick. When all is clear, release the rocket by pulling back on the trigger release slide with your forefinger.



The launch was successful if the rocket moved almost straight up. Was your launch a success? If not, repeat Activities 1-1 through 1-4.

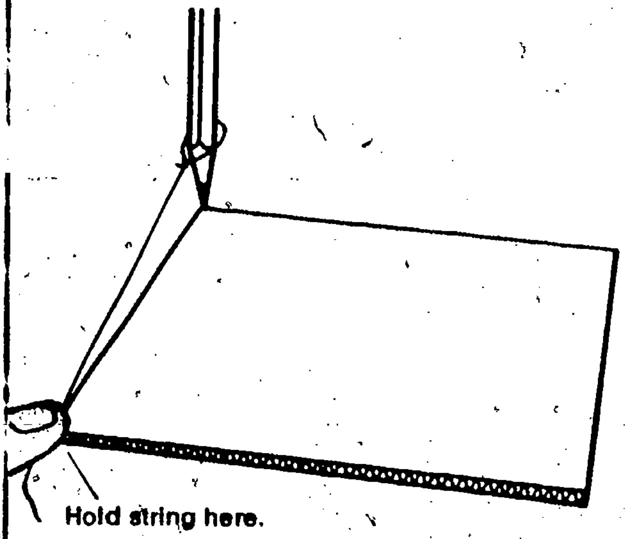
Once you have mastered getting a good launch, you are ready to begin your investigation of rocketry. You will try to find out what effect certain variables have on how high your rocket goes. To accomplish this, you need to be able to measure the launch height.

You and your partners should return to the classroom, where you will make a height-measuring instrument. Your team will need the following:



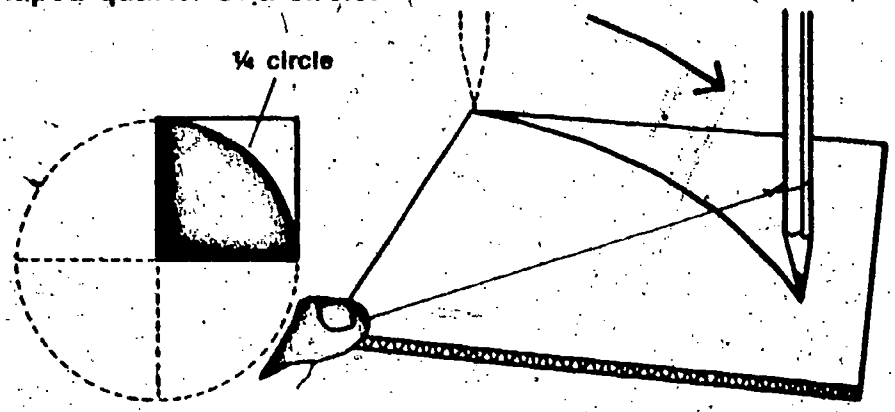
- 1 piece of string, 40 cm long
- 3 square pieces of cardboard, each at least 25 cm on an edge
- 1 pencil
- 1 pair of scissors
- 1 protractor
- 1 ruler

Continue to work with your partners, sharing the equipment as necessary. Each member of the team should make his own height measurer from his piece of cardboard.

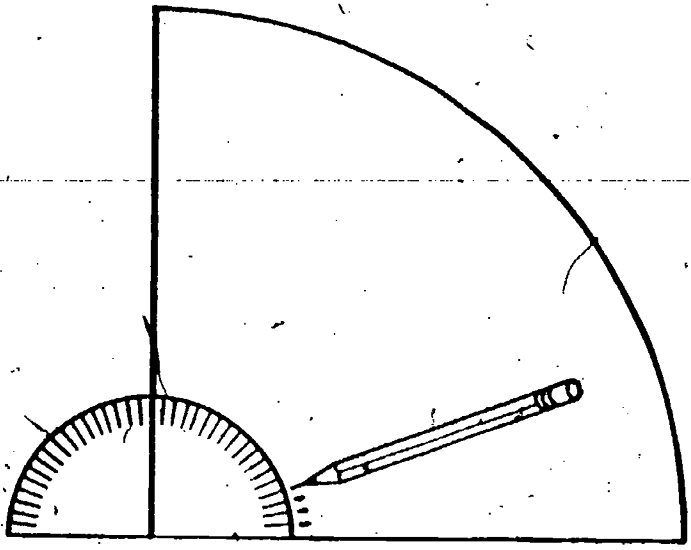


ACTIVITY 1-5. Tie a small loop in one end of the string. Slip the point of your pencil through the loop. Hold the pencil at one corner of the cardboard and stretch the string to the other corner; hold it securely with your thumb.

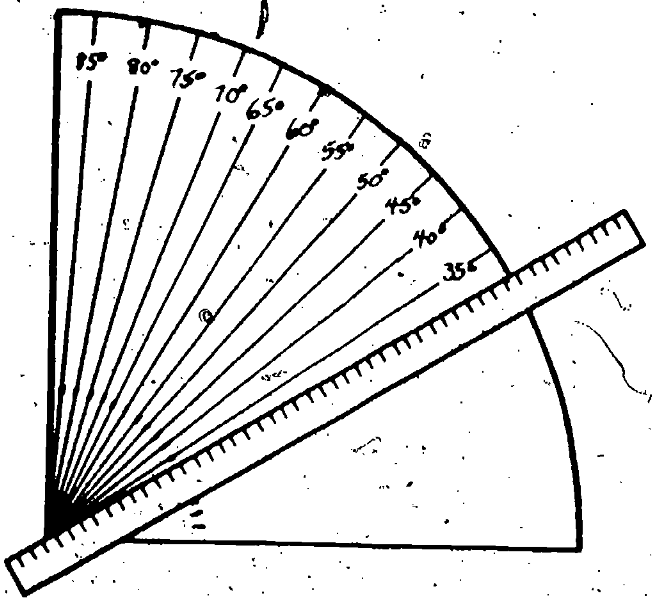
ACTIVITY 1-6. Swing an arc with your pencil, letting it make a curve from corner to corner of the cardboard square. If the cardboard tends to slide, ask a partner to hold it securely as you draw. With the scissors, cut along the arc to get a pie-shaped quarter of a circle.



ACTIVITY 1-7. Place the protractor on your quarter-circle as shown. Starting at 0 degrees on your protractor, make a pencil mark on your cardboard every 5 degrees. Make your work as neat as you can. Your pencil must be sharp and the marks accurate.



ACTIVITY 1-8. Use a ruler or a straightedge to draw straight lines from the right-angle corner through each mark to the curved edge. Label the number of degrees on each line as shown.



The instrument you have constructed is called a *quadrant* because it is made from one fourth of a circle. Early mariners used simple wooden quadrants to measure the altitude angle of stars.

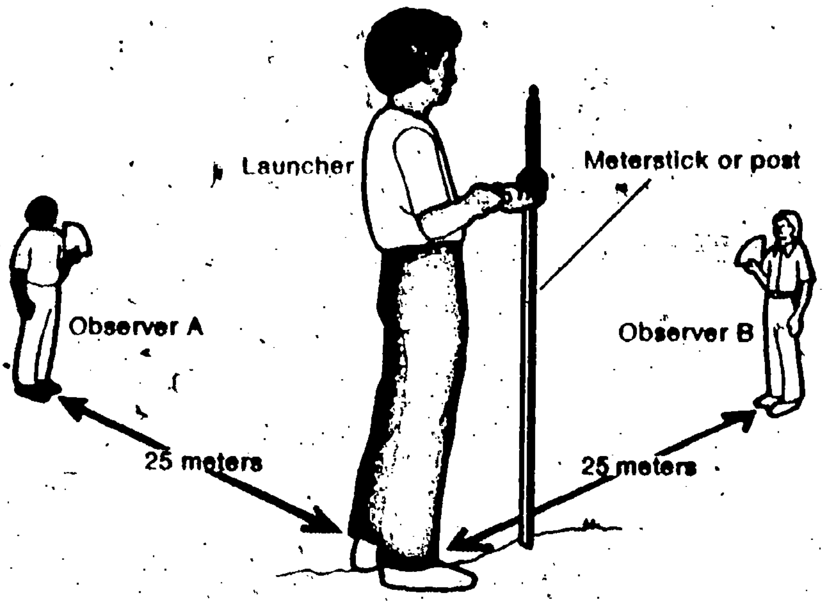
Now you are ready to collect data on your rocket launch. Your team will need your teacher's permission to go outside, as well as the following equipment:

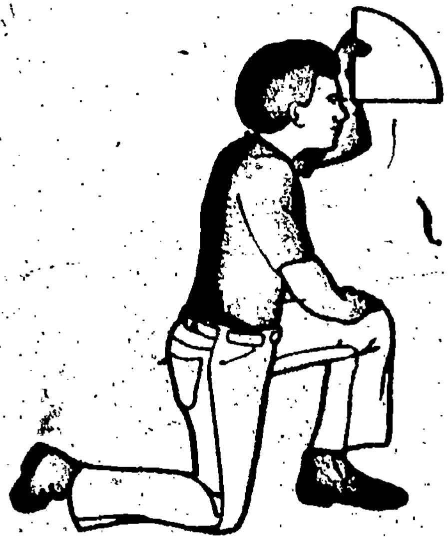
3 cardboard quadrants
1 plastic water rocket, with pump and filler funnel
1 5-liter bucket, half full of cold, clean water
1 100-ml calibrated beaker
1 meterstick

Once again, take your equipment to an open area away from buildings, trees, and wires. Two members of your team will act as observers while the third member launches the rocket.

Before launch, each observer may want to practice sighting on some stationary objects.

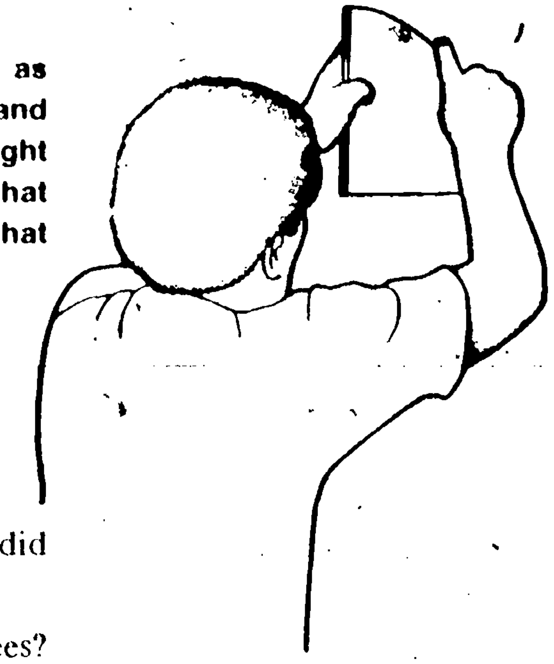
ACTIVITY 1-9. When ready to launch, select a good site. Each observer should be 25 meters from that spot in different directions.





ACTIVITY 1-10. Observers should hold the quadrants on edge with the center point at eye level. Crouch down if necessary, so that the bottom of the quadrant is about the same distance above the ground as the rocket. Sight along the bottom edge directly at the bottom of the rocket. Then the launcher should repeat the launch procedure given in Activity 1-4. If enough metersticks are available, you may want to rest the quadrant on one to steady it.

ACTIVITY 1-11. Hold the quadrant steady with one hand as the rocket is launched. Move the first finger of the other hand along the edge of the quadrant, following the rocket's flight until it reaches the highest altitude. Keep your finger at that point until you can read the number of degrees. Record that number.



☐**1-1.** What angle did Observer A get? What angle did Observer B get?

☐**1-2.** Did each observer get the same number of degrees?

☐**1-3.** If your answer to question number 2 was No, what reasons can you give for the difference?

If you have time, you may want to repeat Activities 1-10 and 1-11 to check your results. You may want to take turns launching so that each member of your team gets to use his quadrant.

Using Table 1-1, an observer 25 meters away from the launch site can find out how high the rocket went. The height in meters appears directly below his last observed angle.

Table 1-1

Height Converter for Observer at 25 Meters

Angle	0°	5°	10°	15°	20°	25°	30°	35°	40°
Height	0 m	2.2 m	4.4 m	6.9 m	9.1 m	11.7 m	14.4 m	17.5 m	21.0 m
Angle	45°	50°	55°	60°	65°	70°	75°	80°	85°
Height	25.0 m	29.8 m	35.7 m	43.3 m	53.6 m	68.7 m	93.3 m	141.8 m	285.8 m

☐**1-4.** What height corresponds to the angle measured by Observer A?

☐**1-5.** What height corresponds to the angle measured by Observer B?

☐**1-6.** What is the average of the two heights?

If you were able to get the rocket to go nearly straight up and if the observers measured about the same angles, consider your launch a success.

Now back to the question you need to answer: What variables affect how high the rocket goes? To express it another way: What thing or things can be changed to make the rocket go higher?

From time to time in this unit, you will be asked to do "problem breaks." These are problems for you to solve, without much help from your book or from your teacher. The problems will usually help you understand what you are studying in the chapter. But that's not their major purpose. They are designed to give you practice in problem solving and in setting up your own experiments. You should try every problem break—even the tough ones. And in most cases you should have your teacher approve your plan before trying it. The first problem break in this unit is coming up next.

PROBLEM BREAK 1-1

The water that was forced out of the rocket must have had something to do with the rocket's going up. The air that was forced into the rocket must also have been important. These two factors should be investigated to determine their effect on the height that the rocket reaches. Design an experiment that will allow you to measure the effect of these two variables. You will probably want to use several different amounts of water (measured in milliliters) and air (measured by the number of pump strokes). However, investigate only one of the variables at a time. Control (keep constant) all other variables.

Try to find two other people to work with as a team. Outline your procedure in your Record Book. Describe in a few words what you plan to do and what you expect to happen. Then get your teacher's permission to try your experiments. Record your data carefully. Be sure to use two observers to measure the height the rocket reaches. This height is a measure of performance of the rocket. Follow the steps for rocket launching in Activities 1-1 through 1-4.

Caution *In working with the variable of amount of air, don't over-pump the rocket. Twenty strokes is the suggested maximum.*

☐**1-7.** Describe how increasing the amount of water affects the height reached by the rocket.

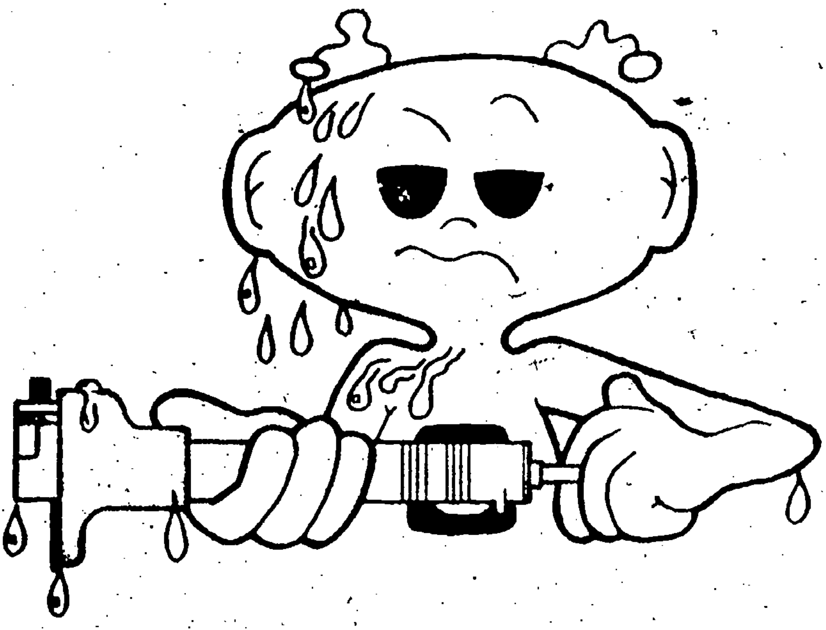
☐**1-8.** Describe how changing the amount of air affects the height reached by the rocket.

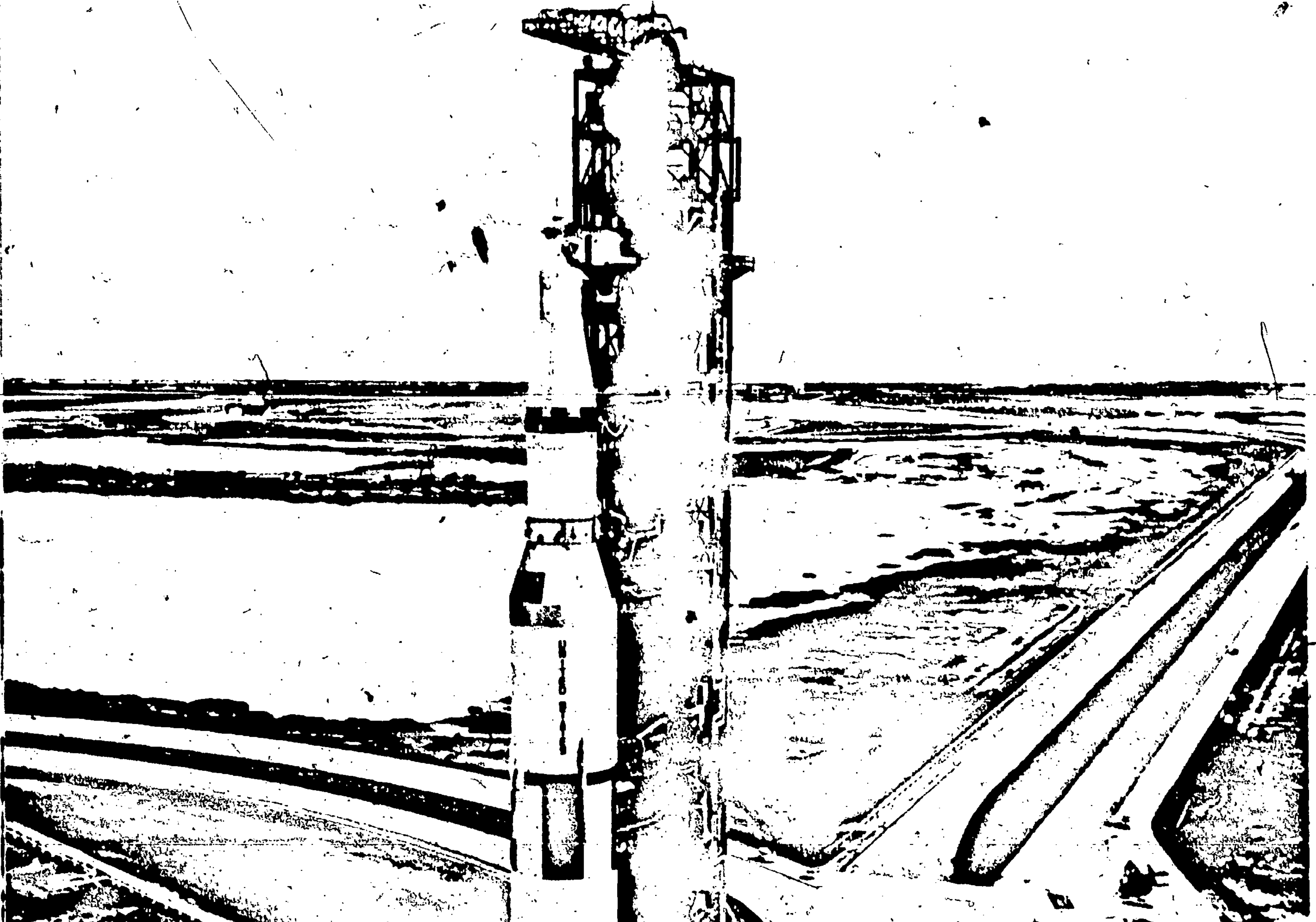
In Problem Break 1-1, you have learned what effect two variables can have on how high the rocket goes. But you may still wonder why these variables cause the rocket to go up at all. Just why should water and air make it rise? Something about the combination of these variables influences the rocket by giving it a push upward.

☐**1-9.** Perhaps you would like to give your own ideas on how air under pressure and water cause an upward push on the rocket. There is a space provided in your Record Book.

To check your ideas, you will continue to investigate the upward push in the next two chapters.

Before going on, do Self Evaluation 1 in your Record Book.




USA
USA

What a Reaction!

Chapter 2

A Saturn-Apollo rocket is a very large object. It stands more than 100 meters tall—more than the length of a football field—and has a base about 10 meters in diameter. When fueled, it weighs 3,000 tons—as much as 24 diesel-electric freight locomotives.

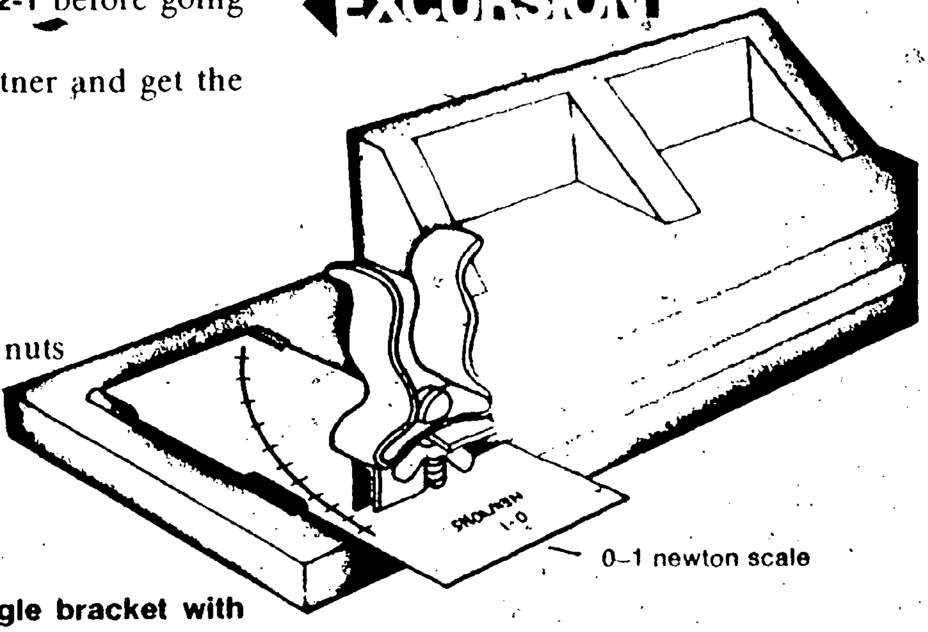
Yet when the tail of flame shoots out of the base, one of these rockets lifts noisily off the pad and heads into the sky. How is this immense machine able to get off the ground? Where does all the upward push come from? To get started in answering this question, you need to look at a very much smaller and simpler push.

A push is a force. So is a pull. You will be working with such forces throughout much of this unit. Therefore, you'd better know how to measure them. Perhaps you already do. In fact you may have used a special force-measuring device in Volume 1 of ISCS. If not, do **Excursion 2-1** before going ahead in this chapter.

EXCURSION

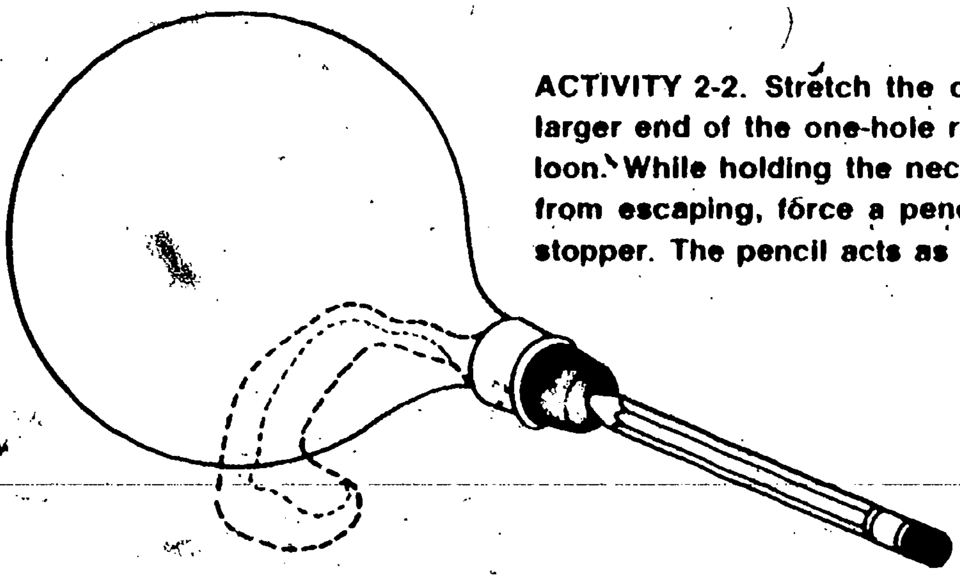
Now back to that small push. Find a partner and get the following equipment:

- 1 balloon
- 1 one-hole stopper (#1)
- 1 force measurer, with thin blade
- 1 0–1 newton scale
- 1 angle bracket, with 2 bolts and 2 wing nuts
- 1 clamp



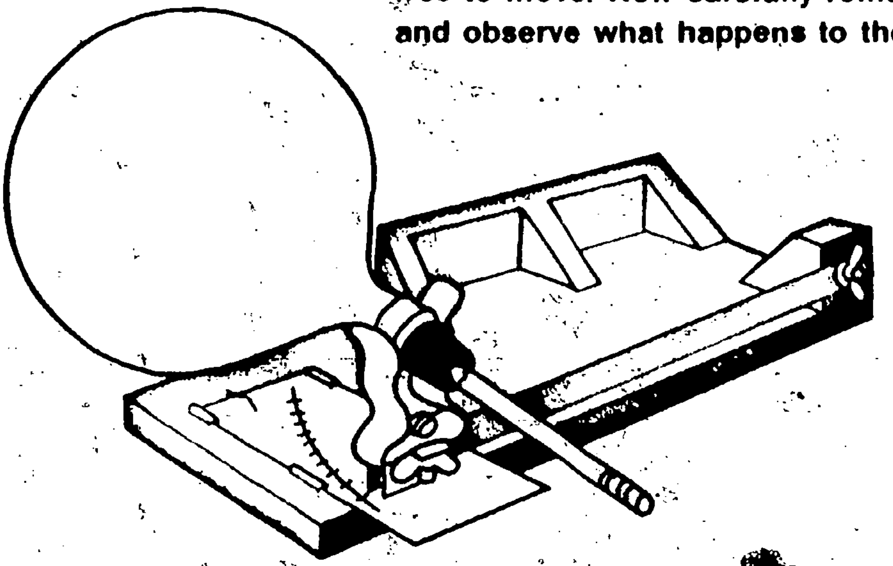
0–1 newton scale

ACTIVITY 2-1. Fasten the clamp on the angle bracket with bolt and wing nut. Using the remaining nut and bolt, attach the angle bracket to the end of the force-measurer blade. Be sure to use the thin blade and the 0–1 newton scale.



ACTIVITY 2-2. Stretch the opening of the balloon over the larger end of the one-hole rubber stopper. Blow up the balloon. While holding the neck of the balloon to keep the air from escaping, force a pencil securely into the hole in the stopper. The pencil acts as a plug.

ACTIVITY 2-3. Slide the stopper into the clamp on the force measurer. Zero the 0–1 N scale. Although the balloon may rest on the force measurer or the table, the blade must be free to move. Now carefully remove the pencil by twisting it and observe what happens to the blade as the air escapes.



☐**2-1.** Does the force measurer indicate that a force is acting when the pencil is in the stopper?

☐**2-2.** Does the force measurer indicate that a force is acting when the pencil is removed?

Repeat Activities 2-2 and 2-3 and try to measure any change you observe.

☐**2-3.** Was the direction of the force acting on the blade the same as, or opposite to, the direction of the air as it rushed out?

☐**2-4.** How much force was acting?

Figures 2-1 through 2-3 may help to explain what you observed. With the balloon inflated, the air inside exerts the same force in all directions. This force is called its *pressure*. The air pushes outward against the sides of the balloon and against the end of the pencil that closes the hole in the stopper. Only eight force arrows are shown in the diagram, but actually they can be considered to be countless. Since equal forces act in all directions, the forces are in balance. Thus, the balloon does not move. Its sides are merely pushed outward against the outside air, which pushes back.

When the pencil is removed from the stopper, air rushes out. The air within the balloon continues to push on the inside of the balloon in all directions. At the outlet, however, there is no balloon to push on. With the force still pushing on the inside of the balloon at the point opposite the outlet, you have an *unbalanced* force condition. This *unbalanced* force causes the balloon to move, pulling the force-measurer blade in that direction.

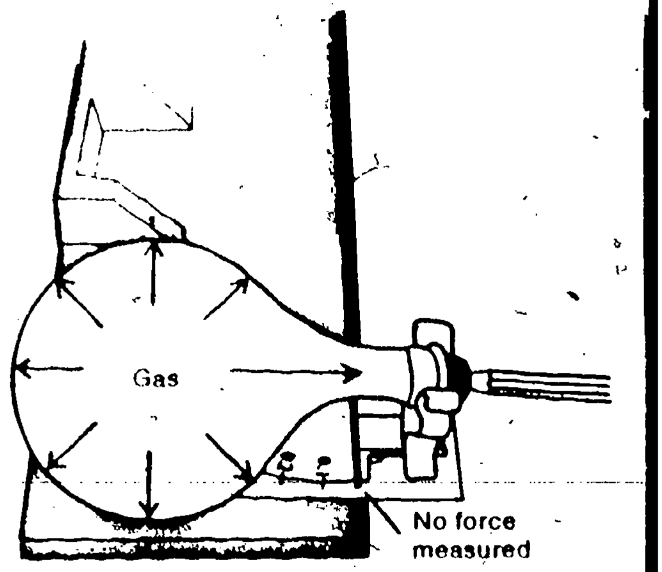


Figure 2-1

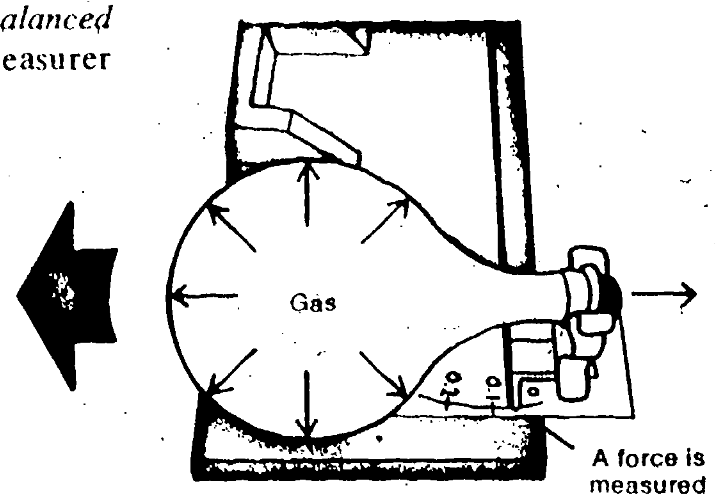


Figure 2-2

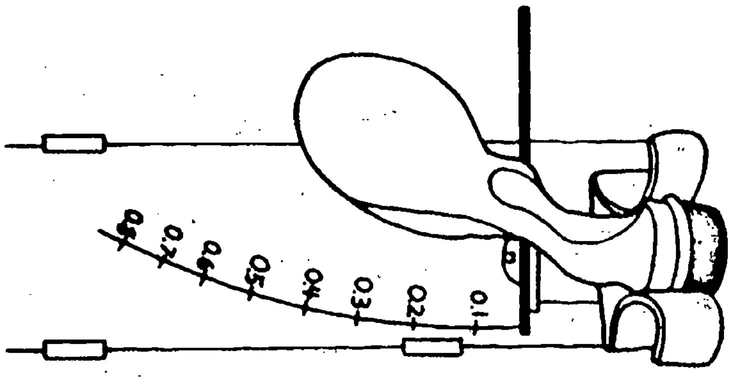


Figure 2-3

No force measured

As the air continues to rush out, the pressure (forces) inside the balloon gets smaller. Eventually, it drops to zero. With no force inside the balloon, the walls collapse and movement stops. The blade then returns to zero.

How does this idea of pressure on the inside and unbalanced force apply to your water rocket?

☐**2-5.** Suppose the rocket has been loaded, has been pumped with air, and is ready for launch. Are the inside forces in balance?

☐**2-6.** When the trigger release slide is pulled, the water rocket rises into the air. What unbalanced force acting on the water rocket causes it to move?

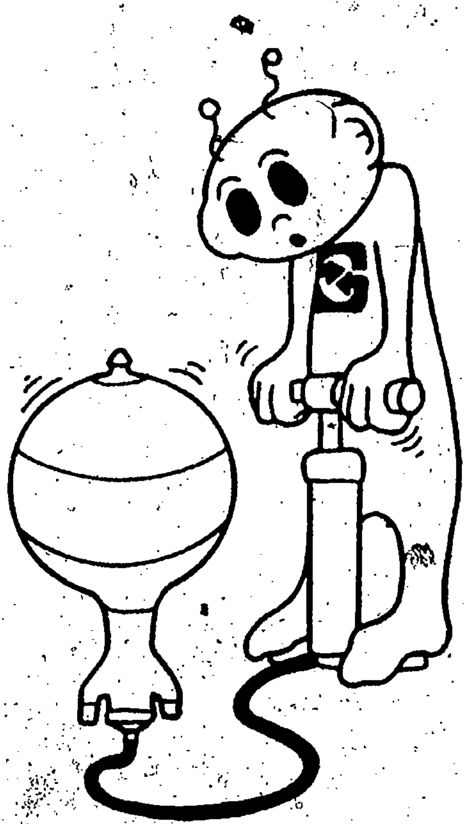
☐**2-7.** What could you do to increase this unbalanced force?

If you had trouble with the last two or three questions, think back to Problem Break 1-1. You tried to find out what effect a change in the amount of water or a change in pressure (number of pump strokes) had on the rocket's performance. You found that both variables affected how high the rocket rose.

☐**2-8.** Suppose you filled the rocket with water but pumped in no air, and then pulled the trigger release slide. Would the rocket have risen?

☐**2-9.** Suppose you added no water to the rocket but pumped 15 strokes of air into it, and then pulled the trigger release slide. Would there be any upward unbalanced force on the rocket?

Check your answers to questions 2-8 and 2-9 by doing Problem Break 2-1.

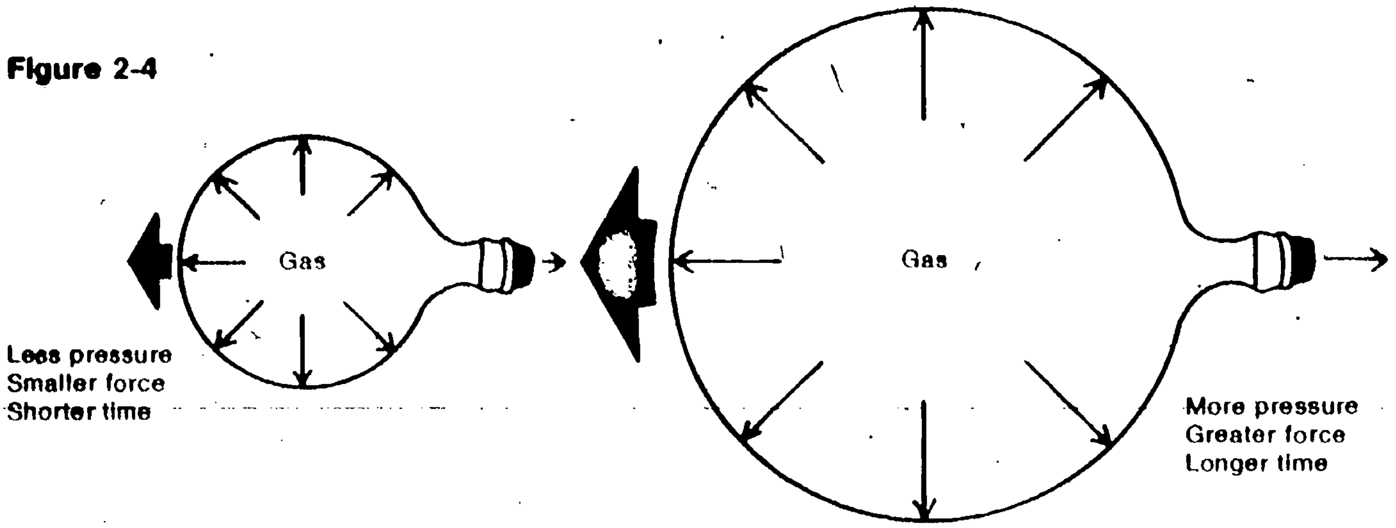


PROBLEM BREAK 2-1

Find out how high the water rocket will go when filled with water but not pumped. Then find out how high it goes when pumped with air but carrying no water. Record the results of your investigation in your Record Book.

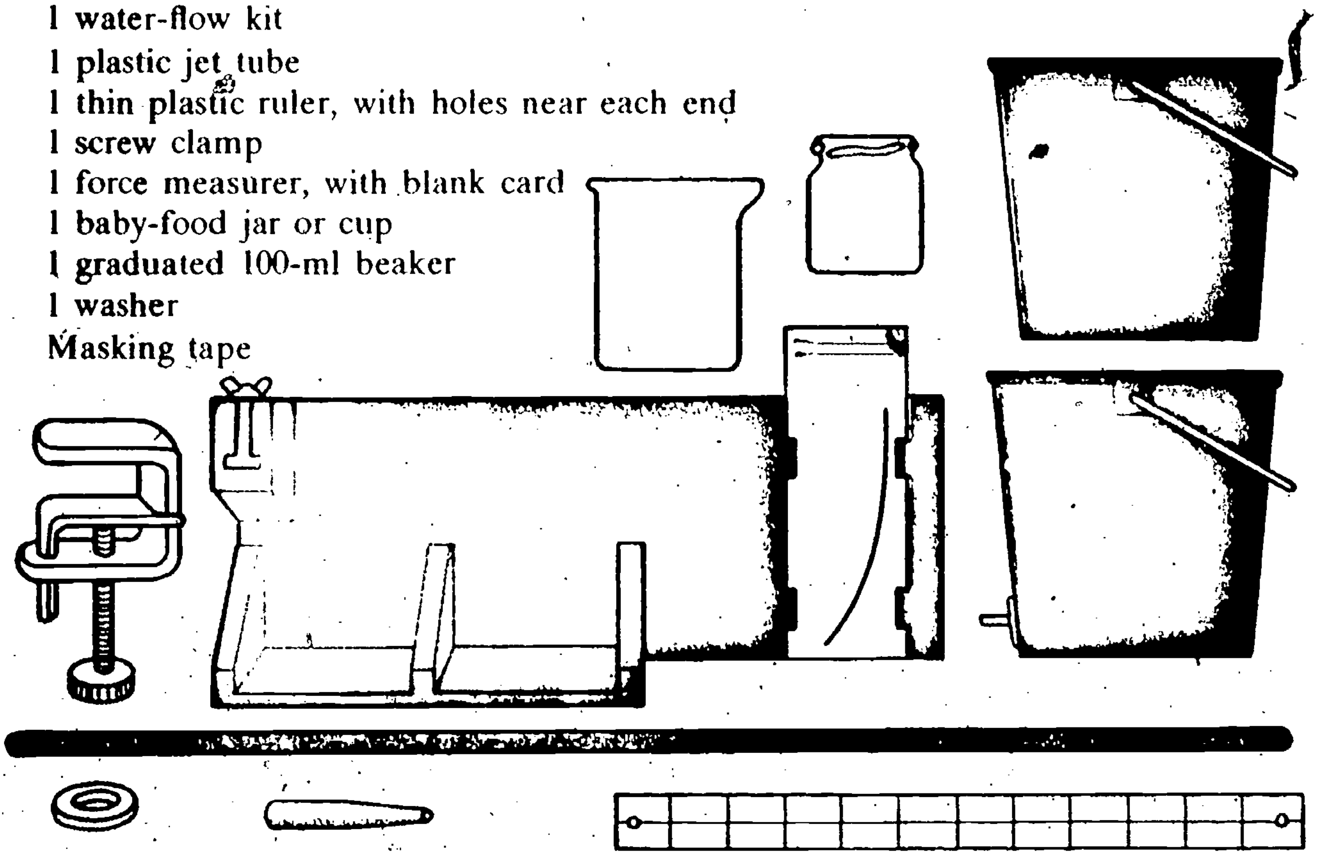
In the case of your water rocket, it isn't hard to see how air pressure can change the unbalanced lift force. Think back to the balloon activity. If you put more gas (air) into the balloon, there would be more gas to come out, giving you an unbalanced force for a longer time. In addition, the gas in the balloon would have greater pressure and thus would cause a greater unbalanced force to push the balloon forward. Figure 2-4 illustrates this.

Figure 2-4

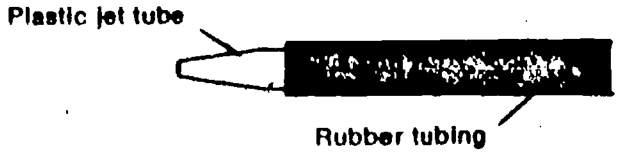


But why does the water have such an important effect on the unbalanced lift force? The rocket just won't go far at all without the water. The effect of air pressure and water on lift force must be closely related. To observe this relationship in the water rocket is very difficult. Things just happen too fast. You need a simpler system, which can be controlled. Such a system is the rocket test stand. To prepare one, you should work with two partners again. Your team will need the following equipment:

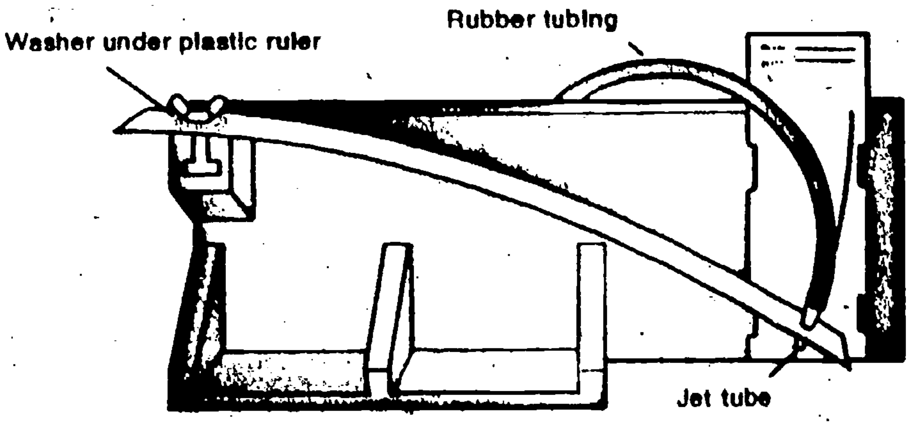
1 water-flow kit
1 plastic jet tube
1 thin plastic ruler, with holes near each end
1 screw clamp
1 force measurer, with blank card
1 baby-food jar or cup
1 graduated 100-ml beaker
1 washer
Masking tape



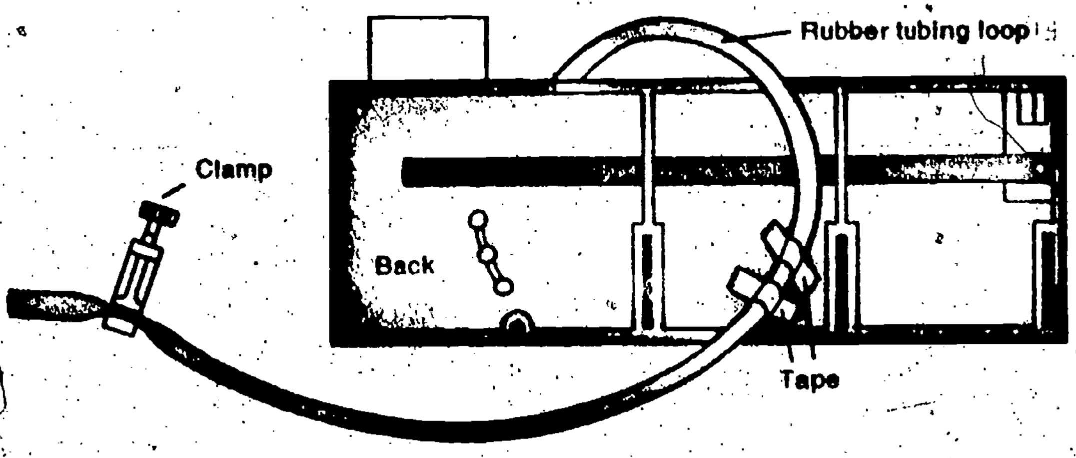
ACTIVITY 2-4. Slide the large end of the plastic jet tube about 1 cm into the open end of the rubber tubing.



ACTIVITY 2-5. Remove the steel blade from the force measurer. Put a washer and then the plastic ruler on the bolt. Replace the wing nut. Insert the jet tube in the hole at the other end, with the jet pointing downward.



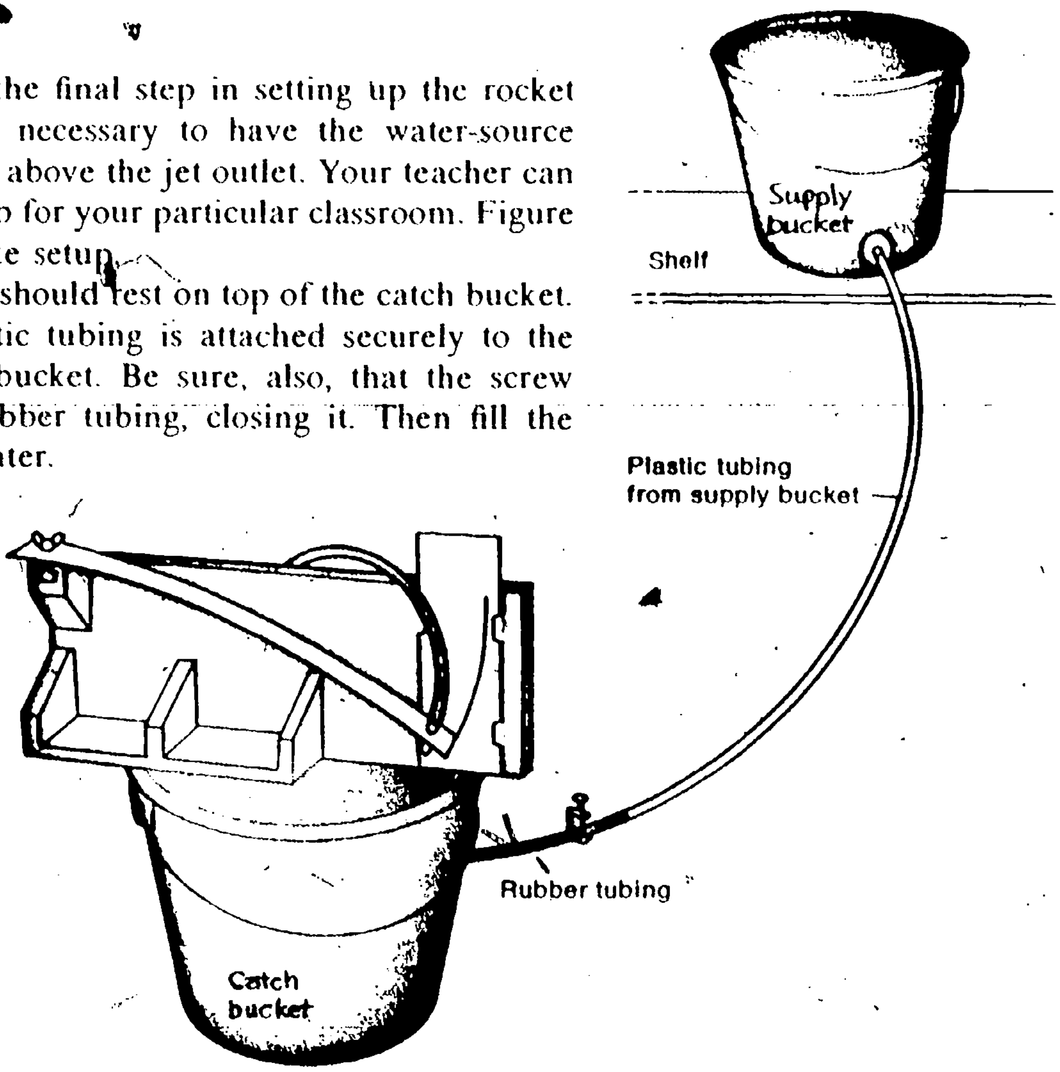
ACTIVITY 2-6. Loop the rubber tubing over the top of the force measurer, and fasten it to the back with tape. Be sure that the loop is large enough to clear the force-measurer blade, thus allowing it to move freely. Slide a screw clamp onto the rubber tubing and tighten the screw, closing the tube.



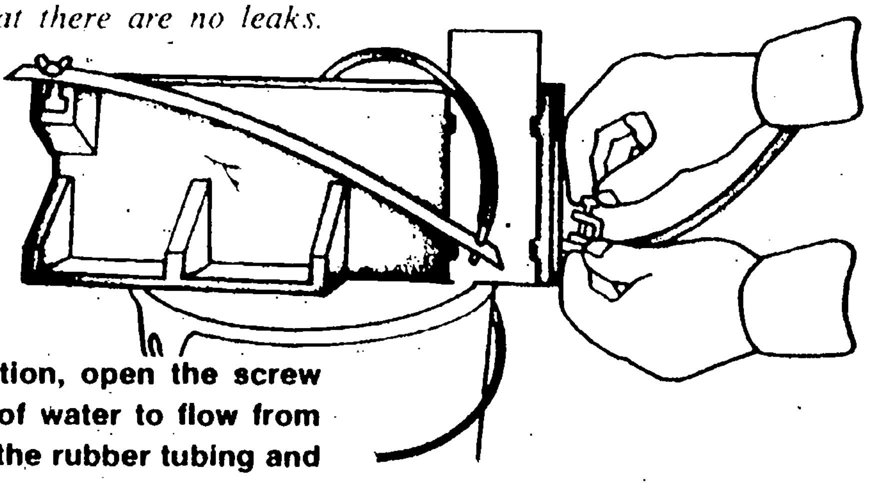
You are ready for the final step in setting up the rocket test stand. It will be necessary to have the water-source bucket about 2 meters above the jet outlet. Your teacher can help you with the setup for your particular classroom. Figure 2-5 shows the complete setup.

The force measurer should rest on top of the catch bucket. Be sure that the plastic tubing is attached securely to the drain on the supply bucket. Be sure, also, that the screw clamp pinches the rubber tubing, closing it. Then fill the supply bucket with water.

Figure 2-5



Caution *Check your tubing to see that there are no leaks.*

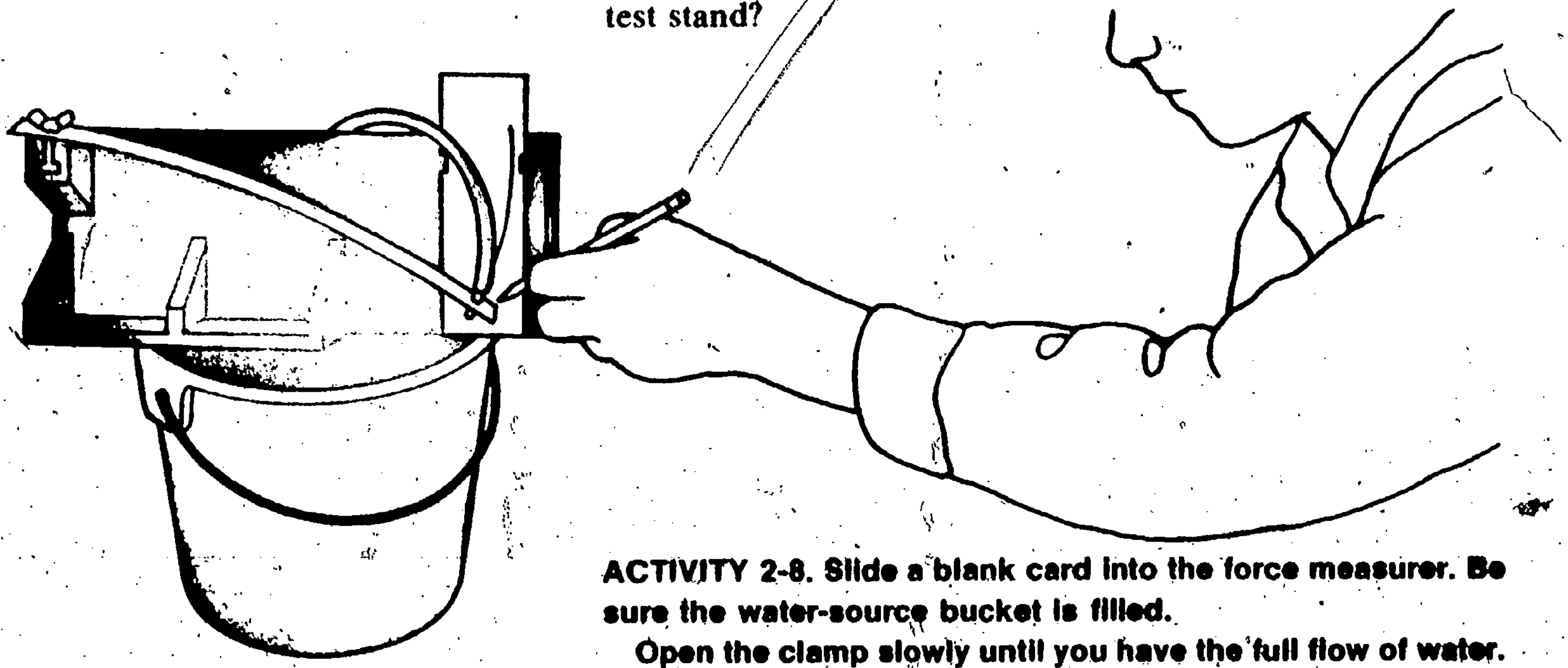


ACTIVITY 2-7. With everything in position, open the screw clamp slowly to allow a small stream of water to flow from the jet. If necessary, adjust the loop in the rubber tubing and the tape on the back of the force measurer so that the blade moves freely in a position about like that shown. Be sure the blade does not rest on the bottom support. Allow the water to run until all air bubbles are out of the tubing. Then close the screw clamp again.

☐**2-10.** As you opened the screw clamp, what happened to the plastic force-measurer blade?

As you opened the screw clamp, you should have noticed an effect on the blade. It moved up. Some force lifted the blade to a higher position. You can try Activity 2-7 again if you wish. When water flows through the jet, a lift force is produced. This is like the lift force that occurs when water shoots out of your rocket. Your rocket test stand is an apparatus you can use to measure that lift force. All it needs is a scale.

☐**2-11.** Why won't your newton scale work for the rocket test stand?



ACTIVITY 2-8. Slide a blank card into the force measurer. Be sure the water-source bucket is filled.

Open the clamp slowly until you have the full flow of water. Close it again slowly. Do this several times until you can mark the no force, or zero, point and the maximum force point with a pencil. Then observe for a moment the way the water comes out with the clamp partly open.

☐**2-12.** As you opened the screw clamp, how was the speed of the water coming out the jet affected?

☐**2-13.** As you opened the screw clamp, how was the amount of water coming out the jet affected?

It is difficult to measure the speed of the flowing water directly. But there is a simple way to estimate the speed by measuring something else. You can judge how fast the water is escaping by measuring the volume of water collected in a given time interval. All you have to do is collect the water as it escapes from the jet.

Use your equipment to get answers to the next three questions.

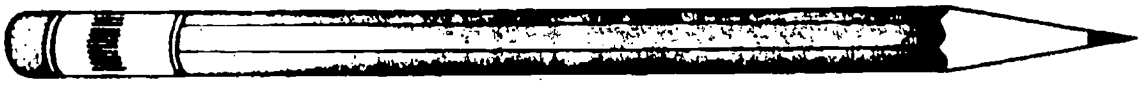
☐**2-14.** How much water is released in 10 seconds when the screw clamp is closed?

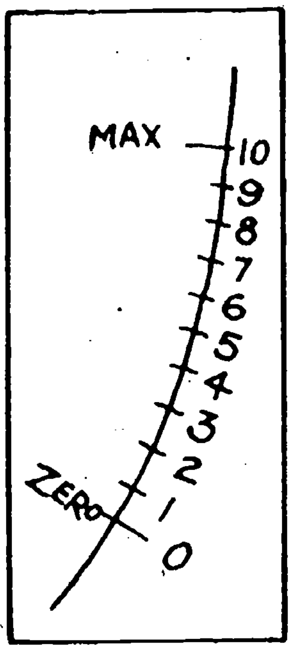
☐**2-15.** How much water is released in 10 seconds when the screw clamp is half open?

☐**2-16.** How much water is released in 10 seconds when the screw clamp is all the way open?

☐**2-17.** Suppose the amount of water flowing from the jet in 10 seconds is doubled. What would you estimate to be the increase in flow speed?

You are now ready to find out how speed of flow affects the lift force on the rocket.





ACTIVITY 2-9. Remove the card from the force measurer. You should have already marked the zero point and the maximum point on the card. Divide the space between the two marks into 10 equal parts. Use any method that you can devise. But be sure that the parts are equal. Number each mark as shown.

With your apparatus, various positions of the screw clamp will change the amount and the speed of the water flowing from the jet. This changes the lift force. To see how the force varies with speed of flow, do Problem Break 2-2.

PROBLEM BREAK 2-2

With your two partners, determine the volume of water that must come out of the jet in 10 seconds to maintain each of the forces marked on your force scale 1 through 10. A suggested procedure follows.

1. One person should act as timer, another as the catcher of the water, and the third as the operator of the screw clamp.
2. Open the clamp until the desired force is indicated on the scale. Water should flow out the jet and into the catch bucket. Timing should then begin.
3. When the timer says "Start!" shove the jar or cup under the jet. Catch the water for 10 seconds. At the signal from the timer, simply remove the cup. Then the operator can close the clamp.
4. Be sure to pour the water back into the supply bucket whenever it gets low. Don't move the supply bucket!
5. Keep accurate data in the space provided in your Record Book.
6. Using a container with a ml scale, measure the amount of water caught in the jar.
7. At least two readings should be taken at each setting, and an average found for the table.

☐**2-18.** In Figure 2-6 in your Record Book, sketch a graph of the data you have collected.

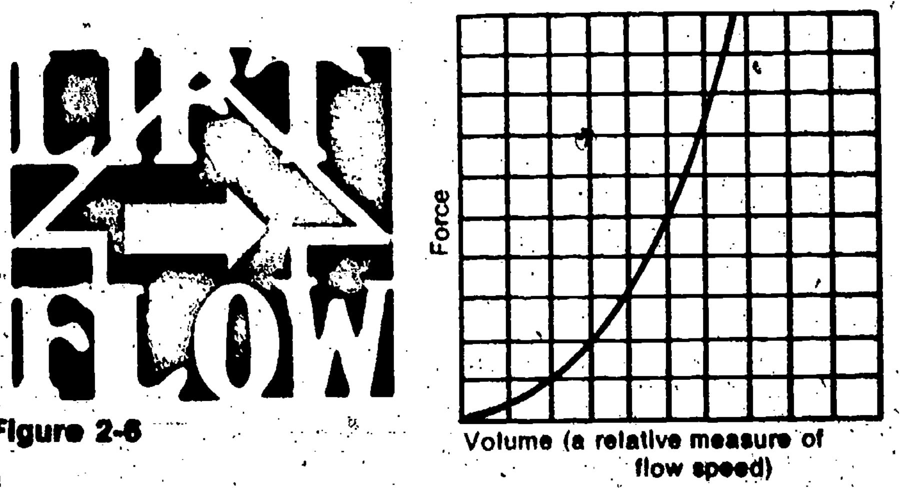


Figure 2-6

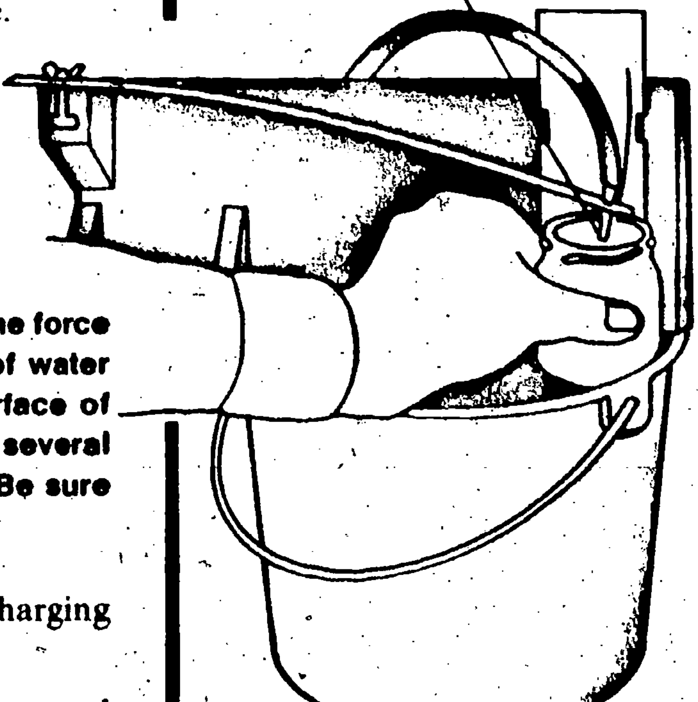
☐**2-19.** When flow speed increases, how is lift force affected?

You have answered the basic question asked in this chapter: How do pumped air and water affect the lift force on the water rocket? The steady flow of water out of the rocket provides a lifting force. The faster the flow, the greater the force. Increasing the air pumped (pressure) increases the pressure force. This in turn increases water-flow rate. Thus, an increase in lift force occurs.

Before you leave the chapter, there is one other effect you should investigate. Problem Break 2-3 deals with an important error that some people make when they think about rockets.

PROBLEM BREAK 2-3

Some people think the push of the escaping gases on the air outside is what moves a rocket along. This idea suggests that the more air behind the rocket, the more force (thrust) it will have. See for yourself whether this is the case.



ACTIVITY 2-10. Open the clamp all the way and note the force on the blade. With the jet running, raise the full jar of water under the jet so that the discharge is under the surface of the water. Note the force under this condition. Do this several times until you are sure that you see what happens. Be sure that the blade and tip are not touching the jar.

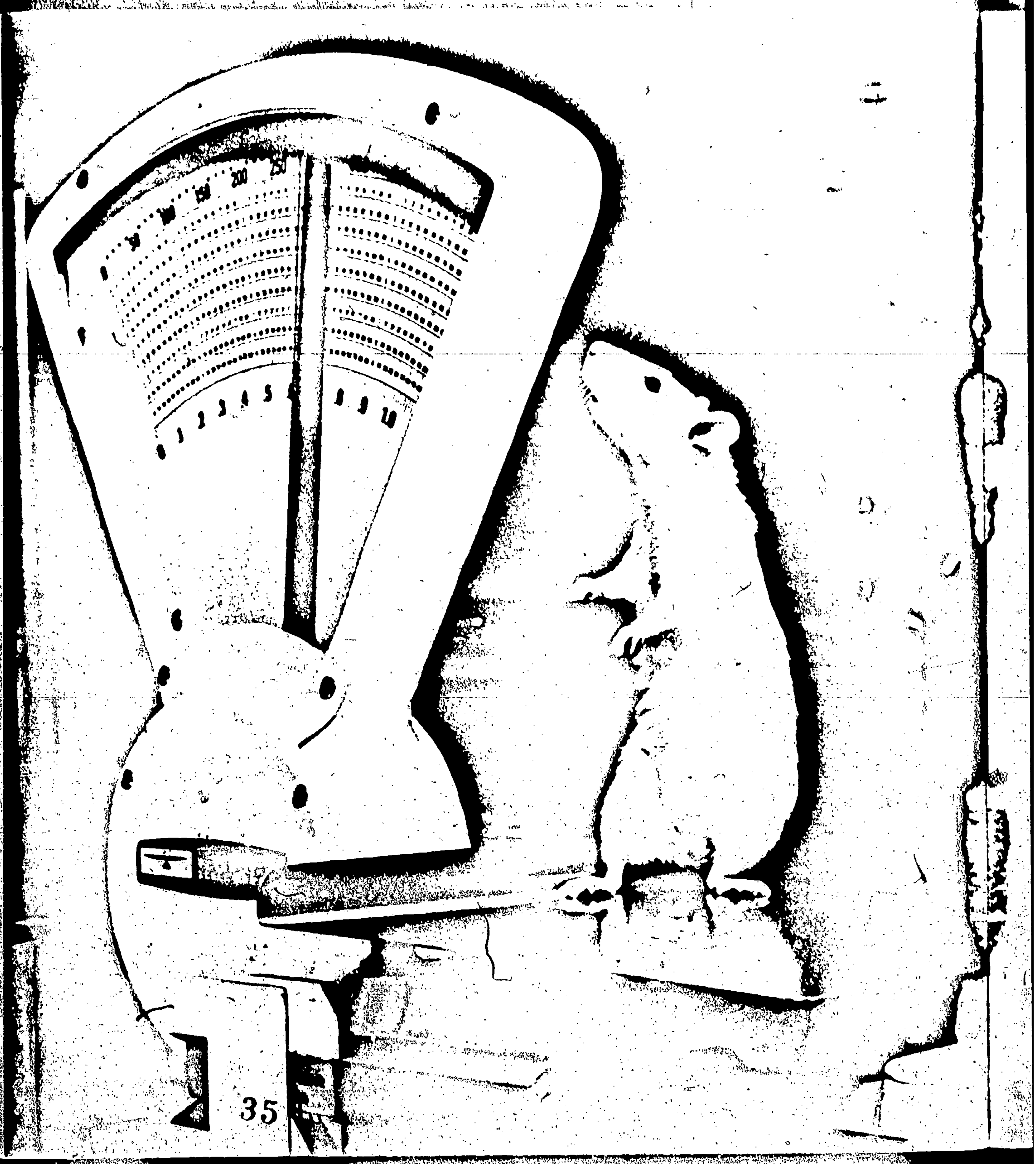
☐**2-20.** What force did you measure with the jet discharging underwater?

☐**2-21.** How did this force compare with the force measured with the jet out of the water?

☐**2-22.** How would you explain the difference in force if there was any?

☐**2-23.** Do the results of this activity agree with the ideas of those people mentioned?

Before going on, do Self-Evaluation 2 in your Record Book.


200
250

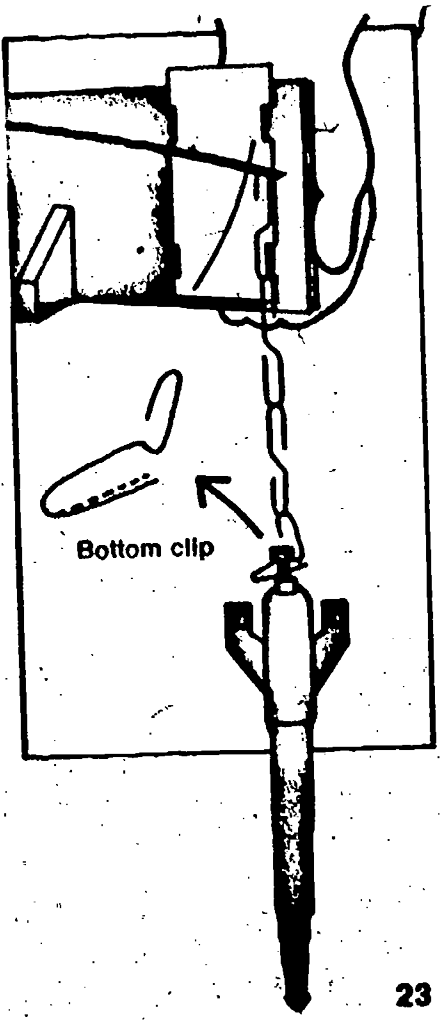
How Much Is Needed?

Chapter 3

By now you have some idea of what gives the force, or thrust, that puts a rocket into space. To get your water rocket launched, you put water inside it. The pump added air under pressure. The volume of the water and the speed with which it was forced out gave the thrust you needed to get your rocket up.

But how much force is necessary to get the rocket to rise? Let's see if you can find out the answer by making a few measurements. Select two partners and get the following equipment for your team:

1 force measurer, with thin and thick blades
2 cards with premarked scales (0–1 N and 0–10 N)
1 dry water rocket
1 funnel
1 pail of water
4 paper-clip hooks
1 100-ml beaker or other container that can be used to measure water in ml



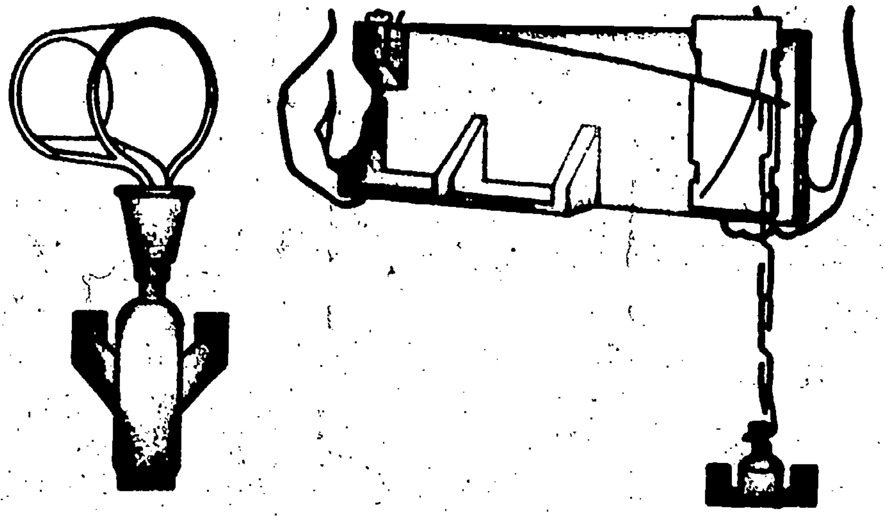
ACTIVITY 3-1. Use the thin blade for now. Open the 4 paper clips and link them together as shown. Zero the force measurer with only the clips in place. Bend the large end of the bottom clip as shown, and fit it over the flange of the rocket. Support the empty rocket in an upside-down hanging position. Did you remember to use your 0–1 newton scale?

☐**3-1.** What is the force-measurer reading in newtons?

You have measured the force of gravity on the mass of the empty rocket. This measure is the rocket's empty weight. You know that the rocket must have water in it for best performance. You can think of the water as the rocket fuel. Refer back to Problem Break 1-1 in Chapter 1 to find the number of ml of water used to push the rocket to its greatest height.

☐**3-2.** How many ml of water did you use to send the rocket to its greatest height?

The water added to the rocket has mass. Air was also added to make the rocket go. It, too, has mass, but its mass is small compared with the mass of the water. Therefore the increase in the rocket's mass is due primarily to the added water. You can find out how much mass was added by using your force measurer.

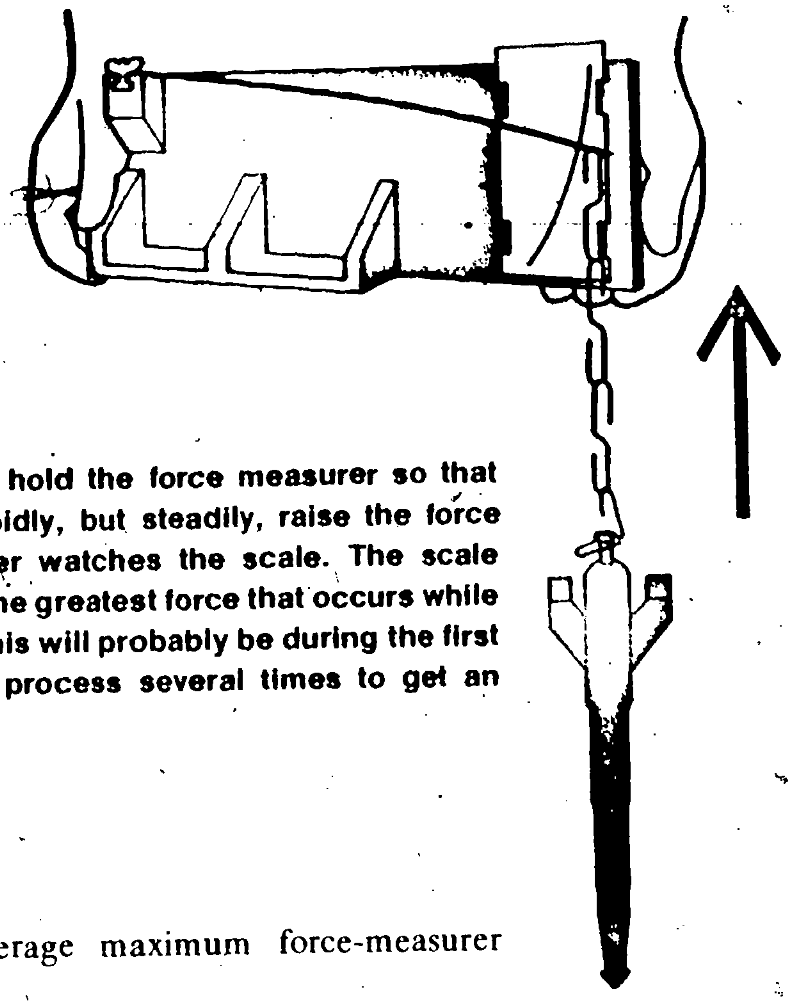


ACTIVITY 3-2. Using the funnel and calibrated container, add to your rocket the number of ml of water given in your answer to question 3-2. Weigh the fueled rocket again as you did in Activity 3-1. You may have to use the thick blade and the 0–10 newton scale.

☐**3-3.** What is the weight in newtons of the fueled rocket?

This total weight is the force of gravity acting on the rocket and its contents. It is the force that must be overcome before the rocket will rise.

☐**3-4.** If the rocket is to rise, and not just hang in space, what must happen?



ACTIVITY 3-3. Once more, hold the force measurer so that the rocket hangs free. Rapidly, but steadily, raise the force measurer while one partner watches the scale. The scale observer should watch for the greatest force that occurs while the rocket is being lifted. This will probably be during the first second of lift. Repeat the process several times to get an average.

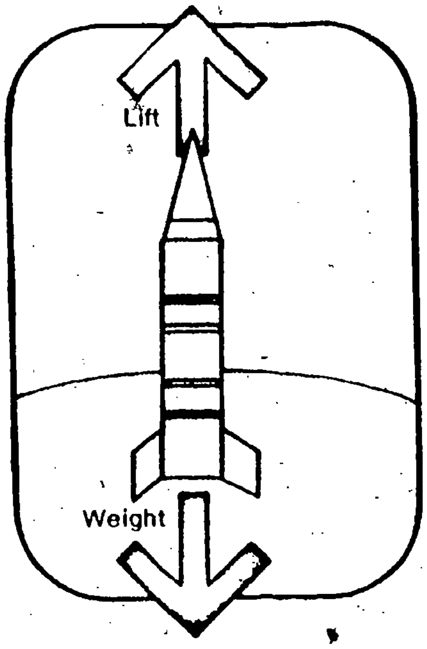
☐**3-5.** What was the average maximum force-measurer reading on rapid lift?

☐**3-6.** How does the rapid-lift force compare with the force of gravity on the fueled rocket? (Look back at your answer to question 3-3.)

The additional force needed to give the rocket motion shouldn't have surprised you. An unbalanced force must be exerted on an object at rest to get it moving.

☐**3-7.** Suppose an upward force that is equal to the weight of the rocket and its contents is applied. Would the rocket move upward? Explain your answer.

Recall when you lifted your water rocket with the force measurer; you probably noticed that the amount of an unbalanced force measured depended on how fast you lifted.



To say it another way, the greater the unbalanced lift force, the faster the lift speed. Thus, the farther the rocket will have gone since lift-off. Figure 3-1 illustrates this.

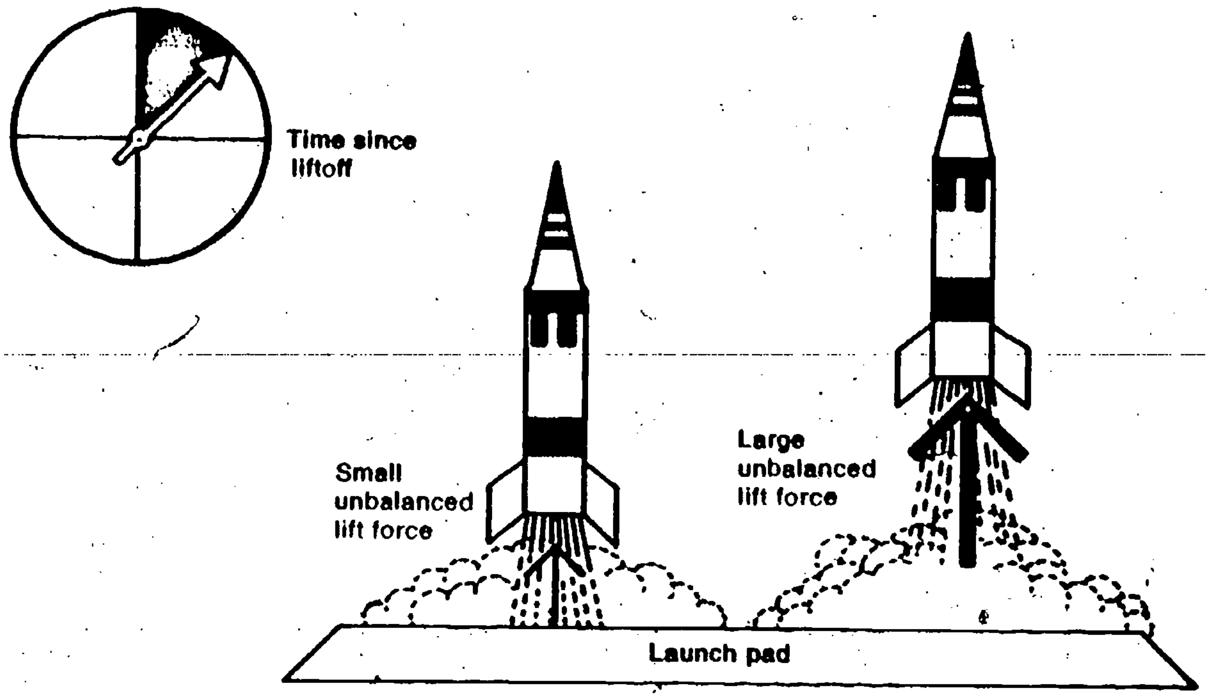


Figure 3-1

Another important thing is happening to your water rocket as it lifts off from the launch pad. It is related to the mass of the rocket and its contents.

☐**3-8.** Does the total mass of the rocket plus its contents remain constant throughout its flight? Explain your answer.

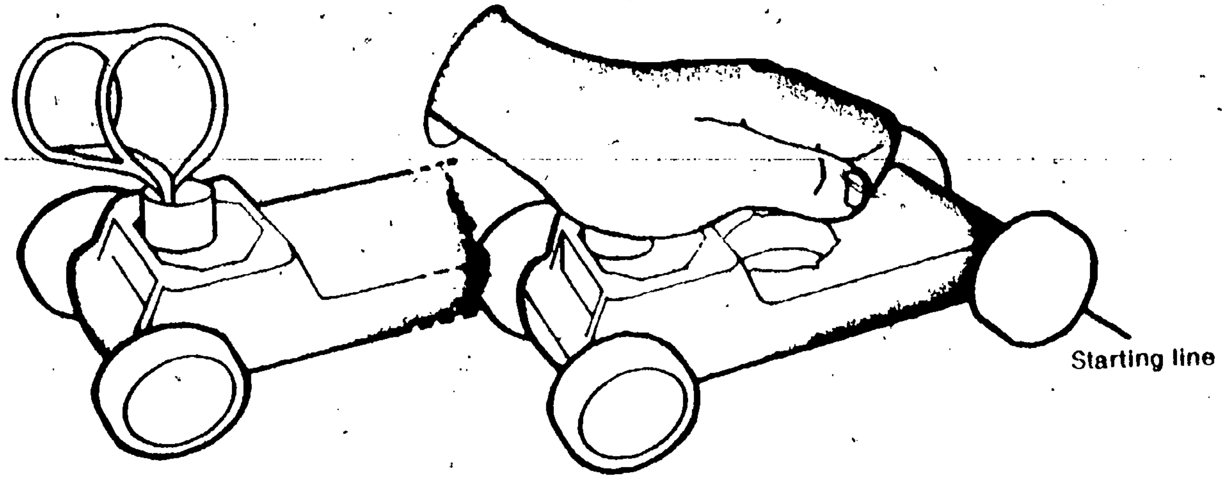
You should investigate the effect this change in mass of the rocket has on its performance. To do so, you need to work with 3 or 4 other classmates who are at this point in the text. Your team will need the following materials:

1 cart, with water clock
1 jar for water
1 meterstick

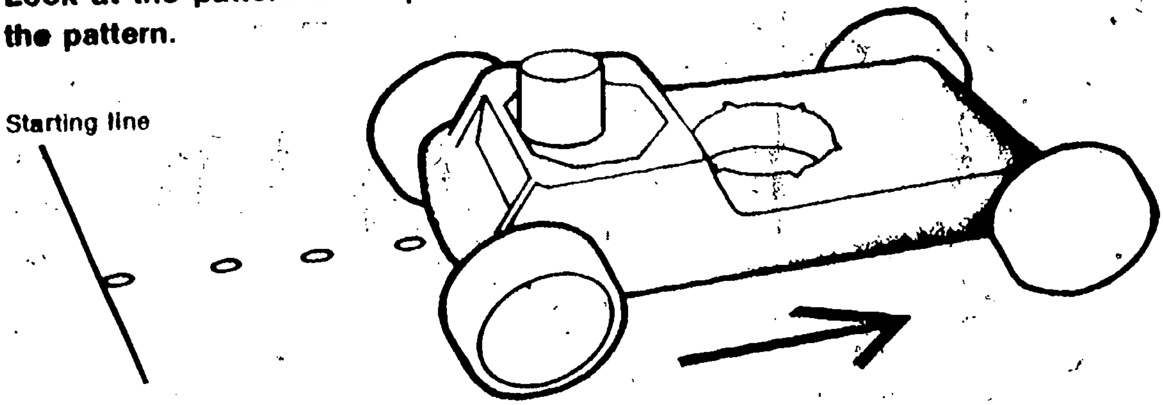
Look for a flat, fairly smooth surface at least 2 meters long. If this amount of space is available on a table, use it. Otherwise, you will need to do the activity on the floor.

First, you need to use the water-clock cart to see what can be measured with it.

ACTIVITY 3-4. Place the water clock in position on the cart and fill it completely with water. Place the front of the cart on a line you have marked on the table or floor. Then push down gently with your palm to start the water dripping.



ACTIVITY 3-5. Now give the cart a gentle push until its back wheels reach the line. Then stop pushing and let it coast. Look at the pattern of drops it leaves behind. Don't disturb the pattern.



☐**3-9.** Did the speed of your cart in Activity 3-5 increase, decrease, or stay the same after you stopped pushing?

You may need help with question 3-9. Each drop falling from the cart takes the same amount of time to form and reach the surface. Thus, the distance between drops on the surface can tell you whether the cart's speed was unchanging, increasing, or decreasing. It can also tell you the amount of change between each time interval.

In Figure 3-2, three water-drop tracks are shown.

☐**3-10.** Which track in Figure 3-2 indicates no change in cart speed? Which track indicates an increase in speed? Which track indicates a decrease in speed?

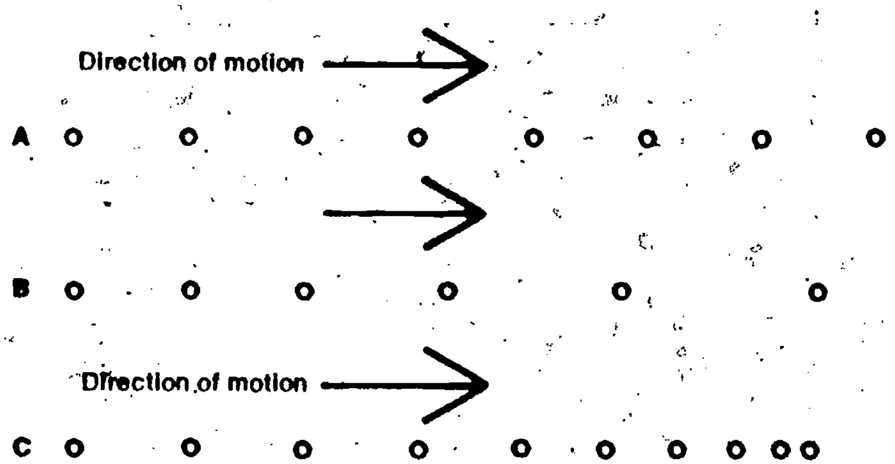


Figure 3-2

ACTIVITY 3-6. Measure the distance between each pair of drops from Activity 3-5. Start with the drop nearest to the point where you stopped pushing the cart. Make your measurements to the center of the drops. List the distances in Table 3-1 of your Record Book.

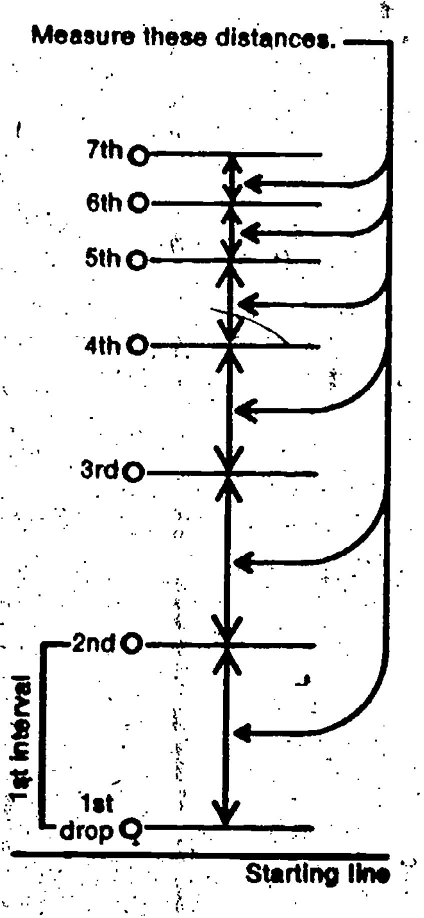


Table 3-1

Interval	Distance Traveled (in cm)
1st	
2nd	
3rd	
4th	
5th	
6th	
7th	

The shorter distances indicate that the cart slowed down after you stopped pushing it. That's no surprise, of course. What good is all this then?

Your water-clock cart can be used to identify changes in speed. All you have to do is look for changes in the distance between drops.

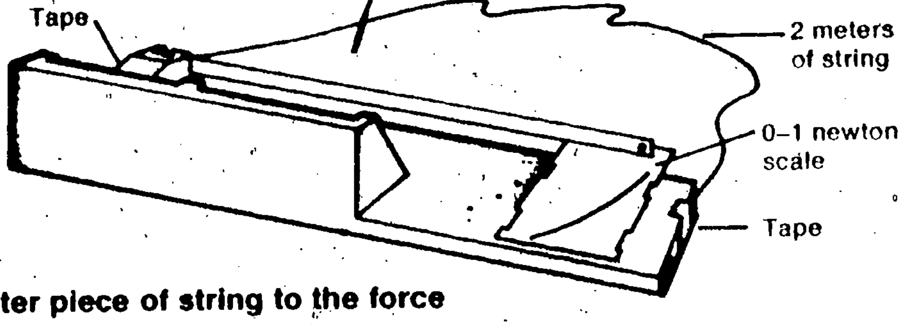
☐**3-11.** What must have happened to the speed of the cart if (**a**) the distance between drops increases? (**b**) the distance between drops decreases? (**c**) the distance between drops stays the same?

Now you can find out how speed, mass, and force are related. To do this, your team will continue working with the cart. You will also need:

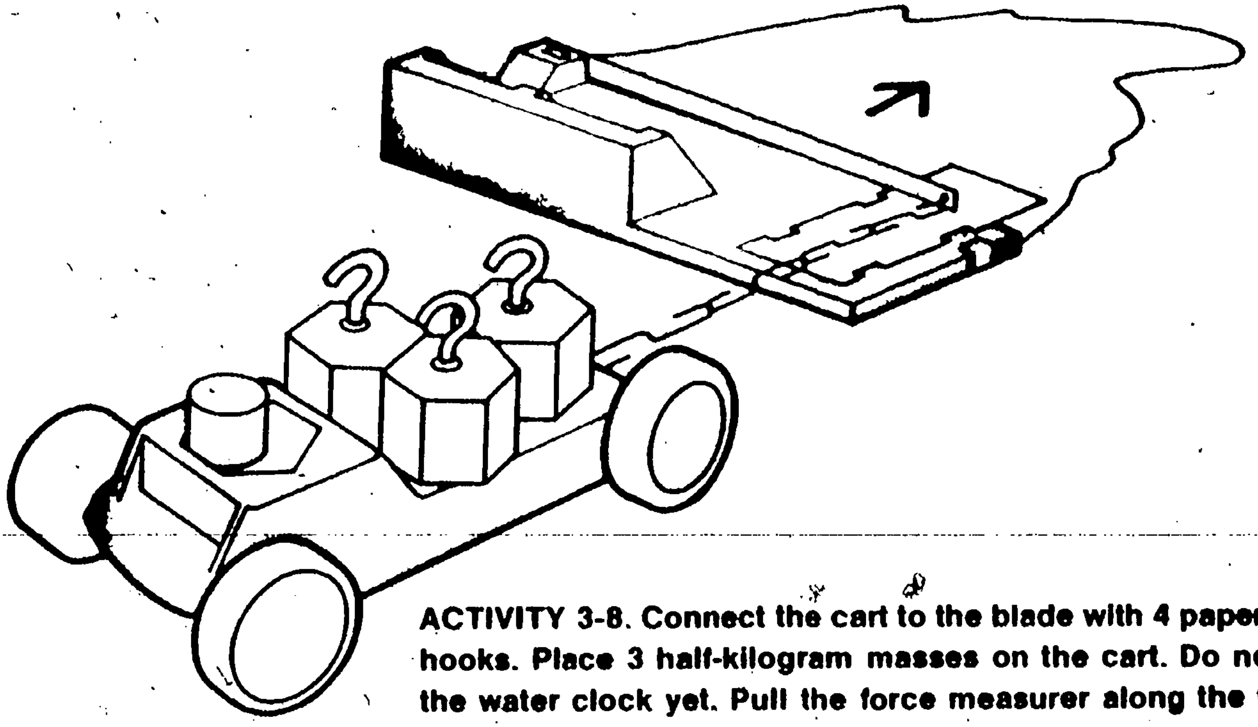
1 force measurer, with thin blade and 0–1 newton scale
4 paper-clip hooks
1 piece of string, 2 meters long
3 half-kilogram masses
Tape

The questions you want to investigate are these: When a constant unbalanced force is applied to an object, how will the object's speed change? and What effect will result if the object also loses some of its mass?

You can use the force measurer to apply a constant force on the cart. And you can vary the mass of the cart by loading it with half-kilogram masses and then removing them one at a time. The cart would then be like the rocket that moves upward under a constant force while its mass gets less and less as its fuel is used up. Try the cart experiment and see what happens.

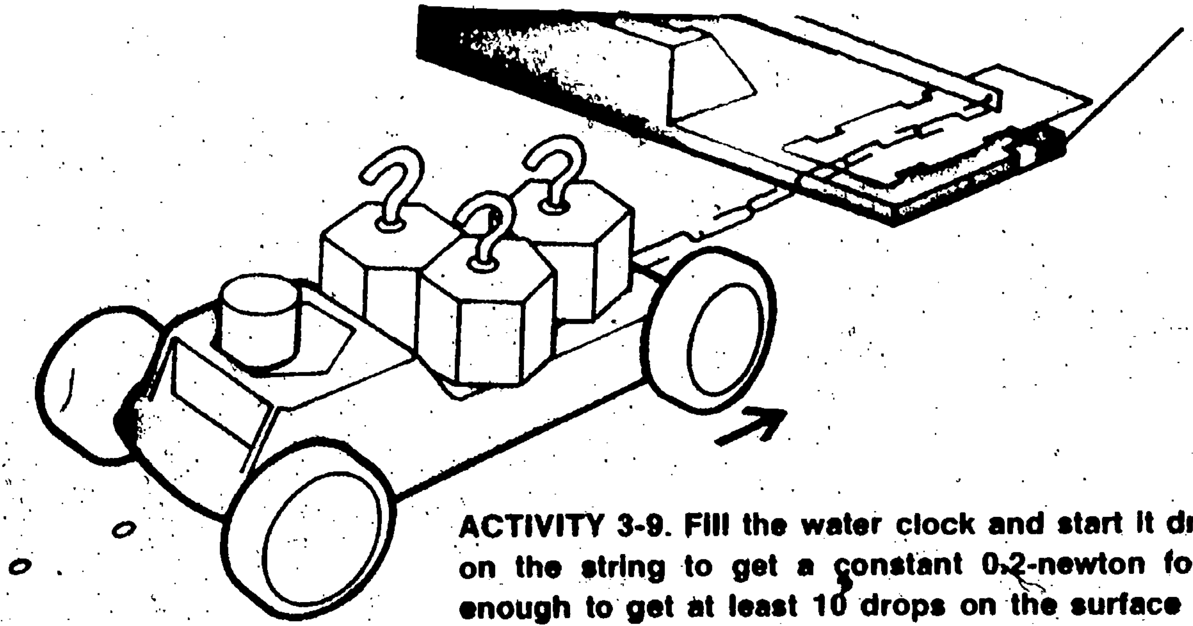


ACTIVITY 3-7. Fasten the 2-meter piece of string to the force measurer with tape as shown. Then lay the force measurer on its back. Zero the force measurer while it is in this position. Have the thin blade in place and use the 0–1 newton scale.



ACTIVITY 3-8. Connect the cart to the blade with 4 paper-clip hooks. Place 3 half-kilogram masses on the cart. Do not fill the water clock yet. Pull the force measurer along the table or floor, trying to keep the force on the cart constant at 0.2 newton.

You will need to practice to keep the force constant at 0.2 newton. Make several runs until you can do it. The force may vary a little above or below the correct amount, but the blade should stay fairly close to the 0.2 mark.



ACTIVITY 3-9. Fill the water clock and start it dripping. Pull on the string to get a constant 0.2-newton force. Go far enough to get at least 10 drops on the surface of the table or floor. Examine the pattern of drops.

Caution *If you are working on a table, be sure to have one of your partners stop the apparatus at the edge.*

☐**3-12.** With a constant force applied, did the cart gain speed, lose speed, or travel at a constant speed?

Using the same method you used in Activity 3-6, measure the distance between drops with a ruler or meterstick. You should measure that section of the run where you maintained the force at 0.2 newton. You probably noticed that the force measurer tends to jump to a higher measurement as you start the pull and then bounces back as you release your pulling force. It will take practice to get this constant force over a 2-meter run. Wherever you start measuring, you should measure each distance in order from that point on. List the distances in Table 3-2 in your Record Book under "Total mass: 2.0 kg." (Remember, you used 3 half-kilogram masses on the cart. The cart itself has a mass of one-half kilogram.)

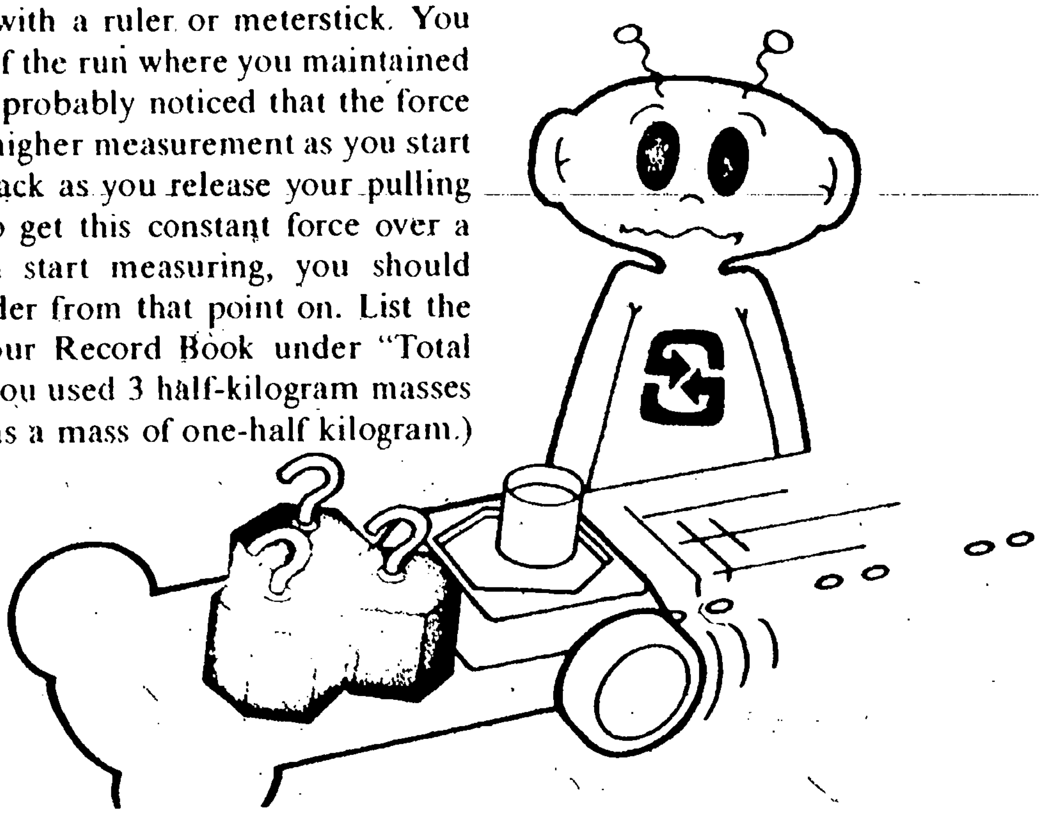
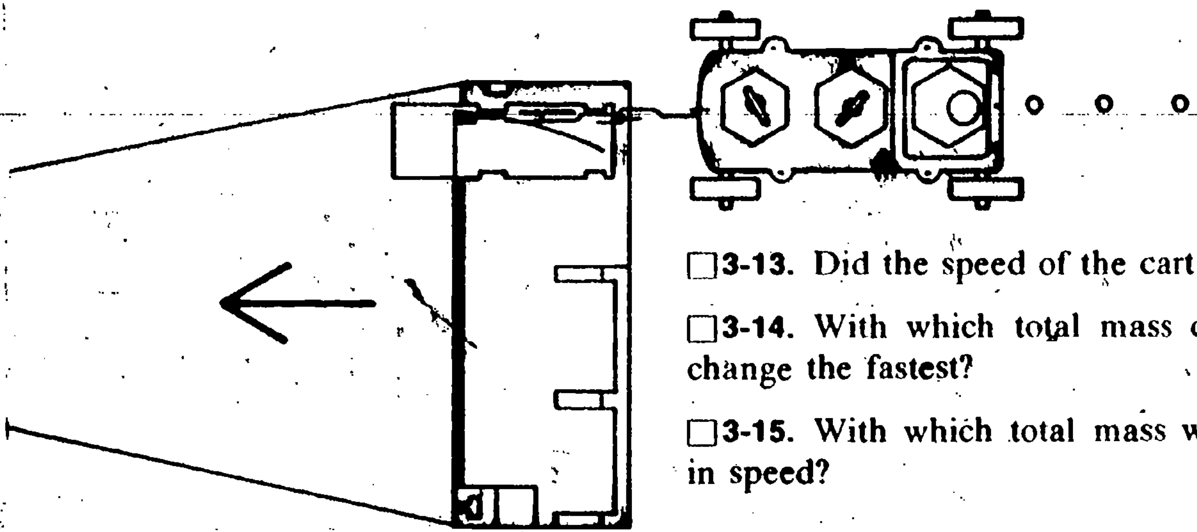


Table 3-2

	Distance (in cm)			
Time interval	Total mass: 2.0 kg	Total mass: 1.5 kg	Total mass: 1.0 kg	Total mass: 0.5 kg
1st				
2nd				
3rd				
4th				
5th				
6th				

ACTIVITY 3-10. Remove one mass from the cart and repeat the pulling activity. Be sure the water clock is operating and the force is kept constant at 0.2 newton. Record the distance measurements in Table 3-2 under "Total mass: 1.5 kg." Then repeat the activity with one mass on the cart, and again with no mass on the cart. Record the measurements in Table 3-2. During each run, keep the force as close as you can to 0.2 newton.



☐**3-13.** Did the speed of the cart increase during each run?

☐**3-14.** With which total mass did the speed of the cart change the fastest?

☐**3-15.** With which total mass was there the least change in speed?

Perhaps you can see from this activity that a constant unbalanced force on a body will cause its speed of motion to increase. A greater increase will occur if the mass of the body also decreases. At this point you ought to take stock of what you have found out and see how it applies to the rocket launch. The following list may help you.

1. Some combination of water and air pressure gives the best rocket performance.
2. The speed of water flow out of the rocket produces a forward force, or thrust, on the rocket.
3. This unbalanced force in the rocket chamber pushes the rocket forward.
4. The amount of force needed to get the rocket off the ground is any amount that is greater than the weight of the loaded rocket.
5. With a constant unbalanced force, the speed of the rocket continues to increase.
6. The greater the unbalanced force, the faster the speed increases.
7. The loss of mass from the rocket causes its speed to increase even faster.

If you were a careful observer, you may have found out another thing. When you fired the water rocket, the water was forced out rapidly. In a very short time, there is no more water to apply an upward force. The rocket then slows to a stop at its maximum height and returns to the ground.

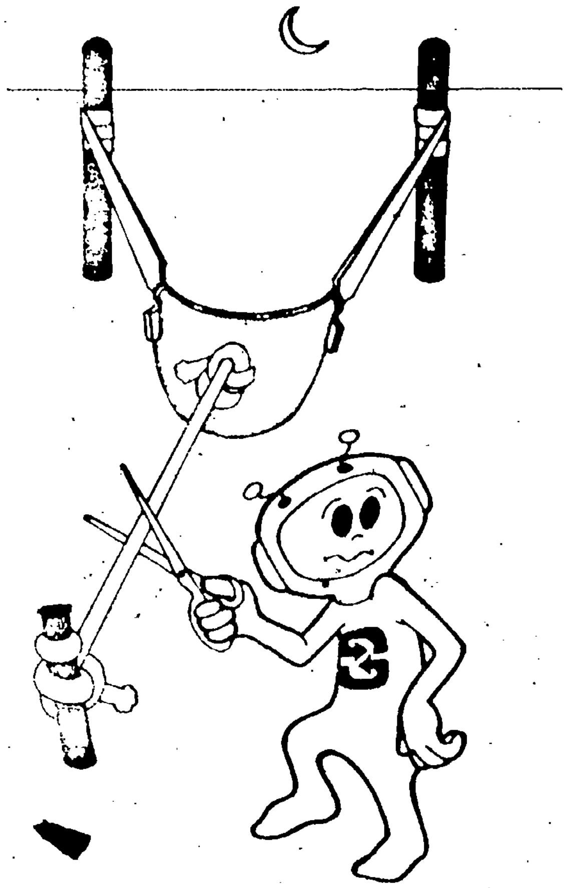
Apparently the length of time that a force is applied has an effect on the speed that a rocket attains. You could add that point to the list.

8. The longer an unbalanced force is applied, the more the rocket will speed up.

☐**3-16.** If you could continue to apply an unbalanced upward force on the rocket for a longer time, what would happen to it?

☐**3-17.** When the rocket starts to fall back to the earth, what force is then unbalanced?

You used water and air as the fuel to make your rocket leave the ground. The Saturn rocket uses a kerosinelike fuel mixed with oxygen. This mixture is burned in the combustion chamber, producing the hot gas that exerts pressure and pushes the rocket on its journey. This hot gas rushes out the nozzle of the engine in much the same way that the gas (air) shot out of the balloon in the activity you did earlier. But because there is so much fuel being burned, it continues to rush out for a much longer time than does the gas from the balloon or the water from your water rocket.

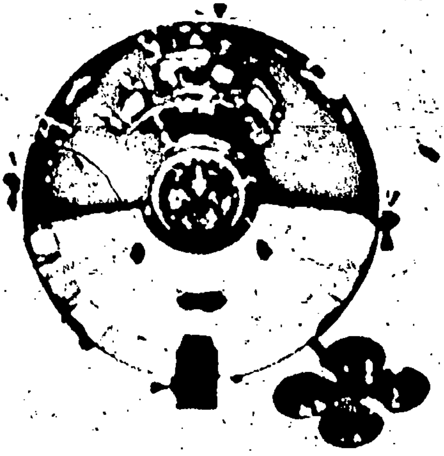


Perhaps you would like to know more about the way fuel and oxygen react in a real rocket. Or you may want to know how the hot gases that are produced push the rocket. If so, do **Excursion 3-1**, "The Big Push."

In addition to those variables you have studied, there are other factors that affect the speed of a rocket at higher altitudes. You will work with these in the next chapter.

After all the fuel is gone, there is good reason for ejecting the first stage on a rocket. To examine the effect of discarding the first stage and to see why rockets are built in stages, do **Excursion 3-2**, "One Stage at a Time."

Before going on, do Self Evaluation 3 in your Record Book.



All Systems Are Go

Chapter 4

You have learned how to get a rocket higher and how to make it go faster. But what must be done to put the space vehicle into orbit or to send it on its way to the moon? The ideas of an old scientist friend may help you with these questions.

About 300 years ago, Issac Newton described the paths that a body would follow if it were given a sidewise (horizontal) push. He pictured the body as being projected from the top of a mountain at V (Figure 4-1). Orbits from V ending at D, E, F, and G respectively are for bodies that were thrown with increasingly greater horizontal speeds. Newton theorized that if the body were given enough horizontal speed, it would continue to move all the way around the earth, as in A. In other words, the body would go into orbit.

How much horizontal speed would be necessary to put the body into orbit around the earth? An activity can help you begin finding out. Work with two partners. You will need the following equipment:

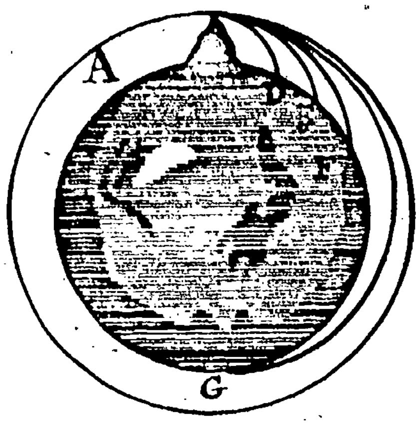
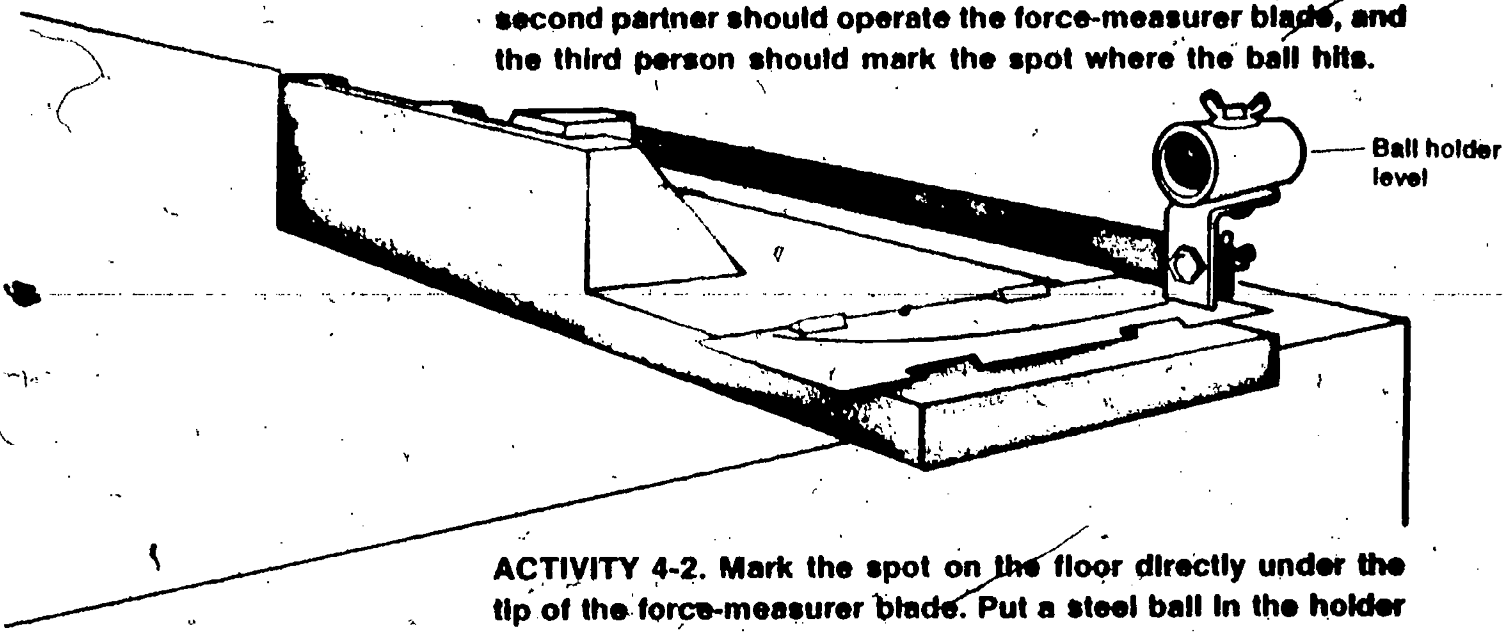


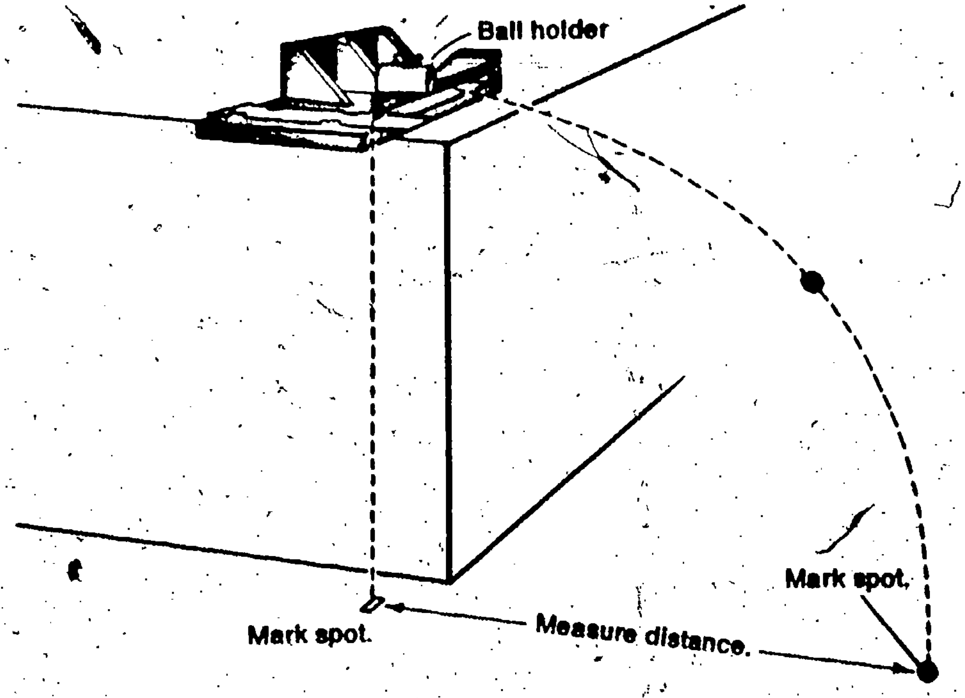
Figure 4-1

1 force measurer, with thick blade and 0–10 newton scale
1 ball holder, with 2 bolts and 2 wing nuts
1 steel ball
1 meterstick

ACTIVITY 4-1. Fasten the ball holder to the end of the thick force-measurer blade. Zero the scale. Hold the force measurer at the edge of the table in a spot where the steel ball can be projected without hitting other objects. One partner should hold the force measurer securely to the table, the second partner should operate the force-measurer blade, and the third person should mark the spot where the ball hits.

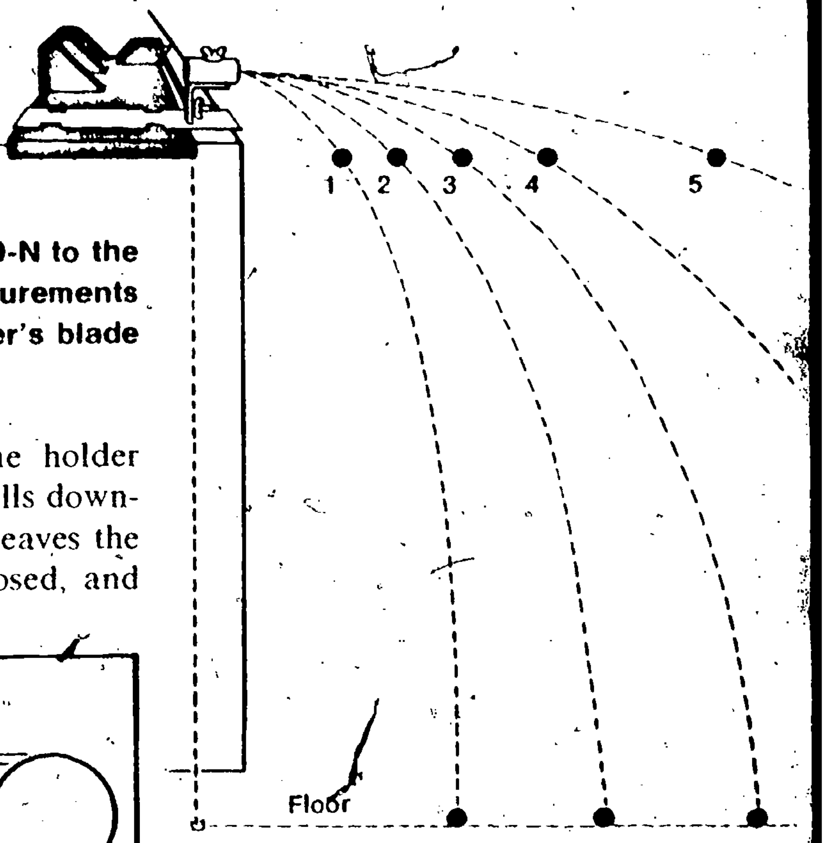


ACTIVITY 4-2. Mark the spot on the floor directly under the tip of the force-measurer blade. Put a steel ball in the holder and apply a 2-N force to the blade. Mark the spot where the ball hits the floor. Measure the distance between the two spots and enter the measurement in Table 4-1. (You may wish to get an average measure for the 2-N trial.)



Trial No.	Force (in newtons)	Distance (in meters)
1	2	
2	4	
3	6	
4	8	
5	10	

Table 4-1



ACTIVITY 4-3. Apply forces of 4-N, 6-N, 8-N, and 10-N to the steel ball. Measure the distances and enter the measurements in Table 4-1. Remember to keep the force-measurer's blade tip over the spot you marked on the floor.

While the ball is supported in the holder, the holder pushes upward on the ball as strongly as gravity pulls downward. Figure 4-2A shows this. As soon as the ball leaves the holder, as in 4-2B, the force of gravity is unopposed, and the ball falls.

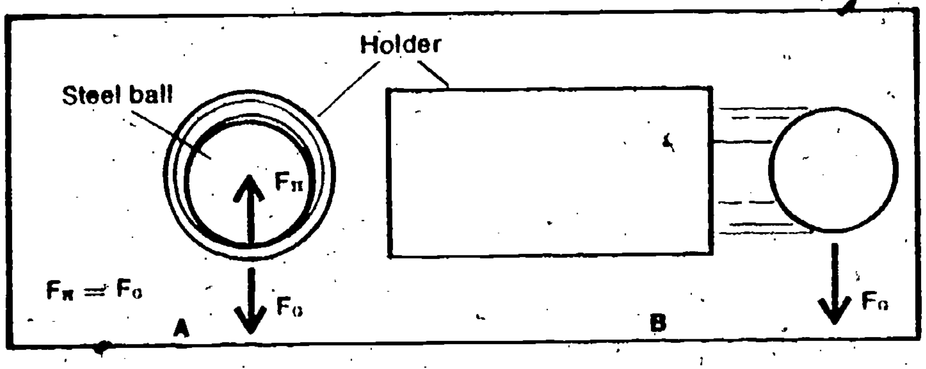


Figure 4-2

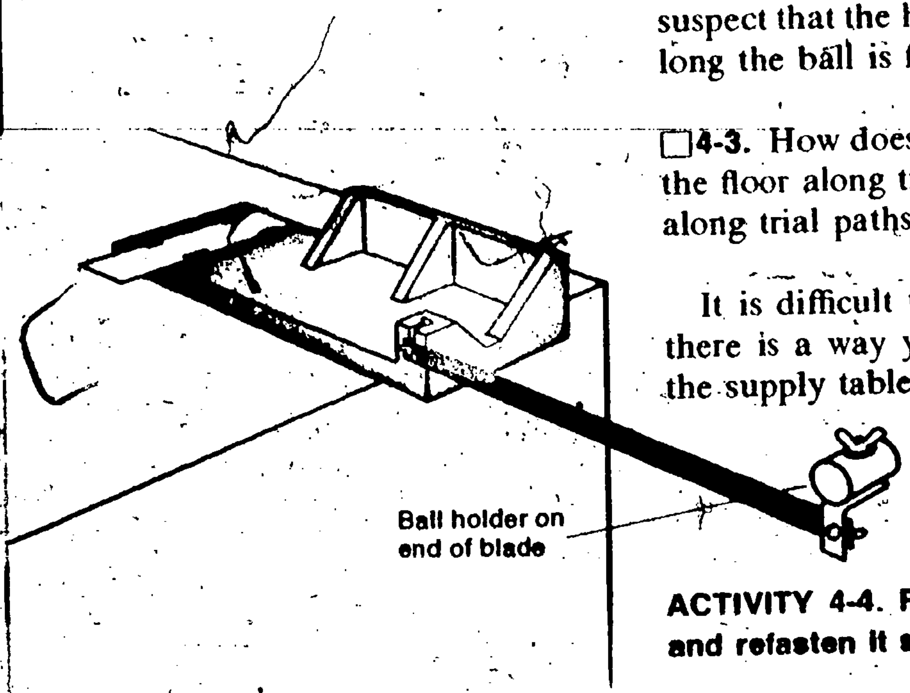
☐**4-1.** Did the horizontal distance the ball traveled before hitting the floor seem to depend on the amount of force applied?

☐**4-2.** What do you think would happen to the ball if you applied more and more horizontal force?

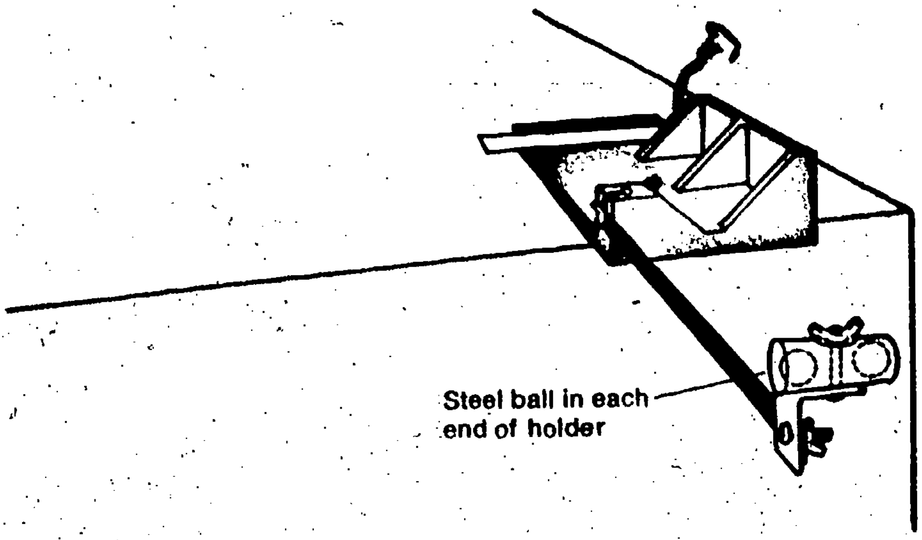
The horizontal distance the ball travels through the air depends on how much force you apply, and you may also suspect that the horizontal distance traveled depends on how long the ball is falling.

☐**4-3.** How does the length of time it takes the ball to reach the floor along trial path 1 compare with the length of time along trial paths 2, 3, 4, and 5?

It is difficult to be sure about your answer, isn't it? But there is a way you can check. Get another steel ball from the supply table.

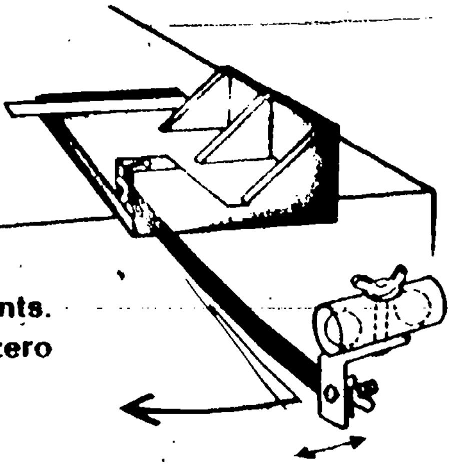


ACTIVITY 4-4. Remove the blade from the force measurer, and refasten it so that it points in the opposite direction.



ACTIVITY 4-5. Put a ball in each end of the holder. Have one partner hold the force measurer firmly on the table. Pull the blade back a small amount and release. ***Listen carefully for the sound of the balls hitting the floor.***

☐**4-4.** Did the balls strike the floor at about the same time?



ACTIVITY 4-6. Try pulling the blade back different amounts. But don't pull it back more than about 3 cm from the zero position.

3 cm
maximum

You probably noticed that one ball fell almost straight down to the floor, but the other went out and then down, following a longer path before it hit.

☐**4-5.** Did the distance that the one ball was projected make any difference in the time it took to reach the floor?

☐**4-6.** What does this activity suggest about the time it takes for the ball to reach the floor along the various paths in Activity 4-3?

☐**4-7.** So far as you can tell, does the time to reach the floor depend on how fast the ball is moving horizontally?

☐**4-8.** Does the time of flight seem to depend on the horizontal distance that the ball moves?

☐**4-9.** What two motions does the ball have after the force is applied?

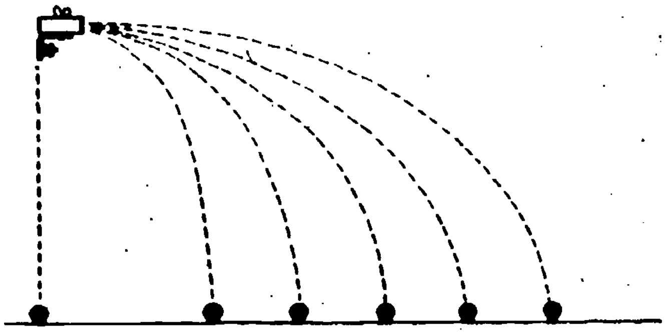
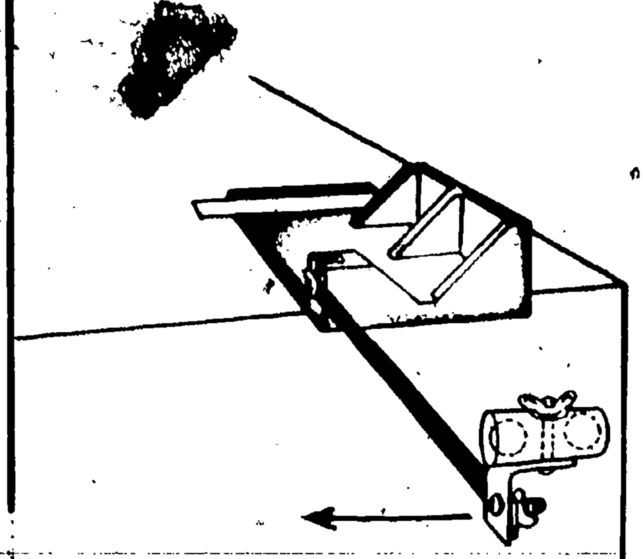


Figure 4-3

From this activity, it appears that the force of gravity always acts to move the ball downward. This downward motion is independent of (not affected by) the horizontal motion of the ball. In other words, the force applied to project the ball horizontally has no effect on the force of gravity. That's why it takes the ball the same length of time to fall to the floor, whether it falls straight down or along a curved path. As long as the ball falls from the same height, the time of fall will be the same. (See Figure 4-3.)

One other thing about falling bodies. Does the time of fall depend on the mass of the object? Get a glass marble the same size as the steel ball, and do the following activity.



Steel ball
and glass marble
in holder

ACTIVITY 4-7. Put the glass marble and the steel ball in the holder and launch them as before. Listen for the sound as they hit the floor. Try changing them around so that each one is projected and each one is dropped.

The steel ball has more than twice the mass of the glass marble.

☐**4-10.** Did the mass of the ball make a difference in the time of fall?

The scientist Galileo made measurements on falling bodies. He found that near the earth an object will fall almost 5 meters in one second. If you would like to know more about Galileo's work, do **Excursion 4-1,** "Time to Fall."

EXCURSION ▶

PROBLEM BREAK 4-1

Your job is to figure out how fast you would have to propel an object to put it into orbit. This is called the *orbiting speed.* Use your knowledge of the way bodies move and the forces that act on them. You should enter the orbiting speeds for the different altitudes of the satellite in Table 4-2 in your Record Book.

To begin the problem, you need to find the orbiting speed at the surface of the earth. Of course, you realize that air friction would slow an object at this low altitude. However, you are only interested in what the speed would have to be. To help you get started, do the following thought experiment.

Suppose you moved your ball launcher to the shore of the ocean on a day when there were no waves to stop the ball. As you increased the propelling force, the steel ball would go farther and farther before falling into the ocean. You know that the surface of the ocean is not really flat. It curves downward with the curve of the earth. Suppose you could propel the ball fast enough so that its curving path was exactly the same as the curve of the earth's surface (Figure 4-4).

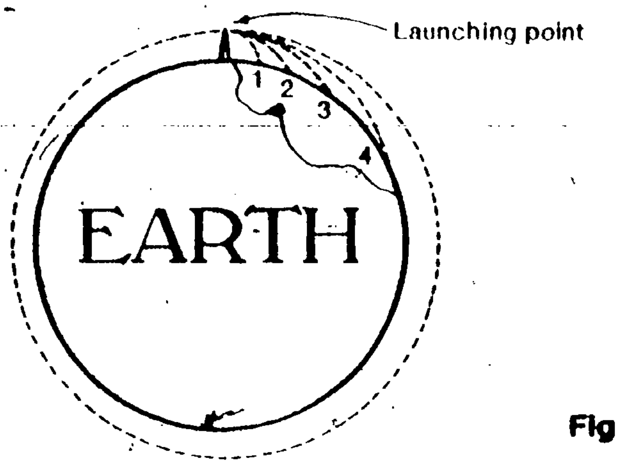


Figure 4-4

☐**4-11.** What would happen to the ball?

Near the earth an object will fall about 4.9 m in one second. If you set your imaginary launching platform at a height of 4.9 m above the surface and if the earth were flat, your ball would hit the earth in one second no matter how far you threw it. But the earth is curved—it curves downward about 4.9 m for every 8 km of distance around the surface. Thus, an object traveling at a speed of 8 km per second would always remain at the same height above the surface as your launching platform (see Figure 4-5).

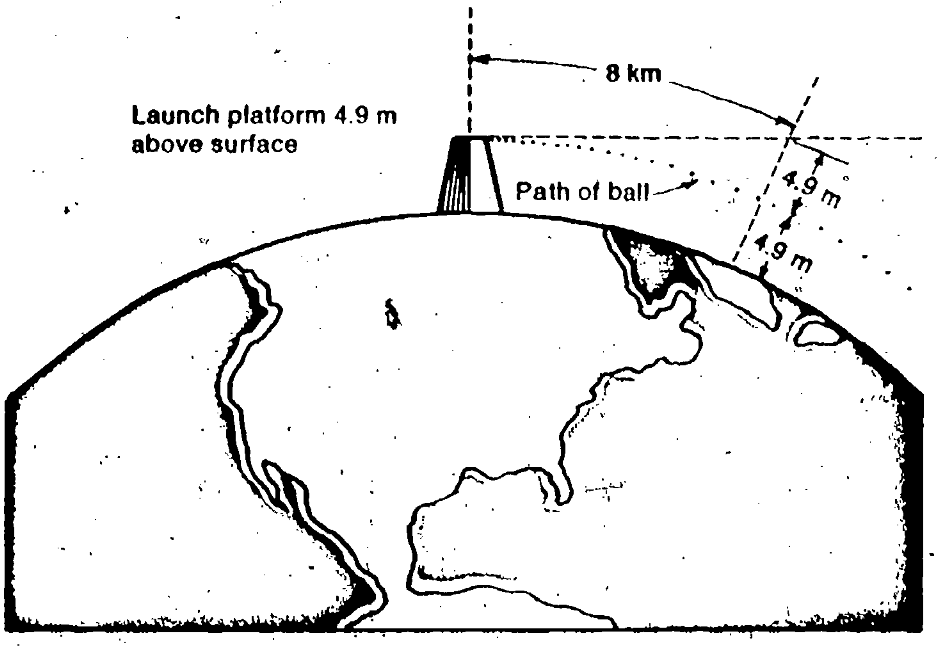


Figure 4-5

The thought experiment should have given you the orbiting speed for a body just above the surface of the earth. Enter this figure on the first line of Table 4-2 in your Record Book.

☐**4-12.** Would the orbiting speed be the same, faster, or slower at a height 10,000 km above the earth?

If you had trouble with this question, you will discover the answer as you complete Table 4-2.

Table 4-2

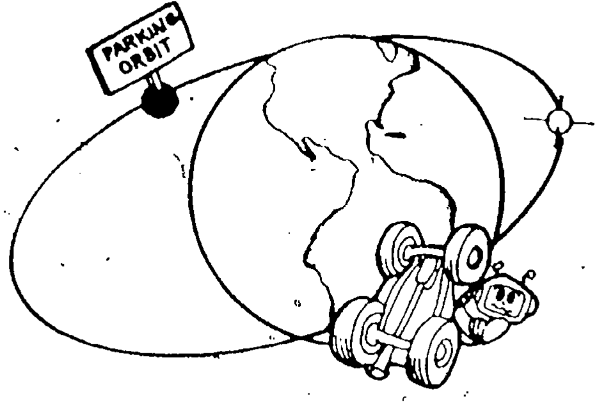
Height of Satellite Above Surface (in km)	Fraction of Speed at Surface of Earth	Orbiting Speed of Satellite (in m/sec)
0 (at surface)*	1.00	
160	0.99	
1,000	0.92	
2,000	0.86	
3,000	0.82	
4,000	0.78	
5,000	0.74	
6,000	0.71	
7,000	0.68	
8,000	0.66	
9,000	0.64	
10,000	0.63	
380,000	0.13	

*Consider this the same as 4.9 m above the surface.

As you move farther out from the earth, the force of gravity decreases. Thus, a body will not fall as far in one second. At the lowest satellite orbit height, 160 km, gravity will be 0.99 of the surface value. At that height an object will fall 0.99 of 4.9 meters in one second. This is slightly less than 4.9 meters in one second. With this smaller amount of fall toward the earth, the orbiting speed will have to be 0.99 of the surface orbiting speed to stay the same distance from the surface of the earth. Find this amount and enter it on the second line of Table 4-2 in your Record Book.

Figure the fraction of the surface orbiting speed for each height. Complete the table by filling in these speeds.

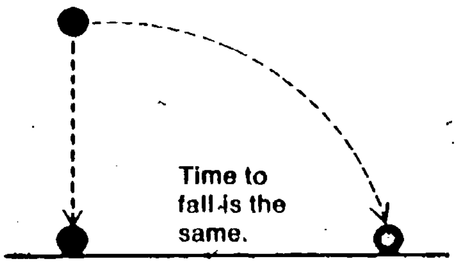
The moon is a natural satellite of the earth. At a distance from the earth of 60 earth radii (380,000 km), the gravity pull of the earth is much less than at the surface. The orbiting speed of the moon is only about 0.13 of the speed of a satellite close to the earth's surface. The last line that you filled in in Table 4-2 is the orbiting speed of the moon.



Even 300 years ago, Newton realized that an object could not be orbited at the surface of the earth. The air drag would slow it too much. But at an altitude of 160 km, the friction of the air is very small. This distance is the *parking orbit* that is used for satellites.

Now let's sum up your knowledge about the motion of an object above the earth's surface.

1. The time that it takes an object to fall to the earth is not dependent on the body's horizontal speed or its mass. The time of fall does depend on the force of gravity (Figure 4-6). Near the surface of the earth, the force of gravity causes a body to fall 4.9 m in one second.



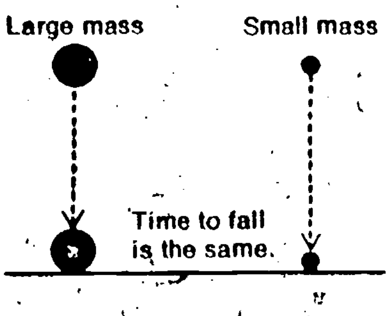


Figure 4-6

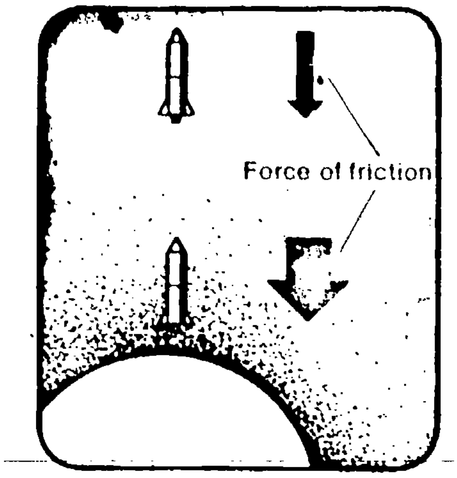


Figure 4-7

2. The atmosphere near the surface of the earth exerts a force on a moving object. The air particles rub against the object and slow it. The friction of the particles against the object produces heat. As the moving object gains altitude, the atmosphere becomes thinner; fewer particles are there. Thus the frictional force is less, and there is less drag on the object (Figure 4-7). For the Saturn-Apollo rockets, air drag is enough to cut down the speed of the rocket at first-stage engine shut-down by about 460 m/sec from what it would be if there were no air drag at all. However, the rocket continues to climb rapidly upward because of its mighty thrust.
3. The force of gravity, which you investigated in Chapter 3, makes it hard for the rocket to get away from the earth. This force is an extremely important one throughout space, as the effect is felt not only from the earth but from the moon and other heavenly bodies as well. Near the surface of the earth, gravity exerts a large force on a body. As the body goes away from the earth's surface, the force of gravity decreases (Figure 4-8). For example, at a point 6,500 km above the earth's surface (about twice the distance from the center of the earth to the surface), gravity force is only ¼ what it is at the earth's surface.

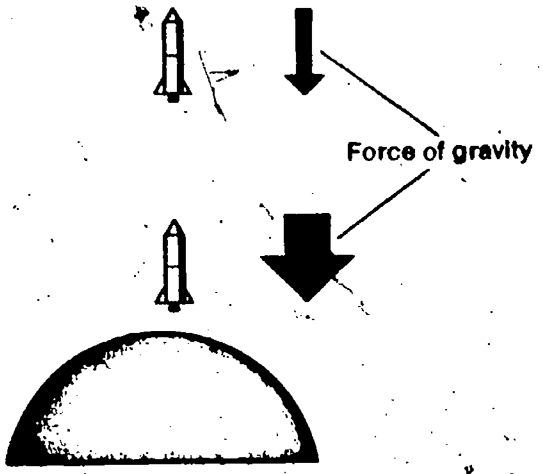


Figure 4-8

EXCURSION

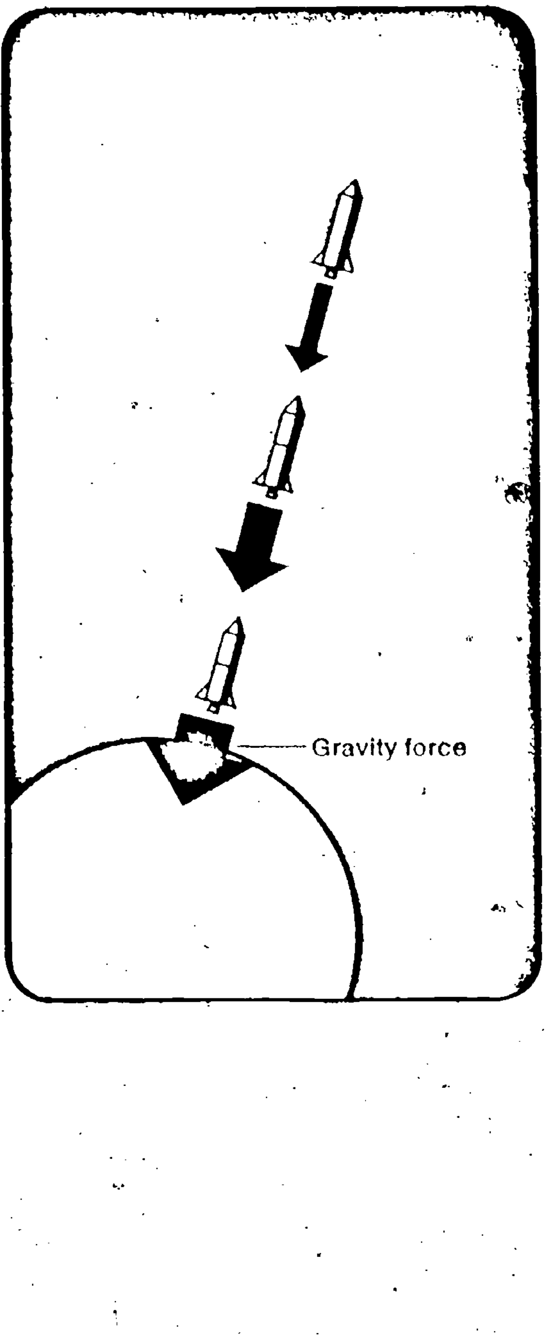
If you would like to find out more about gravity and its effect on objects, try **Excursion 4-2,** "The Falling Apple."

The force of gravity on an object is called the object's weight. The data in Table 4-3 illustrates how the weight of an object changes as it gets farther from the earth's surface.

☐**4-13.** Using the data in the table and the grid in Figure 4-9 in your Record Book, draw a graph of the change in weight with increased distance from the earth's surface.

Table 4-3

Distance from Earth's Surface (in km)	Weight of Object Exerting 100 N at Surface
0	100
100	97
200	94
500	86
1,000	75
1,500	66
2,500	52
3,500	42
4,500	34
5,500	29
6,500	25
7,500	21
8,500	18



Use your graph to answer the next two questions.

☐**4-14.** At what distance from the earth's surface is the weight $\frac{1}{2}$ (50 N) of what it is at the surface?

☐**4-15.** At what distance is the weight $\frac{1}{4}$ (25 N) of what it is at the surface?

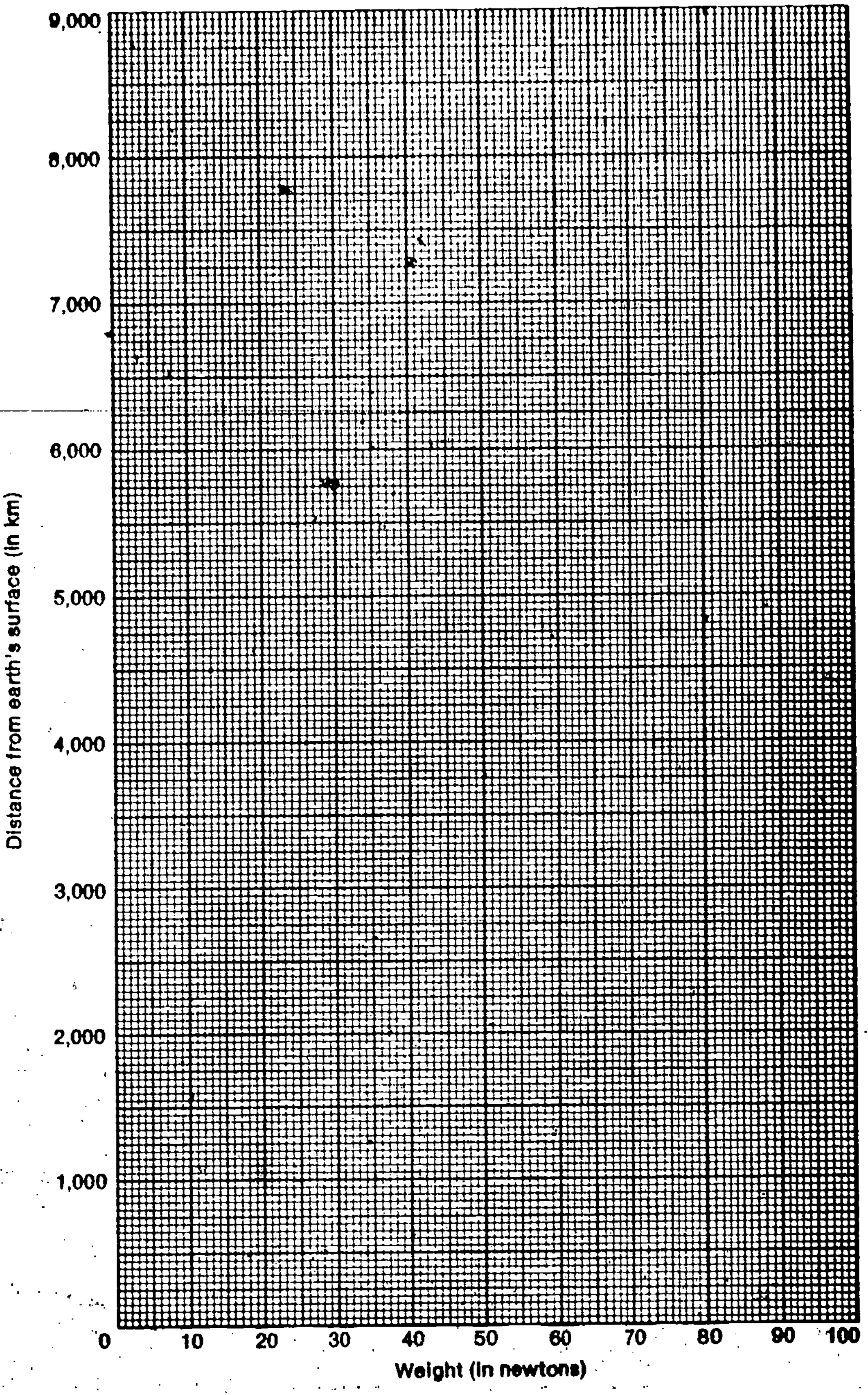

9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
Distance from earth's surface (in km)
0
10
20
30
40
50
60
70
80
90
100
Weight (in newtons)

Figure 4-9

Notice that question 4-15 could be answered in two ways. It does not state "from what" the distance is to be measured. If you did **Excursion 4-2,** you know that the force of gravity acts as if all the mass were concentrated at the center of each body. To really compare the forces of gravity, you should add the distance to the center of the earth (the earth's radius) to your distance from the surface. The distance to the center of the earth is 6,371 km (Figure 4-10). Add this to the distance in question 4-15.

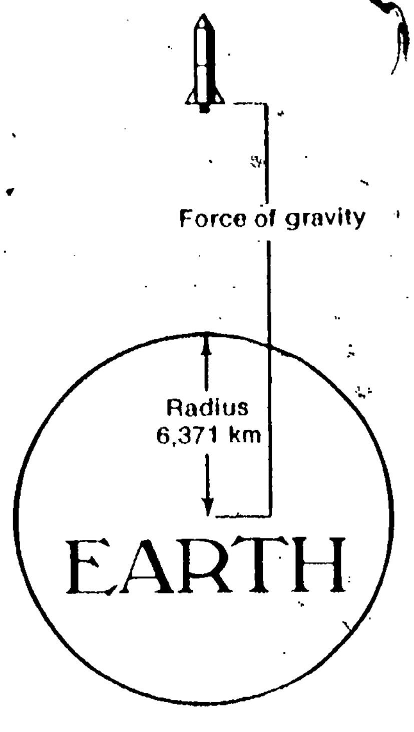


Figure 4-10

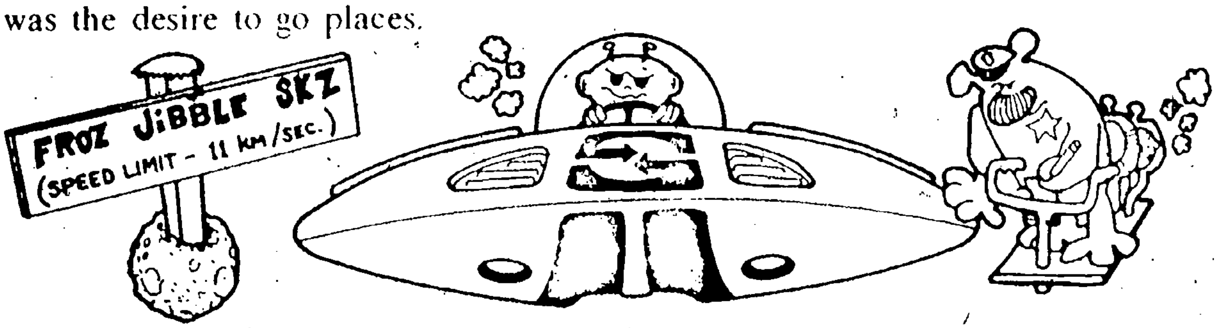
☐**4-16.** At what distance from the center of the earth is the weight 25 N ($\frac{1}{4}$ of what it is at the surface)?

The force of the earth's gravity gets smaller and smaller as a rocket speeds away from its surface. However, this force, even though small, continues to exist.

If there is no place where the earth's gravity is zero, it seems reasonable to conclude that a rocket shot straight up will eventually fall straight back to the earth. How, then, can it be put in orbit around the earth? As you have found, it is necessary to give it a horizontal shove to get it into orbit.

TO THE MOON

It's no fun just to get in a car and drive around the neighborhood. You like to go somewhere, to take trips, to see things. The same is true in space travel. The first space flights were concerned with the problem of getting away from the earth and getting into orbit. Once this was mastered, there was the desire to go places.



Let's start with a rocket on the pad and follow it all the way on a journey into deep space. This will help sum up all the ideas that have been developed in this unit.

☐**4-17.** For the rocket to lift off the pad, how must the thrust force compare with the weight force of the loaded rocket?

☐**4-18.** How will the amount of thrust produced by the engines at ground level compare with the thrust at higher altitudes?

☐**4-19.** As the rocket rises faster and faster, what force opposing its motion will increase to a maximum and then decrease?

☐**4-20.** What other force opposes the rocket motion and decreases as the rocket gets farther from the earth?

You recently found that an object just above the surface of the earth would have to travel 8 km per second in order to stay the same distance from the earth.

☐**4-21.** How many miles per hour is 8 km per second?

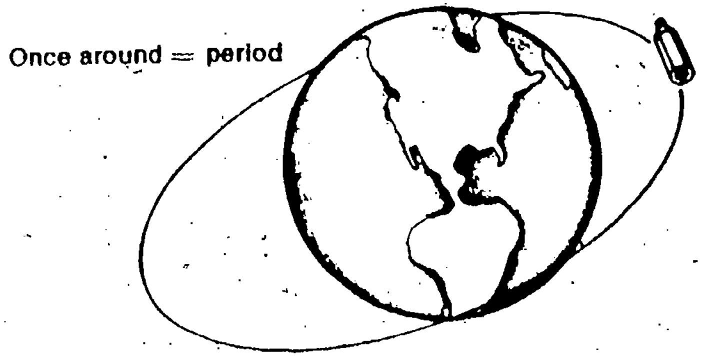
Just above the surface of the earth, the force of gravity is large and the atmosphere is thick. Both of these factors act against the rocket.

The pull of gravity and the thickness of the earth's atmosphere decrease as you go away from the earth's surface. With less gravity, spacecraft far above the earth don't need to travel as fast as those at lower altitudes to stay in orbit.

☐**4-22.** The time needed for a satellite to go once around in its orbit is the *period* of that satellite. What is the earth's period as a satellite of the sun?

☐**4-23.** How many seconds would it take for the object traveling at 8 km per second to make one trip around the earth? (The circumference of the earth is about 40,000 km.)

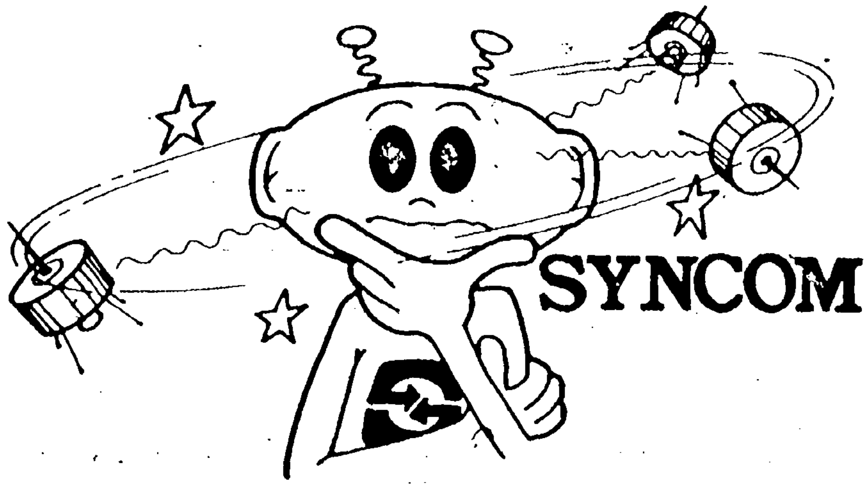
☐**4-24.** What effect would a higher orbit have on the period of a spacecraft?



Not only does the speed of a body decrease as it orbits farther from the earth, but the body also has farther to travel. So the period gets greater (it takes longer to go around) because of a slower speed and a greater distance. A spaceship orbiting at an altitude of 161 km has a period of just under 90 minutes, and it travels at almost 8,000 meters per second. The moon, a natural satellite of the earth, has a period of 27⅓ days. At its distance—380,000 km—it takes the moon 27⅓ days to orbit the earth. And because of decreased gravity, the moon's speed is only about one eighth the speed of the spaceship that closely orbits the earth.

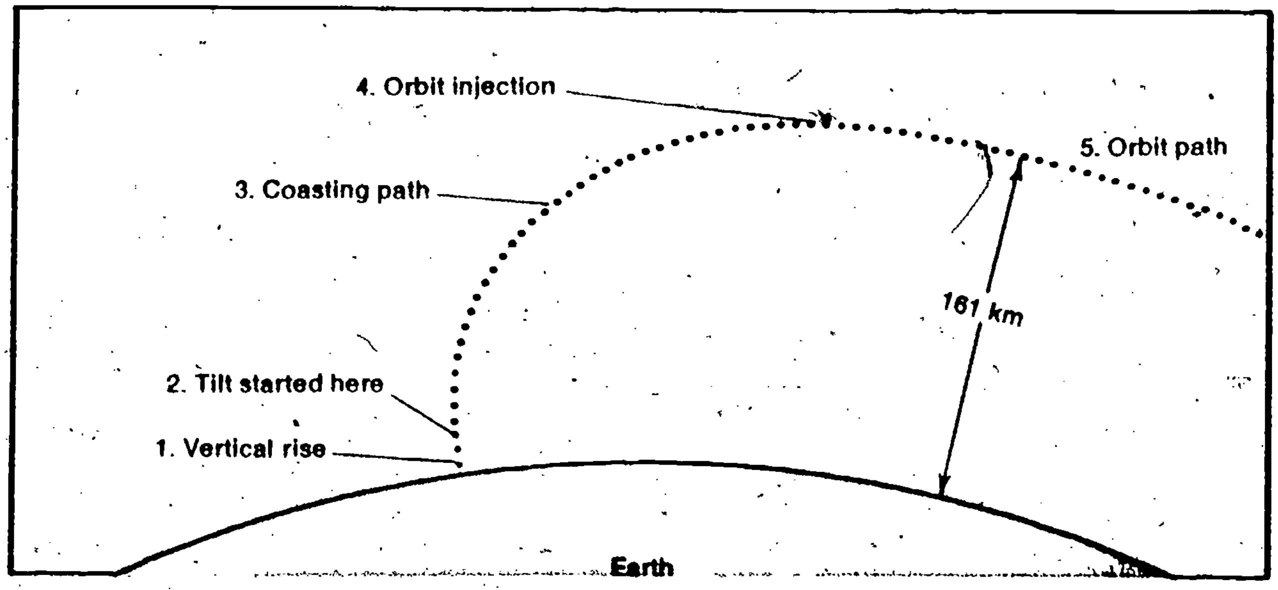
If you would like to take a further look at satellite orbits, do **Excursion 4-3,** "Orbiting Syncom."

EXCURSION



Let's get back to our rocket ship. Putting a satellite into orbit involves five steps. Figure 4-11 illustrates these steps.

Figure 4-11



1. The rocket rises vertically from the pad.
2. After rising some distance vertically, it is tilted.
3. It climbs on a curving path to orbit height.
4. As the rocket reaches the necessary speed for orbiting, the engines shut down.
5. It then moves along the circular orbit path. (The orbit will be circular only if the rocket has exactly the right speed. If it is less than the correct amount, the satellite will come back closer to the earth. There it will encounter denser atmosphere, which will slow it even more and eventually cause it to return to the earth or burn up.)

It is now time for the rocket to head out into space. How can this be done? The key is more speed. A slightly greater speed gives an elliptical orbit, but if the speed is increased enough, the rocket will escape into space. The following figures and explanations will help to make this clear.

At speeds less than about 8 km/sec (28,800 km/hr), the object will reenter the earth's atmosphere and return to the surface (Figure 4-12).

Figure 4-12

If the speed is exactly correct for the altitude of the object, a circular orbit will be the result. At an altitude of 161 km, this speed is just under 8 km/sec (Figure 4-13).

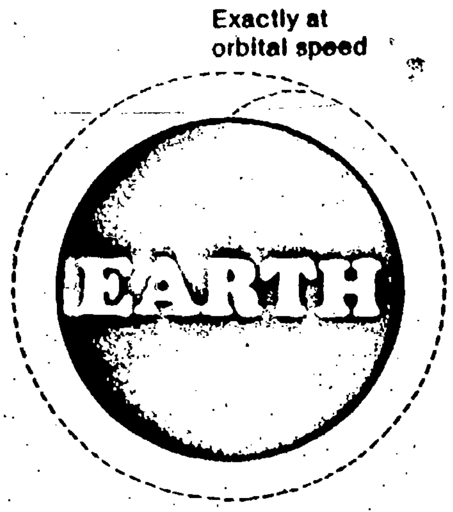


Figure 4-13

At speeds from 8 km/sec to 11 km/sec (28,800 km/hr to 40,000 km/hr), the orbit will be elliptical. The greatest speed will be closest to the earth (perigee). The slowest speed will be farthest from the earth (apogee). (See Figure 4-14.)

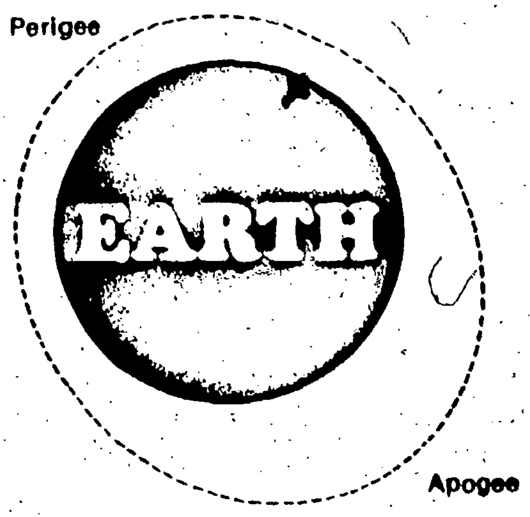


Figure 4-14

If a speed of greater than 11 km/sec (40,000 km/hr) is reached, the object will escape the gravitational pull of the earth. It will head for outer space (Figure 4-15). This necessary speed is given to the Apollo spacecraft by a "burn" of just under 6 minutes of the third-stage booster. This additional force increases the speed just over 3 km/sec.

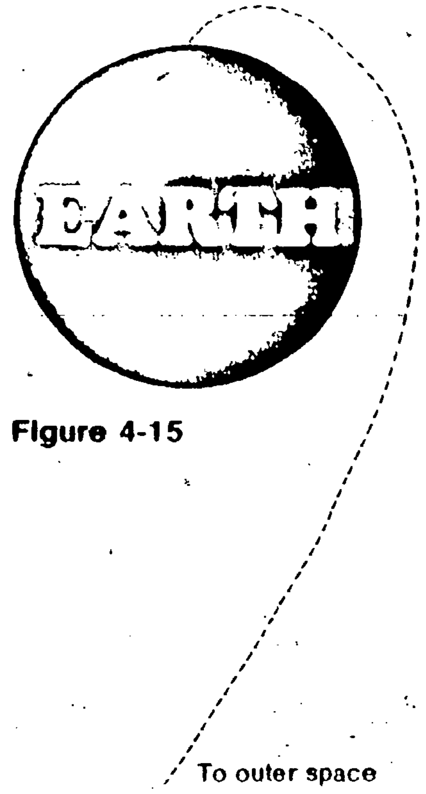


Figure 4-15

If the spacecraft leaves its parking orbit around the earth at just the right time, it will head for the moon. It will be on a "free-return path." This means that with only slight corrections, it will swing around the moon and head back to the earth. Figure 4-16 diagrams this path, which looks like a huge figure 8.

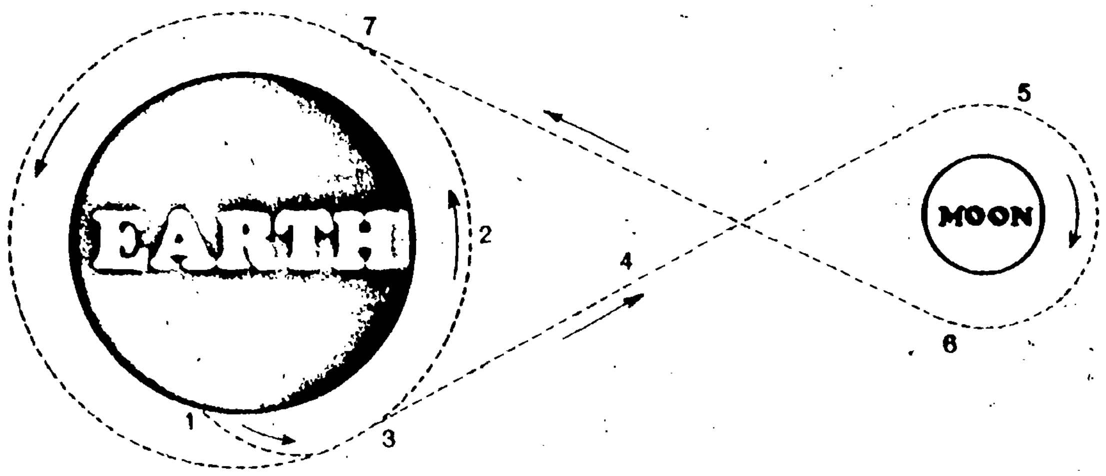


Figure 4-16

No rocket power is needed on this free-return path to and from the moon. The spacecraft would continue this figure-8 path indefinitely, swinging first around the moon and then around the earth.

Here are the steps needed to get the free-return path to and from the earth to the moon (Figure 4-16).

1. Lift-off and insertion in parking orbit
2. Parking orbit around the earth
3. Insertion in free-return path to the moon
4. Free-return path to the moon
5. Capture by the moon's gravity and half-orbit around the moon

6. Leave the moon's gravity and head back to the earth on free-return path
7. Capture by the earth's gravity and half-orbit around the earth

☐**4-25.** If a spacecraft is to stay in a moon orbit for a while, what must be done?

☐**4-26.** What must be done for a spacecraft to leave a moon orbit and get back to the earth?

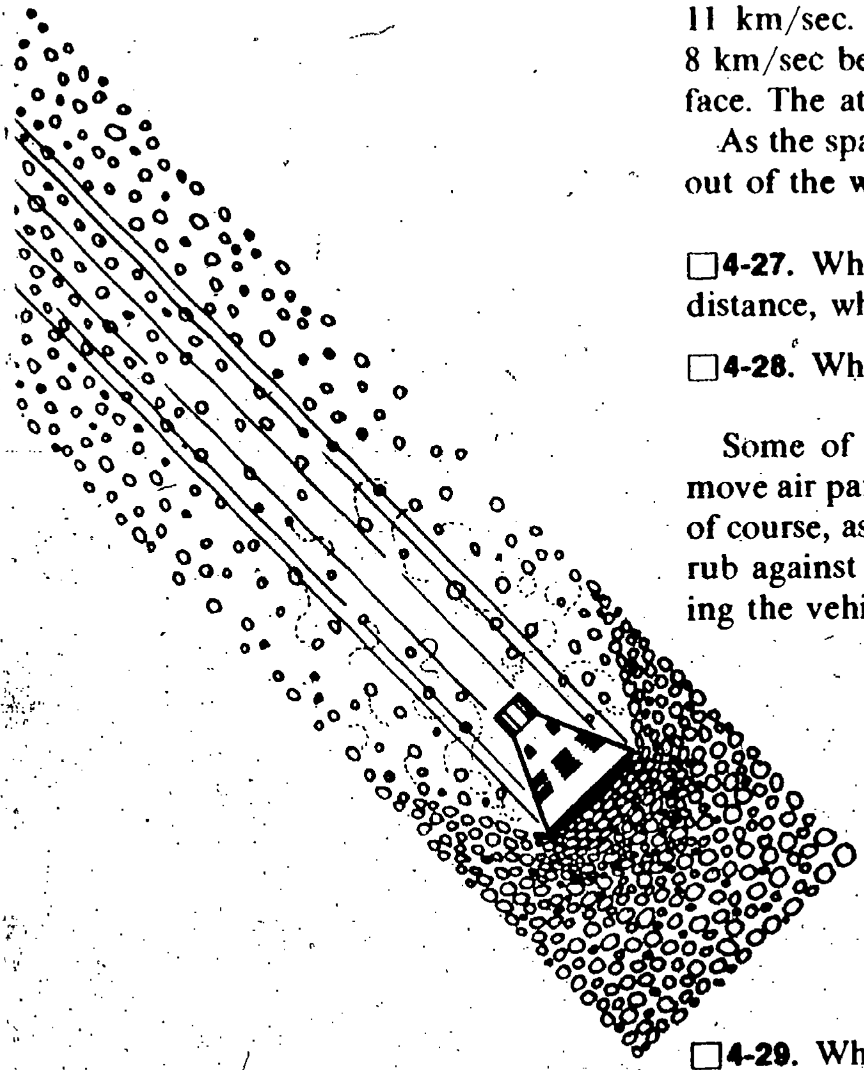
If the craft is to return to the surface of the earth, its direction (point 6, Figure 4-16) must be changed a little. Instead of entering an earth orbit (point 7, Figure 4-16), the craft heads closer to the earth into the upper atmosphere. Its speed at the time it enters the atmosphere is about 11 km/sec. This high speed must be decreased to below 8 km/sec before the craft can come back to the earth's surface. The atmosphere makes this slowing down possible.

As the spacecraft begins to hit air particles, it pushes them out of the way.

☐**4-27.** When a force is applied to move something some distance, what is done?

☐**4-28.** When work is done, what else is involved?

Some of the motion energy of the spacecraft is used to move air particles aside. Thus, the craft is slowed down. And, of course, as the air particles are pushed out of the way, they rub against the spacecraft. This causes friction (drag), slowing the vehicle still more.



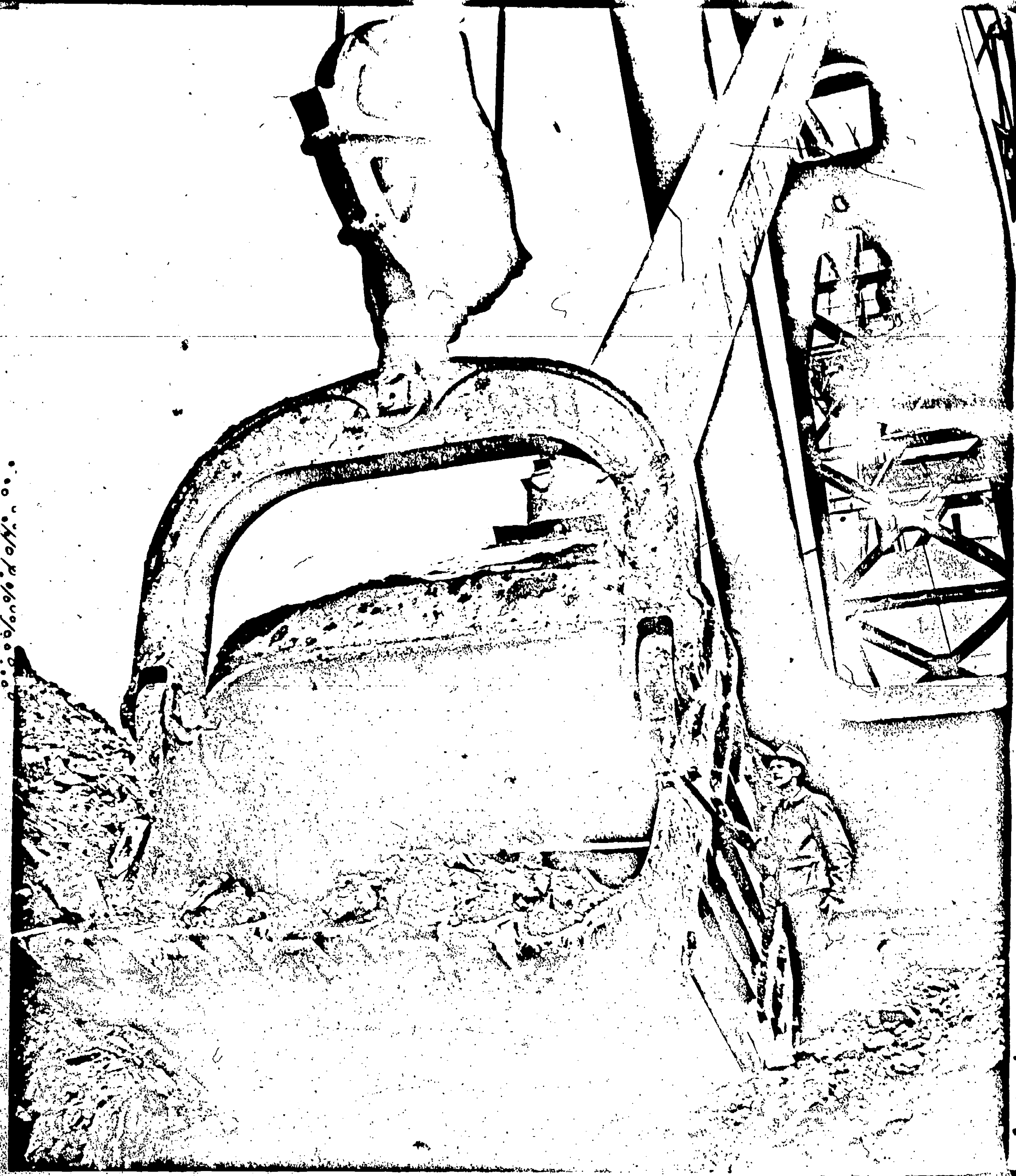
☐**4-29.** When friction drag is present, what happens to the surroundings?

At the enormous speed of a spacecraft, a huge amount of heat is produced, so much that the craft and its occupants would burn up without some kind of heat shield. You may recall that it takes heat to melt or boil a material. Perhaps the heat that would otherwise do damage can be sidetracked by using it to melt and boil a coating on the outside of the spacecraft. With such a material as a heat shield, the heat energy would be used up as it gradually melted and boiled the coating away and the occupants could stay cool. Such a material is now used on the outside of spacecraft, and it doesn't harm the vehicle as it burns up. It just gets rid of the heat. If you would like to know more about this process, called *ablation,* do **Excursion 4-4,** "Losing Heat."

EXCURSION

You have found out some things about rockets and their operation. You have also found out about travel in space. Who knows? You might be an active member of a space team to the moon some day.

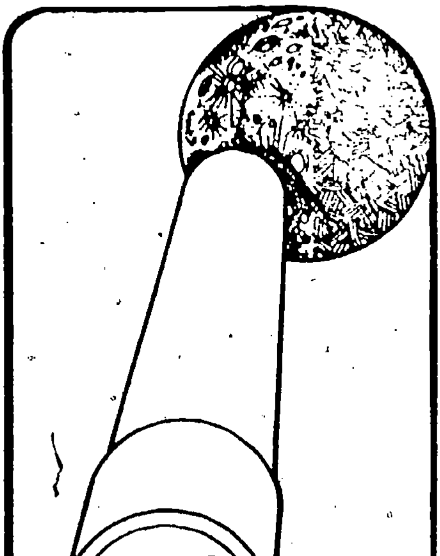
Before going on, do Self Evaluation 4 in your Record Book.



Creating Craters

Chapter 5

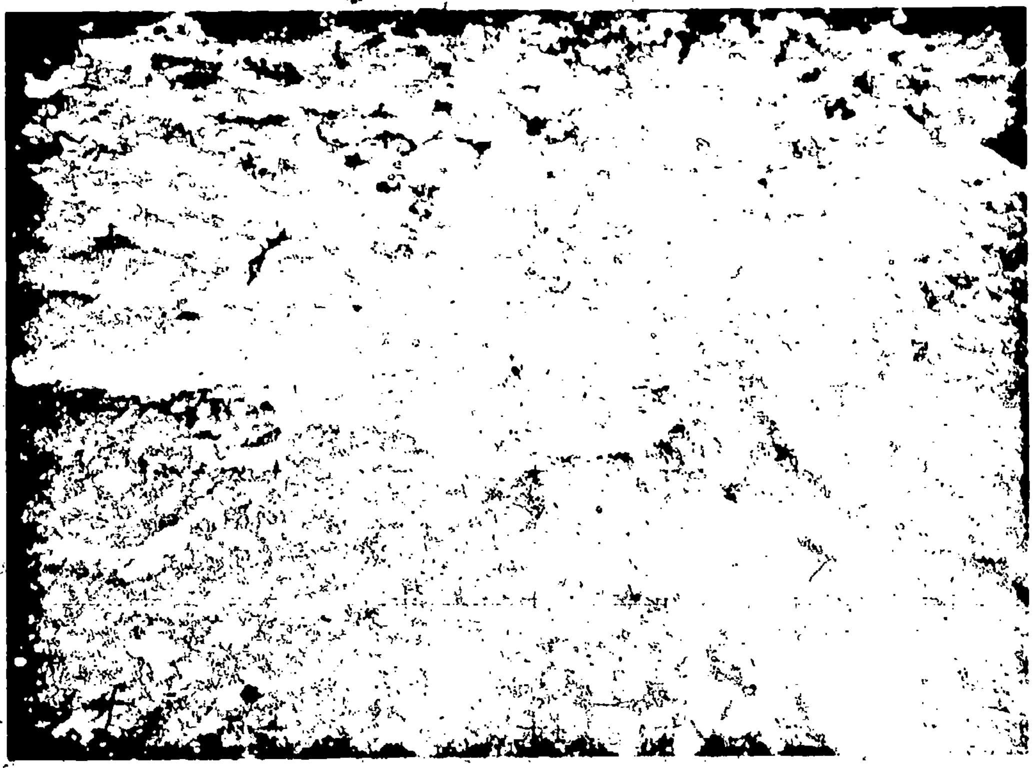
Until the time of Galileo, people thought the surface of the moon was smooth. They believed the pattern of dark areas on the moon's surface was like a stain or tarnish.



When Galileo looked at the moon through his telescope, he decided that the surface was not smooth. He believed the shadows and light spots were valleys and mountains similar to those on the earth. He thought the large dark areas were water.

In Galileo's day, scientific writing was done in Latin. The Latin name for sea is *mare* (pronounced "mah-ray"). This word is still used on many charts of the moon today. The Apollo 11 astronauts landed on Mare Tranquillitatis (in English, the Sea of Tranquility).

Galileo also saw shapes that looked like the craters of volcanoes. Some of these had long, light-colored streaks radiating from them far out over the surface of the moon. The streaks became known as rays. Some of the craters were given names. They were named for famous men, like Galileo, Copernicus, and Kepler.



Few people who looked at the moon from the earth could see the things that Galileo described. One of the difficulties with looking at a surface from far away is that it is so hard to see features as they really are. Everything seems flat.

There are some very tall mountains on the moon. Some are as high as the tallest earth mountains. Distance has a great effect on how high they appear to be.

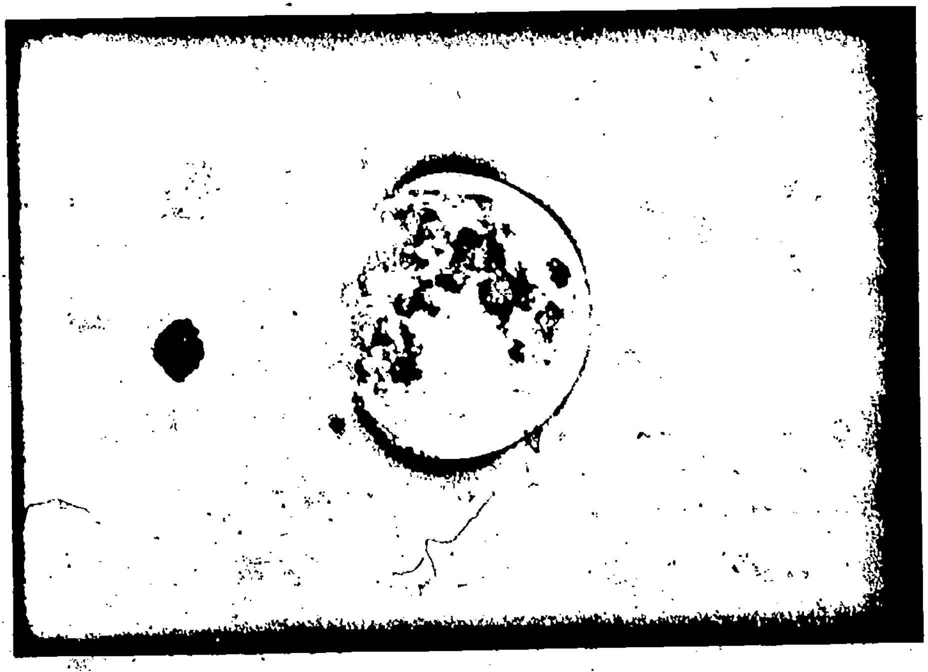
☐**5-1.** If you were to look back at the earth from far out in space, would you be able to see the height of its mountains?

Figure 5-1 shows an astronaut's view of a moon mountain.

Figure 5-1

A great deal has been learned about the moon since Galileo's time. More photographs, plus rocks and soil, have been sent back from orbiting satellites and brought back by men who have been there. Of course there are still many things to be learned (Figure 5-2).

Figure 5-2



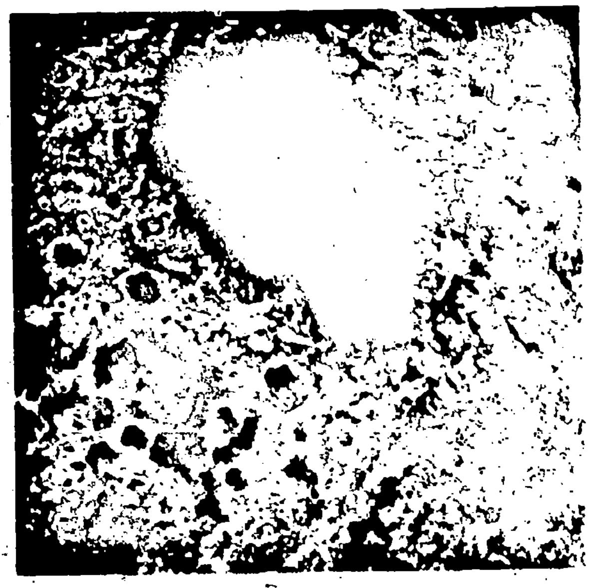
Scientists are particularly interested in finding out how the moon's surface became as it is. In fact, they are concerned with how the moon came into being and how its age is related to that of the earth. Other questions about the moon might include these:

1. Did the moon start as a hot, melted globe of matter, which then cooled down?
2. Was the moon once a part of ~~the~~ earth—a fragment that became separated from it long ago?
3. Was the moon built slowly out of pieces of material that came together as they moved through space around the earth and the sun?
4. Has the moon always been cold and airless?
5. Were there ever any volcanoes there?

For the rest of this unit, you will be studying some surface features of the moon. Some comparisons will be made with earth features. These comparisons and some activities may help you explain how the moon's surface got the way it is.

Begin your study by examining some moon and earth photos. Figures 5-3 through 5-6 show craters and mountains on the moon.

Figure 5-3



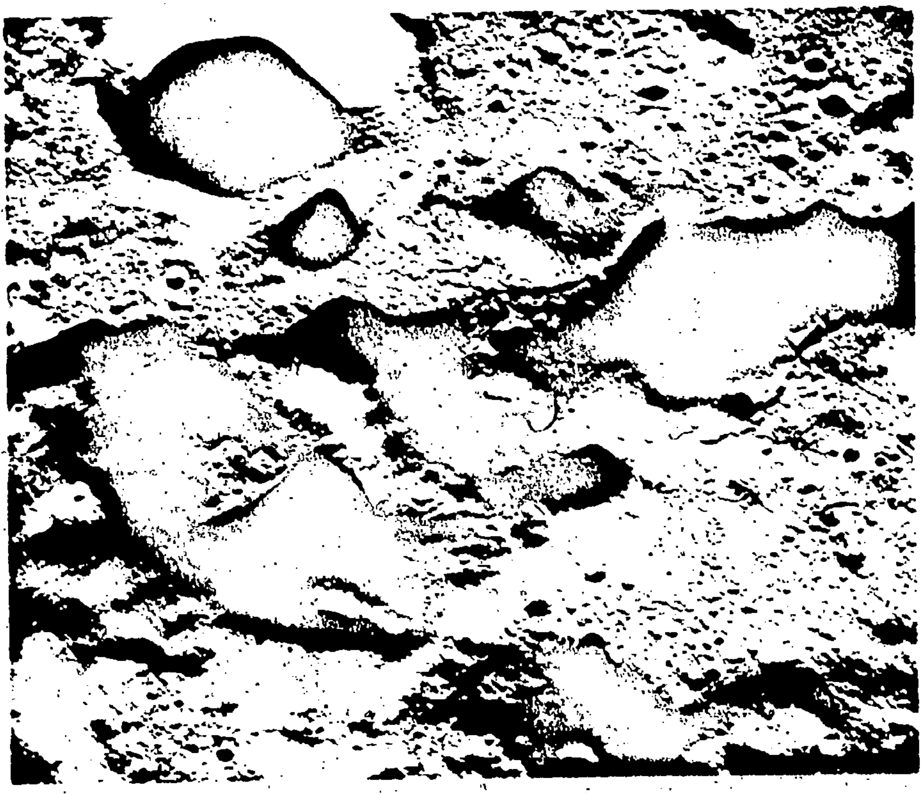


Figure 5-4

Figure 5-5

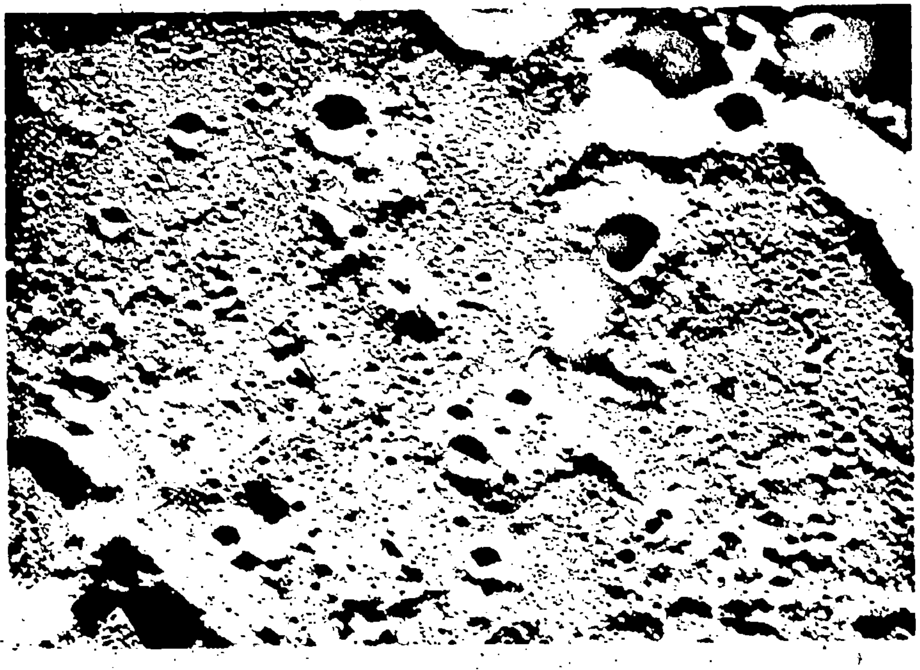
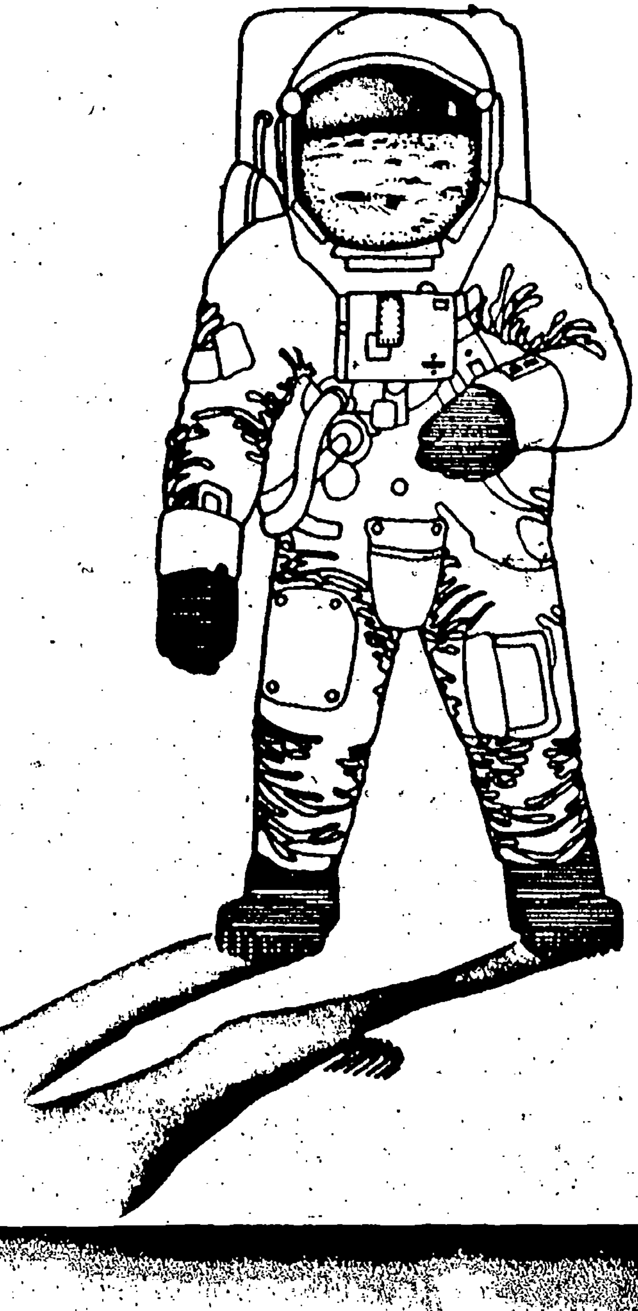


Figure 5-6



☐**5-2.** What do you think could have caused the craters shown in Figures 5-4 and 5-5?

☐**5-3.** What might have produced the groove that runs through the crater in Figure 5-5?

You probably had reasons for the answers you gave to questions 5-2 and 5-3. But it's not easy to decide. It might help to be able to examine features on the earth similar to the ones shown, if there are any.

There are various kinds of craters on the earth. You know what a crater is—it's like a bowl-shaped hole. In the following photos, you will have the opportunity to examine some of these bowl-bottomed holes. As you do, see if you can spot the differences in them. Perhaps this will help you later, when you examine similar features on the moon's surface.

Many cinder cones, with craters in the top, can be found on the earth. This one is in Lassen Volcanic National Park. Note the related lava flows. Also notice that there is a double cone (Figure 5-7).

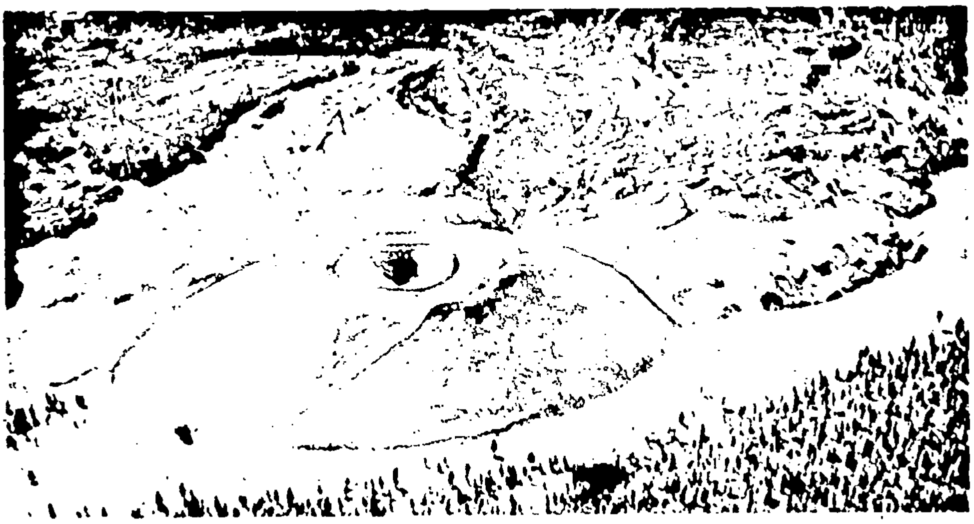
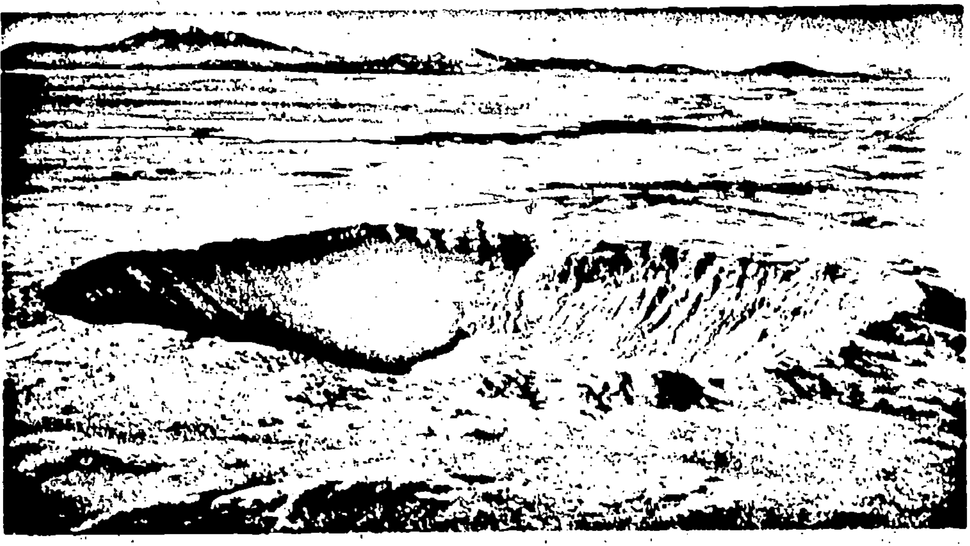


Figure 5-7

Meteor Crater near Winslow, Arizona, has a raised rim. Metallic fragments have been found around the rim. The floor of the crater is about 150 meters below the surrounding ground. There are no other features like it in the immediate vicinity (Figure 5-8).

Figure 5-8



This is Crater Lake, a national park in Oregon. After erupting centuries ago, the upper half of the volcanic mountain collapsed into the center, forming a huge pit that filled with water. Just over the rim can be seen the flat-topped cone of Wizard Island, a newer volcano that arose from the old shell (Figure 5-9).

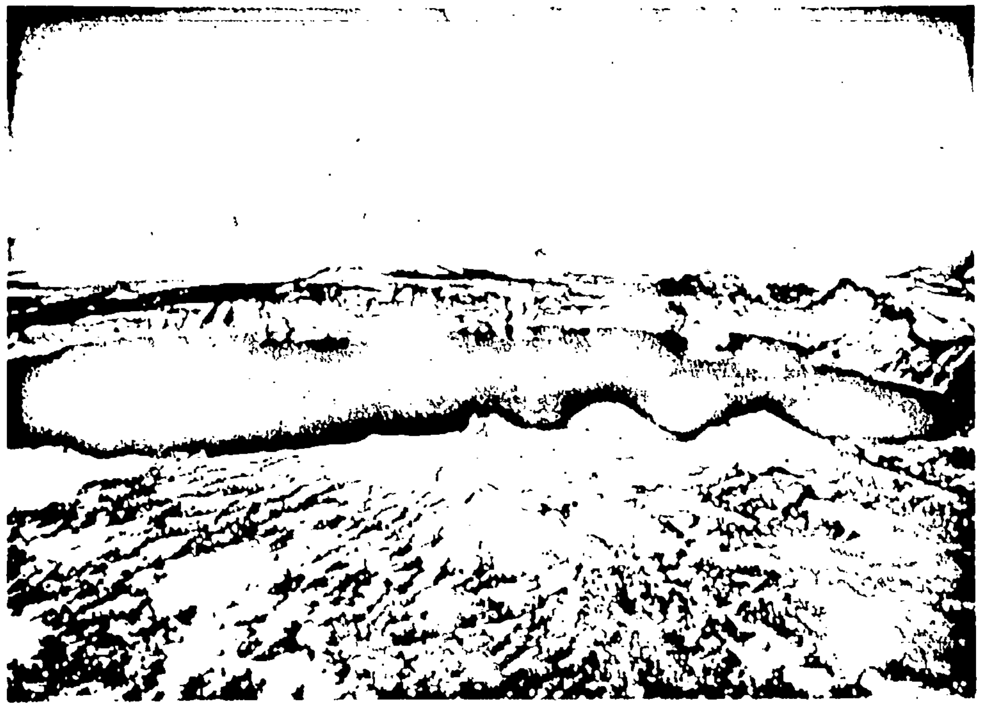


Figure 5-9

Wolf Meteorite Crater in Australia was discovered in 1947. Notice the raised rim. The floor is below the level of the surrounding terrain (Figure 5-10).

Figure 5-10

An underground atomic blast was set off at a test site in Nevada. The resulting circular hole is about 365 meters in diameter. Notice how material was thrown out. The crater walls are quite sloping instead of vertical (Figure 5-11).

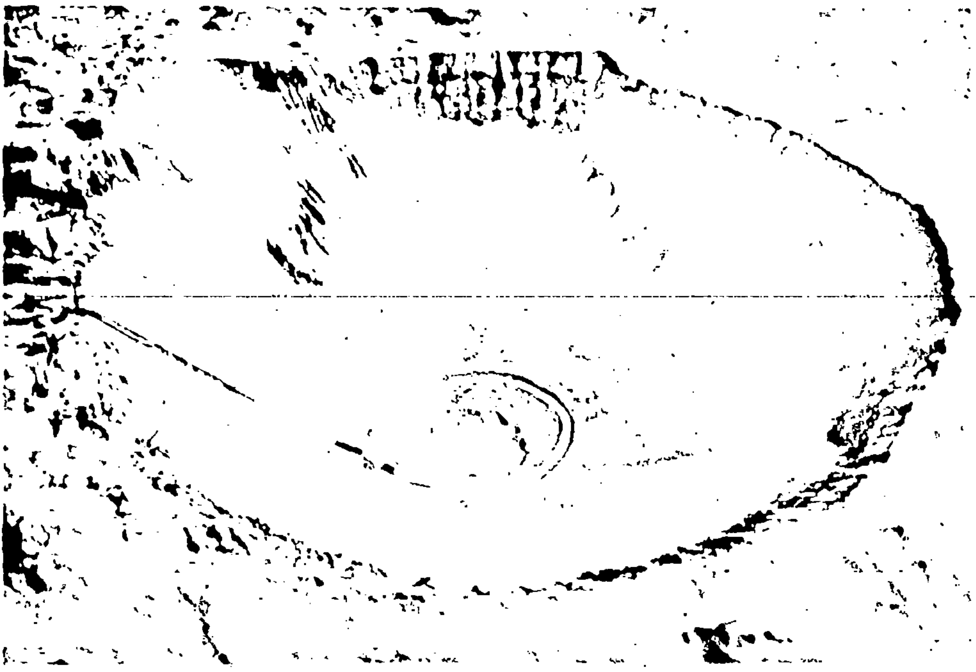
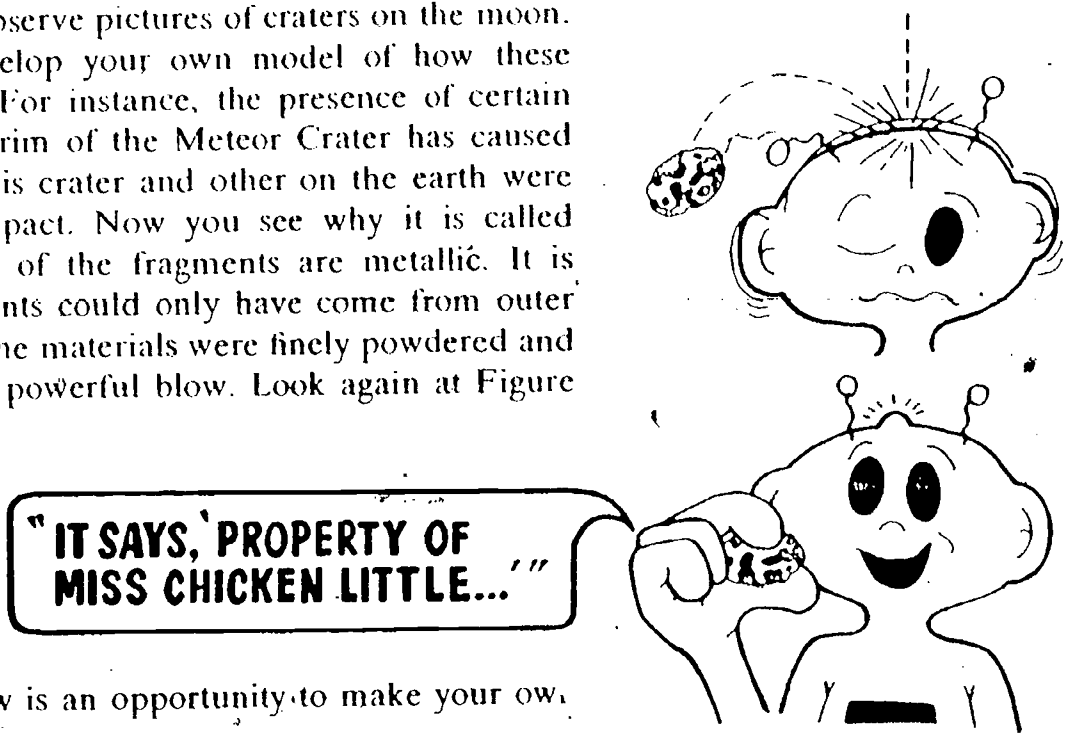


Figure 5-11

This active volcano in Alaska has a well-defined crater. The cone was built by former eruptions, but only steam and gases are sent out now (Figure 5-12).

Figure 5-12

What you've learned by examining features on the earth can help you as you observe pictures of craters on the moon. Perhaps you can develop your own model of how these craters were formed. For instance, the presence of certain materials around the rim of the Meteor Crater has caused scientists to believe this crater and other on the earth were caused by meteor impact. Now you see why it is called Meteor Crater. Some of the fragments are metallic. It is believed these fragments could only have come from outer space. In addition, some materials were finely powdered and broken up, as if by a powerful blow. Look again at Figure 5-8.



What you need now is an opportunity to make your own craters.

At first glance, moon craters most nearly resemble meteor craters on the earth. Figure 5-13 shows one of each.

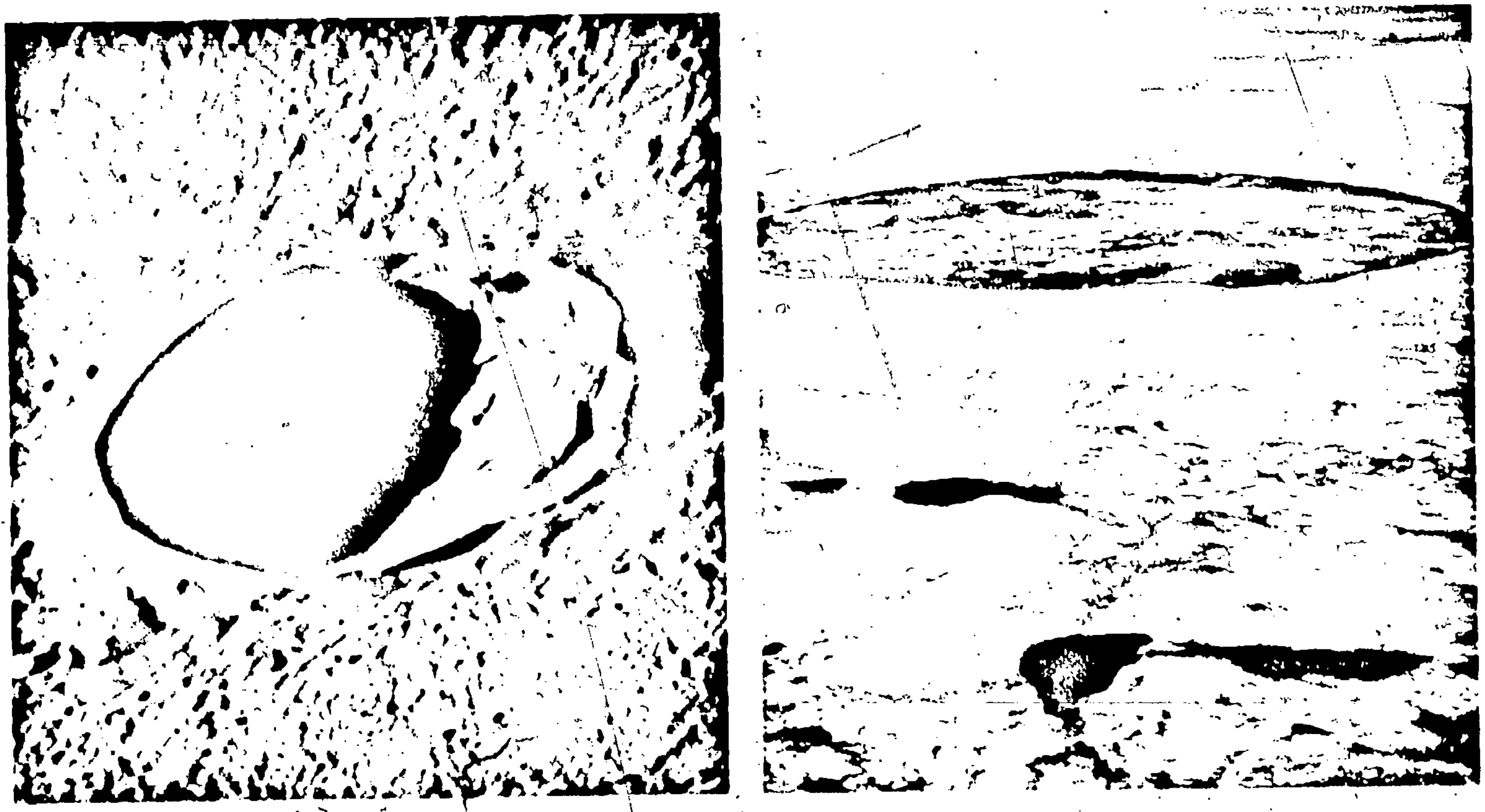
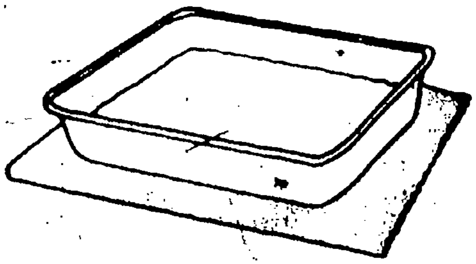


Figure 5-13

You can see for yourself how craters like these are formed. Remember, however, that a real meteor striking a surface would be traveling at a very high speed. Your activity can only approximate what would really happen if a high-speed meteor struck the moon's surface. You will need the following equipment:

1 aluminum pan
1 sheet of newspaper
1 small steel ball
1 meterstick
Sand
1 floodlight or unshaded bulb
1 small glass marble
1 meter of thread
Tape

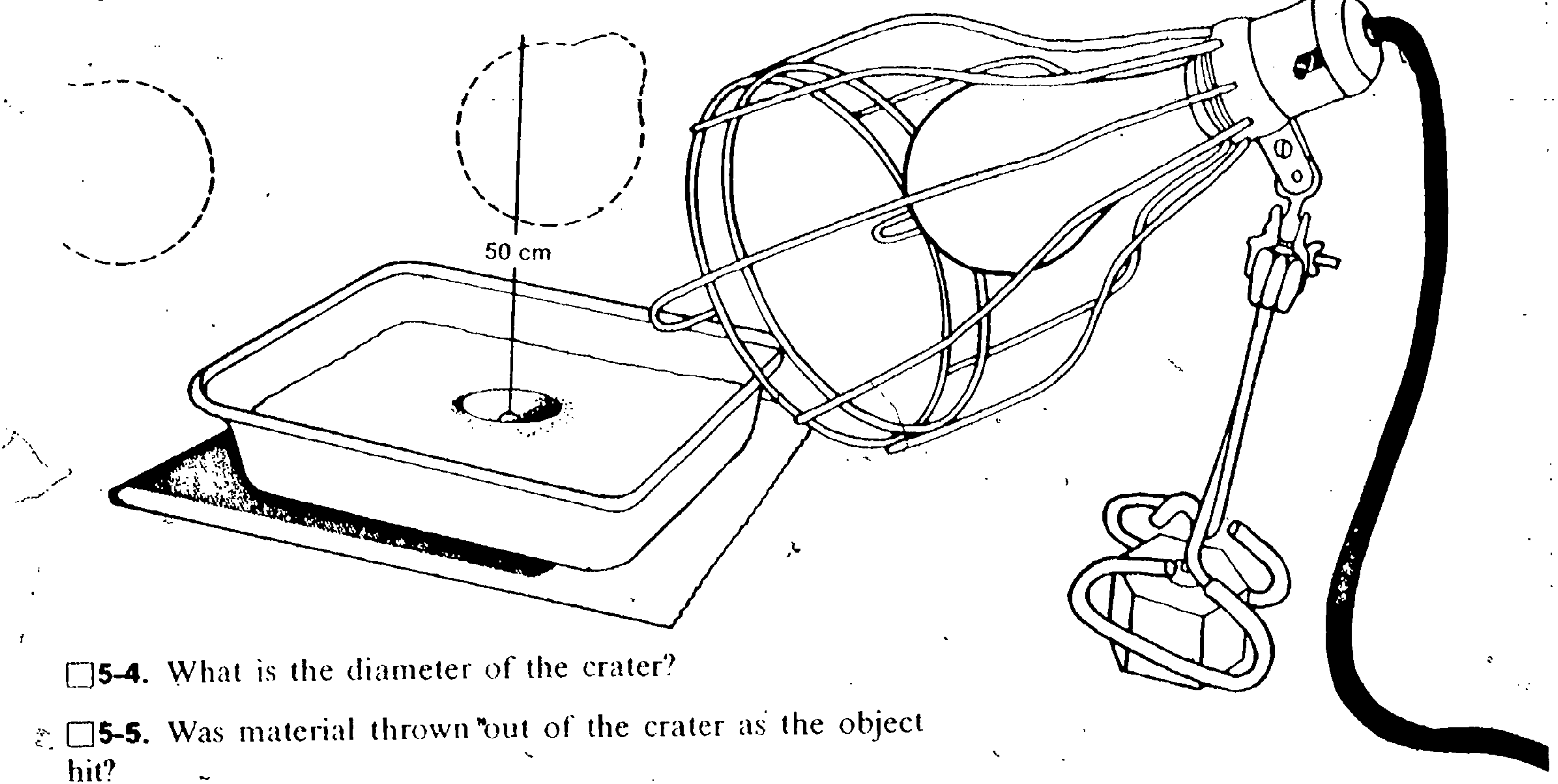
ACTIVITY 5-1. Lay the sheet of newspaper on the floor. Place the pan in the center of the newspaper. Pour sand into the pan to a depth of about 3 cm. Smooth the sand with your hand, but do not shake the pan or pack the sand down.



ACTIVITY 5-2. Attach the thread to the ball with a small piece of tape.

ACTIVITY 5-3. Hold the ball 50 cm above the sand. Leave some slack in the thread so that when you release the ball, it won't be jerked back.

ACTIVITY 5-4. Drop the small steel ball into the sand from the 50-cm height. Gently lift the ball straight up out of the sand. Then examine the crater that was formed. Use the floodlight to illuminate the crater from the side at different angles. Measure the diameter of the crater.



☐**5-4.** What is the diameter of the crater?

☐**5-5.** Was material thrown out of the crater as the object hit?

☐**5-6.** Is there a raised rim around the crater?

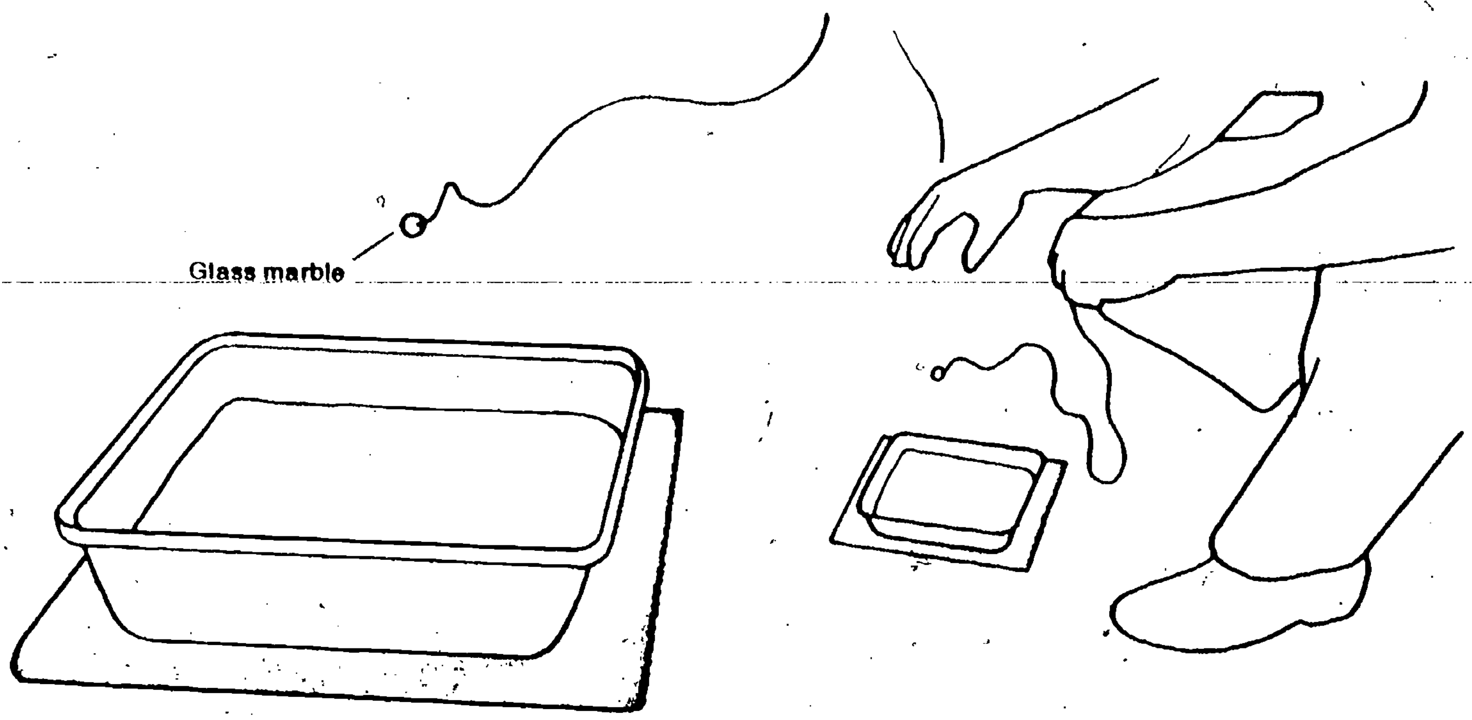
☐**5-7.** Is the floor of the crater below the level of the surrounding surface?

☐**5-8.** How many times greater is the diameter of the crater than the diameter of the ball?

When the ball hits the sand, it does work on it to move it out of the way. To do work, a body must have energy.

From your past experience, you may recall that the energy of a body in motion depends on its mass (the quantity of matter) and its speed (how fast it is traveling). You can test the effect of these factors by varying them, one at a time, and measuring the diameter of the crater formed. First, try changing the mass. You have already used the steel ball, so now you can use the glass marble.

ACTIVITY 5-5. Smooth out the sand, but do not pack it down. Drop the glass marble from the same 50-cm height. Remove the marble and measure the diameter of the crater.



☐**5-9.** What is the diameter of the crater?

☐**5-10.** Compare the size of the crater formed by the glass marble with that formed by the steel ball.

The mass of the steel ball is more than twice that of the glass marble. Although you could not measure how much, you probably noticed that more sand was removed by the impact of the steel ball.

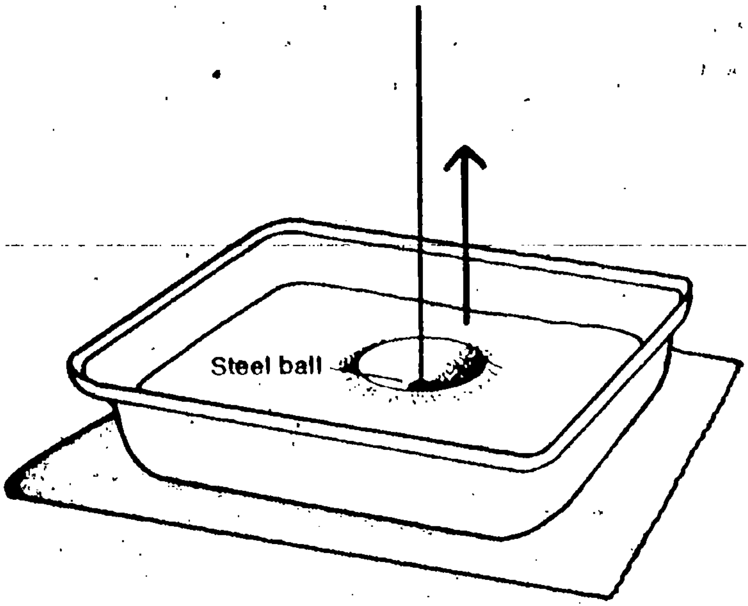
Next, try varying the speed. Two simple rules will help you in making this test.

EXCURSION

1. Objects of the same size when dropped from the same height fall at the same speed, no matter how heavy they are. **Excursion 4-1,** "Time to Fall," should help you understand this statement.
2. A body hits at a greater speed if it is dropped from a greater height.

Rule 1 means that the steel ball and the glass marble fell at equal speeds in Activities 5-4 and 5-5. Rule 2 will enable you to test the effect of speed on crater formation.

ACTIVITY 5-6. Smooth out the sand again, but do not pack it down. Drop the steel ball into the sand from a height of 1 m. Measure the diameter of the crater after removing the ball.



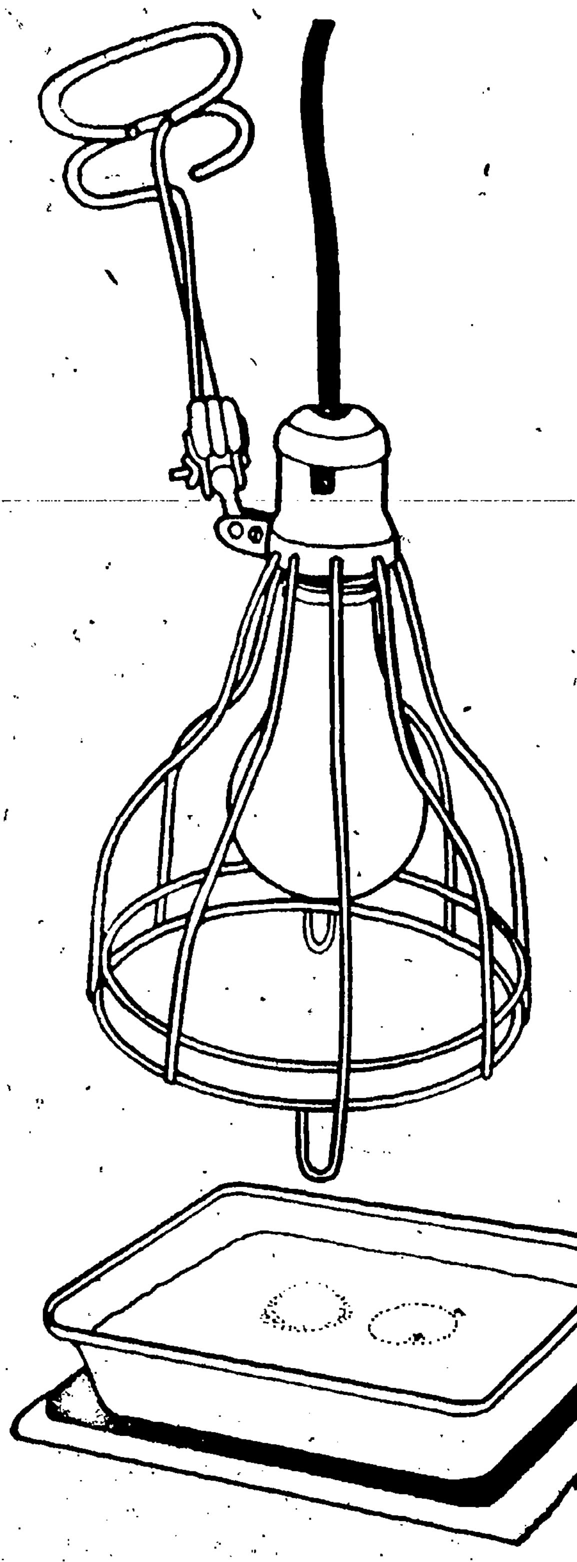
☐**5-11.** What is the diameter of the crater?

☐**5-12.** Compare the size of the crater formed by dropping the ball from 1 m with the one formed by the 50-cm drop.

Your investigation should have shown that both the mass of the object and its speed have an effect on the size of the crater that is formed. Most meteors that have been studied are composed of generally similar materials. They were not as different as your steel ball and glass marble. Therefore, an increase in mass would mean a meteor of greater diameter.

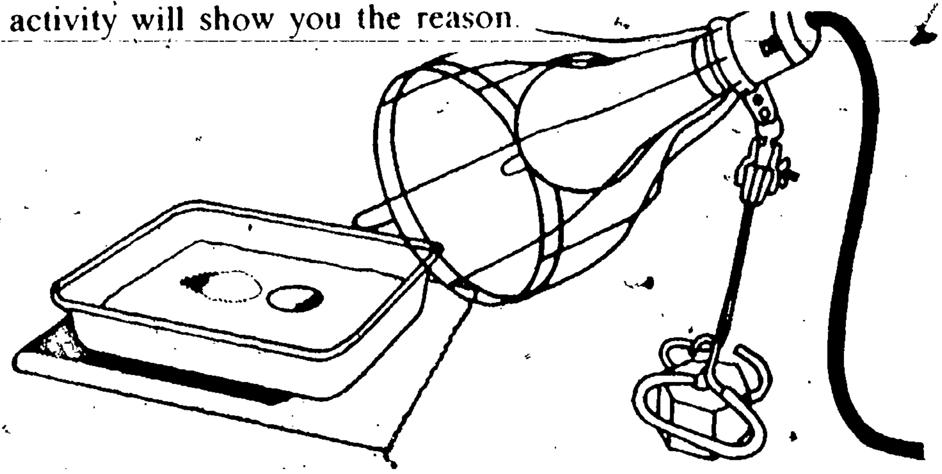
You probably found that the diameter of the crater was about three times greater than the diameter of the steel ball. You probably also found that the diameter of the crater increased by about 1½ times with an increase in the speed of the object (caused in this case by the greater height from which the ball was dropped). At the enormous speeds at which meteors hit the surface of the earth, geologists estimate that the diameter of the crater formed is usually about twenty times the diameter of the meteor!

☐**5-13.** If the meteor crater is about 1,200 meters in diameter, what do you predict was the diameter of the meteor that created it?



An object so large and traveling at a high speed must have created a blast like an atomic bomb. The terrific heat generated by the energy of impact vaporized part of the earth's surface and part of the meteor. Perhaps you noticed the similarity of the crater formed by the underground atomic blast (Figure 5-11) and the Arizona, Australia, and Quebec craters. Scientists believe impact explosions made them all look somewhat alike.

You will be investigating other kinds of surface features shortly. But perhaps you would like to know why the floodlight was used to illuminate the craters you formed. The next activity will show you the reason.



ACTIVITY 5-7. Form another impact crater in the sand by dropping a steel ball. Close to the crater, make a circular hill by pouring some extra sand onto the surface. Light the area from the side with the floodlight.

☐**5-14.** Describe the appearance of the hill and the crater when lighted from the side.

ACTIVITY 5-8. Move the floodlight so that it shines straight down on the hill and the crater.

☐**5-15.** In what way did a change in the angle of lighting change the appearance of the features on the sand surface?

Observers of the moon have found that they can tell much more about the features if the light comes from the side. The depths of craters and heights of mountains are more clearly defined than with lighting from above. The following figures illustrate this.

Figure 5-14

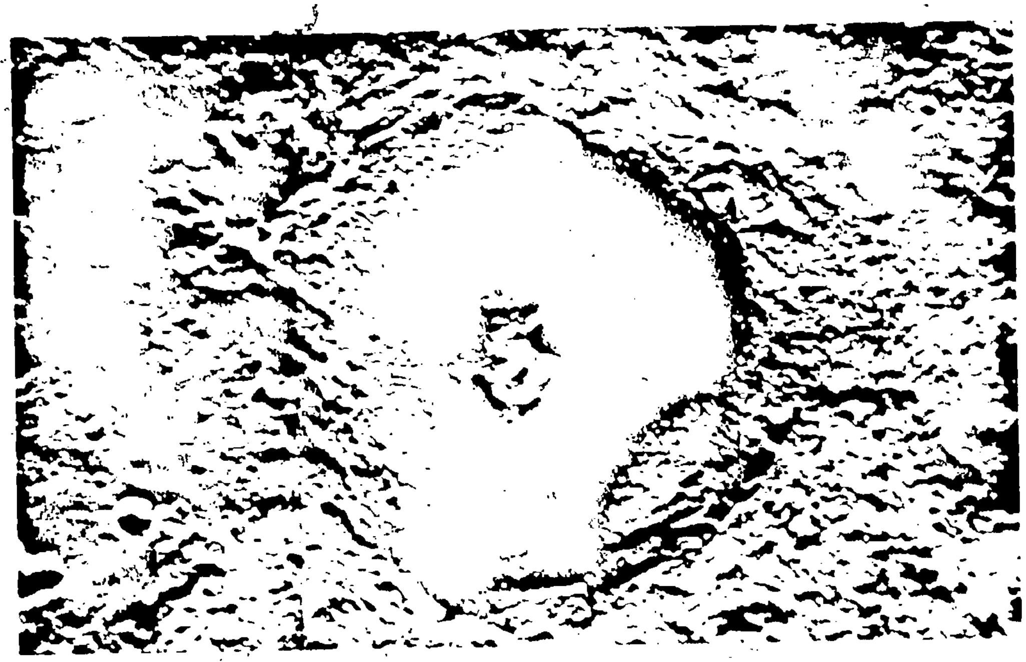


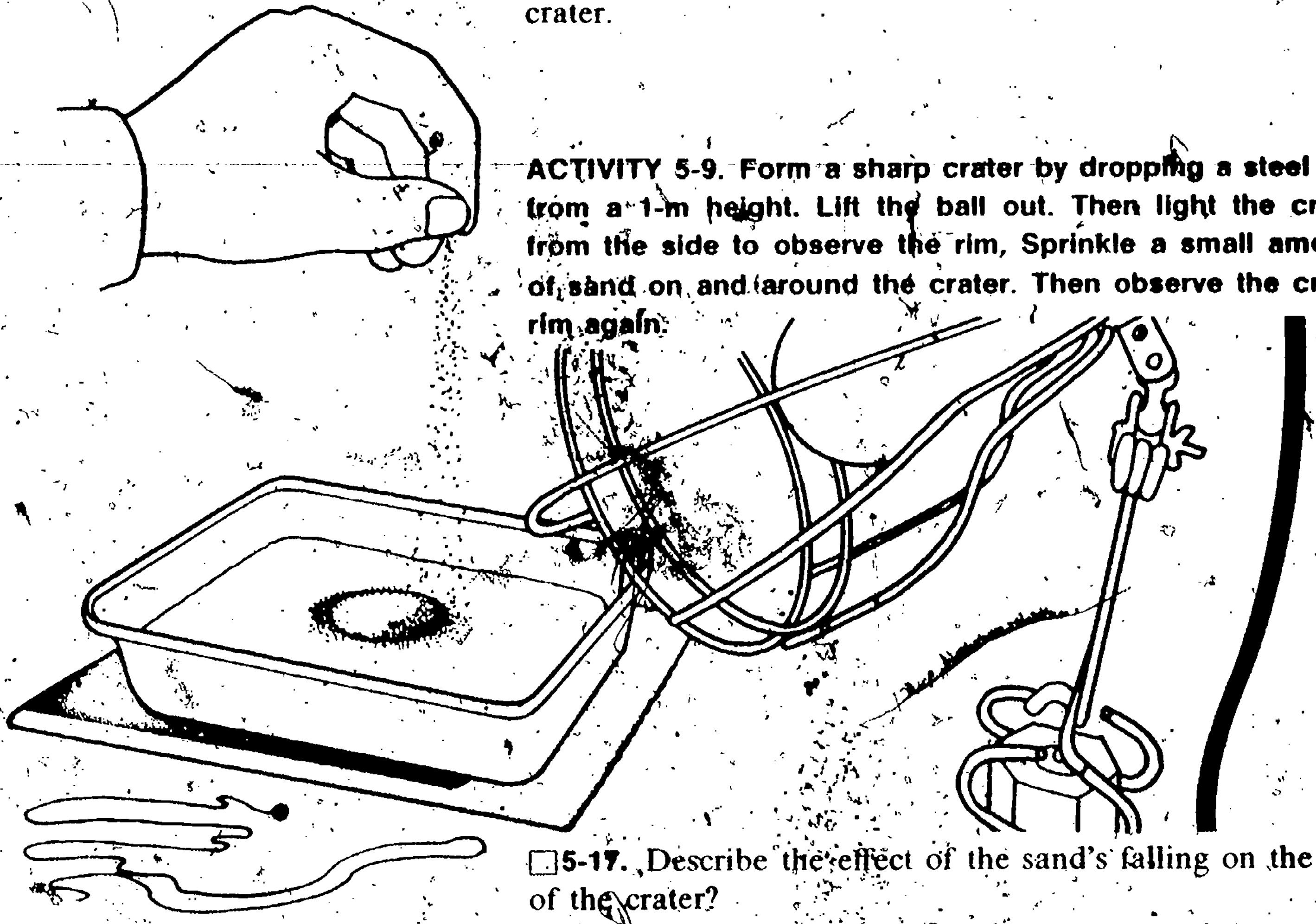
Figure 5-15

Both photos are of a large crater on the far side of the moon. Figure 5-14 was made with the sun overhead. Figure 5-15 had the sun shining from the side. Notice how the details show up in Figure 5-15.

☐**5-16.** From which direction was the light coming in Figure 5-15, above or below?

Many craters on the moon do not have sharp rims. They look as if they have been worn down or eroded since they were formed. You can make this happen with your sand crater.

ACTIVITY 5-9. Form a sharp crater by dropping a steel ball from a 1-m height. Lift the ball out. Then light the crater from the side to observe the rim, Sprinkle a small amount of sand on and around the crater. Then observe the crater rim again.



☐**5-17.** Describe the effect of the sand's falling on the rim of the crater?

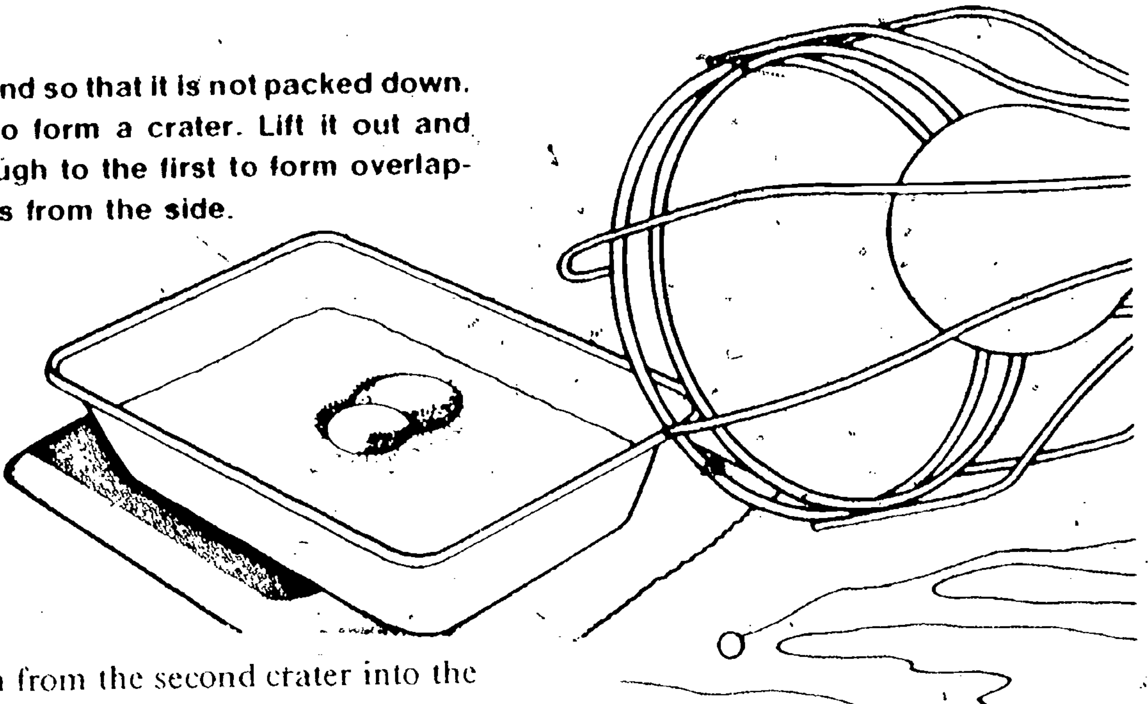
There is no weather on the moon's surface. That is, there is no rain, snow, or wind. With no weather, you would expect the surface to stay sharp and clean. But scientists believe the moon is constantly bombarded by particles from space.

☐**5-18.** How would constant bombardment of small particles affect the sharpness of the moon's features?

☐**5-19.** Suppose a large object struck the surface near a crater. What do you predict would happen?

Now check your prediction.

ACTIVITY 5-10. Repour the sand so that it is not packed down. Drop a steel ball from 1 m to form a crater. Lift it out and then drop it again close enough to the first to form overlapping craters. Light the craters from the side.



☐**5-20.** Was material thrown from the second crater into the first?

☐**5-21.** Suppose you didn't know which crater was formed first. Could you tell, by the overlapping pattern, which crater is the older and which the younger? Explain your answer.

PROBLEM BREAK 5-1

In the moon photo shown in Figure 5-16, there are several craters and hills. Make a rough sketch in Figure 5-17 of your Record Book, identifying the hills with a small h and the craters with a small c. If you can identify the overlapping craters, put a 1 on the one that was formed first, a 2 on the one that came next, and a 3 on the youngest one.

Figure 5-16

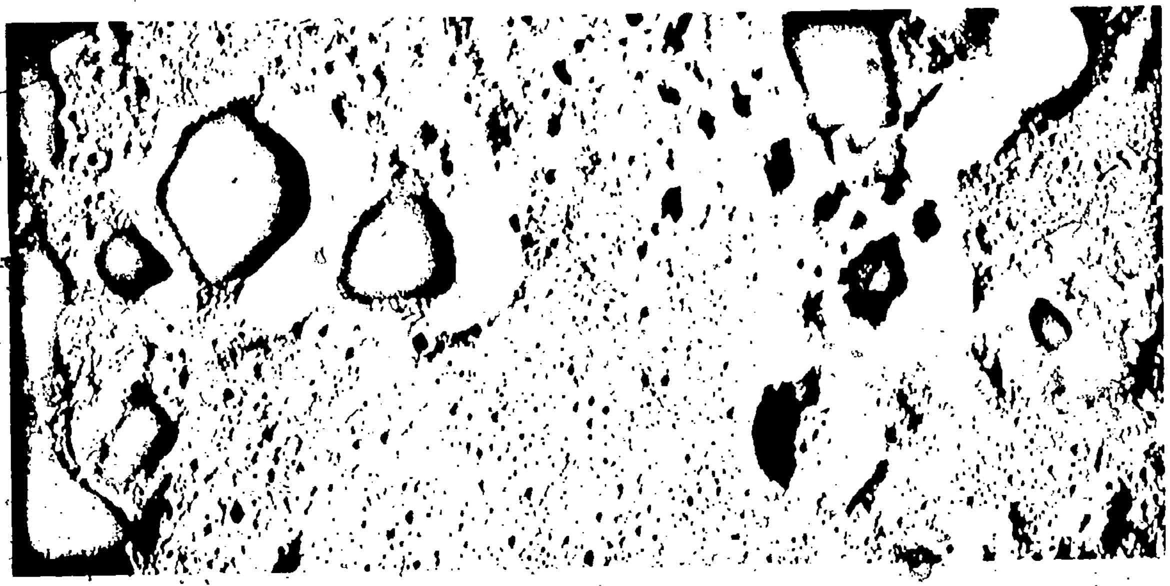
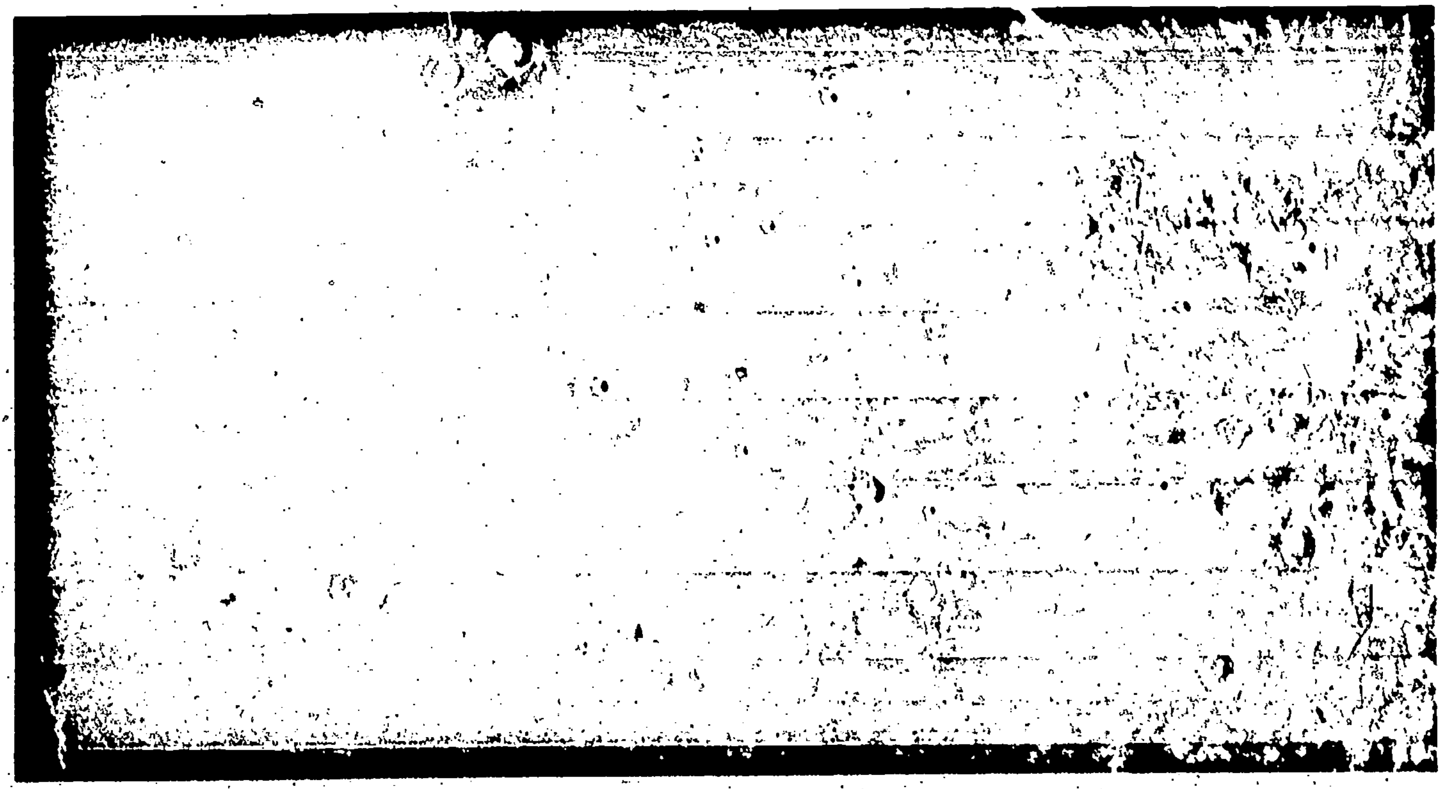


Figure 5-17

Galileo and other scientists who studied the moon long ago saw that some craters looked very different from others. Streaks of light-colored material seemed to branch out from them. One of the best known groups of these craters is shown in Figure 5-18. The large crater Copernicus is at the right edge in the photo. Kepler is to the left of Copernicus, just right of center. Aristarchus is to the left of center and above Copernicus and Kepler.

Figure 5-18



You probably noticed that the streaks, which are called *rays,* go out from the crater like spokes of a wheel. They cross the dark surface areas and other craters. A closer look at part of the area might help. Figure 5-19 is a closer view of Aristarchus, showing the rays in more detail.

Figure 5-19

Figure 5-20 is a still closer look at Aristarchus. Notice what appear to be ripples in the surface material.

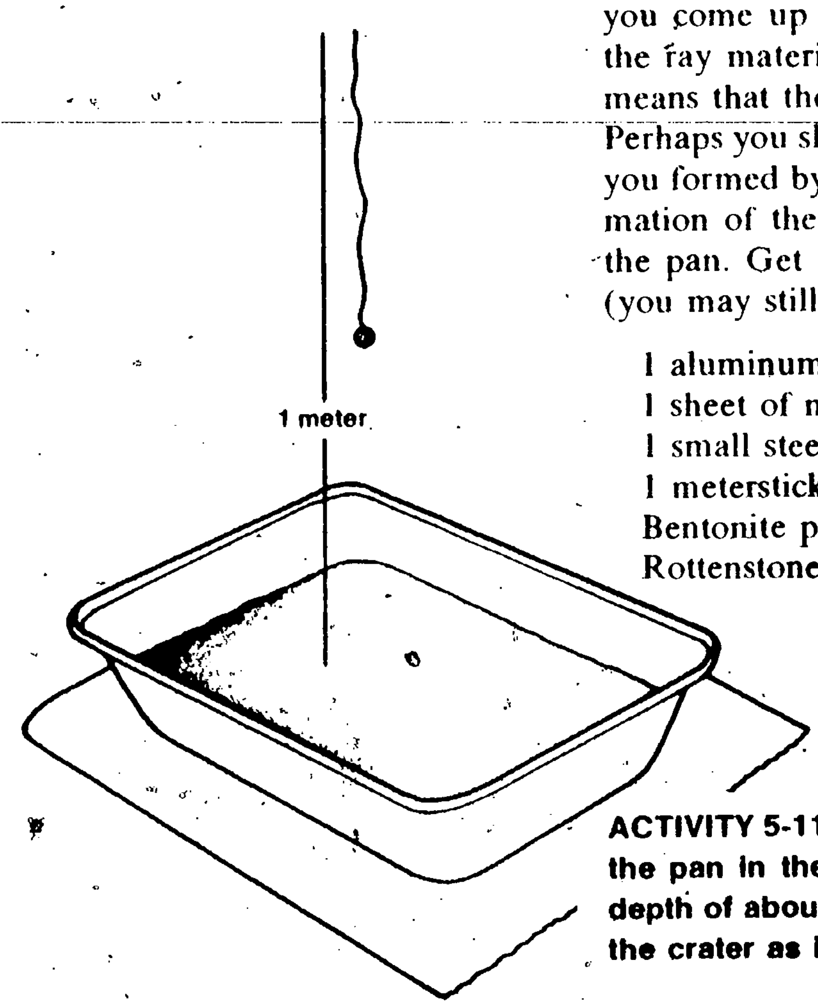
Figure 5-20

☐**5-22.** Where do the materials that form the rays seem to have come from?

☐**5-23.** Why do you think the rays are lighter colored than the surrounding area?

Question 5-23 is difficult. But a little thought might help you come up with a good answer. You probably said that the ray materials seem to have come from the crater. This means that they came from below the surface of the moon. Perhaps you should make a closer examination of the craters you formed by dropping the steel ball. For a better approximation of the moon's surface, use a different substance in the pan. Get any of the following materials that you need (you may still have the first four items):

1 aluminum pan
1 sheet of newspaper
1 small steel ball, with thread attached
1 meterstick
Bentonite powder
Rottenstone



ACTIVITY 5-11. Spread the newspaper on the floor, and place the pan in the center. Pour the bentonite into the pan to a depth of about 2 cm. Drop the steel ball from 1 m, observing the crater as it forms.

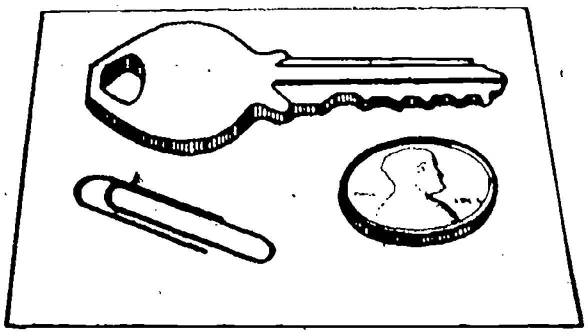
☐**5-24.** Was material thrown out of ~~the~~ crater?

☐**5-25.** Did it form a ray system of a different color than the surface?

Apparently, something happened on the moon to cause the material on the surface to be darker than the material under the surface. The same thing did not happen with the bentonite. What could have darkened the surface of the moon?

You know that the moon has no weather conditions as we know them on the earth, and it has no air.

With no atmosphere to cut down the light from the sun, the moon has much more intense sunshine. The radiation also lasts for a longer moon day. Could it be that the various rays from the sun have a darkening effect on the moon's surface? You can see whether they have a similar effect here on earth. You will need the following things:

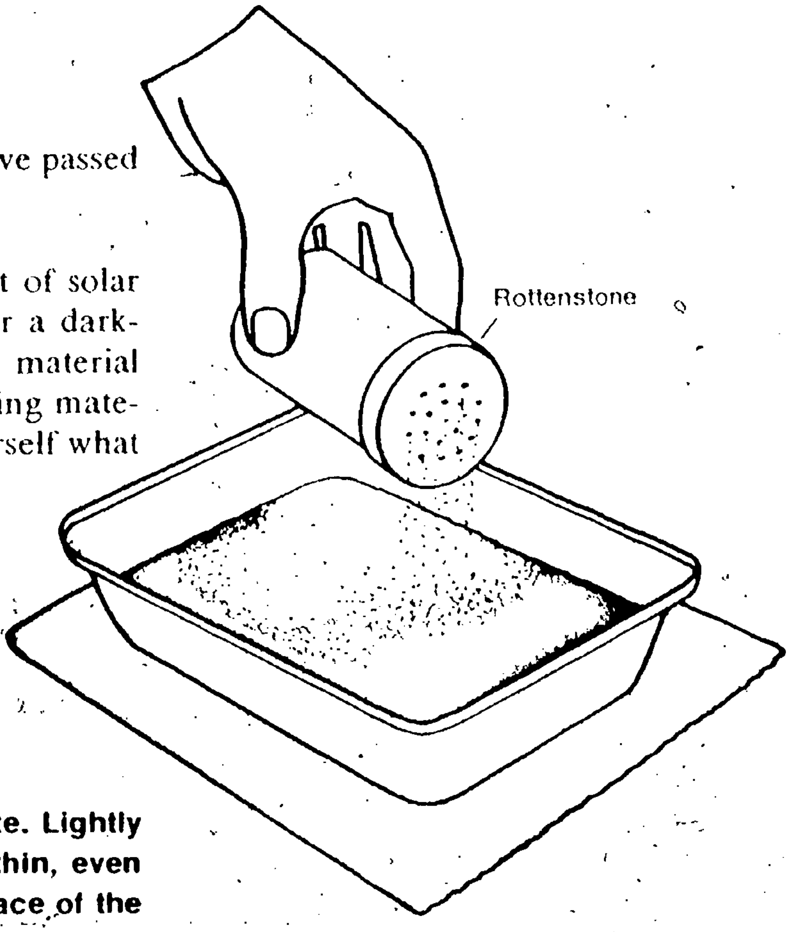


- 1 square of light-sensitive paper (protected from light until ready for use)
- Coin, key, and other opaque objects

ACTIVITY 5-12. Lay the light-sensitive paper on a window ledge or other spot where it can receive bright sunlight. If it is an overcast day, use the floodlight. Lay a key, a coin, and other objects on the paper. Let them remain for several minutes.

☐**5-26.** Describe the paper after several minutes have passed and the objects have been removed.

Light rays *do* darken some materials. The effect of solar radiation on the moon's surface might account for a darkening of the top layer. The top layer protects the material underneath from the sun's rays. Thus, the underlying material should be lighter in color. You can see for yourself what happens when a meteor strikes such a surface.



ACTIVITY 5-13. Smooth the surface of the bentonite. Lightly shake the rottenstone over the surface so that a thin, even layer is formed. This dark layer represents the surface of the moon, darkened by solar radiation. Now drop the steel ball from a 1-m height.

☐**5-27.** Describe your observation of the crater that formed.

☐**5-28.** Do the rays that are formed resemble the ones from certain craters on the moon?

The rays on your model of the moon's surface probably don't extend very far. The ones on the moon seem to continue for very long distances. Some thought about the conditions on the moon as compared with those on the earth should help to explain this difference.

☐**5-29.** How does gravity on the moon compare with that on the earth?

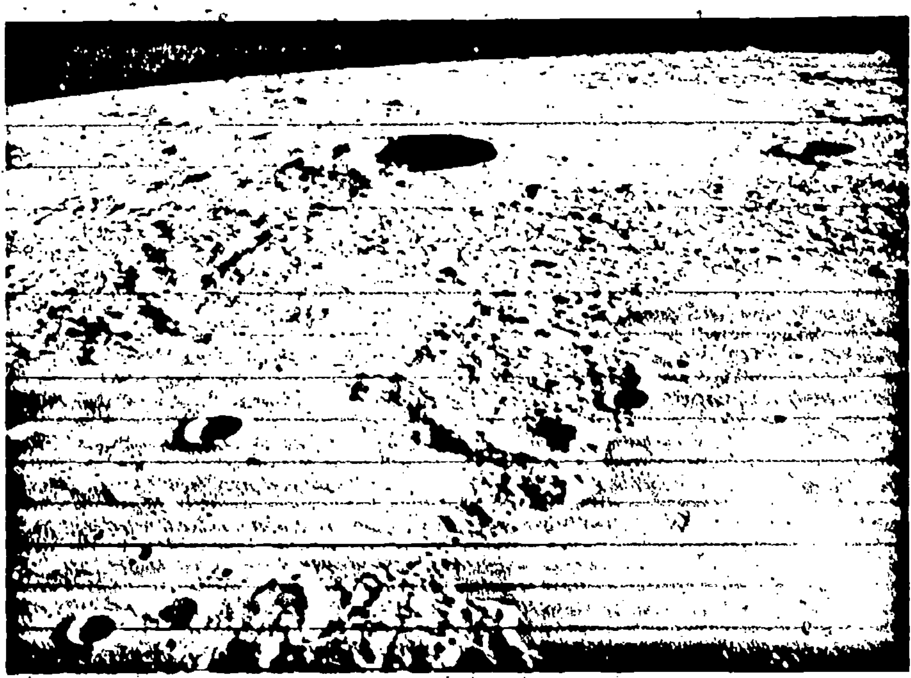
☐**5-30.** How would air resistance on the moon compare with that on the earth?

EXCURSION

If you are not sure of your answers to the last two questions, try **Excursion 5-1,** "Less Force."

It is believed that when large meteors hit the moon and formed craters such as Aristarchus, Copernicus, and Kepler, many pieces of the meteors and of the moon were thrown out of the crater. The speed at which this material was thrown must have been tremendous. With no air resistance and much less gravity than on the earth, some of these particles left the moon and went into space. Some are known to have been captured by the gravity of the earth.

Figure 5-21



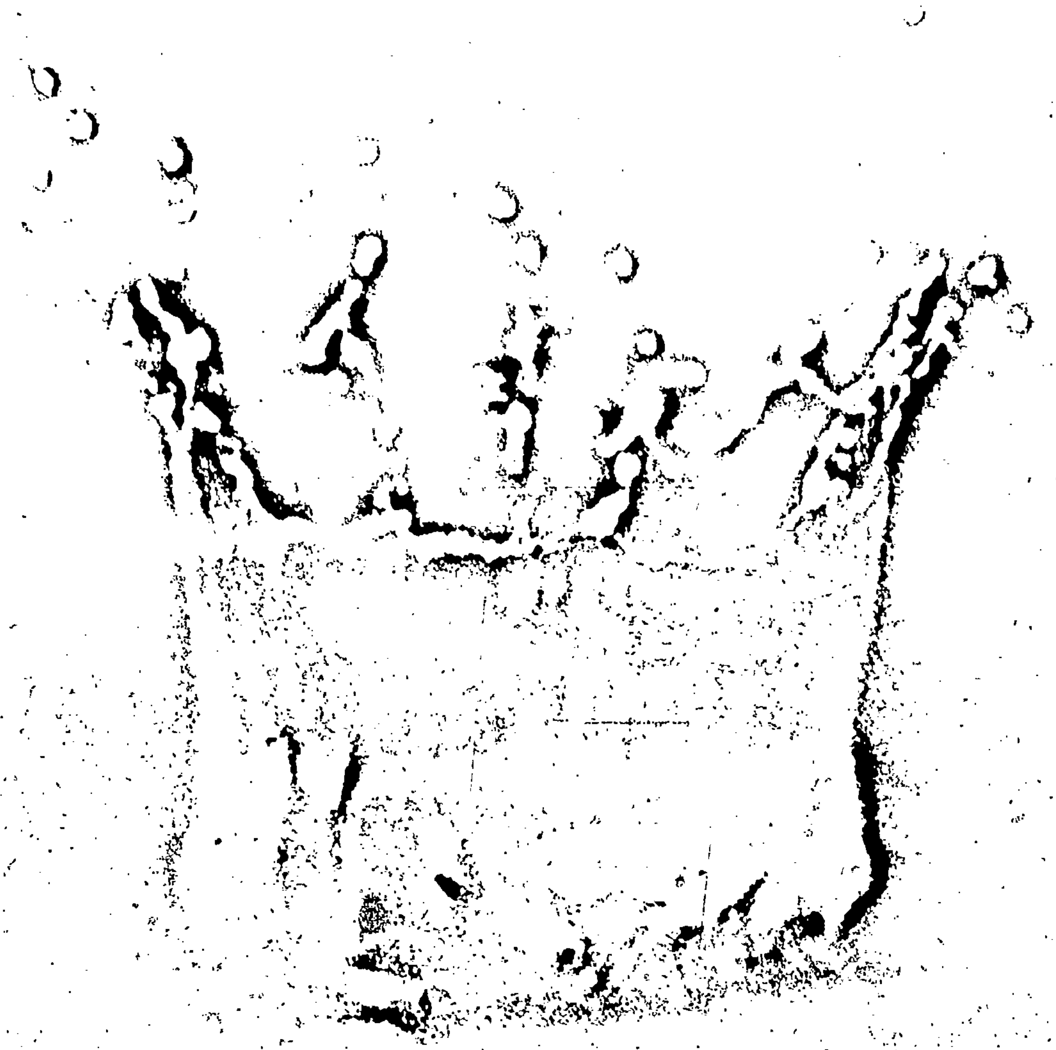
If you look closely at the rays extending from the crater Kepler, you can see they consist of many small craters (Figure 5-21). Each of these is surrounded by ejected dust. This dust sometimes forms in dunes like sand dunes on the earth.

Sand dunes on the earth are formed by the movement of sand by water or air.

☐**5-31.** Are dust dunes on the moon formed in the same way as the sand dunes on the earth? Explain your answer.

Apparently many of the large craters on the moon were formed by meteors. This does not mean that other things, like volcanic action, could not have formed craters. There may be examples of other kinds of craters in areas that you have not yet examined. But from your observations of features on the earth and a comparison with the moon's features, you probably agree with scientists that meteor impact was a major cause of the large holes in the surface of the moon.

Before going on, do Self Evaluation 5 in your Record Book.



Peaks and Flows

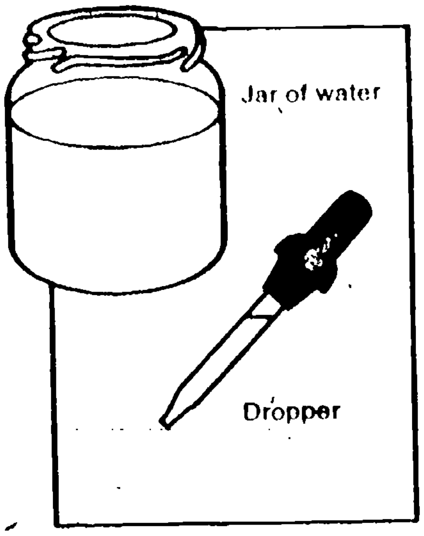
Chapter 6

You have spent most of your time looking at holes in the surface of the moon. Perhaps you noticed another feature about these lunar craters that is unusual. Some of the large craters have central peaks extending up from the flat crater floor. Figure 6-1 is a view of the crater Theophilus. The central peaks (arrow) show very clearly. The crater is almost 100 km in diameter and approximately 6.5 km deep. The central peak is more than 2,000 meters high. It compares with the tallest mountain in the eastern United States.

Figure 6-1

Scientists know that when a meteorite strikes a surface at high speed, a tremendous amount of heat is produced. They believe both the surface and the meteorite melt. Thus, both behave like liquids. This liquid behavior could certainly affect the appearance of the surface following the impact. To see what effect may occur, you need to examine the behavior of liquids on impact. To do this, you will need the following equipment:

1 medicine dropper
1 jar or glass of water



ACTIVITY 6-1. Fill the dropper with water. Hold it a short distance above the jar of water. Let one drop of water fall, watching the surface of the water in the jar carefully.

Repeat Activity 6-1 several times, watching the surface of the water from different viewpoints.

☐**6-1.** Describe the action of the surface of the water as the drop hits it.

Giving an accurate description was probably difficult. The action occurs very fast. High-speed photographs have been taken of a drop hitting the water's surface (Figure 6-2).

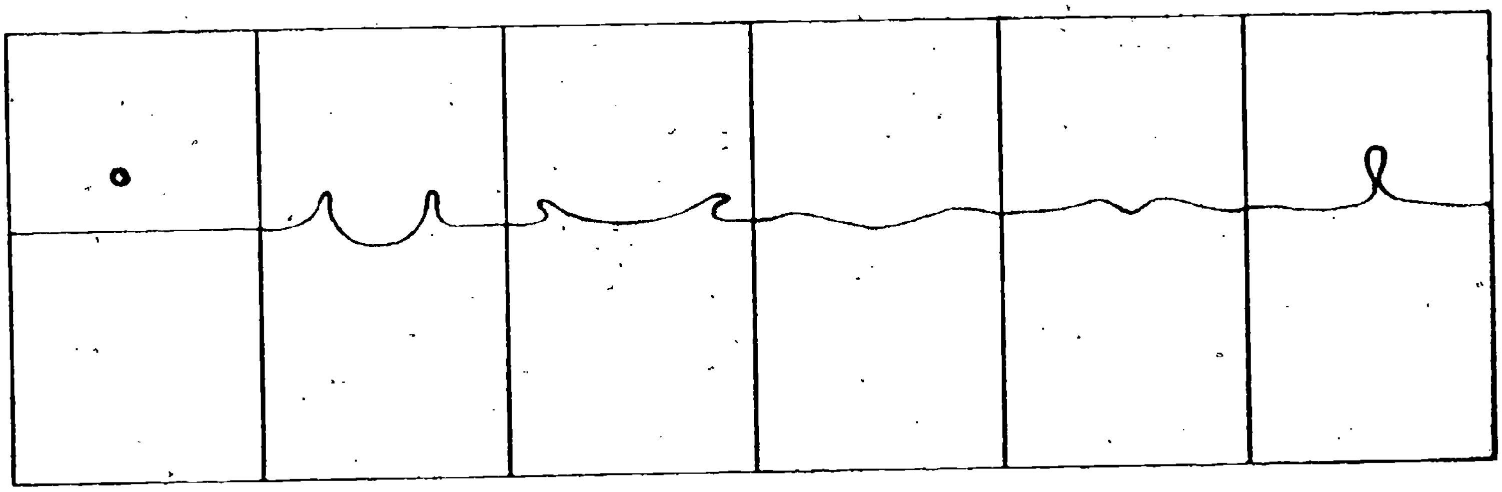


Figure 6-2

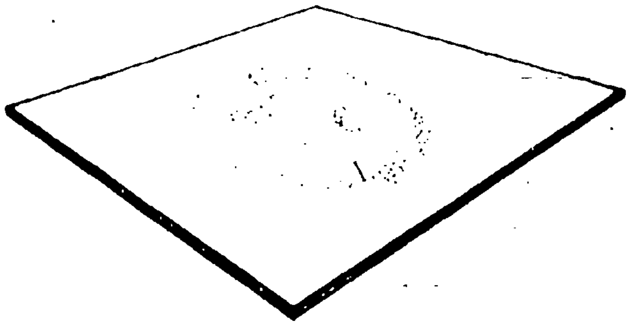
Here is the sequence of events.

1. The drop nears the surface.
2. A crater forms as the drop hits.
3. The crater widens.
4. The crater flattens.
5. The edges of the crater flow back toward the center.
6. A central peak forms as the edges come back together.

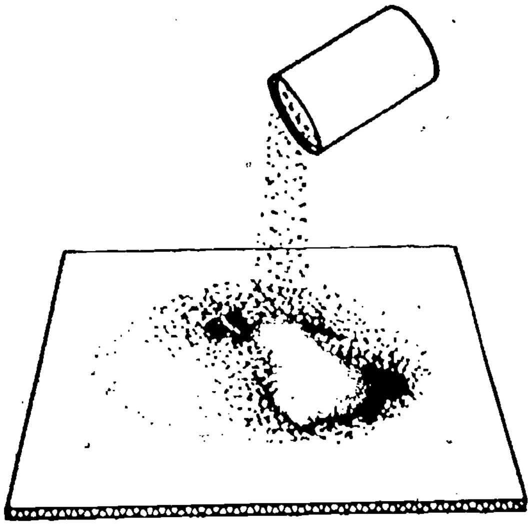
Now find out what happens when a drop of water hits the bentonite surface that represents the moon. In addition to the medicine dropper and water, you will need the following:

1 piece of cardboard
Bentonite
Rottenstone

ACTIVITY 6-2. Spread a layer of bentonite on the center of the cardboard. Have the layer vary in thickness from about 2 mm in one spot to just barely covering the cardboard in another.

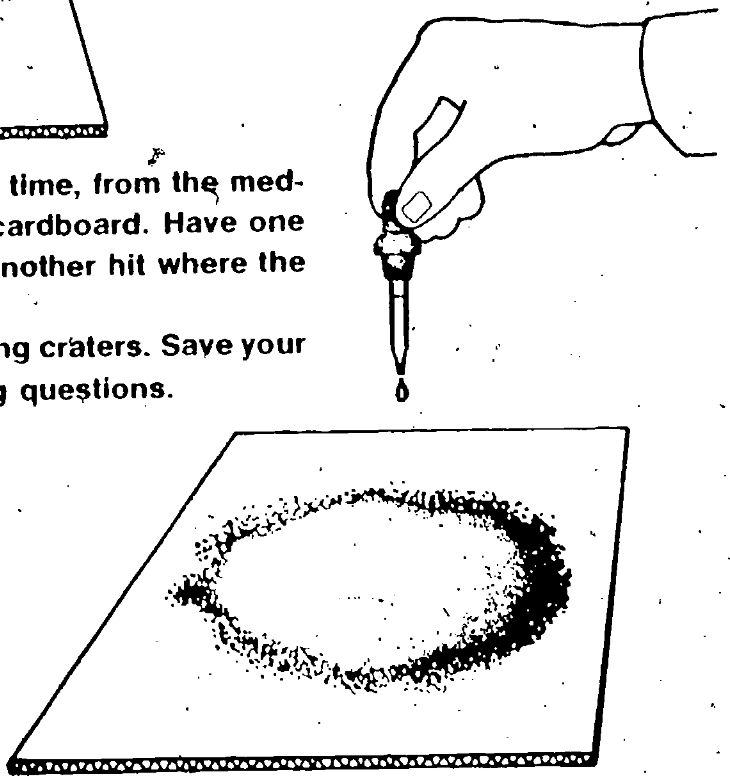


ACTIVITY 6-3. Dust a very thin layer of rottenstone over all the bentonite layer.



ACTIVITY 6-4. Drop water, one drop at a time, from the medicine dropper onto the material on the cardboard. Have one drop hit where the layer is thick. Have another hit where the layer is thin.

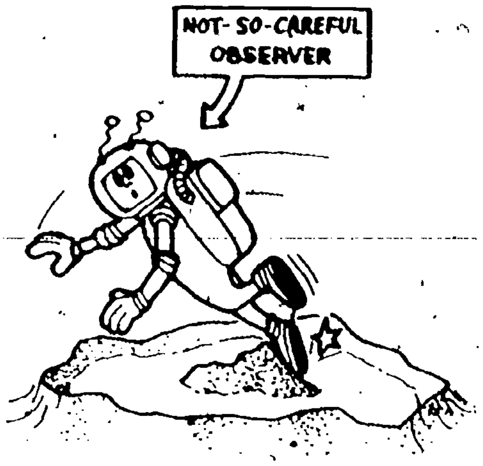
Try to get at least one pair of overlapping craters. Save your craters to help you answer the following questions.



☐**6-2.** Can you identify any central peaks in the drop craters?

☐**6-3.** If your answer to question 6-2 is Yes, did the most pronounced peaks form where the layer was thick, or thin?

☐**6-4.** Use what you learned in this activity to explain why you think some craters on the moon have central peaks and others do not.



Not all the features that stick up from the floor of craters are formed in the same way as the central peaks. For a number of years, careful scientific observers have sighted what appeared to be glowing red spots in the region of the crater Aristarchus (Figures 5-18 and 5-19). In fact, the floor of Aristarchus is surprisingly similar to that of Hawaiian volcanoes. Therefore, it is believed some kind of volcanic activity may still be in progress on the moon.

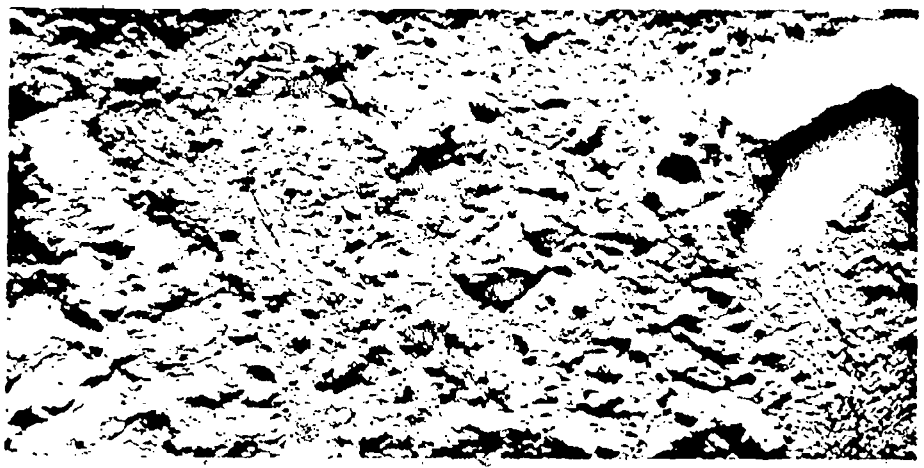


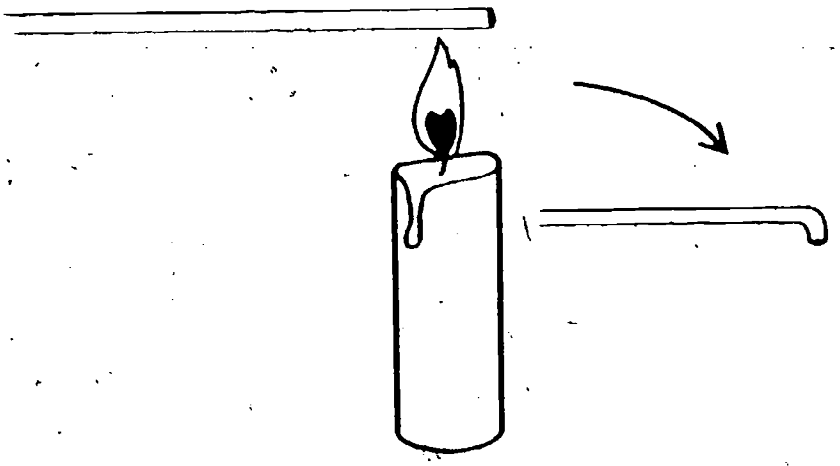
Figure 6-3

Figure 6-3 shows a closeup of Aristarchus. Note the fairly flat, ridged floor and the many dome-shaped hills.

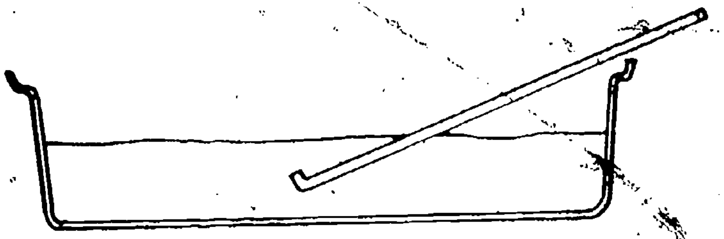
In one type of volcano, solid material consisting of cinders, ash, and rock is thrown out of a central opening. A simple activity can show you what type of formation can be expected. You will need the following equipment:

1 plastic straw
1 candle (or burner if available) and matches
1 pan of sand
1 sheet of newspaper
1 floodlight

ACTIVITY 6-5. Light the candle. Gently heat the straw about 1 cm from the end. Move it back and forth over the flame as you heat it. When it starts to bend, remove it from the flame and form a right angle bend as shown. Blow out the candle.



ACTIVITY 6-6. Lay the newspaper on the table, and place the pan of sand on it. Push the bent part of the straw under the surface of the sand, with the bend pointing upward. Gently blow into the straw.



The crater and mound that you have just formed should look a bit like the one shown in Figure 5-7 and another you can see in Figure 6-4. However, there is one difference. When a cinder cone is formed, like that shown in Figure 6-4, a lot of material is brought up from under the surface.

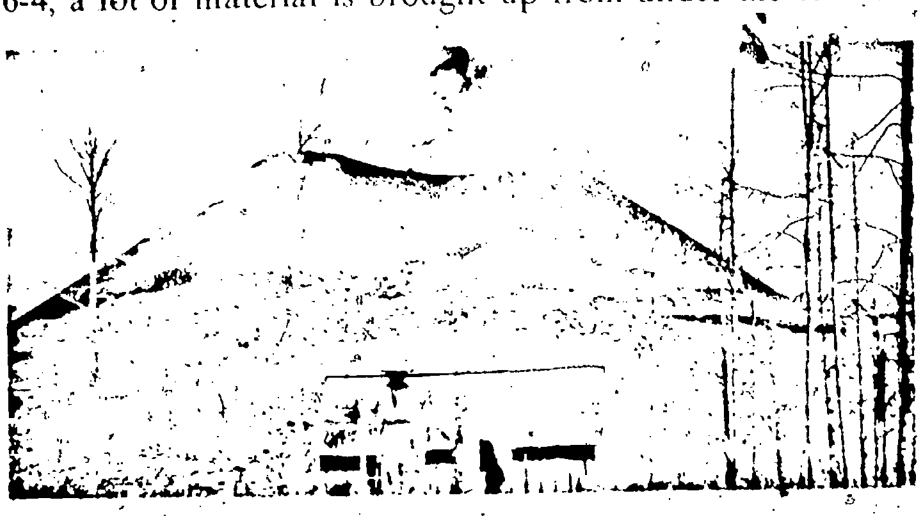
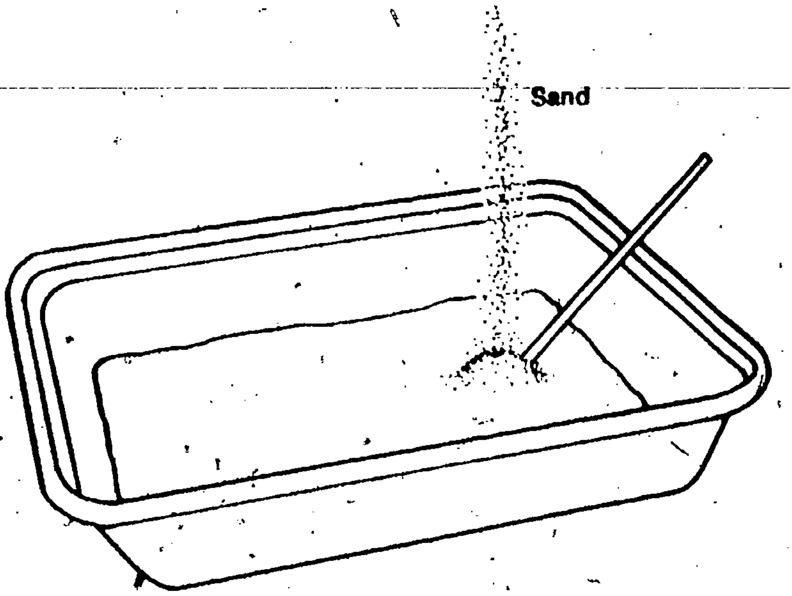


Figure 6-4

The cinder cone of Parícutin, one of the few volcanoes that have formed in modern times, is in Mexico. It began to grow in a cornfield in 1943 and is now more than 400 meters high (Figure 6-4).

Using the straw, you may have found you didn't have enough material to be lifted by the air. Try doing the activity in a slightly different way.



ACTIVITY 6-7. Blow into the straw as before, but at the same time pour sand from your hand into the crater. You will be furnishing the material from above instead of underneath. Continue blowing for a short time after you finish pouring.

☐**6-5.** How does the shape of the cone compare with the cinder cones in Figures 5-7 and 6-4?

☐**6-6.** Is the position of the crater in the mound similar?

☐**6-7.** Is the shape of the crater similar?

☐**6-8.** What is the position of the crater floor with respect to the surrounding area?

☐**6-9.** What happened to the ejected material?

Several cinder cones show on the far wall of the moon crater Copernicus (Figure 6-5). There are also craters nearby that look different from those in the cones. The cone near

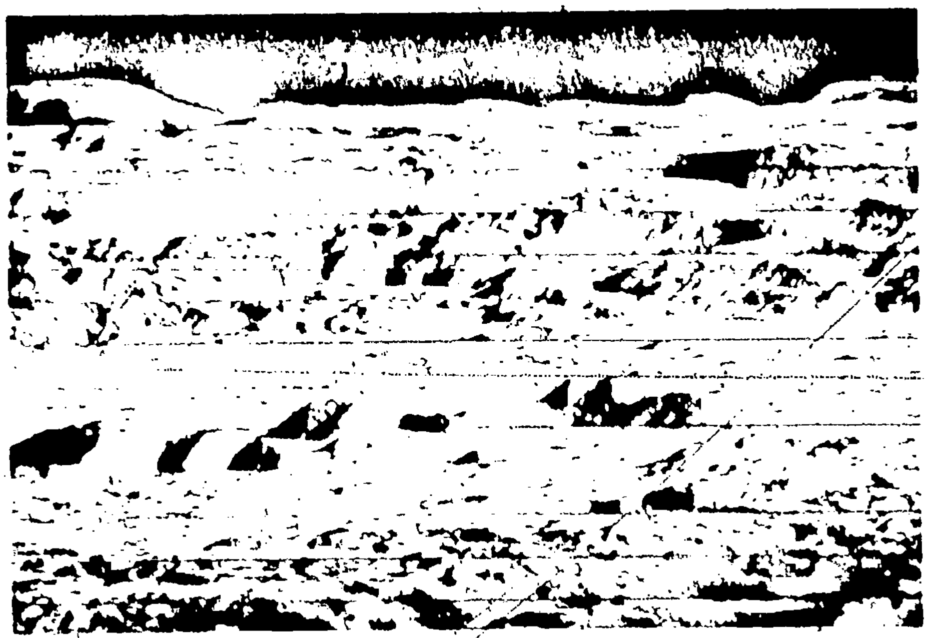


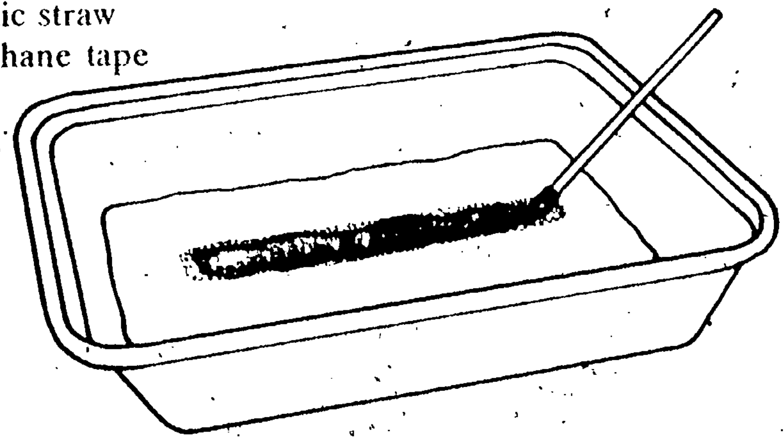
Figure 6-5

the upper left corner shows rocks inside the crater and on the outer slope of the cone. The same features show in the cone at the bottom.

In some earth volcanoes, melted rock builds up pressure under the ground. It bulges the solid rock above it upward.

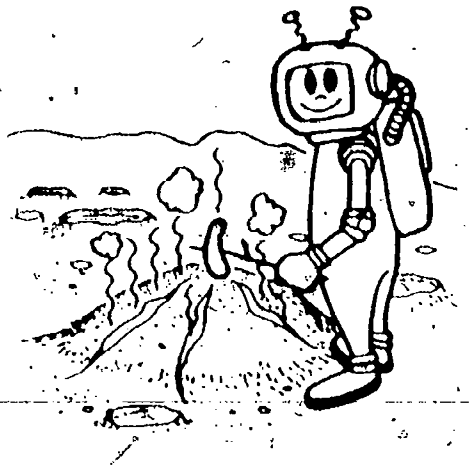
The following activity will help you visualize what happens in such a case. You will need the following equipment:

1 pan of bentonite
1 balloon
1 plastic straw
Cellophane tape



ACTIVITY 6-8. Fasten the balloon to the straw with tape. Dig a deep trench in the bentonite, and lay the balloon in it, with the other end of the straw over the edge of the pan. Cover the balloon with bentonite, and smooth it down. Then blow gently into the straw.

☐**6-10.** Describe the action of the bentonite as the balloon expands.



An underground flow of molten rock, called *magma*, could exert a lifting force like this on the moon's surface. This could have caused the surface to become domed and cracked. If the pressure of the magma were great enough, the fluid lava could have flowed out through the cracks, or fissures, and formed pools, or flows, on the moon's surface. Successive layers of lava could have covered the original dome that was formed, creating a domed mountain.

Figure 6-6

Notice the pattern of domes and ridges in the foreground (Figure 6-6). The crater Marius is in the upper right background. The domes are up to 16 km in diameter and almost 500 meters high. They are similar to volcanic domes in northern California and Oregon. The irregular ridges could have been formed by lava flowing over the surface.

Large areas of California, Oregon, and Washington are covered with lava flows from volcanic activity that occurred centuries ago. When lava cools from its over 1000°C temperature, it forms a rocky layer rich in minerals. On the earth, this surface is changed by weathering. No weathering process takes place on the moon, but the surface becomes scarred by meteor impacts and covered with dust.

☐**6-11.** Why is there no weathering effect on the moon's surface?

Many of the dark sea areas on the moon look quite smooth. Others, however, have domes, cones, and ridges. The seas look as if they might have resulted from lava flow.

Figure 6-7

Figure 6-7 shows the Marius Hills area of the largest mare, The Ocean of Storms. Notice the domes and cones, some of which are believed to be volcanic. Notice also the wrinkled ridges running nearly continuously across the mare.

PROBLEM BREAK 6-1

One of the things that scientists have been most interested in is the relative age of various features on the moon. A principal reason for bringing back samples of rocks was to be able to find out how old they are. It is felt that the age of parts of the moon might tell the age of the earth and also how they both were formed.

But there are ways of telling the relative age of parts of the moon without actually going there. Figure 6-8 shows a large area containing seas, craters, rays, and mountains. A letter and number grid has been added to aid in locating the various features. Try your hand at deciding which features are oldest and which youngest.

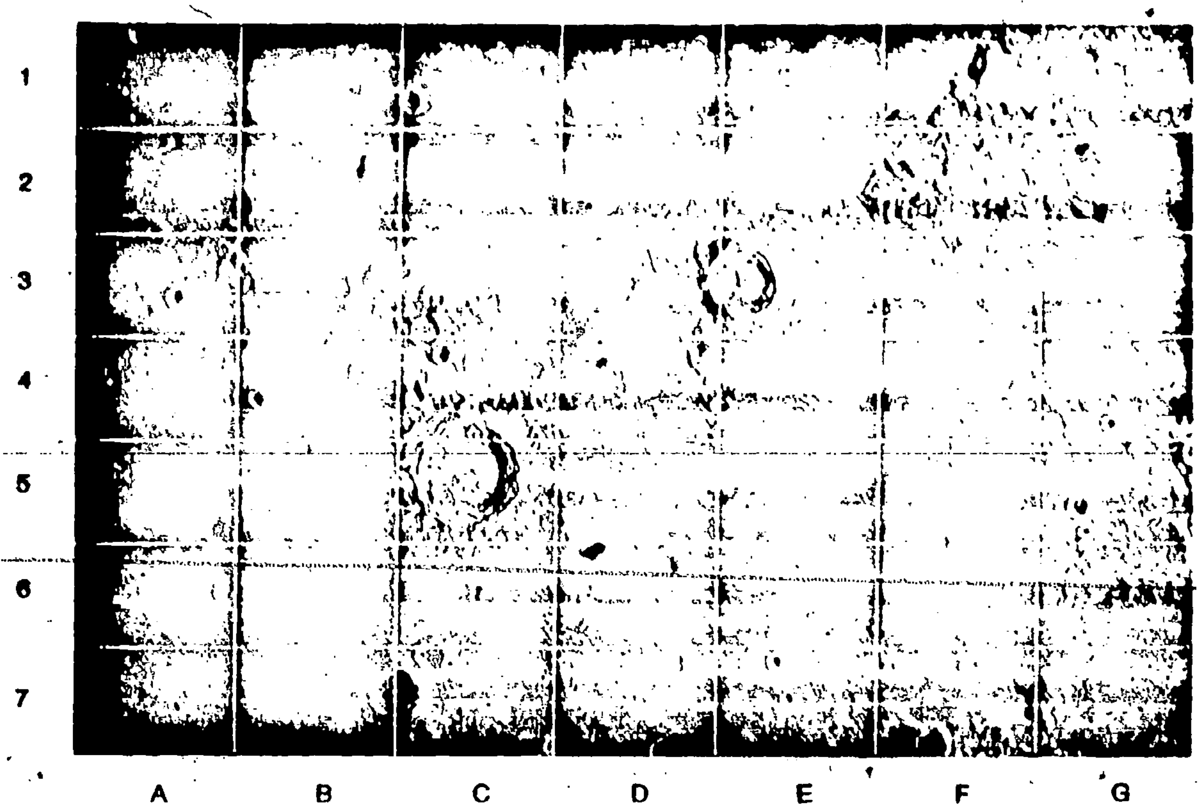


Figure 6-8

The following list identifies the features that will be used in the dating.

1. C 5 is the brightly rayed crater Copernicus.
2. E 3 is the unrayed crater Eratosthenes.
3. D 4 to D 5 is the ghost crater Stadius.
4. E 1 is the crater Wallace.
5. E 3 to G 1 is the Apennine Mountains.
6. EF 1 to E 2 is the Sea of Rains (Mare Imbrium).
7. F 3 to F 4 is Seething Bay.

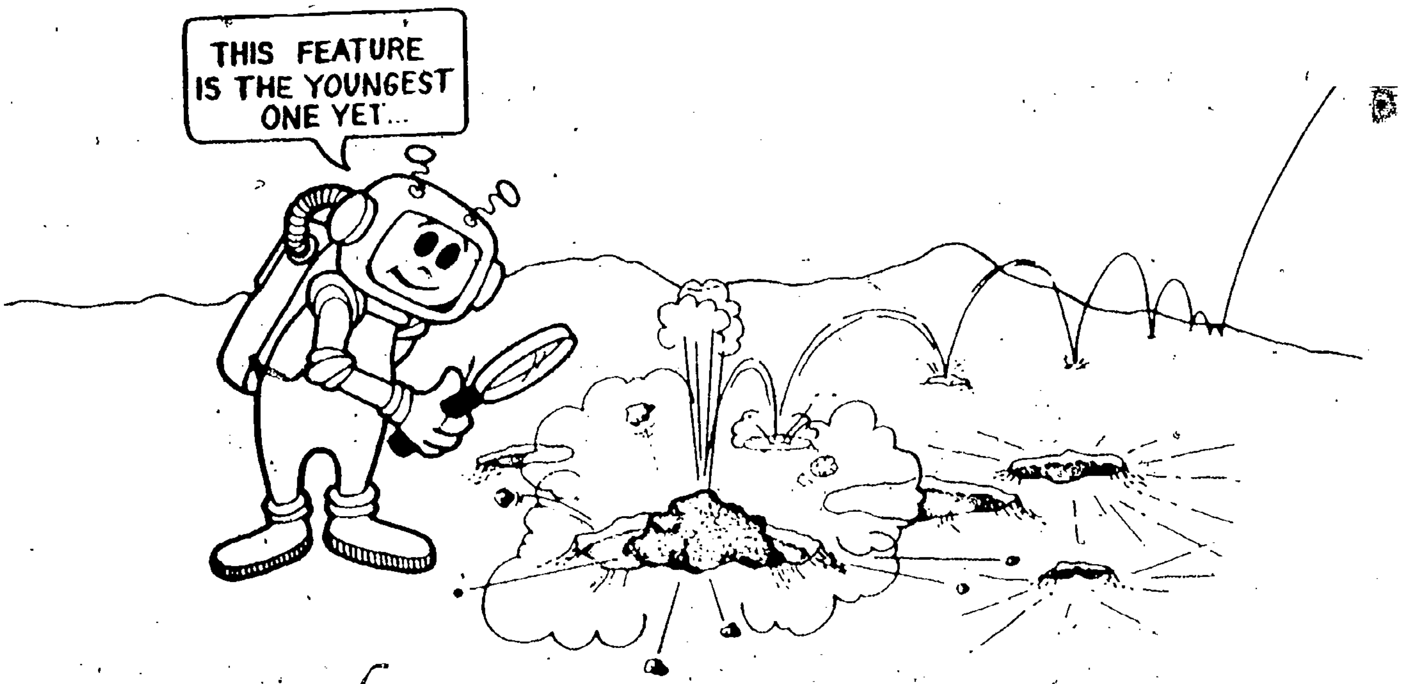
Examine the photo carefully for clues. For instance, you will note that the bright rays from Copernicus extend across the figure in all directions. They even extend right across Eratosthenes. Some of the craters have very little dark mare material in their floors; others are partly filled with it, like Wallace, or completely submerged, like Stadius.

The black mare material comes right up to the Apennine Mountains, like waves lapping on a seashore. In fact, if you look at the moonchart in your classroom, you will see that these mountains are only part of a huge chain of mountains that continue around the Sea of Rains for almost a full circle. It looks as if an extremely large crater had been formed, with the mountains as the rim of the crater.

Make a list of the seven features above, having the oldest feature at the top of the list and the youngest feature at the bottom. If you feel that you can't tell the difference in age between two things, list them together (as the same age). Use all the available clues in making your decisions. Then write one sentence about each of your choices, telling how you decided on its place in the list.

You have investigated the appearance of some of the big features on the moon. The activities should have provided a possible explanation for the way craters, peaks, and some ridges were formed. It also may have helped you see how the relative ages of features on the moon are judged.

Before going on, do Self Evaluation 6 in your Record Book.



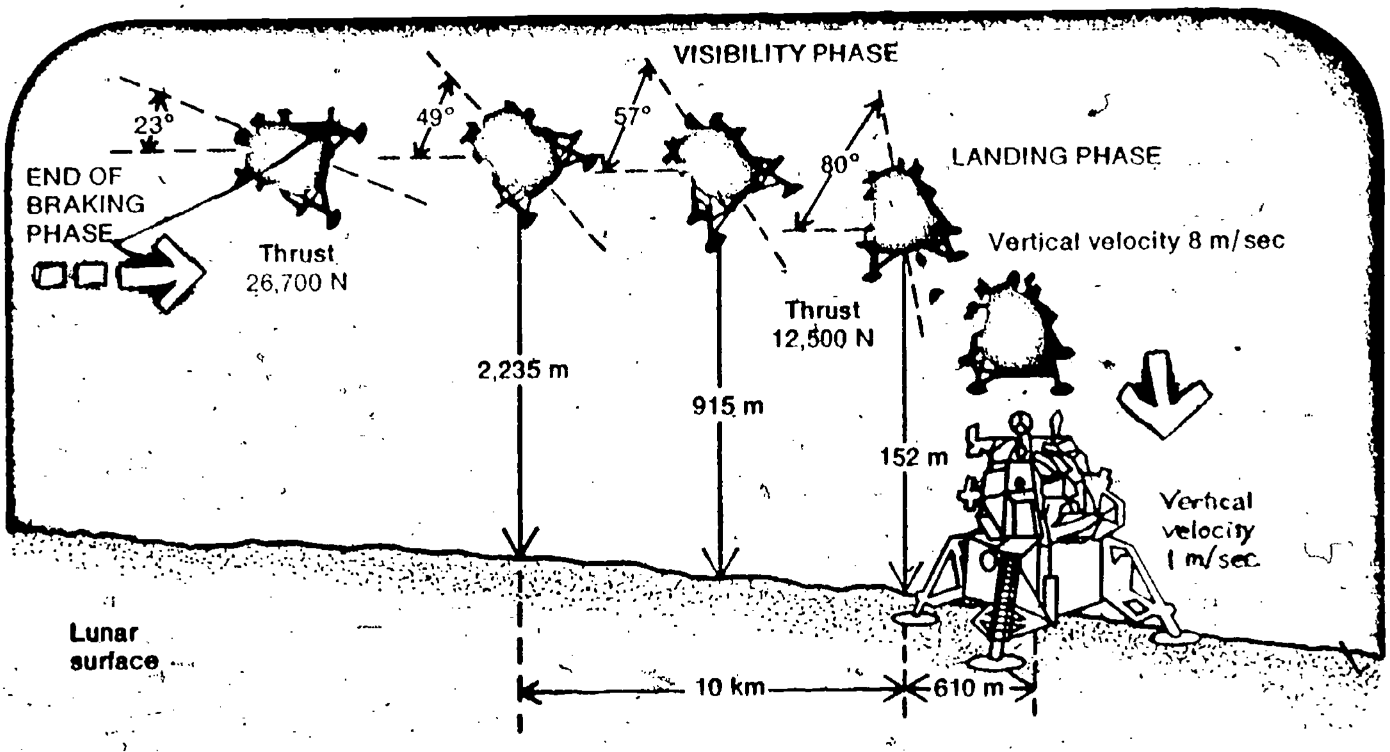
A Day on the Moon

Chapter 7

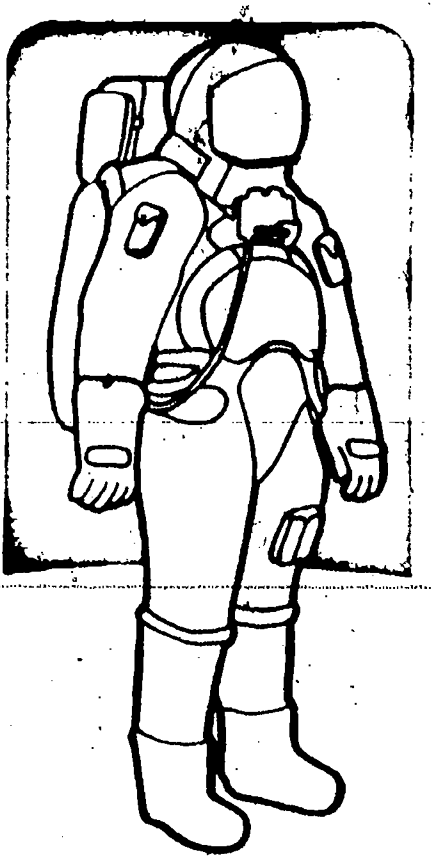
Your spacecraft has been orbiting the moon while you've examined its features from a distance. Now its time to descend to the surface.

The method of getting down has been worked out. While in lunar orbit, the lunar module (LM) separates from the command module. One person remains in lunar orbit in the command module while the other two descend in the LM (Figure 7-1).

Figure 7-1



☐**7-1.** From the observations you have made, list the things you might encounter at your landing site that could make the landing difficult.



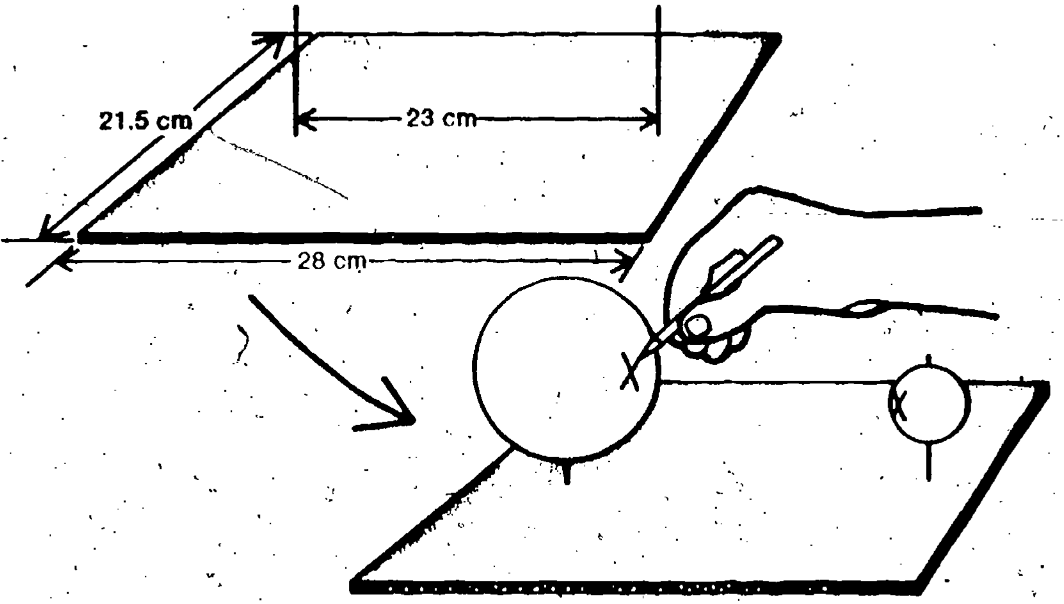
Before leaving the LM, you would put on a heavy protective suit.

☐**7-2.** With this heavy suit, it would be somewhat difficult to walk around on the earth. Why would it be easier to walk on the moon?

Suppose you stepped out onto the moon's surface just at sunrise. How many hours of sunlight would you have to investigate its surface? In other words, how long is a moon day?

For most places on the earth, daylight usually lasts only part of each 24-hour period. What is a moon day like? The following activity can show you. Work with a partner. You will need the following apparatus:

1 floodlight
1 large Styrofoam ball
1 small Styrofoam ball
2 T-pins
1 piece of cardboard

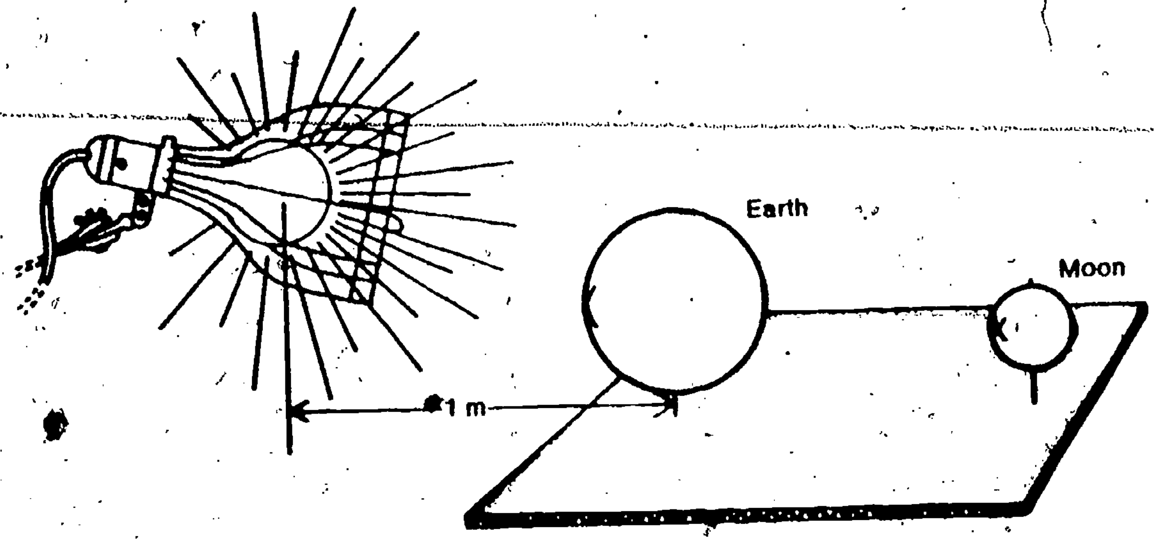


ACTIVITY 7-1. Push the two T-pins up through the cardboard at the positions shown. Push the large Styrofoam ball onto one pin, and the small ball onto the other pin. Mark an X on each of the balls with a pencil or pen.

ACTIVITY 7-2. Set up the floodlight about 1 m away on the table or floor. Turn the balls until you have the X marks in line and facing the floodlight.

The light represents the sun. The large ball represents the earth and the small one the moon.

We know that the same side of the moon always faces the earth. Therefore, the X mark on the moon must always be toward the earth.



When the earth rotates once, this represents a 24-hour day. On your Styrofoam earth—the large ball—the X would move in a complete circle during that period.

☐**7-3.** How much of the earth's surface could be seen from the moon in this 24-hour period?

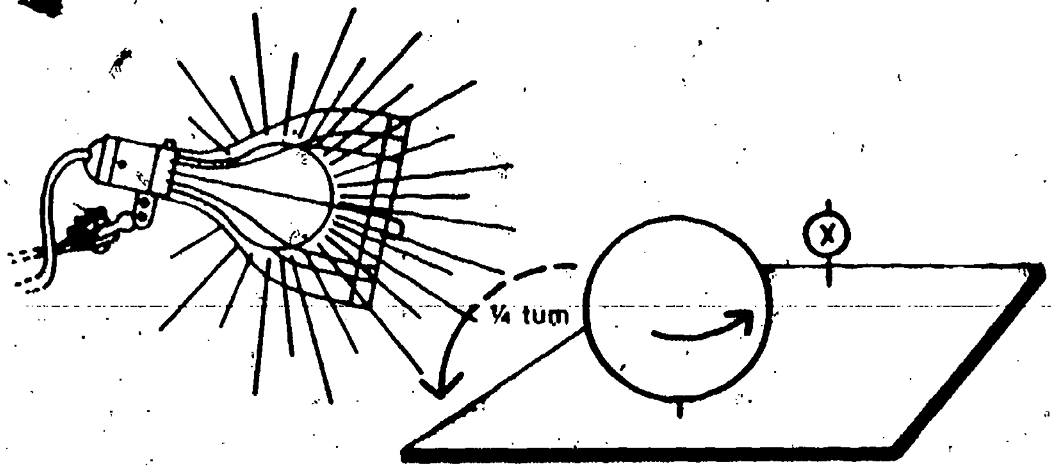
☐**7-4.** How much of the moon's surface would an observer on the earth see during the 24-hour period?

☐**7-5.** Would the side of the earth that is toward the moon in Activity 7-2 be sunlit, or dark (moonlit)?

☐**7-6.** Would an observer on the earth see a full moon, a half moon, or a new moon (unlighted)?

The entire earth-moon system, as represented by the cardboard and balls, rotates once in relation to the sun every 29½ days. So in a little over a week (seven earth days), the system would make a quarter turn.

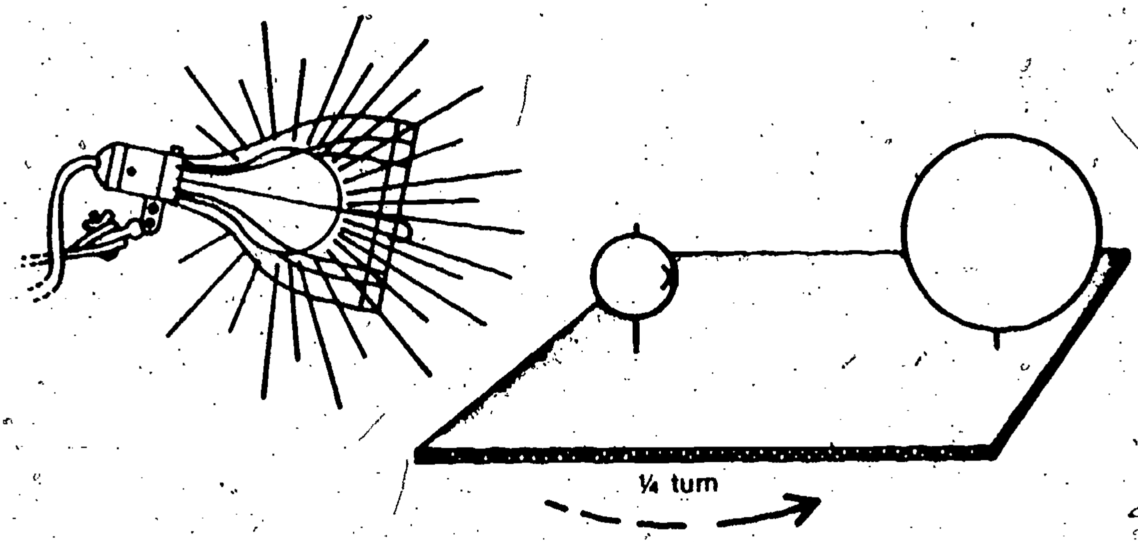
ACTIVITY 7-3. Turn the cardboard counter-clockwise as shown. Remember the X on the moon must always point toward the earth.



The floodlight (sun) is now shining across the cardboard. The earth has rotated on its own axis (pin) a little more than seven times.

☐7-7. As seen from the Styrofoam earth, how much of the moon is lighted?

☐7-8. As seen from a man at X on the moon, how much of the earth is lighted?

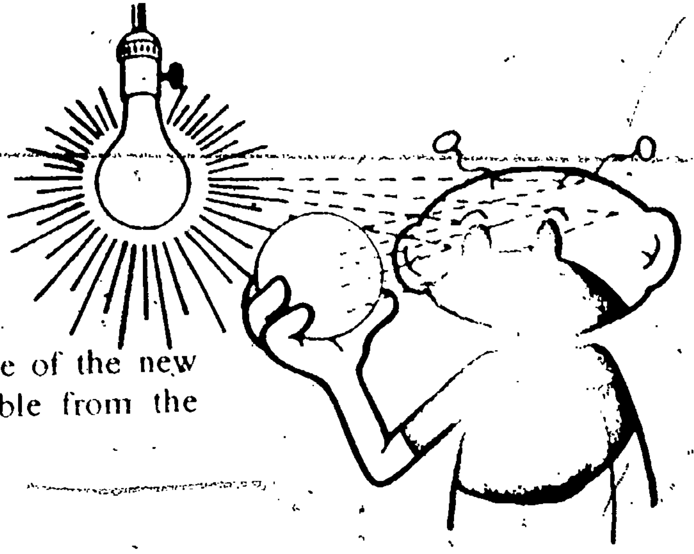


ACTIVITY 7-4. In just over seven days more, the earth-moon system rotates another quarter turn. Rotate the cardboard as shown. The moon is now closer to the sun, with the X still toward the earth.

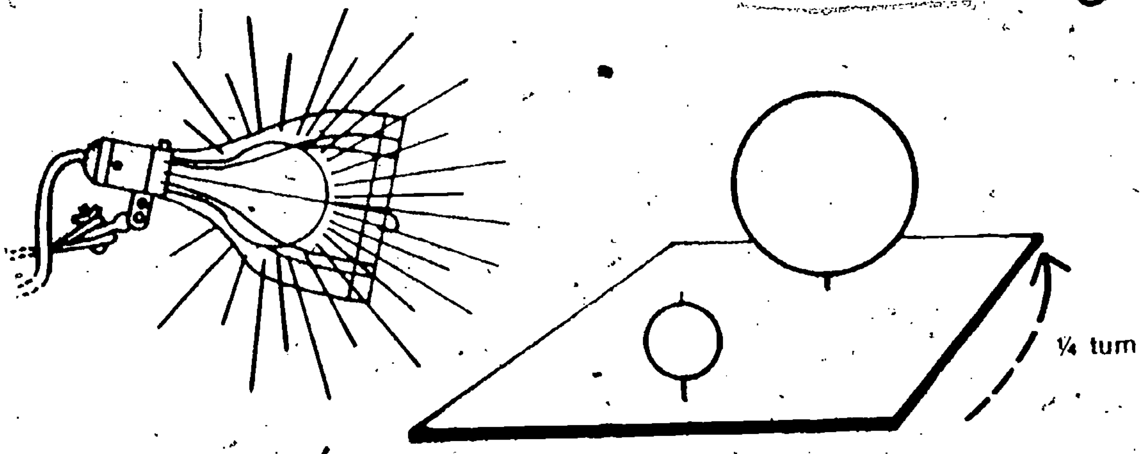
☐**7-9.** As seen from the earth, how much of the moon is now lighted?

The moon in Activity 7-4 is called a *new* moon. Actually it is not completely dark on the side toward the earth. An observer can make out some of the larger features.

☐**7-10.** Where does the light come from that shines on the face of the moon, making it slightly visible?



If it weren't for this source of light, the face of the new moon would be completely black and invisible from the earth.



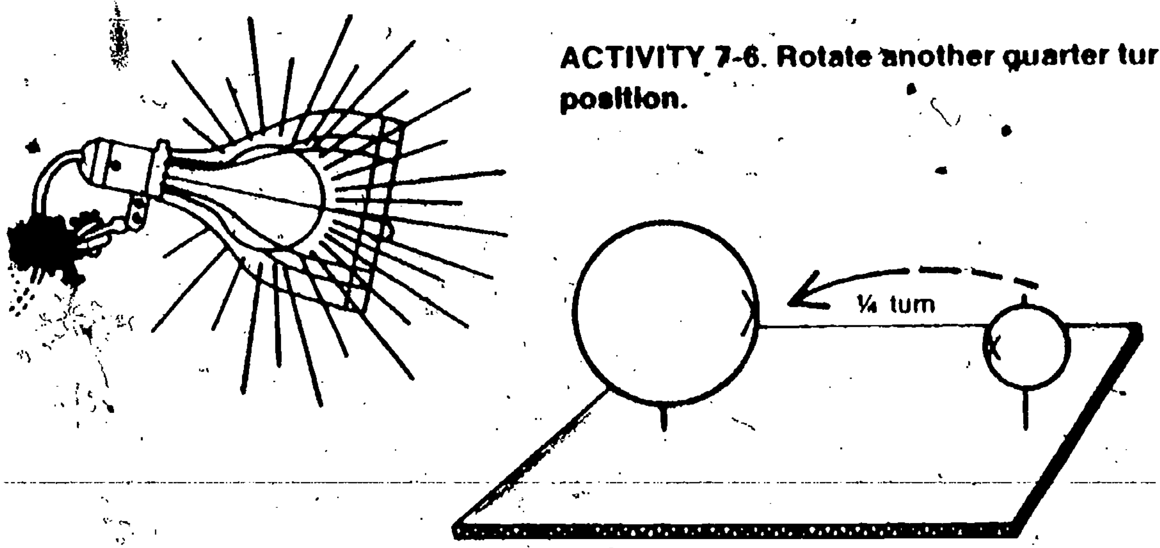
ACTIVITY 7-5. Rotate the earth-moon system another quarter turn. The X on the moon is still toward the earth.

☐**7-11.** As seen from the earth, how much of the moon is lighted?

☐**7-12.** As seen from the moon, how much of the earth is lighted?

The line down the face of the moon where the light and shadow meet is called the *terminator*. It is the line of either sunrise or sunset.

ACTIVITY 7-6. Rotate another quarter turn back to the original position.



The complete circuit has taken 29½ earth days. In other words, the earth has revolved 29½ times with respect to the sun, while the whole system turned once around. The X on the moon still faces the earth.

☐7-13. How many times did the moon rotate with respect to the sun during the 29½ day period?

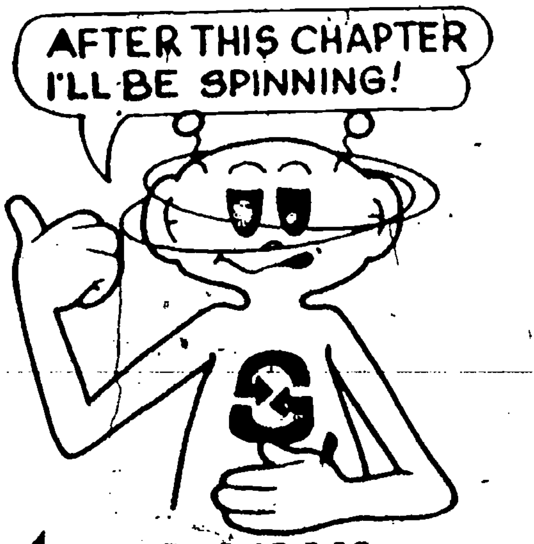
Rotation of the moon with respect to the sun would be counted by the number of times in a given period the X faced the sun. Remember that you started and ended with the X facing the sun.

Here is one other thing to set the record straight. While the earth-moon system is turning, it also makes one complete trip around the sun each 365¼ days. Figure 7-2 illustrates this.

You can duplicate this picture with your model system by moving the cardboard earth-moon system around the floodlight sun. The floodlight would have to turn to face the rotating bodies at all times. You are really dealing with a solar system and an earth-moon subsystem. Check the following list of motions to be sure that you can visualize all of them.

1. The earth-moon subsystem revolves around the sun once every 365¼ earth days.
2. The moon revolves around the earth once every 29½ earth days.
3. The earth rotates on its axis once every earth day (24 hours).
4. The moon rotates on its axis once every 29½ earth days.

☐**7-14.** How long is a moon day from one sunrise until the next?



You can probably see now why everything was stated in earth days. A moon day is an entirely different thing. You can also see that if you land on the moon at sunrise, you will have ample daylight to make observations.

With the same side of the moon pointed toward the earth at all times, an earth-based observer never sees the other side of the moon. But in orbit around the moon, there is an opportunity to see and photograph the other side in full sunlight. This has been done.

Perhaps you would like to take a side trip now. If so, do **Excursion 7-1,** "An Excursion to the Far Side."

EXCURSION

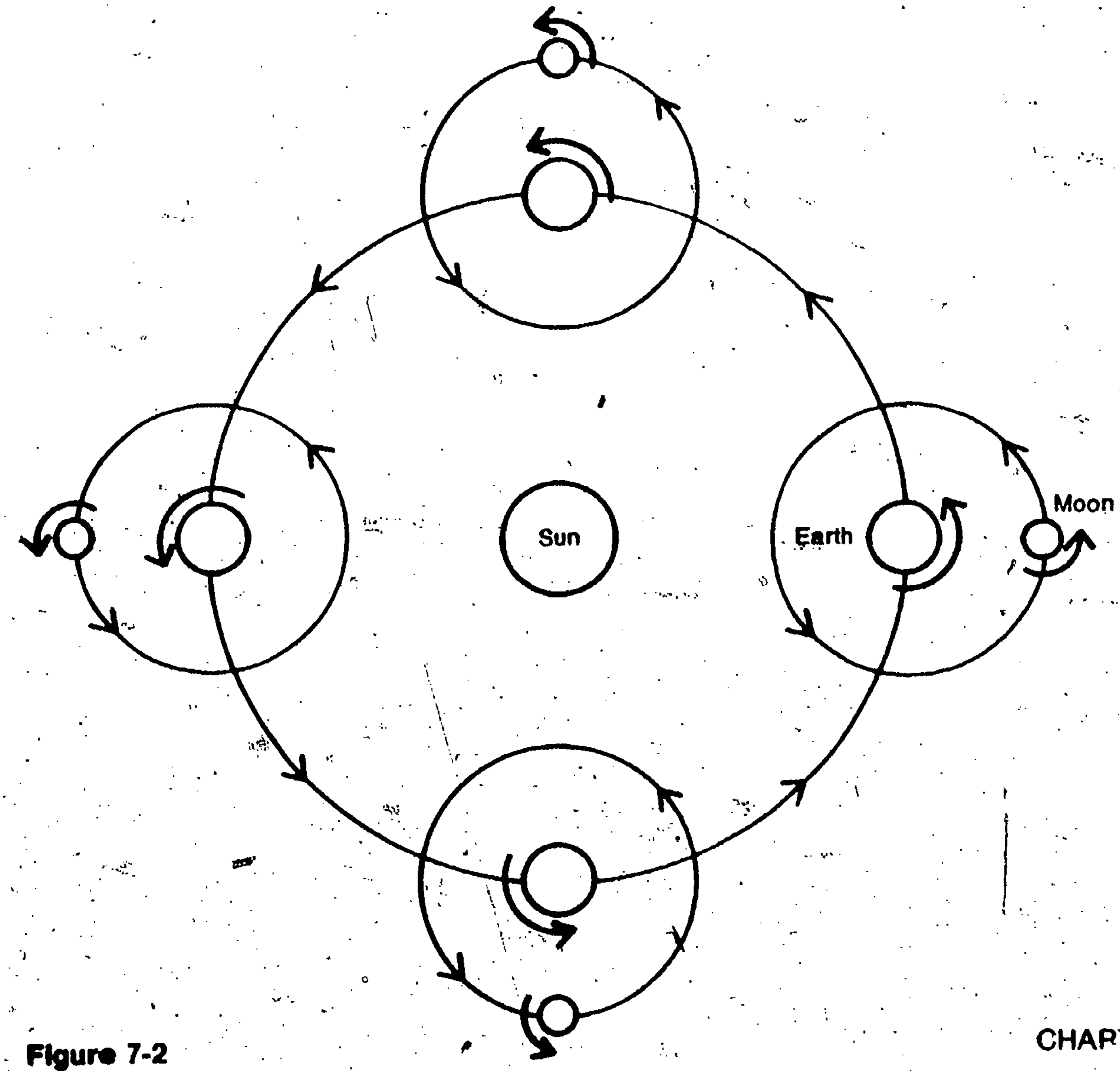
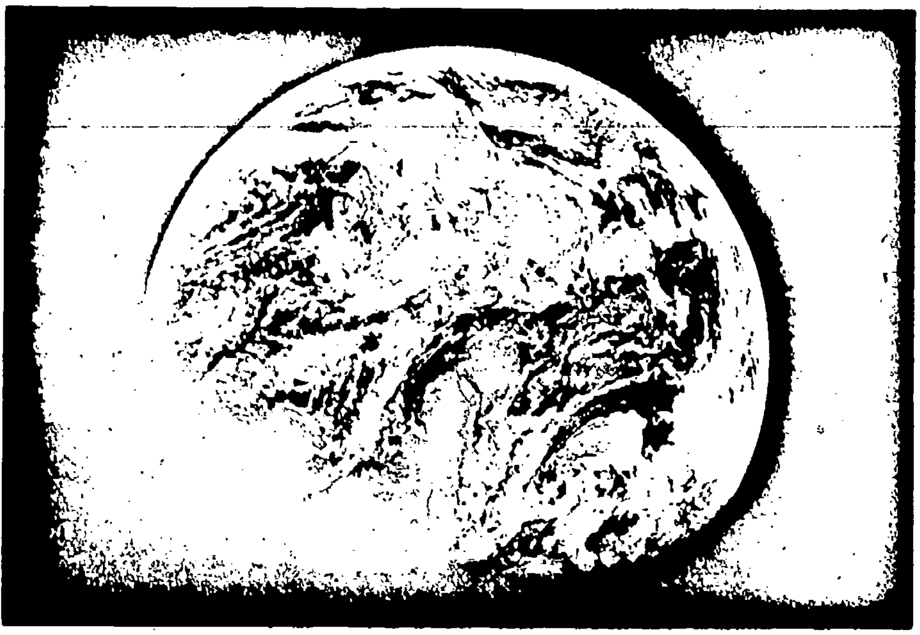


Figure 7-2

Well, your time on the moon is up. You must blast off at the right moment to meet the command module that has been orbiting. After joining up, you discard your moon vehicle and head back for the earth. There she is!

Before going on, do Self Evaluation 7 in your Record Book.



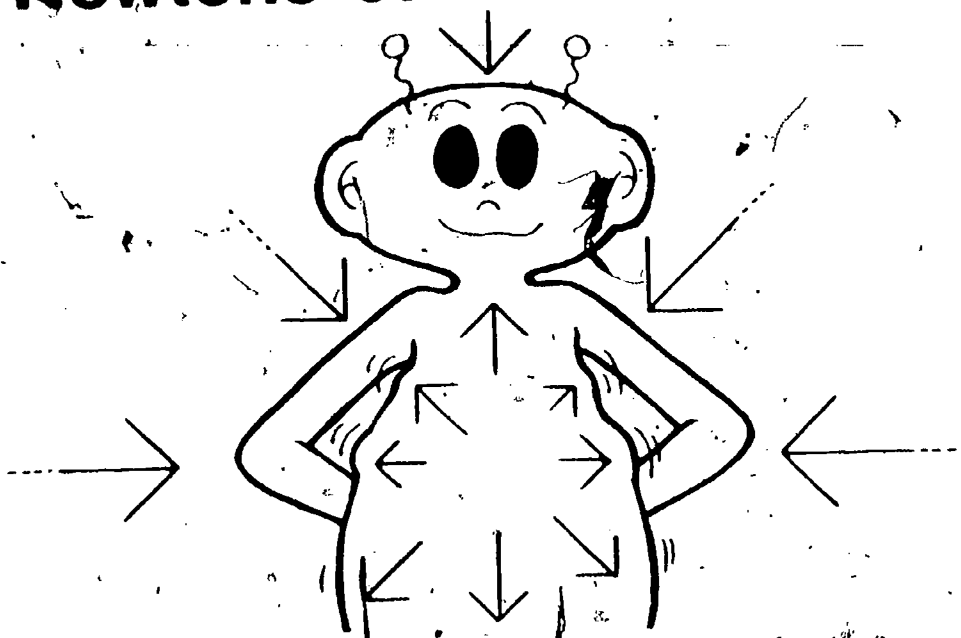
Excursions

Do you like to take trips, to try something different, to see new things? Excursions can give you the chance: In many ways they resemble chapters. But chapters carry the main story line. Excursions are side trips. They may help you to go further, they may help you go into different material, or they may just be of interest to you. And some excursions are provided to help you understand difficult ideas.

Whatever way you get there, after you finish an excursion, you should return to your place in the text material and continue with your work. These short trips can be interesting and different.

Newtons of Force

Excursion 2-1



Look around you. Everything that you can see has a force acting on it. The chair, the desk, your books, even you and your classmates are being pulled toward the center of the earth.

Why don't you notice this pull? Well, it's simply because this pull of gravity is balanced by other forces. Your desk pushes up on this book, and the floor pushes up on your chair, on your desk, and on the people in your room. As long as the force on an object is balanced by an equal and opposite force, the object remains in its present state of motion. Moving objects continue to move; stationary objects remain stationary.

☐**1.** What happens to an object when an unbalanced force (a force that is not balanced by another force in the opposite direction) acts on it?

Let's find out. Suppose one of your classmates drops a rubber ball, as shown in Figure 1.

☐**2.** What happens to the ball?

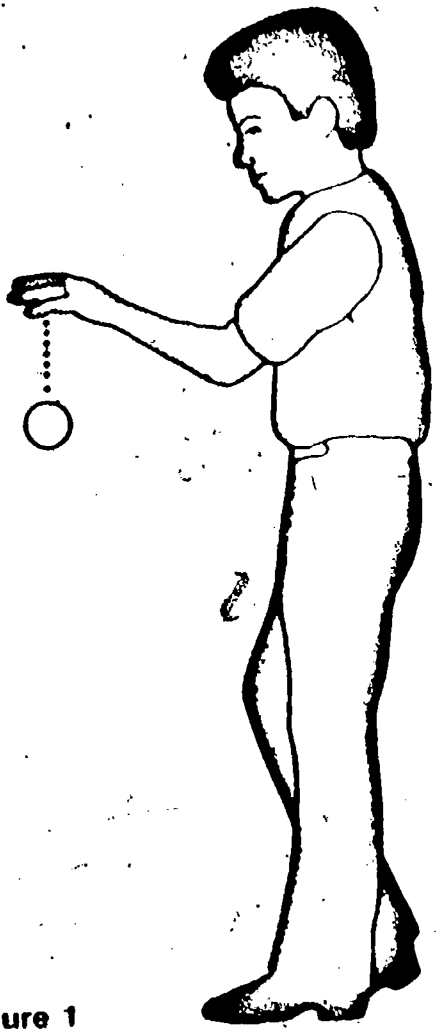


Figure 1

☐3. As the ball falls toward the floor, what happens to its speed?

☐4. When the ball hits the solid floor, what happens to it?

If you had a high-speed camera focused on the ball as it hit the floor, you could see, in detail, what happens. Figure 2 diagrams this.

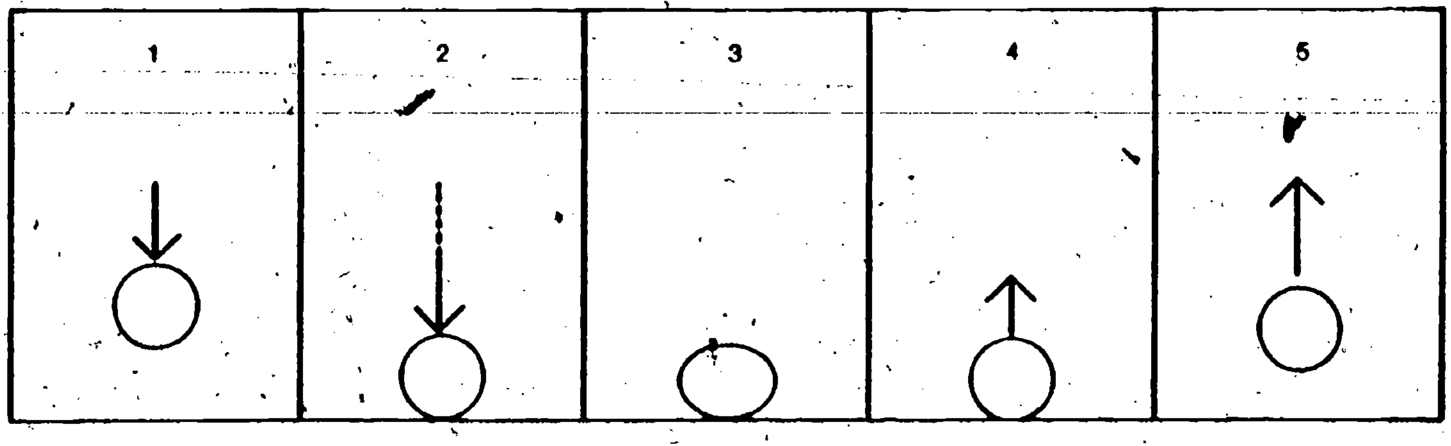


Figure 2

1. The ball approaches the floor.
2. The ball touches the floor.
3. The solid floor stops the bottom of the ball. The rest of the ball continues moving, and the ball is compressed, or flattened.
4. The elastic ball material pushes on the floor and on itself. Then it begins to regain its shape.
5. And it bounces upward.

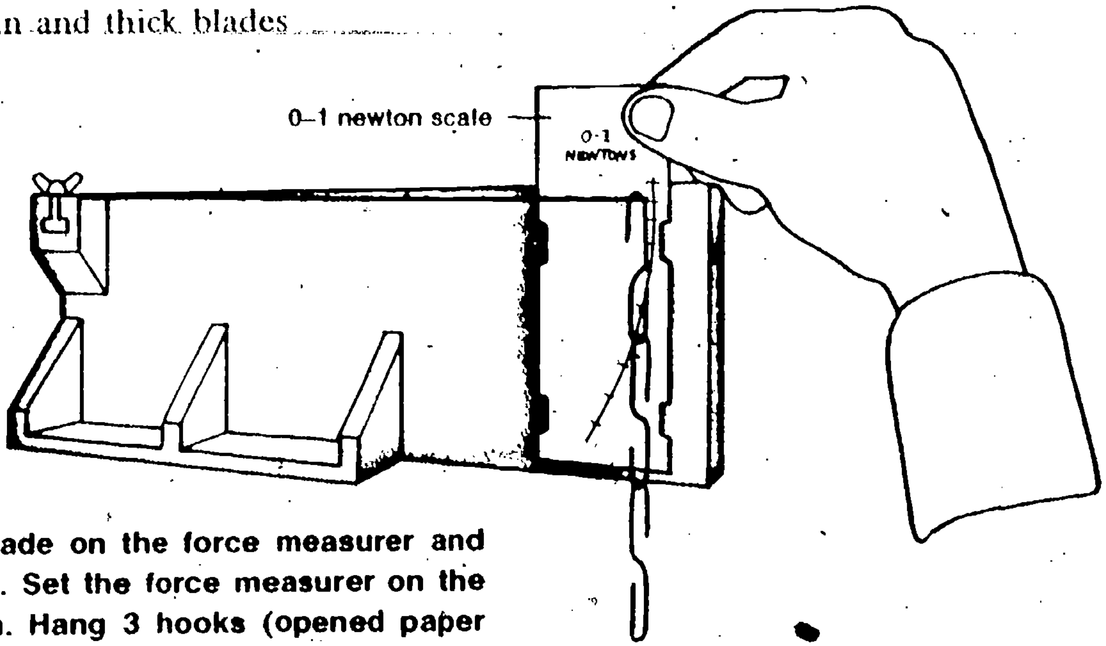
☐5. How must the upward elastic force on the ball compare with the force of gravity to make the ball bounce?

☐6. As the ball continues upward from the floor, what happens to its speed?

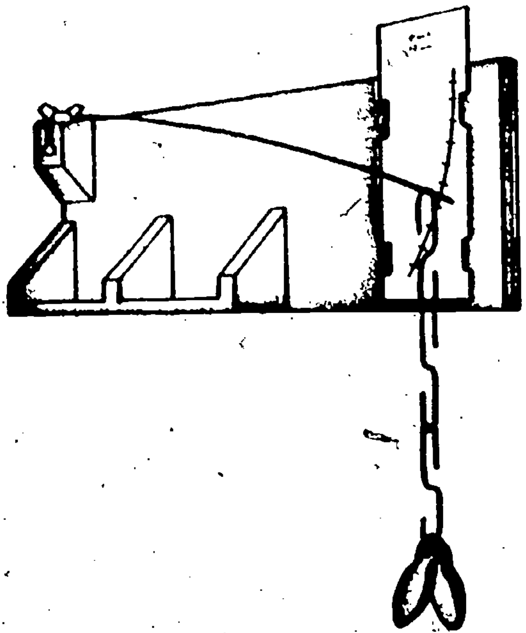
This could all be summed up by saying, "An unbalanced force on an object causes a change in its motion." But in frame 3 of Figure 2, you see another effect of an unbalanced force. A falling ball, stopped by the floor, changes its shape. In this case, one part of an elastic object can't move, and the unbalanced force of motion causes the ball to change shape (compress, then expand).

Measuring force by measuring changes in motion is usually difficult to do. Measuring the change in shape of an elastic object turns out to be an easier way of measuring force. Perhaps you have used an ISCS force measurer before and have seen its blade bend under a force. It's worth looking at again. You will need the following equipment:

1 force measurer, with thin and thick blades
4 sinkers
3 paper-clip hooks
1 0–1 newton scale
1 0–10 newton scale



ACTIVITY 1. Put the thin blade on the force measurer and insert the 0–1 newton scale. Set the force measurer on the edge of the table as shown. Hang 3 hooks (opened paper clips) onto the blade. Zero the scale by moving the card until the zero mark lines up with the blade tip.



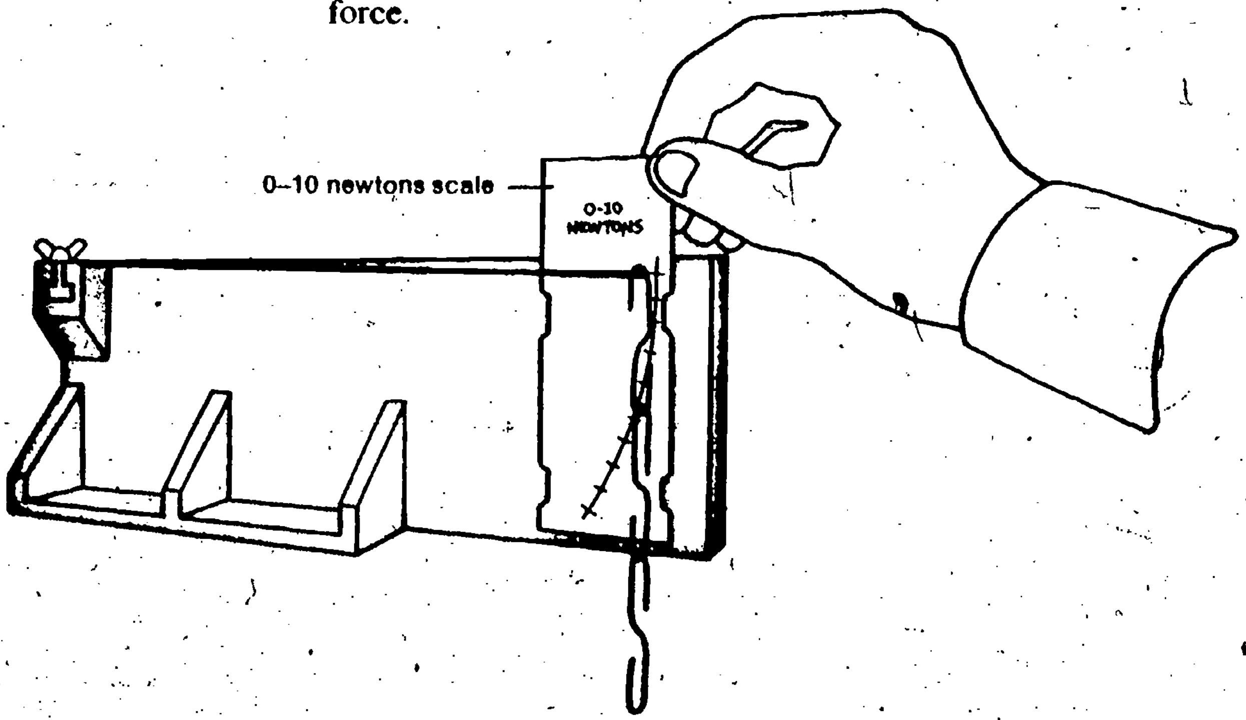
ACTIVITY 2. Hook sinkers, one at a time, to the bottom clip, reading the force after each sinker is added. Keep adding sinkers until the force is about 1 newton.

☐**7.** About how much force in newtons did each sinker exert?

☐**8.** How many sinkers did it take to exert a force of about 1 newton?

The unit of force the newton (abbreviated N) was named after the scientist Sir Isaac Newton, who stated the laws of motion 300 years ago. It is the unit of force that will be used throughout this course.

Notice that the force measurer behaved according to the idea of an unbalanced force causing motion. With no sinkers on the blade, the reading was zero. When sinkers were added, the blade moved down. Being elastic and fastened at one end, the blade changed shape as a result of the added force.



ACTIVITY 3. Remove the sinkers and hooks from the thin force-measurer blade. Replace the blade with the thick one. Insert the 0–10 newton scale. Hang the three hooks on the blade and zero the scale. Then put the same number of sinkers on the bottom hook that you found exerted a force of 1 newton. (See your answer to question 8.)

☐**9.** What does the force measurer read?

☐**10.** How many times more force can the thick blade measure th[illegible] the thin blade can?

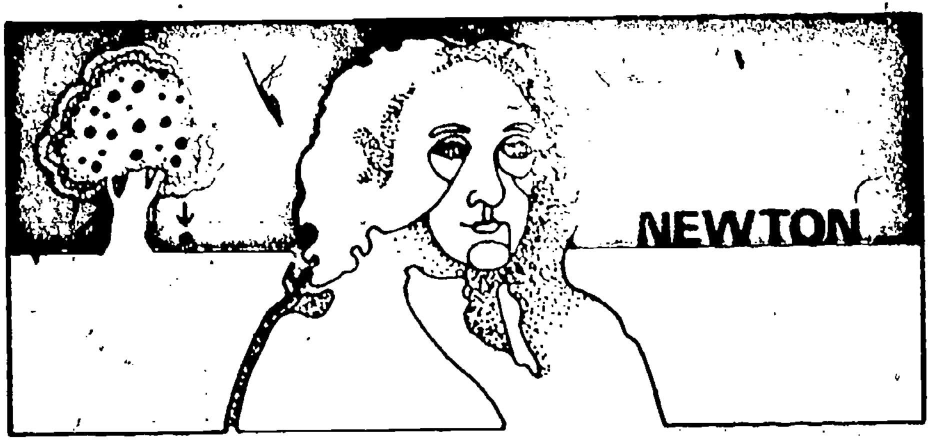
Suppose you wanted to go the other way and use the force measurer for forces only one tenth as great as those measured with the thin blade.

☐11. What would you have to do?

You will be faced with this problem later on in Chapter 2. And you will have another problem too—upward forces.

☐12. Describe how you would use the the force measurer to measure upward forces.

Well, now you know something about forces and what the force unit is. Perhaps you would also like to know a bit more about the laws of force and motion that Newton stated. In simple terms, here is what he said.



1. If all the forces acting on an object are in balance, the object will remain as it is.
2. If an unbalanced force acts on an object, the motion of the object will change. The amount that the motion changes will depend upon how much force acts and how massive the body is.
3. If one object exerts a force on a second object to change its motion, then the second object exerts an equal and opposite force on the first object to change its motion.

You have already had some experience with the first two statements. Your force measurer should have helped you see how they worked. The third one, called the *reaction principle*, is one of the main ideas in rockets. The air and water inside the water rocket exert a force on the rocket's inner walls. At the same time, these walls exert an equal force on the water and air. If for some reason the balance is lost, a change in motion or shape or both will occur.

☐**13.** If the nozzle is opened, will there be a balance of forces?

The Big Push

Excursion 3-1

The method of giving a rocket the necessary push to get it into the sky is based on just one thing—throwing something out the nozzle. The more that is thrown and the faster it is thrown, the greater push there will be.

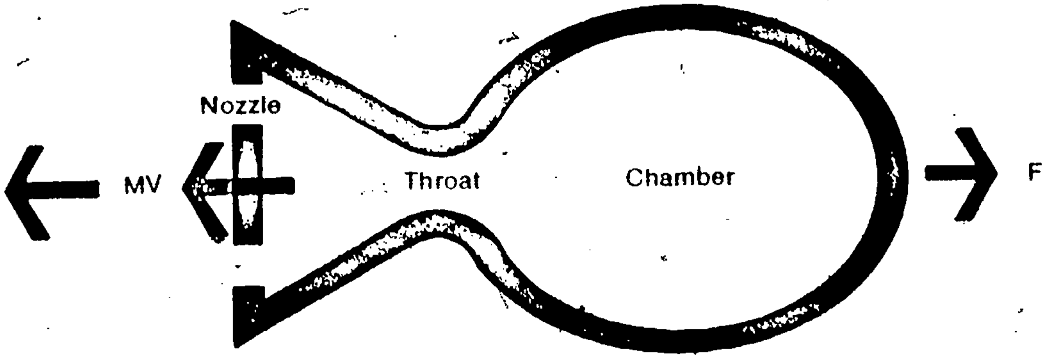


Figure 1

A force is produced in the chamber of the rocket engine. This force pushes material out the nozzle, producing a forward thrust on the rocket. (See Figure 1.) The thrust, F, is equal to the mass, M, thrown out per second multiplied by the speed, V, at which it is thrown.

To get material to shoot out rapidly, a large force must be applied. You probably remember that when a force moves matter, work is done. In order to do work, energy is required.

In the case of your water rocket, air pressure supplied the force necessary to do work. You furnished the energy when you pumped up the rocket. By building up the air pressure, you gave the air a form of potential energy.

☐**1.** What other forms of energy might be used to make matter shoot out of a rocket nozzle?

One of the forms of energy that you listed should have been heat. In your previous science work in Volumes 1 and 2 of ISCS, you developed a model that included some ideas about energy and matter. See how well you can recall those ideas.

☐**2.** What is all matter composed of?

☐**3.** All the different kinds of matter are made up of one or more of the 100 or so kinds of basic particles. What are these particles called?

☐**4.** During a chemical reaction, new combinations of atoms are formed. Where do the atoms in these new combinations come from?

An element is composed of only one kind of atom. Compounds are substances that are composed of two or more kinds of atoms.

☐**5.** Which of the following are formulas representing elements? Which represent compounds? H_2O; Li; $GaCl_2$; HNO_3; N_2; Fe.

☐**6.** Energy changes cause particle rearrangements. Is it also true that particle rearrangements can produce energy changes?

Many rocket fuels are made up of hydrocarbon compounds. These are chemical combinations of the atoms of hydrogen and of carbon. Kerosine, a common rocket fuel, is a mixture of these hydrocarbons. When the molecules of this fuel and pure oxygen react, their particles come together in new ways to form new substances—mostly carbon dioxide (CO_2) and water (H_2O). When this chemical change takes place in the combustion chamber of the rocket, the energy stored in the chemical compounds is released as heat. (See Figure 2.)

When kerosine is burned with pure oxygen, the temperature in the rocket chamber is about 3000° C. With hydrogen as the fuel, the temperature is higher still.

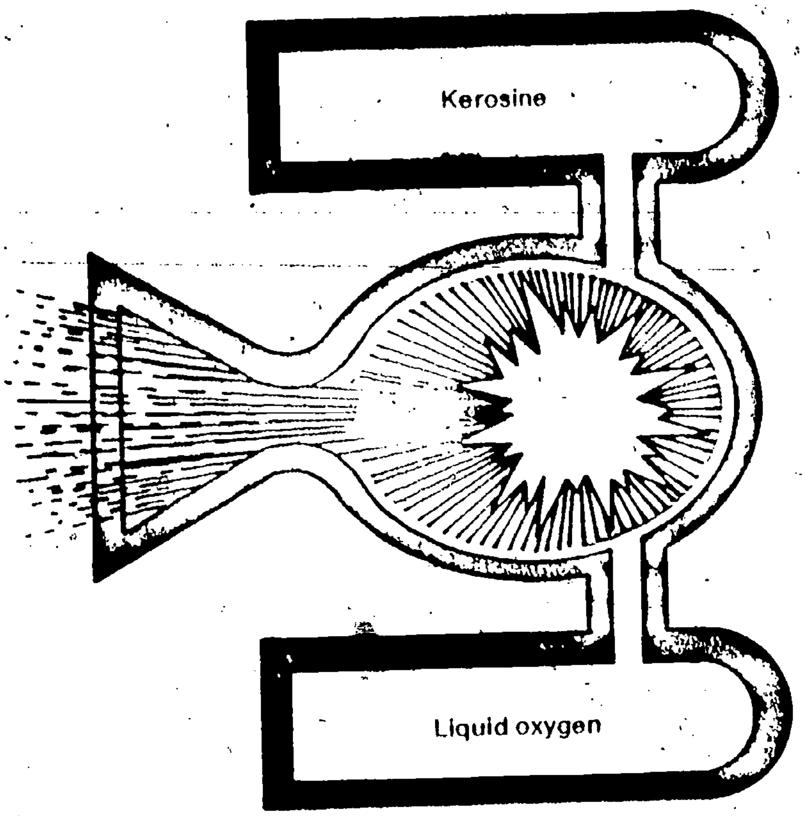


Figure 2

You may remember investigating in ISCS Volume 2 how heat affects the particles of matter. These investigations showed that as heat is added to a substance, its temperature increases. And as the temperature increases, the particles of the substance vibrate and move around with more and more speed. The final effect is expansion of the substance.

In the rocket engine, a great deal of heat is set free as the fuel burns. The particles of reactants and products move very rapidly, and the substance expands. The higher the temperature, the faster the particles move and the more the substances expand.

☐7. What must happen when the swiftly moving particles of the expanding gases strike the walls of the engine?

Whatever fuel is used, the same principle of propulsion applies. Tremendous forces are exerted on the combustion chamber walls because of the bombardment of high-speed particles of expanding reactants and products.

On one side of the engine there is no wall to stop the particles. There is only the opening into the engine nozzle. Since there is no wall to stop the particles, they rush out through the nozzle at high speed, forming the long tail of fire behind the rocket. The unbalanced force on the forward end of the combustion chamber pushes the rocket ahead.

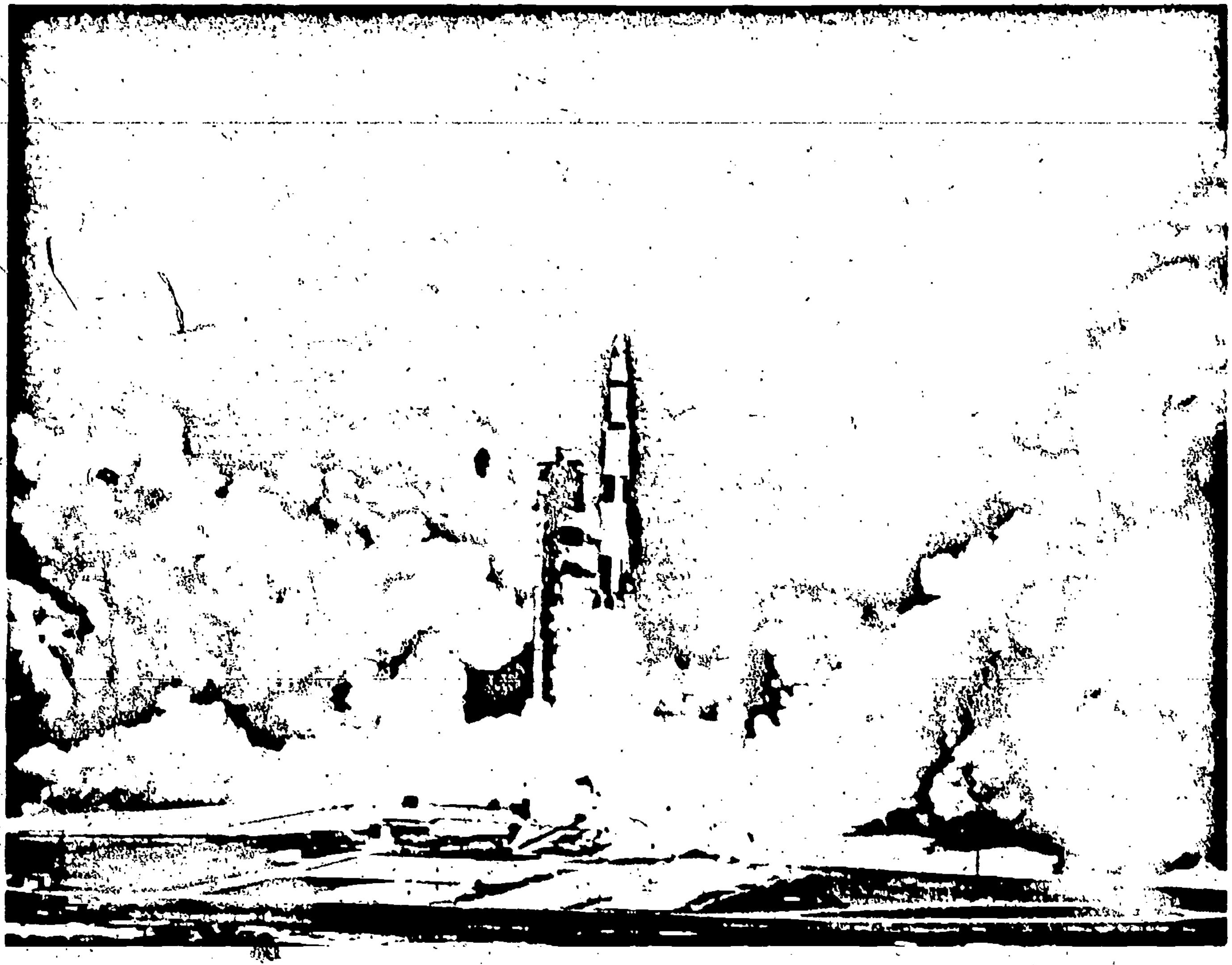


Figure 3

Shown in Figure 3 is the launching of Apollo 16. Note the flames and smoke belching from the first stage.

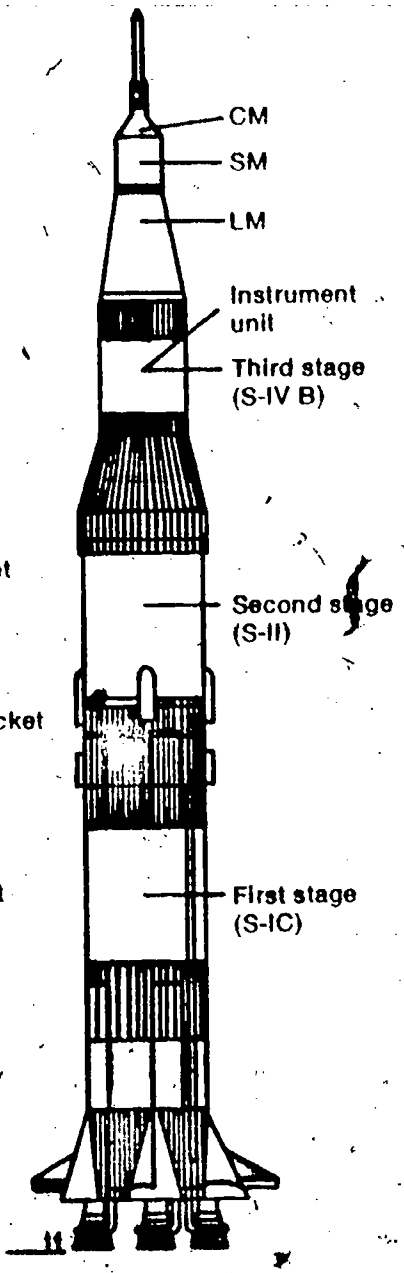
Anything that will burn rapidly can be used as a rocket fuel. One of the most powerful combinations uses no oxygen at all for the reaction. The elements hydrogen and fluorine combine violently, producing a large amount of heat and giving the greatest amount of push per pound of fuel used. Because fluorine is so corrosive and so difficult to handle however, it has not been used successfully in big rockets.

One Stage at a Time

Excursion 3-2

The Apollo spacecraft that has made trips to the moon consist of a command module (CM), a service module (SM), and a lunar module (LM). (See Figure 1.) It has a mass of about 45,000 kg.

Three stages of the Saturn V rocket send the Apollo spacecraft on its way.



The third stage of the Saturn V rocket has a mass of almost 120,000 kg.

The second stage of the Saturn V rocket has a mass of more than 480,000 kg.

The first stage of the Saturn V rocket has a mass of about 2,200,000 kg.

Figure 1

As you can see, the Apollo spacecraft has a small mass compared with the three stages of the Saturn V rocket. To understand why this is so, you first need to do an activity based on an idea that has been around for a long time. Then you can look at how the stages of a rocket operate.

Sir Isaac Newton made the first clear statement of an idea that has been extremely important in science, and especially useful in rocketry. This idea is called Newton's third law of motion. It says, "To every action there is an equal and opposite reaction." In terms that apply to rockets, this means that if you throw something out in one direction from a vehicle, there will be a force on the vehicle to push it in the opposite direction. You can investigate this important idea by using the water-clock cart.

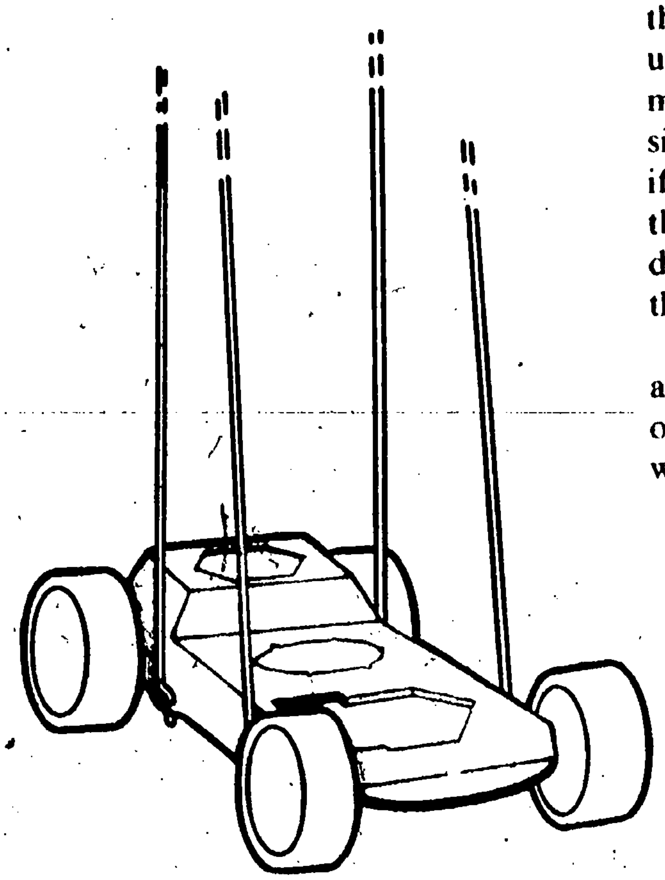
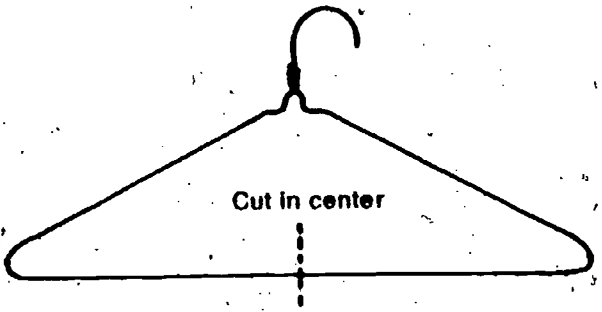


Figure 2

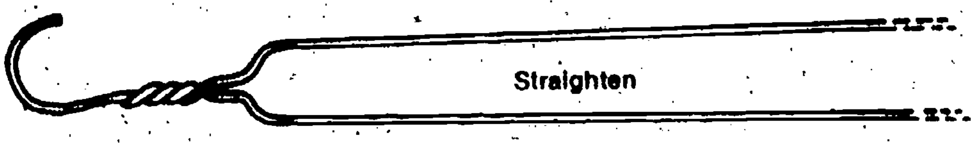
You will need the apparatus shown in Figure 2. If this apparatus has already been constructed by another student or your teacher, skip Activities 1 through 4. Otherwise, you will need the following equipment:

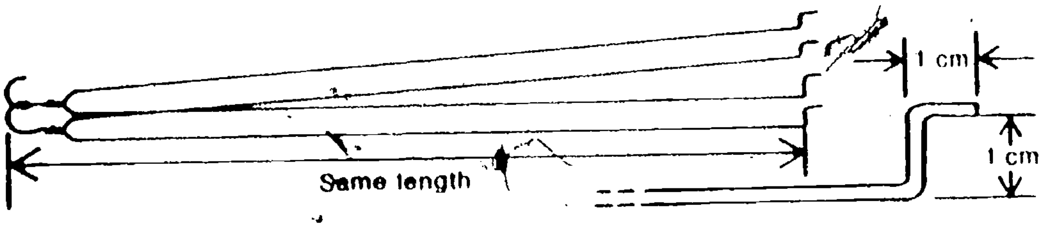
1 cart, without water clock
2 metal coat hangers
1 half-kilogram mass
4 lead sinkers
1 small piece of tape
1 piece of string, 0.5 meter long
2 paper clips
Scissors
Pliers or vise

ACTIVITY 1. Using a wire cutter, cut each coat hanger in the exact center of the horizontal bottom bar.



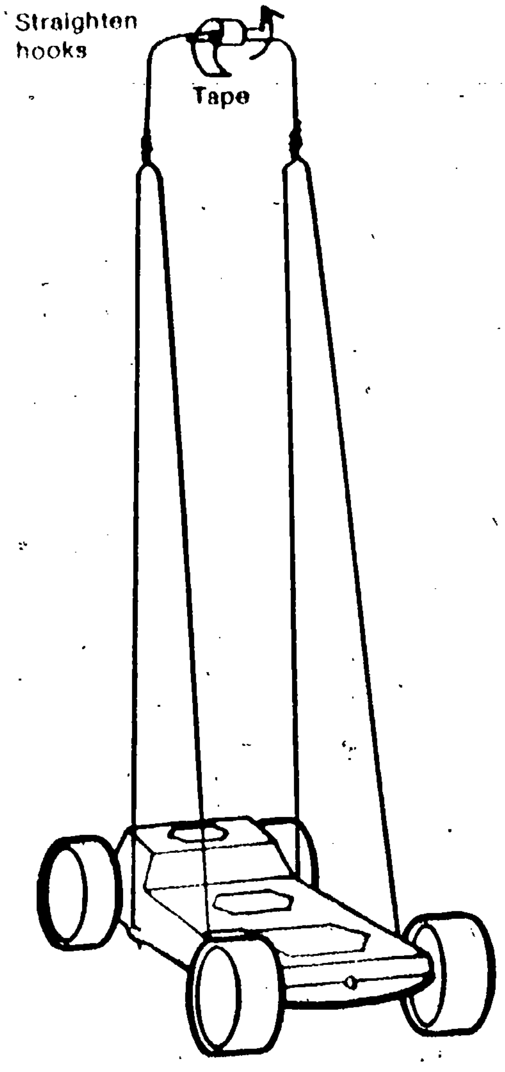
ACTIVITY 2. Straighten all the bends in the wire of each hanger. Do not change the hook or the twisted part of either one.

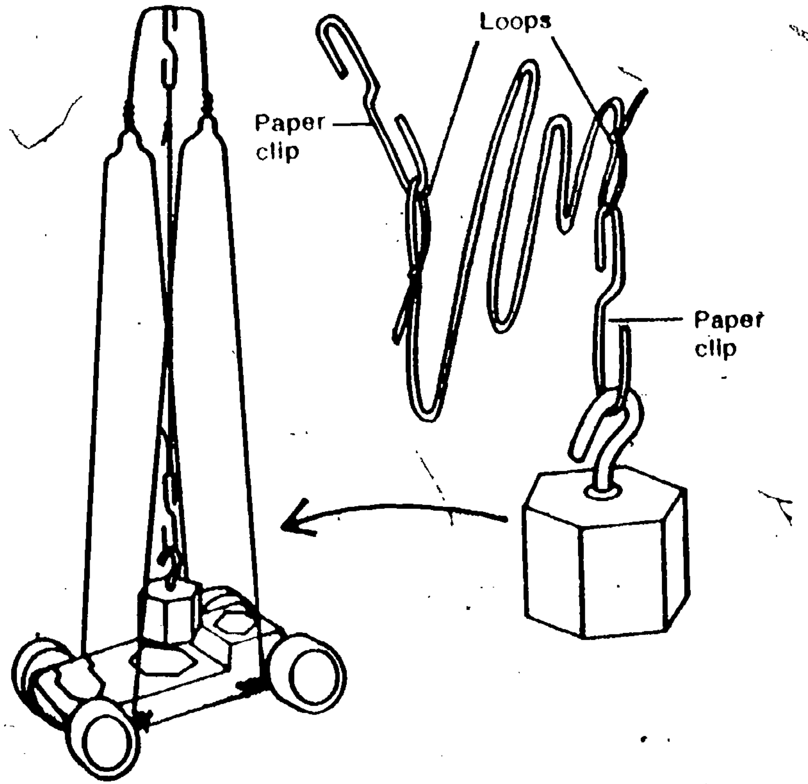




ACTIVITY 3. Using pliers or a vise, make two 90° bends in the two ends of each hanger as shown. Be sure that, when the bends are made, the distances from the top of the hook to the first bend are all the same for both hangers.

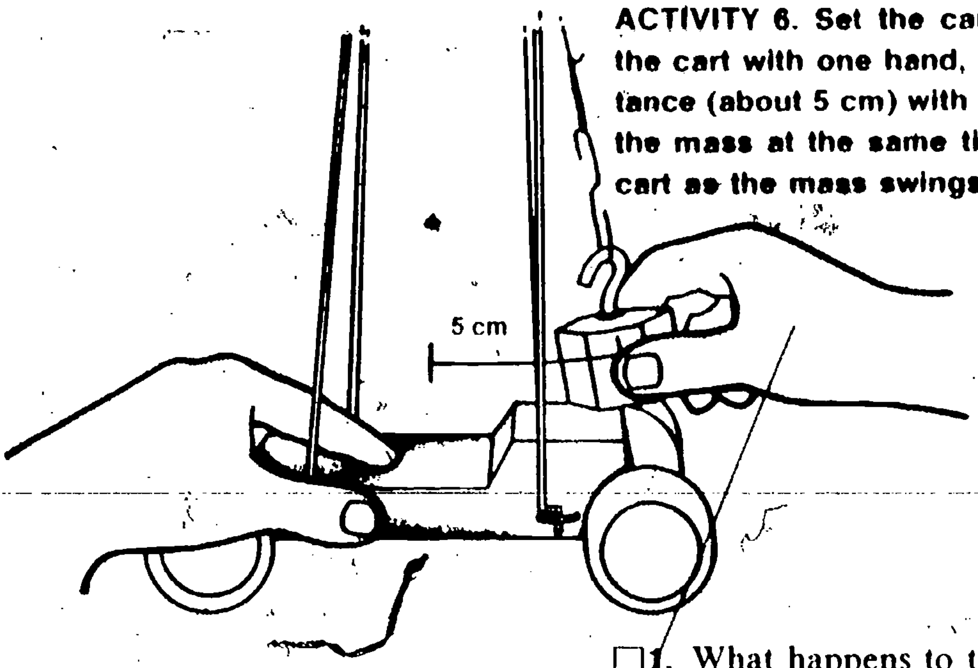
ACTIVITY 4. Insert the two ends of the hangers into the two holes on each side of the cart. Straighten the hooks on the top of the hangers so that they point inward. Put a small piece of tape around them to hold them together.





ACTIVITY 5. Make a loop in one end of the piece of string. Open a paper clip, and hook it over the top of the hangers. Slip the loop over the bottom of this hook. Make a loop in the other end of the string, and attach another paper-clip hook. Hang the half-kilogram mass on the bottom hook. Adjust one loop, if necessary, so that the mass swings freely without hitting the cart.

ACTIVITY 6. Set the cart on a smooth, level surface. Hold the cart with one hand, and pull the mass back a short distance (about 5 cm) with the other hand. Release the cart and the mass at the same time and observe the reaction of the cart as the mass swings back and forth.

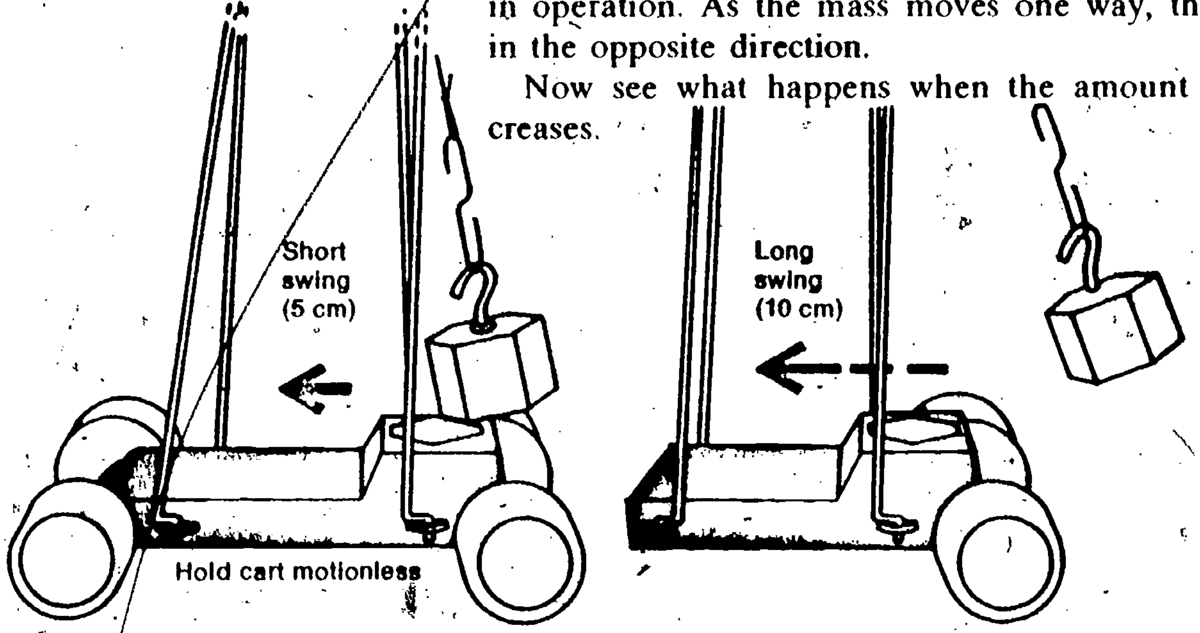


☐1. What happens to the cart as the mass swings?

☐2. As the mass moves in one direction, in what direction does the cart move?

You should have observed the "opposite reaction" idea in operation. As the mass moves one way, the cart moves in the opposite direction.

Now see what happens when the amount of swing increases.



ACTIVITY 7. Hold the cart so that it cannot move. Pull the mass back about 5 cm, and let it swing. Count the number of short swings that it makes in 10 seconds. A "swing" is a round trip from the starting position. Then pull the mass back about twice as far, and let it swing. Count the number of long swings that it makes in 10 seconds.

☐3. What is the number of short swings it made in 10 seconds?

☐4. What is the number of long swings it made in 10 seconds?

☐5. Is the number of swings in 10 seconds about the same in the two trials?

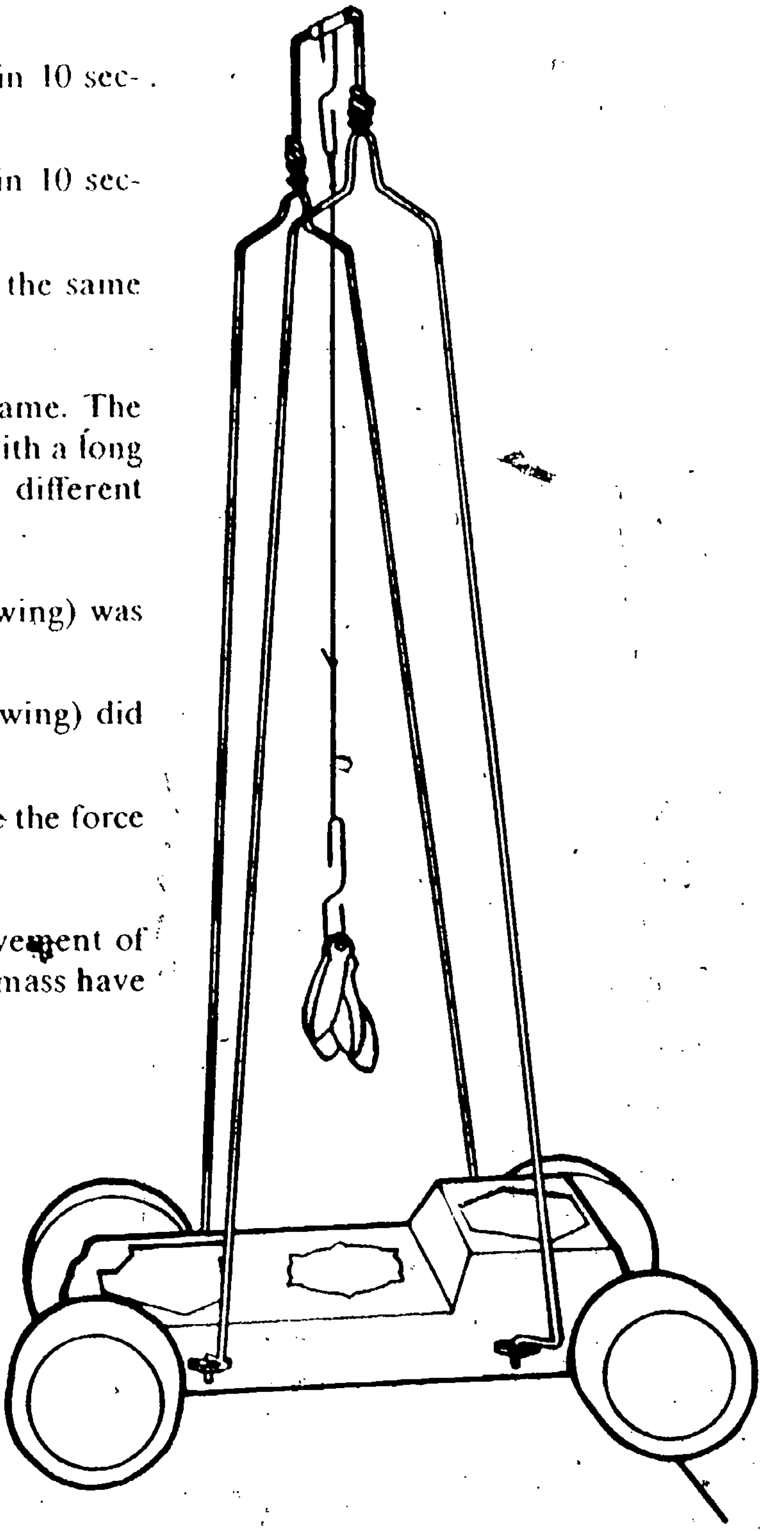
The time for each swing should be about the same. The distance that the mass travels, however, is greater with a long swing. Therefore, the speed of the mass must be different in the two cases.

☐6. In which case (the short swing, or the long swing) was the speed of the mass greater?

☐7. In which case (the short swing, or the long swing) did the cart receive the greater push?

☐8. Does increasing the speed of the mass increase the force acting on the cart? How do you know?

The speed of the swinging mass affects the movement of the cart. Would increasing the amount of swinging mass have any effect?



ACTIVITY 8. Mark the cart's position. Then measure the distance that the cart moves as a result of one swing of the half-kilogram mass. Next, remove the mass, and replace it with 4 sinkers. Swing the sinkers from the same position as you did the mass, and again measure how far the cart moves during one swing.

☐9. What distance did a swing of the half-kilogram mass move the cart?

☐10. What distance did the swing of 4 sinkers move the cart?

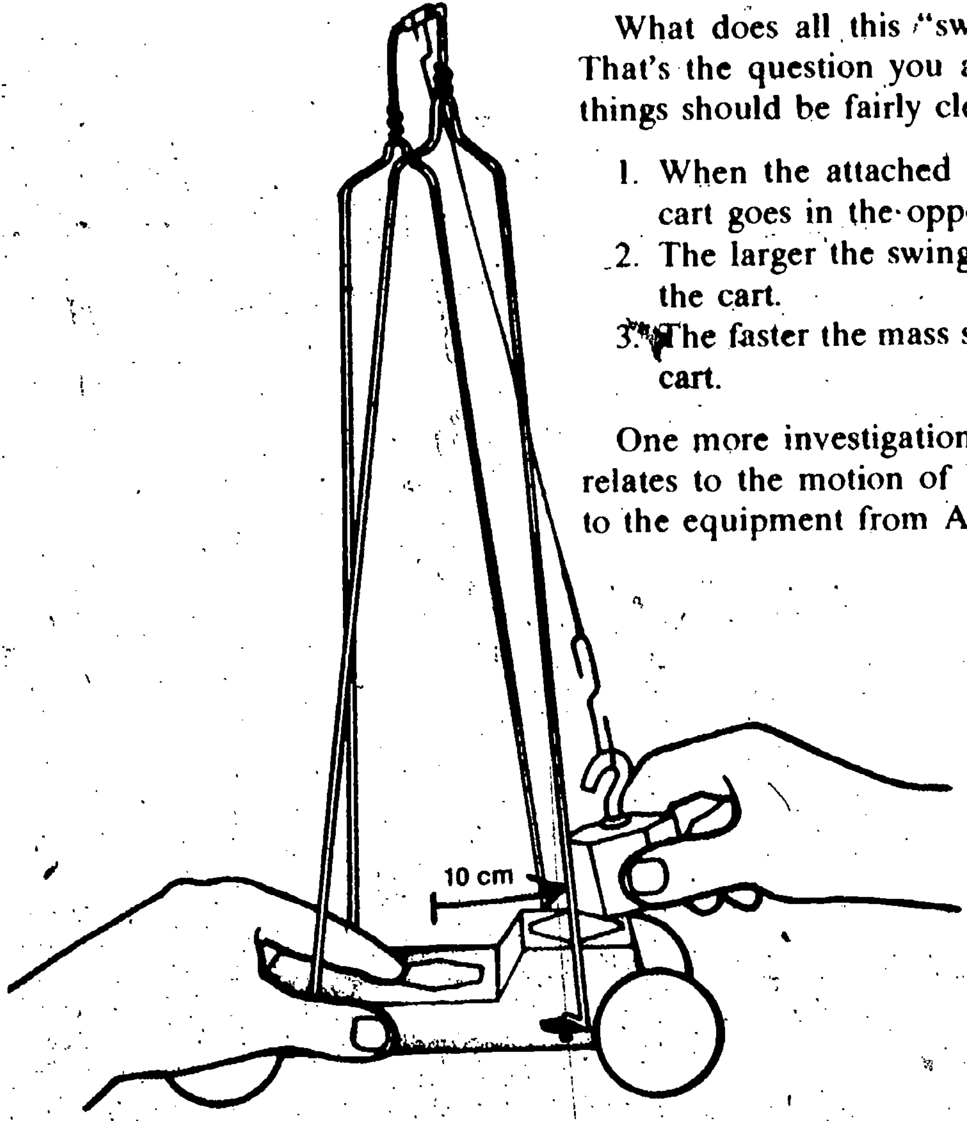
☐11. Compare the distances that the cart is moved by the swing of the half-kilogram mass and by an equal swing of the sinkers.

The amount of mass being swung does have an effect on motion of the cart. A greater mass produces more reaction than a smaller mass.

What does all this "swinging" have to do with rockets? That's the question you are probably asking. Well, several things should be fairly clear by now.

1. When the attached mass swings in one direction, the cart goes in the opposite direction.
2. The larger the swinging mass, the greater the speed of the cart.
3. The faster the mass swings, the greater the speed of the cart.

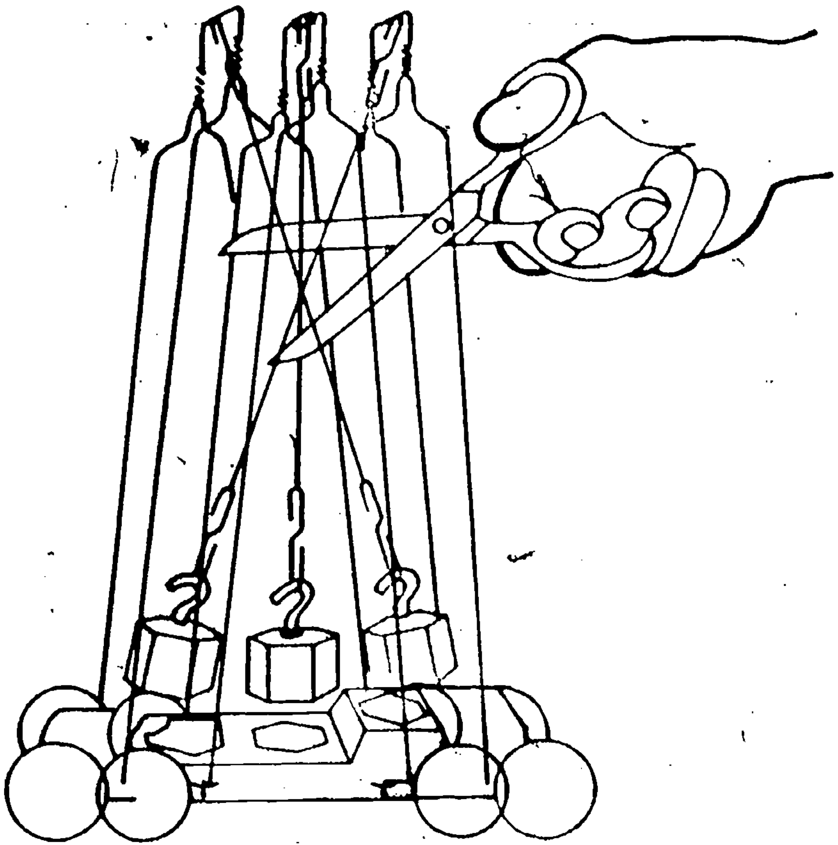
One more investigation should help you see how all this relates to the motion of rockets. All you need, in addition to the equipment from Activity 8, is a pair of scissors.



ACTIVITY 9. Place the reaction cart on the floor with the $\frac{1}{2}$-kg mass hanging. Pull the mass back 10 cm from the hanging position, and release both mass and cart.

☐**12.** Describe the motion of the cart as the mass swings back and forth.

ACTIVITY 10. Again start the mass swinging from the 10-cm position. This time, cut the string just as the mass reaches the midpoint of its swing.



☐**13.** How did the motion of the cart in Activity 10 differ from that in Activity 9?

Newton, and many other scientists since his time, have found that throwing mass away from a movable object produces a change in the object's motion. You have been witnessing that effect. In fact, the force on an object is equal to the rate at which it is thrown away multiplied by the speed at which it is thrown. In other words, force measured in newtons equals mass in kilograms thrown per second times the speed that it is thrown in meters per second.

$$F = (\text{mass/sec})(\text{speed of mass})$$

If 1 kg of mass is thrown away every second at a speed of 1 meter per second, the force on the cart is 1 newton.

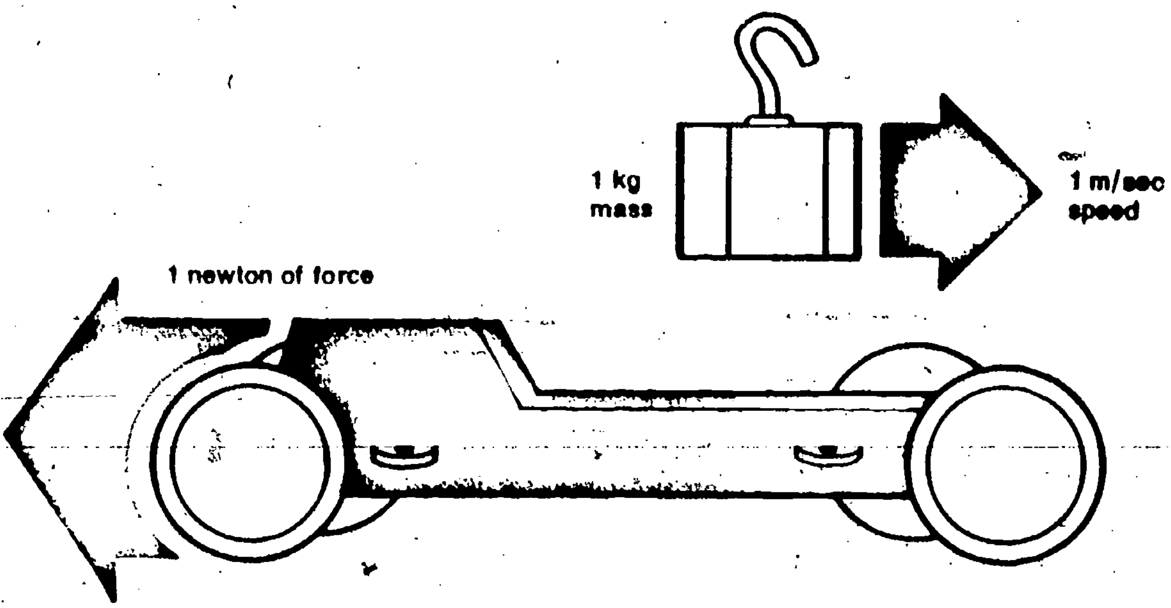
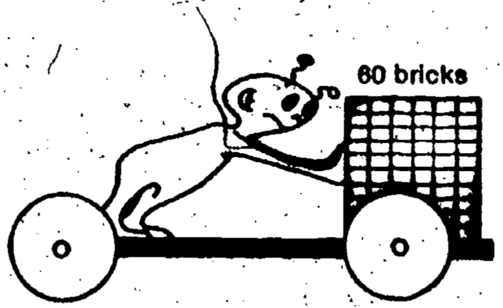


Figure 3

Of course, in your experiment the mass wasn't actually "thrown away" from the cart except when you cut the string. But the reactions due to the swinging mass were about the same as if it had been. There is one big difference, however. In a real rocket, when the mass is thrown out, the total mass of the rocket and its fuel is decreasing. Thus, there is less mass to be pushed ahead by the rocket engine. So a real rocket works even better than your reaction cart.

Now let's get back to those rocket stages. Why are they needed and why is the first one so large?

Suppose Iggy has a cart whose mass is 10 kg, and suppose Iggy's mass is 50 kg. With just Iggy sitting on the cart, the total mass is 60 kg. Now suppose he loads 60 bricks on the cart. Each brick has a mass of 1 kg, so all of them together would make the total mass of the cart and its contents 120 kg. Finally, suppose any number of bricks can be given a speed of 10 meters per second as they are thrown away. The illustrations that follow show the effect this would have on the speed of the cart.



Mass of cart	10 kg
Mass of Iggy	50 kg
Mass of bricks	60 kg
Total mass	120 kg

Figure 4

Suppose Iggy threw all the bricks away at the same time. (This, of course, would be a huge task.)

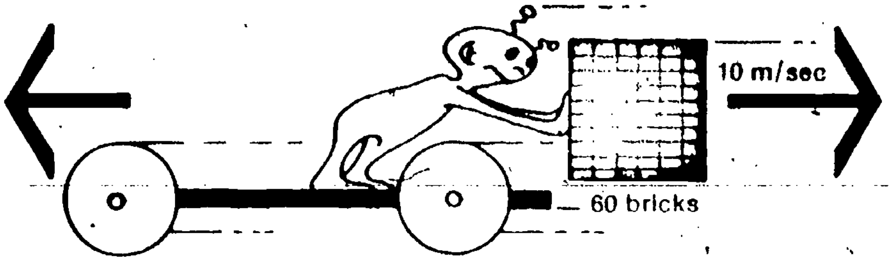


Figure 5

Recall that the force on the cart is equal to the mass thrown away times the speed with which it is thrown. If Iggy threw 60 kg of bricks at 10 m/sec, then the force on the 60-kg remainder (the cart and Iggy) is F = 60 × 10, or 600 N.

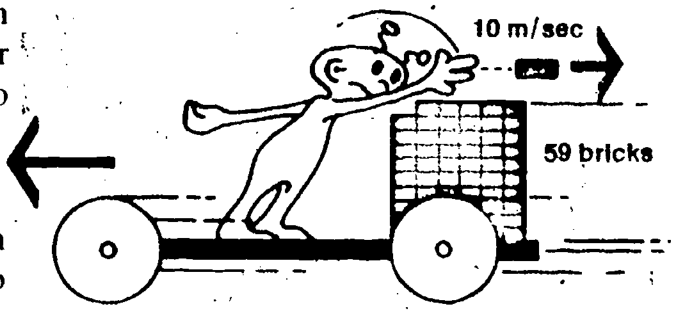
☐**14.** If the cart is at rest when the bricks are thrown, how will the speed of the cart change?

☐**15.** In what direction will the cart move?

Now suppose Iggy throws the bricks out one at a time instead of all at once.

If Iggy threw only 1 brick at 10 m/sec, then the force on the cart would be only $\frac{1}{60}$ as much as before. This smaller force must act not only on Iggy and the cart; it must also act on the remaining 59 bricks.

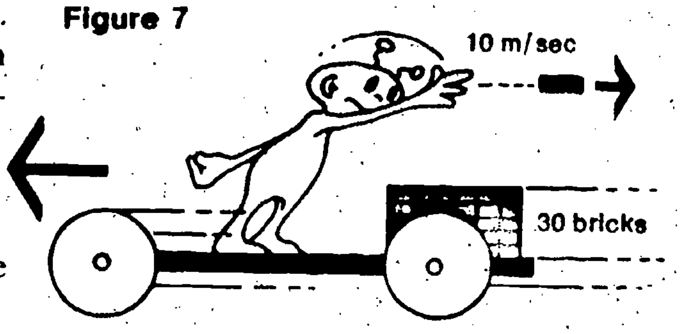
Figure 6



The force from throwing 1 brick is $\frac{1}{60}$ of the force when 60 bricks are thrown. This smaller force is used to speed up almost twice as much mass (Iggy, the cart, and 59 bricks). The change in the cart's speed will be much less than when 60 bricks are thrown away all at once.

With each succeeding brick that Iggy throws, the cart speeds up by a slightly greater amount. When the 30th brick is thrown, the force is still $\frac{1}{60}$ of the force with 60 bricks. But now the cart's total mass is down to $1\frac{1}{2}$ times as much as that of just Iggy and the cart. There are 30 bricks remaining. So the cart will speed up even faster.

Figure 7



Every time another brick is thrown away, the force in the opposite direction produces an increase in speed.

It is possible to calculate how the speed of the cart changes. These calculations show that throwing all the bricks away at once produces more change in speed than throwing them away one at a time.

However, it isn't easy to throw out all the bricks at once. There are two other ways that Iggy could make the cart go faster. He could (1) throw each brick away with a greater speed, or (2) carry a bigger load of bricks to throw away.

There is a limit to the speed that can be given the thrown bricks. So it seems that Iggy will simply have to carry more bricks if he wants to go faster.

Iggy and his cart are like a rocket and its payload. Iggy's mass represents the payload. The cart represents the rocket. The mass of the bricks (fuel) just equals the mass of the cart and Iggy. If Iggy carried 80 times as much mass in bricks as his mass—around 4,000 bricks—the situation would be closer to the fuel-spacecraft mass relationship of the Saturn-Apollo mentioned on the first page of this excursion.

The best way for Iggy to do it would be to have several carts hooked together. As soon as all the bricks were thrown from one cart, he could cut it loose. Then he wouldn't have to use energy to speed up that cart.

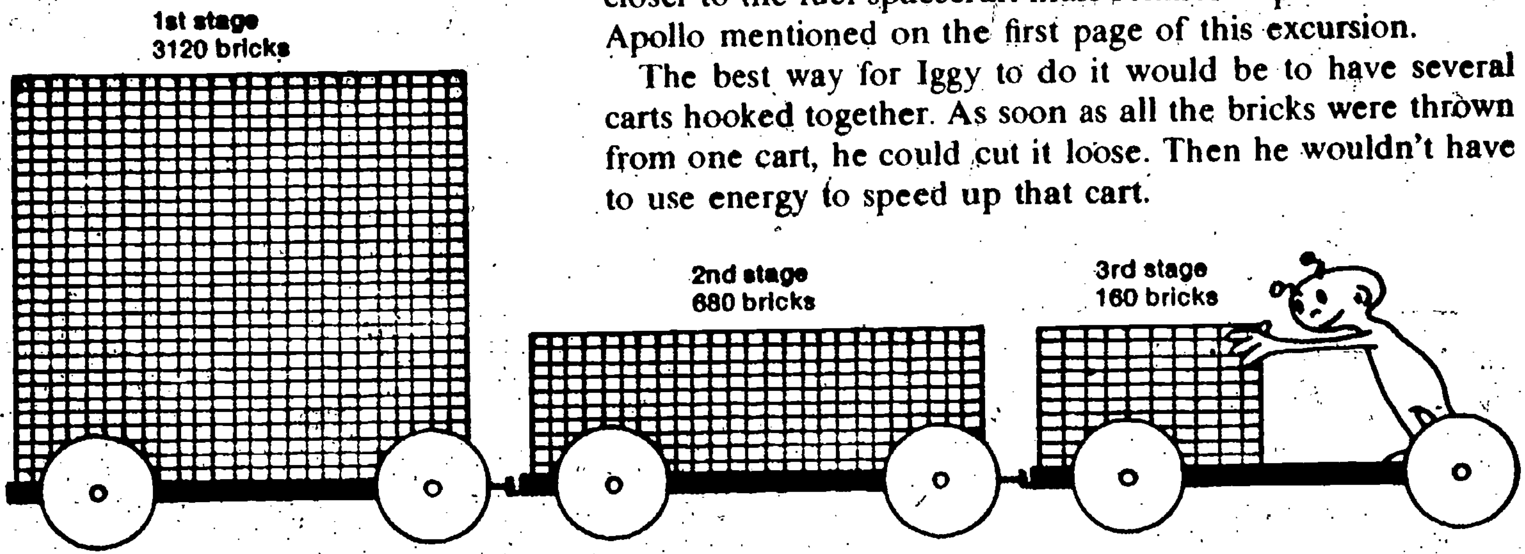


Figure 8

When the 3,120 bricks are thrown from the first stage and the cart is dropped off, about 78% of the beginning mass is gone. Then 17% is thrown away in the second stage, and 4% in the third stage. All that is left is a little over 1% of the amount that started out.

Now perhaps you see the reason for the different rocket stages. And you also can see why such a big first stage is needed on the Saturn-Apollo. After the third stage has put the spacecraft into orbit and sent it on its way to the moon, it is dropped off, too. All that remains of the 2,900,000 kg that lifted off the pad is the spacecraft and the occupants, with a mass of about 45,000 kg.

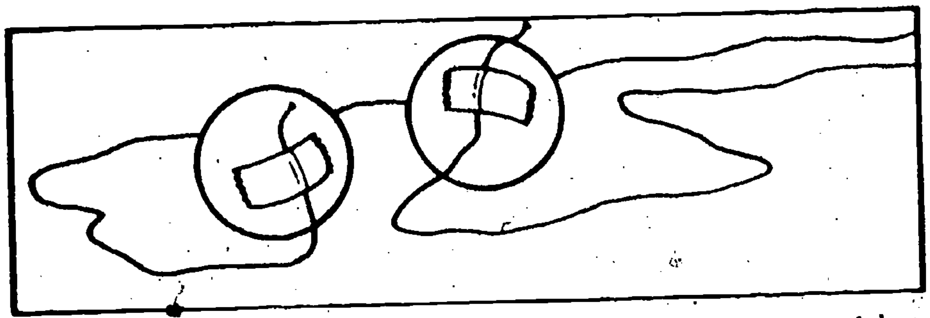
Time to Fall

Excursion 4-1

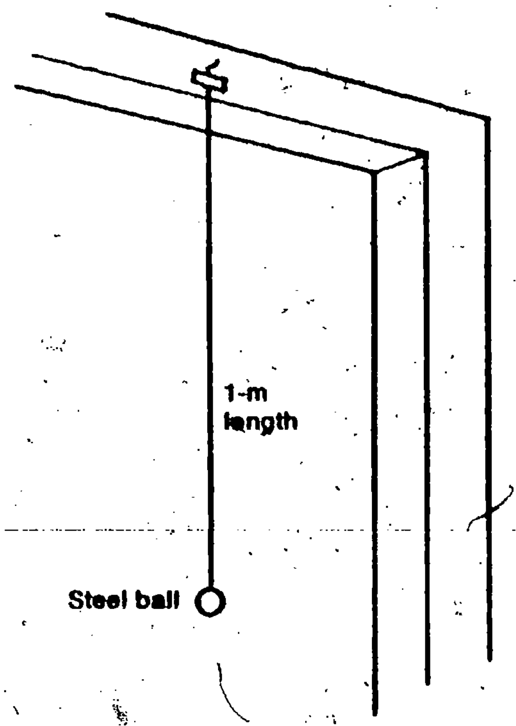
Sometimes incorrect ideas last for a long time. The great Greek philosopher and scientist Aristotle stated some rules of motion that lasted for 2,000 years. The rules were incorrect, but until Galileo tried some experiments, they were generally believed true. One faulty rule that survived from Aristotle's time (384–322 B.C.) declared that heavy objects fall faster than light ones.

Galileo is said to have discovered something about falling objects when he watched the swinging of a chandelier in the cathedral at Pisa, Italy. As he watched the massive object swing back and forth, he timed it with his pulse. When he returned home, he made pendula of different kinds and timed them in the same way. You can do an activity to discover how a pendulum operates, just as Galileo did. You will need the following equipment:

1 steel ball
1 glass marble
2 pieces of string, each 1 meter long
4 small pieces of tape



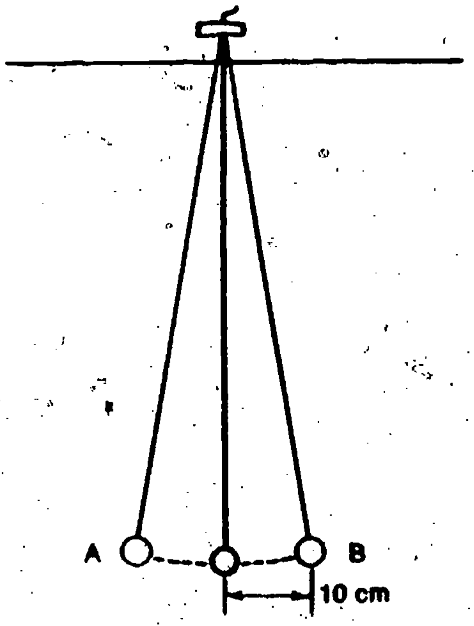
ACTIVITY 1. Use small pieces of tape to fasten one string to the steel ball and the other string to the glass marble.



Now, let's see if you can discover the same thing that Galileo did as he watched the swinging chandelier. First use the steel ball.

ACTIVITY 2. Tape the loose end of the string to the top of an opening such as a door or window. Be sure to select an area where the steel ball can swing freely at the end of the 1-meter string.

ACTIVITY 3. Pull the steel ball back about 10 cm and release it. Use a watch or clock to find out the time it takes for 10 complete swings. A complete swing means the ball swings from A across to B and back to A again. You may want to have someone help you with the counting and timing.

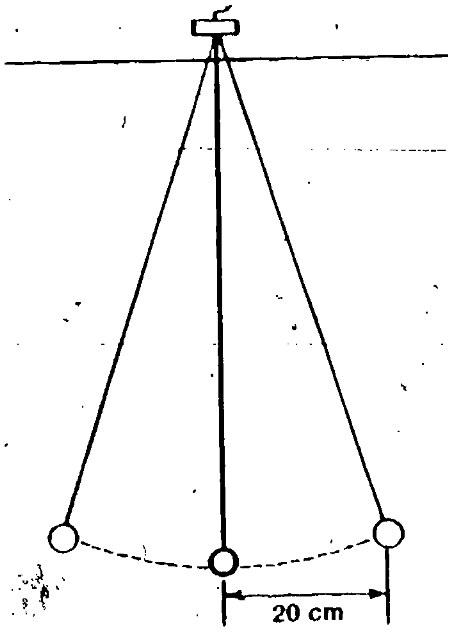


☐**1.** What is the time (in seconds) for 10 complete swings?

☐**2.** What is the time (in seconds) for 1 complete swing?

The time for 1 complete swing of the pendulum (from A to B and back to A) is called the **period.**

ACTIVITY 4. Now pull the steel ball back about 20 cm and release it. Find the time for 10 complete swings again.

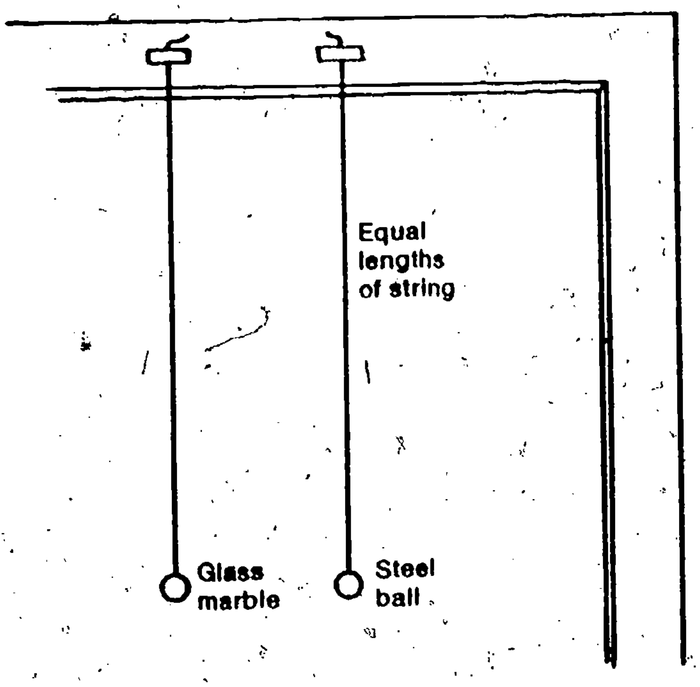


☐**3.** What is the time (in seconds) for 10 complete swings?

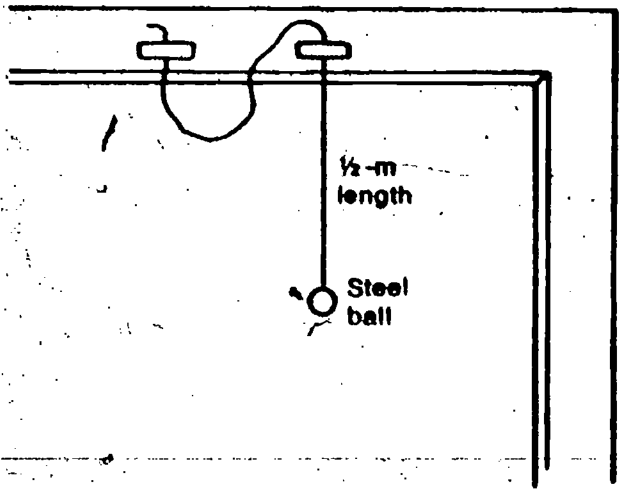
☐**4.** What is the period of the pendulum (time for 1 complete swing)?

Compare the periods in questions 2 and 4. If the timing was done correctly, you should have found them to be the same. This is the discovery that surprised Galileo and led him to further investigation.

Next you will experiment with the mass of the ball.



ACTIVITY 5. Nearby, on the same support, tape the loose end of the string from the marble. Be sure that the free lengths of the two strings are exactly the same. Pull the marble and the ball back a short distance and release them together.



☐5. Compare the periods of the two objects.

The mass of the steel ball is more than twice as great as the mass of the glass marble.

ACTIVITY 6. Shorten the string on the steel ball to $\frac{1}{2}$ meter. Pull the ball back a short distance and release it. Find the length of time for 10 complete swings again.

☐6. What is the length of time for 10 complete swings?

☐7. What is the period of the pendulum?

☐8. How does this period compare with the period that used a 1-meter length of string?

You have now investigated size of swing, mass of the object, and length of the pendulum.

☐9. From your investigations, which of the variables affect the period of the pendulum?

Galileo reasoned that though the object on the end of the string was supported by the string, it was really falling. The string forced the object to travel in an arc. He decided that since objects of different mass take equal time to come down when suspended on strings of the same length, then they should take equal time to fall straight down.

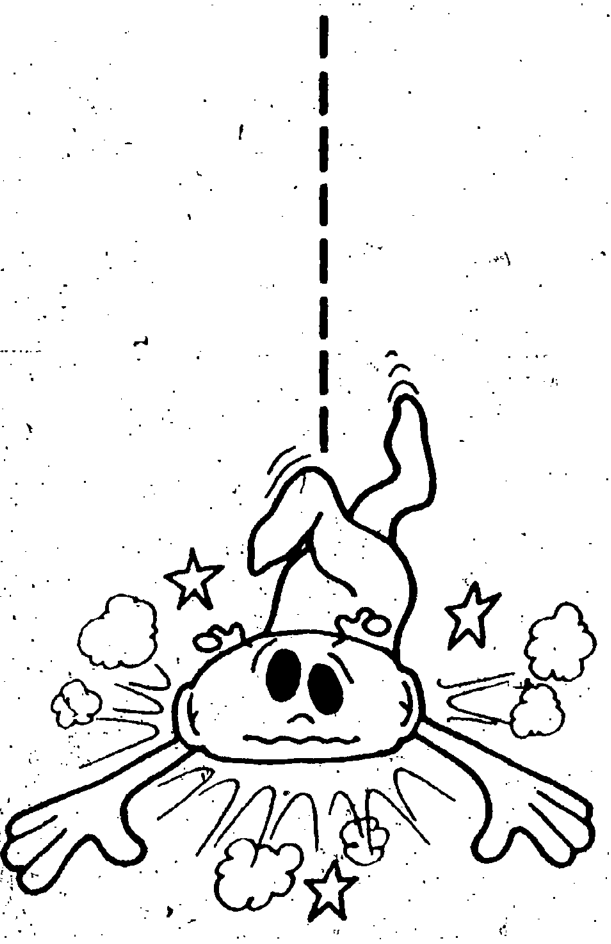
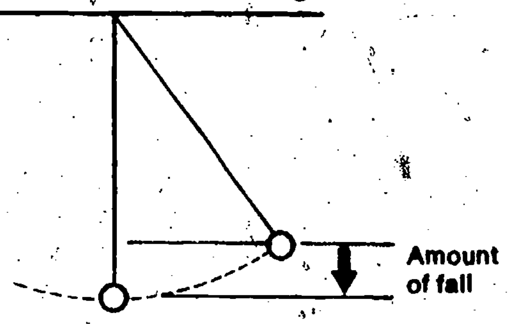


Figure 1



Some stories tell of Galileo's dropping objects from the Leaning Tower of Pisa to test this i[illegible]. The stories are probably imaginary, but the idea is not. Galileo, and other scientists who followed him, discovered that without the friction drag of air, all bodies fall at the same rate at a given location. In the near-perfect vacuum of outer space, a feather, a steel ball, a spacecraft, and the moon all fall equally fast; or, you could say, equally slow.

The Falling Apple

Excursion 4-2

What causes the moon to orbit around the earth? Isaac Newton was sure that it would shoot off in a straight line unless there was a force pulling on it. Galileo, who died in 1642, the year Newton was born, had experimented with moving objects. He had found that you need a force to change motion. From his own investigations, Newton knew that this was true. From your past work, you know this, too.

Suppose a round ball is rolled on a smooth, flat surface.

☐**1.** If no other force acts on the ball, what path will it follow?

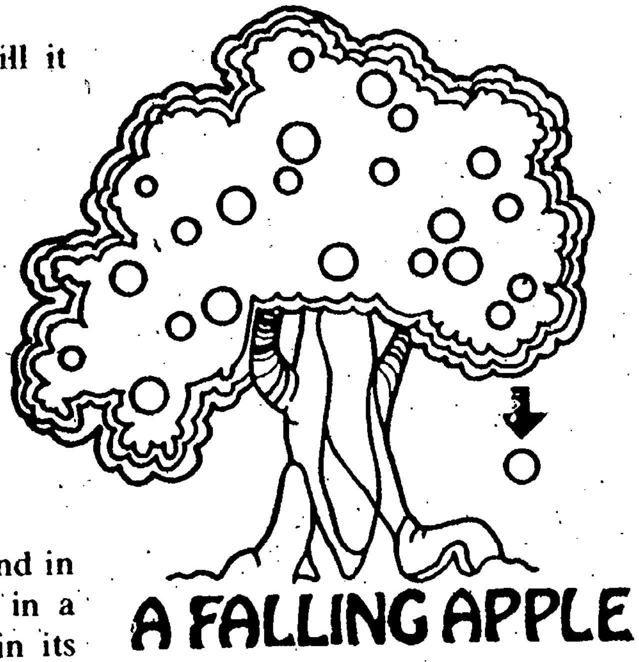


Figure 1

Sometimes the answers to difficult questions are found in strange ways. Newton said that while he was sitting in a garden, he found out why the moon always stayed in its orbital path. As he was thinking of the problem, an apple fell to the ground. Perhaps, thought Newton, the force exerted by the earth on the apple is also exerted by the earth on the moon. The moon might really be falling toward the earth. But if it is, why hasn't it hit the earth?

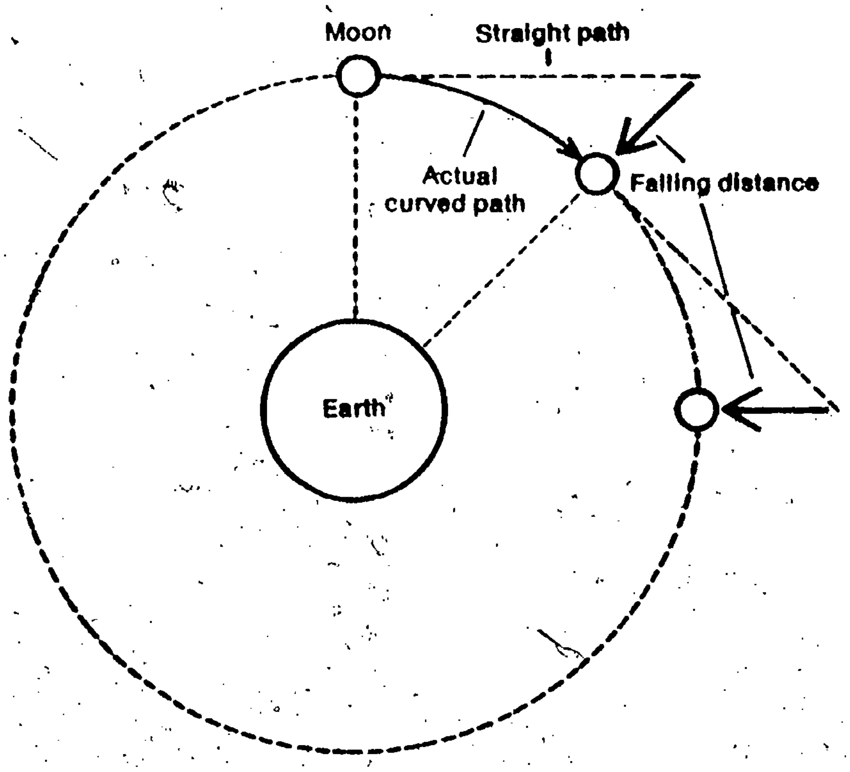
If you could know Newton's entire reasoning, it might have gone like this:

Before the apple fell, it was motionless. When it came loose from the tree, it dropped to earth. Obviously, the earth attracted the apple.

But the moon isn't fastened to a tree. It is moving through space. If no force were acting on it, it would be traveling in a straight line. But a straight path would carry it away from the earth. And I know that the moon follows a curved path around the earth. Perhaps the earth attracts the moon, too. If that attraction were very strong, the moon would soon hit the earth. If it were quite weak, the moon would fast be out of sight. But with exactly the right force of attraction, the moon could move two ways at once. It could travel through space while it drops toward earth. At the end of every second, its fall toward earth could just make up for its movement away. So instead of flying away in a straight line, the moon would continue in a curved path around the earth.

And that is what it does (Figure 2).

Figure 2



A FALLING MOON

Newton used the laws that Kepler had stated for the motion of heavenly bodies. He combined these laws with his own and with Galileo's laws of motion. Newton discovered that bodies attracted each other with a force that depended on their mass (the amount of substance that each contained). He found that the force of attraction also depended on how far apart the bodies were, and that the force changed with the square of the distance between the centers of the objects. In simplified mathematical terms, the relation could be written thus:

$$\text{Force} = \frac{\text{Mass of 1st} \times \text{mass of 2nd}}{(\text{Distance apart})^2}$$

or

$$F = \frac{m_1 \times m_2}{d^2}$$

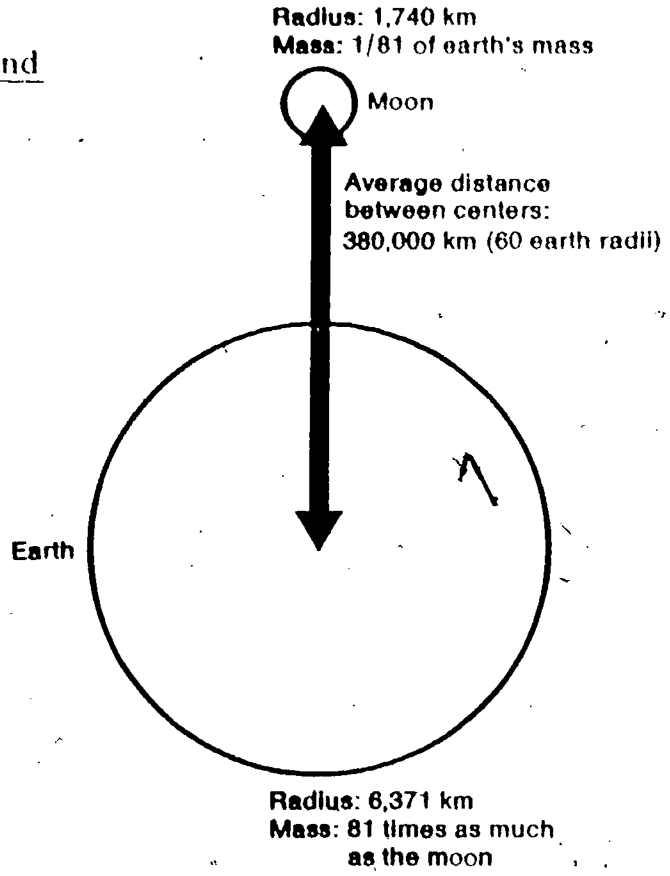


Figure 3

☐**2.** How many earth radii is the apple from the center of the earth?

The moon has been measured to be about 60 earth radii from the center of the earth.

☐**3.** How many times farther away is the moon than the apple from the center of the earth?

Square the number that you got in question 3. (Squaring a number means multiplying it by itself.)

☐4. What is the square of the number?

Your answer to question 4 is the number of times greater the earth's pull of gravity is on the apple than on the moon. Bodies fall according to the pull of gravity on them.

☐5. How many times faster will the apple fall toward the earth than the moon will fall?

The mass of an apple is much less than the mass of the moon. Therefore, the force on the moon will be much greater than the force on the apple. But the speed of falling does not depend on the mass. It depends solely on their distance apart; so the apple still falls 3,600 times faster. An apple, or any other object close to the earth's surface, will fall about 4.9 meters in a second. The moon falls about 1/3600 as much, or just under 0.0014 meter in a second (Figure 4).

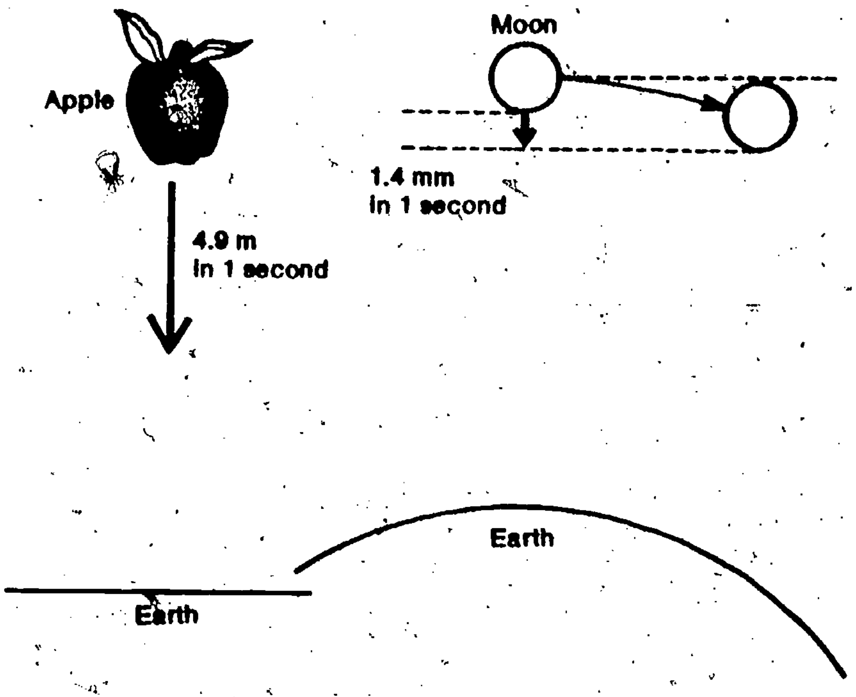


Figure 4

This is only 1.4 millimeters in a second. With the moon's horizontal motion, this amount of fall is just enough to keep the moon going around the earth in a curved path.

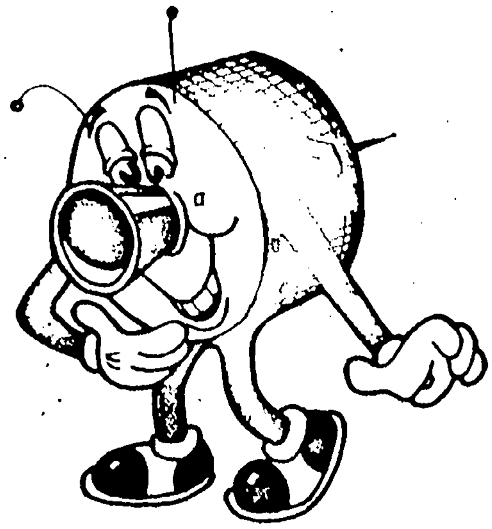
Just think! Newton made these discoveries when he was 24 years old. That's not much older than you.

Orbiting Syncom

Excursion 4-3

You found that the period (the time for one revolution) increases as the satellite goes farther from the surface of the earth. You also found that the speed a satellite must have in order to stay in orbit decreases at greater heights. However, putting a satellite in orbit farther out in space takes more fuel. Therefore, the lowest possible orbit is used unless there is a special reason for having the satellite in a higher orbit. Some of the satellites that have been launched have needed a distant orbit for just such a special reason.

Early in the space age, the value of satellites for communications was recognized. A radio signal could be beamed to the orbiting object, and this signal could be either reflected or rebroadcast to other points of the earth's surface. For this technique to work best, the satellite has to stay over a given point on the earth's surface all the time.



☐**1.** What must the period of the parking orbit be for a good communication satellite?

The earth rotates on its axis once every 24 hours. If a satellite could be orbited at the correct height, it could stay over the same spot on the surface of the earth as the earth turned. Then radio messages could be relayed continuously by the satellite. And with a few more such satellites, radio and television programs could be sent to all parts of the globe.

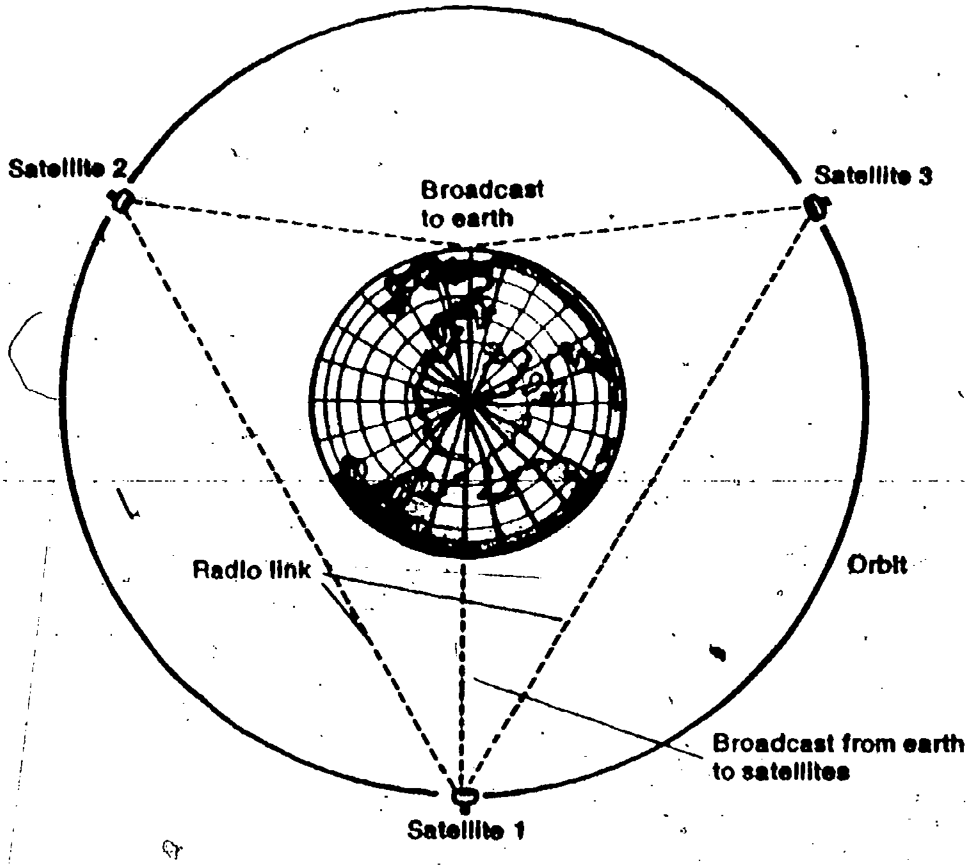


Figure 1

Perhaps you'd like to know how high above the earth a satellite must be to always remain above the same spot. Figure 2 has two graphs on one grid. These graphs show the relationship of both satellite speed and period to satellite height. Using these graphs, you can find the correct height for a satellite that has a period of 24 hours.

The height of the satellite in thousands of km is shown along the side of the page. The period in hours is shown across the top and the speed in km/sec across the bottom. Use the graph to find the answers to the following questions.

☐**2.** The height of a satellite whose period is 24 hours is how many km?

☐**3.** The speed of a satellite whose orbit period is 24 hours is how many km/sec?

☐**4.** How does the speed from question 3 compare with the speed of a satellite in a parking orbit at a height of 161 km?

☐**5.** What is the period of a satellite in the parking orbit at a height of 161 km?

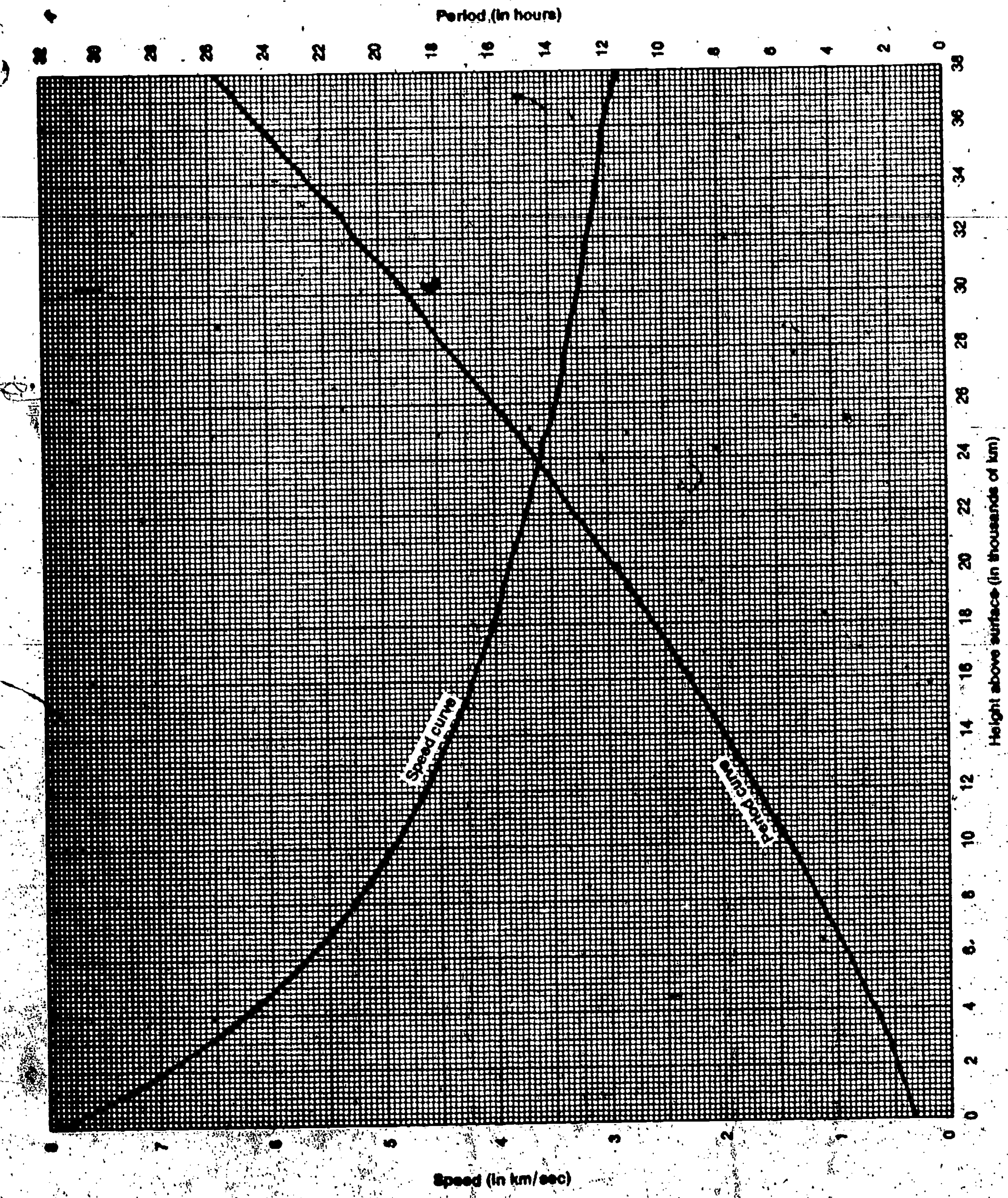

Period (in hours)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Speed curve
Period curve
Height above surface (in thousands of km)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
Speed (in km/sec)
8
7
6
5
4
3
2
1
0

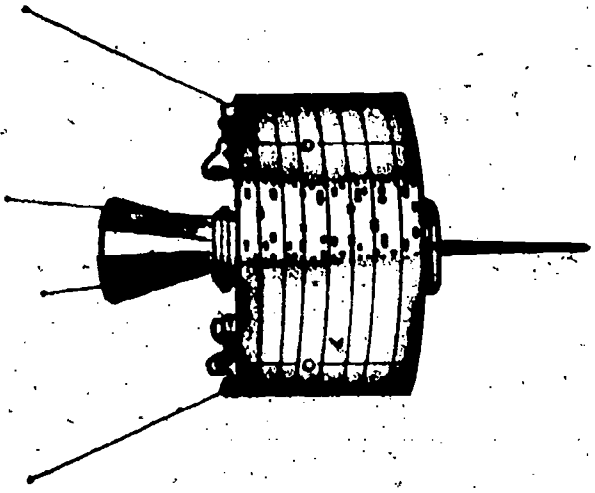
Figure 2

On August 19, 1964, the United States placed Syncom 3 in a 24-hour orbit over the Pacific Ocean. It was used to relay the telecast of the Tokyo Olympics, which it did splendidly. Earlier, Syncom 2 had been placed in a 24-hour orbit over the Atlantic Ocean to handle east-west transmissions in that area.

The name Syncom is derived from "synchronous communication." *Synchronous* is a word meaning "in time with." Thus Syncom is a communications satellite that is in time with the earth's rotation.

It might surprise you to know that it took more fuel to put the satellite in its high orbit than it would have taken to send it to the moon.

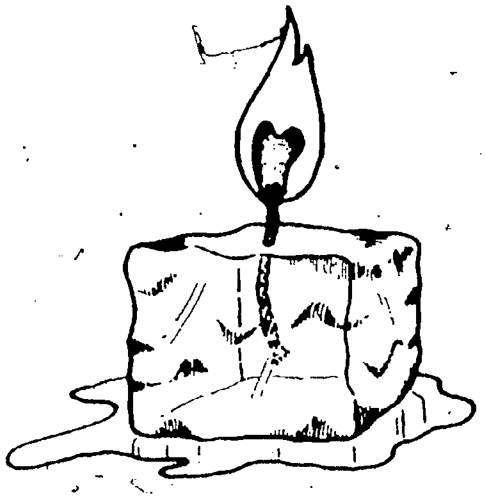
☐6. How can this last statement be explained?



Losing Heat

Excursion 4-4

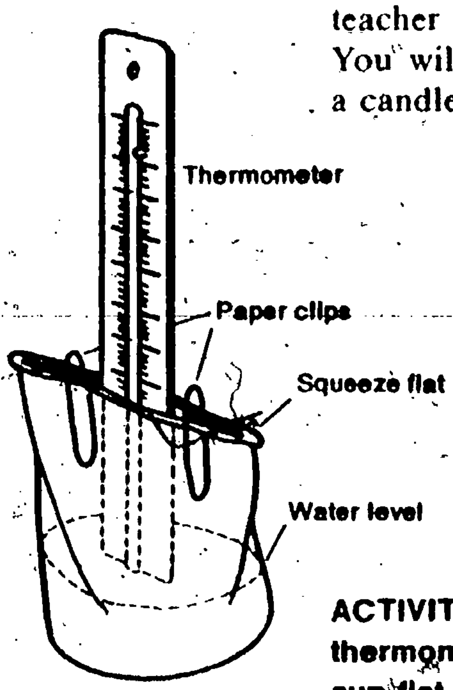
Whenever a solid melts (changes to liquid), or a liquid boils or evaporates (changes to a gas), heat must be involved. For example, heat must be added to ice to change it to liquid water. Much more heat must be added to the liquid water to change it to steam.



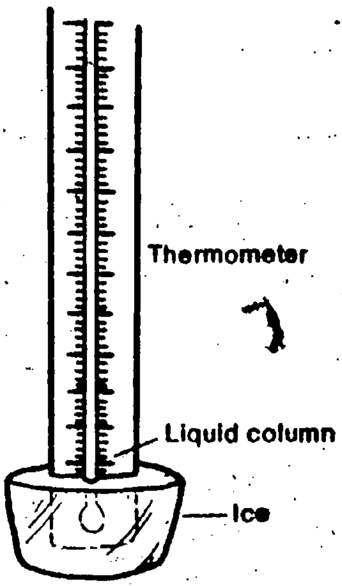
Space travel makes use of this heat-absorbing behavior of substances. When a space capsule returns to the earth's atmosphere, friction due to contact with the air particles produces a huge amount of heat. You may have seen pictures of the charred surface of the spacecraft after its recovery in the ocean. The occupants, however, were unharmed. How can they have survived such a hot ride?

In the early days of space exploration, scientists learned about the dangers of reentry heat. They knew they had to come up with a way to offset the effects of this great heating. They decided to coat one side of the capsule with a solid material that would melt and then boil. If this melting and boiling could absorb most of the reentry heat, the rest of the capsule would be safe. They knew that what was needed was a substance that absorbed a lot of heat as melting and boiling took place. A substance was found, and it was used to coat the heat shield of the capsule. Now, on space flights, as this substance melts and boils away, it removes the excess heat due to friction. This heat-removal process is known as *ablation*—a surgical term that means "removal."

You can see how ablation works by doing an activity. You may want to do this activity at home, where you can use the freezer compartment of your refrigerator. Ask your teacher to lend you a thermometer to take home with you. You will also need a small paper cup, 2 paper clips, and a candle. (Perhaps you have some of these at home.)



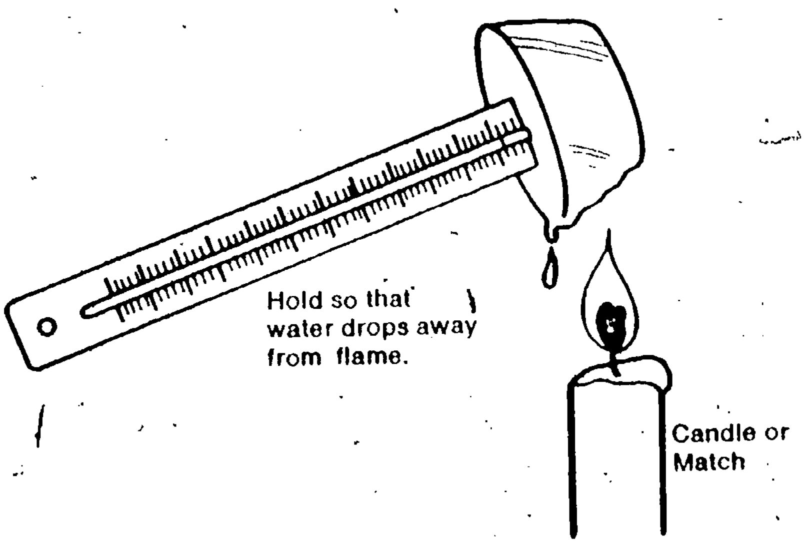
ACTIVITY 1. Put about 50 ml of water in the cup. Set the thermometer in the center of the cup. Squeeze the top of the cup flat to the thermometer, and use the paper clips to hold it. Be sure that the bulb is in the center and covered with water. Put the cup in the freezer compartment overnight.



ACTIVITY 2. Check in the morning to be sure that the water is frozen. Carefully strip off the paper cup. The thermometer bulb should remain inside the ice, but the liquid column should be visible. Read the temperature. Then record it as your answer to question 1.

☐**1.** What is the temperature of the ice?

Now think of the ice coating on the thermometer as representing the heat shield of the space capsule. The thermometer itself can represent the men in the capsule. You now need a source of heat to represent friction. The candle, or some other flame, will do.



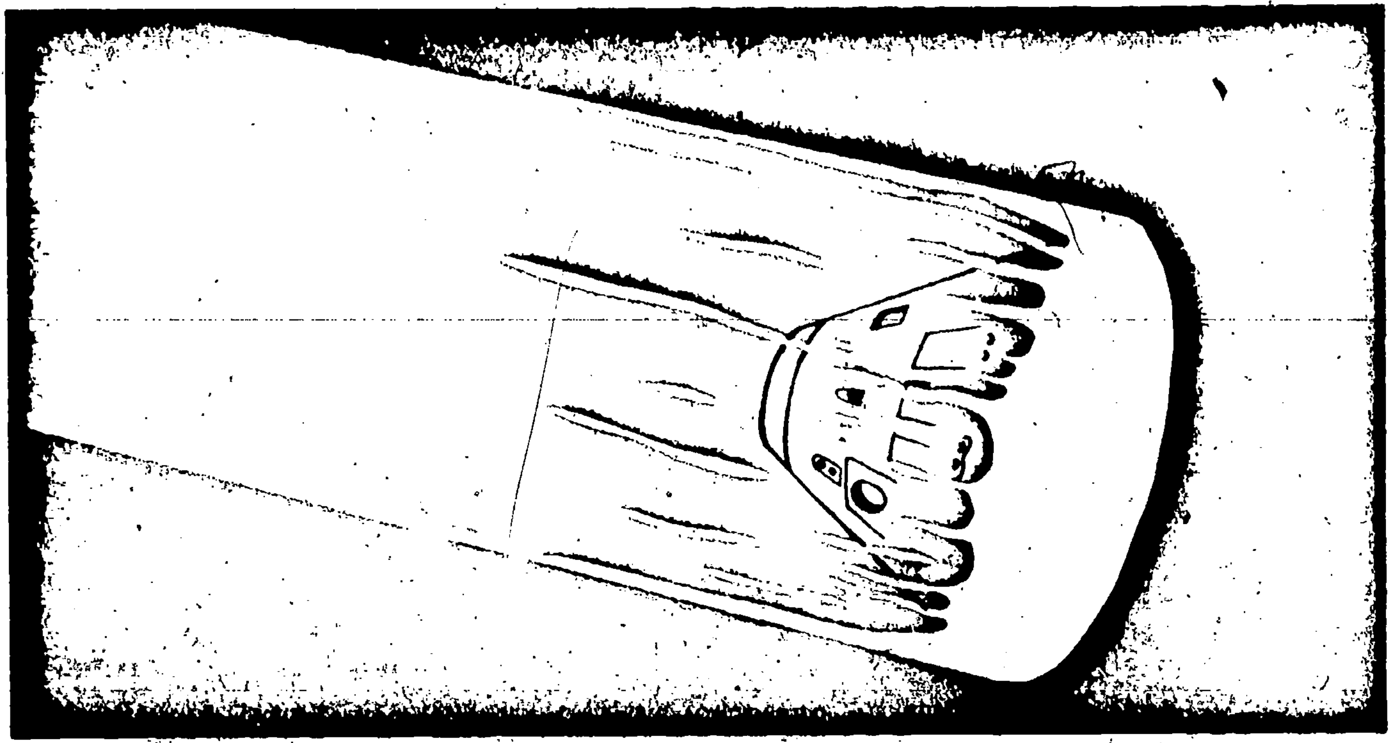
ACTIVITY 3. Hold the ice over a candle or match flame. Be careful not to let the flame hit the thermometer. Also, do not melt the ice enough to let the flame hit the bulb. Continue reading the thermometer as the ice melts.

☐**2.** Did the temperature rise as the ice melted?

☐**3.** What happened to the heat from the flame?

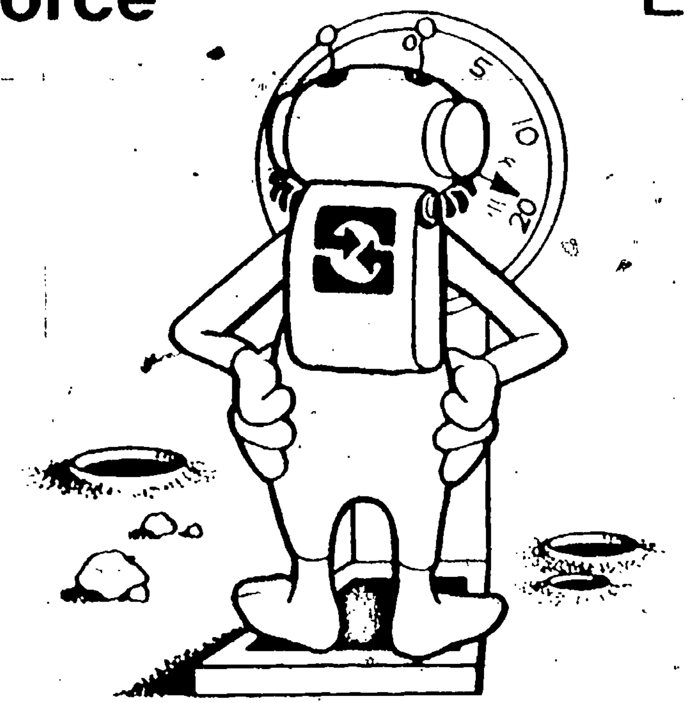
Be sure to return the thermometer to your teacher. Plastics and ceramics (like pottery) have been used as the ablative material on spacecraft. Apollo 12 used a brazed stainless-steel honeycomb with an outer layer of phenolic epoxy resin. (This resin material is similar to the substance that is often used to glue materials together.)

As the capsule entered the atmosphere, it left behind it a meteorlike trail of glowing liquid and gaseous material. Very little heat entered the spacecraft. The heat was carried away, just as the melting ice carried the heat away from the thermometer by changing first to liquid water, then to steam. In this way the astronauts were protected.



Less Force

Excursion 5-1



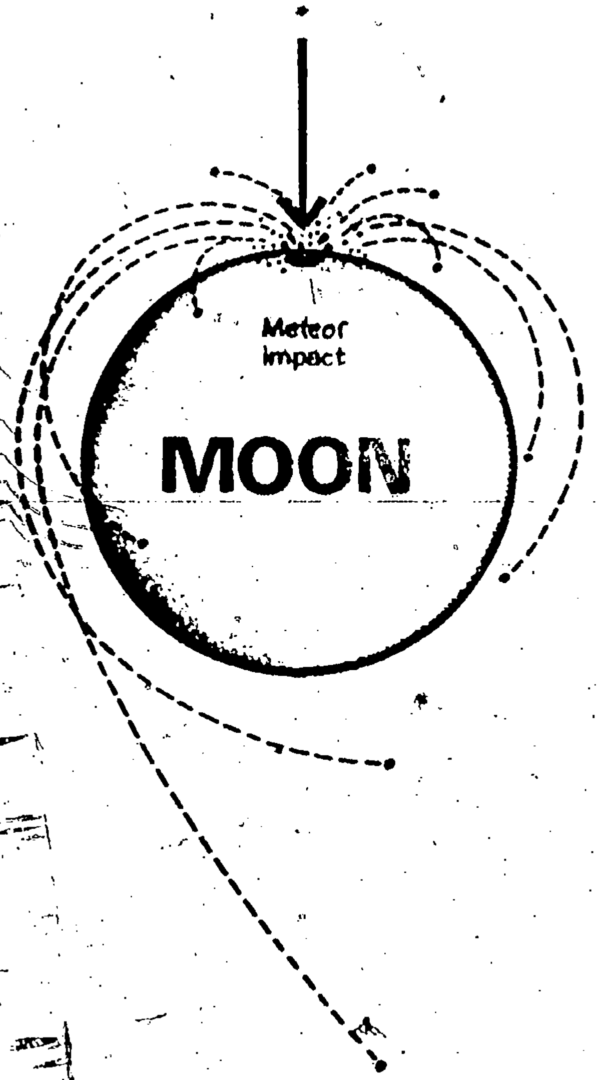
The force of gravity that a body exerts depends partly on the mass of the body. It also depends on how far the center of the body is from whatever object it is attracting.

When both of these factors—mass and distance—are taken into account, the force of gravity exerted by the moon on objects at its surface is only $\frac{1}{6}$ as much as the force of gravity would be if the objects were on the surface of the earth. This means that you or your spacecraft would weigh only $\frac{1}{6}$ as much on the moon's surface as on the earth's surface.

☐**1.** What is your weight on the earth?

☐**2.** What would your weight be on the moon?

Because the moon's force of gravity is weak, it cannot hold an atmosphere. So there is no air on the moon. Thus, an object moving above the moon's surface would have no air friction to slow it down. The smaller pull of gravity and the absence of air friction have a great effect on the way objects move on the moon.



When a big meteor, traveling at speeds up to 65 km per second, strikes the surface of the moon, material is splashed out in all directions. Parts of the surface and of the meteor are melted or powdered. The force of the impact gives some of the pieces speed that takes them halfway around the moon.

The speed of the material that is thrown out determines how far it will go. Some chunks go only a short distance. Then they hit the surface and may form other craters. Other pieces go great distances before hitting the surface. Some materials reach a speed high enough to escape the moon's gravity. These pieces shoot out into space.

☐**3.** When the Apollo 11 astronauts kicked moon dust with their boots, they noted that the particles went a long way before settling to the surface. How do you account for this?

An Excursion to the Far Side

Excursion 7-1

On August 23, 1966, the first Lunar Orbiter provided a view of the far side of the moon and at the same time showed the crescent earth. Figure 1 shows this first, slanting, detailed scene.

Figure 1

Note the roughness and the large number of craters. The spacecraft was almost 1,200 km above the surface of the moon when this photo was made. The Western Hemisphere of the earth is in sunlight.

Now let's suppose you, too, are making this trip. As your spacecraft swings around to the moon's other side, you see some features never observed from the earth.

☐**1.** Why have they not been observed?

From a window in your spacecraft, you can examine some of these rare sights.

Figure 2

Notice the large crater near the bottom (Figure 2). Radiating from it are two deep troughs. This crater has never been named. Perhaps you would like to name it yourself. Another feature that stands out is the dark area with a light spot in it, in the upper right corner. This is the crater Tsiolkovsky, named by the Russians for one of their pioneer space scientists. Let's move in and take a closer look at the troughs and the unnamed crater (Figure 3).

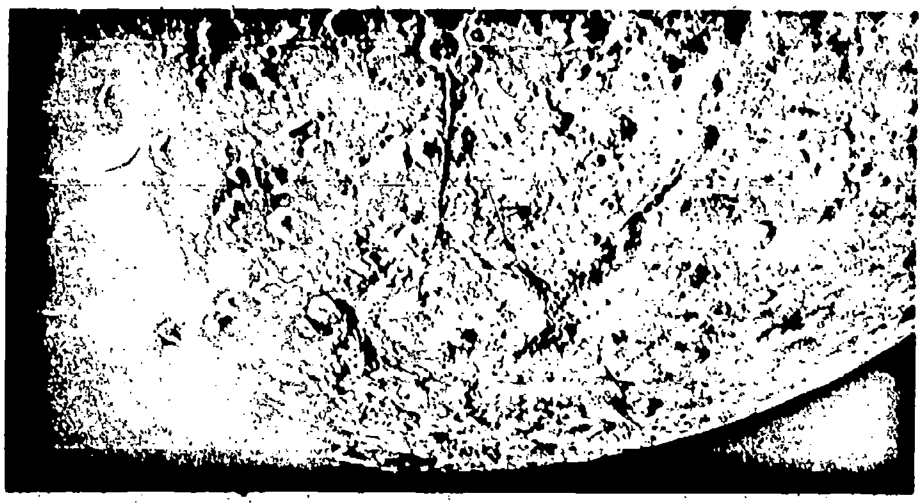


Figure 3

The one trough extends northward for more than 250 km. In some places it is as much as 8 km wide. The edges are sharp. Notice how the trough cuts right across several craters.

☐**2.** From your observations, how would you say the age of the trough compares with similar features on the front side of the moon?

Now you have an even closer look at the huge crater (Figure 4). The southern third of the trough, 1, can be seen entering at the left, about a centimeter below the horizon. The trough ends at the outer rim of the crater. On the right, on the crater floor, is an elongated crater with very dark material, 2, around it.

Figure 4

☐**3.** What do you think could be the source of the dark material around the elongated crater?

Another view of the crater Tsiolkovsky is coming up. It is about 200 km in diameter, with a very dark, smooth floor and a prominent central peak (Figure 5).

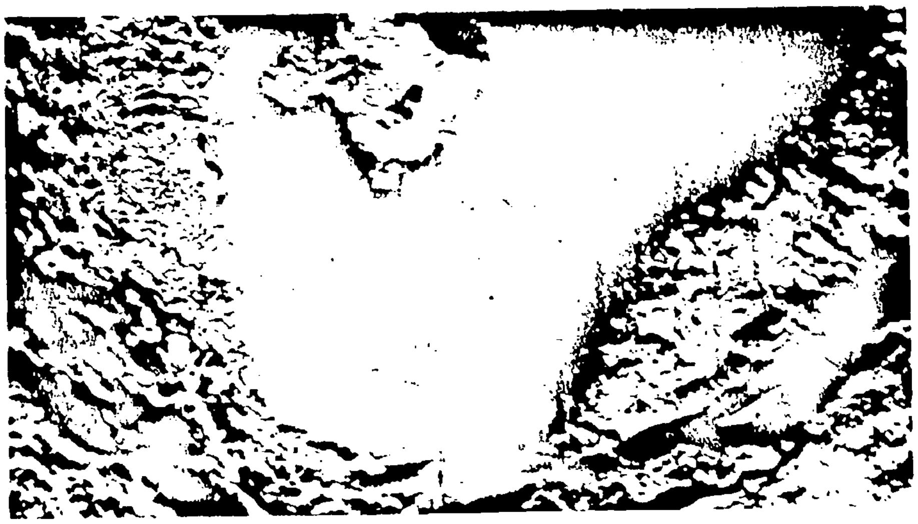


Figure 5

Crater Tsiolkovsky was first viewed on the Russian Luna III photos. The dark material in the floor has no large craters in it. The crater rim is rough and sharp. The area surrounding the crater shows patterns of ejecta.

☐4. What does the lack of large craters in the dark floor suggest?

As you continue your orbit on the far side, you pass over a basin that is about 300 km in diameter. It has a faint inner ring of low hills. There are many craters in the floor (Figure 6). As you look at the photo, imagine that you are hovering above the moon.

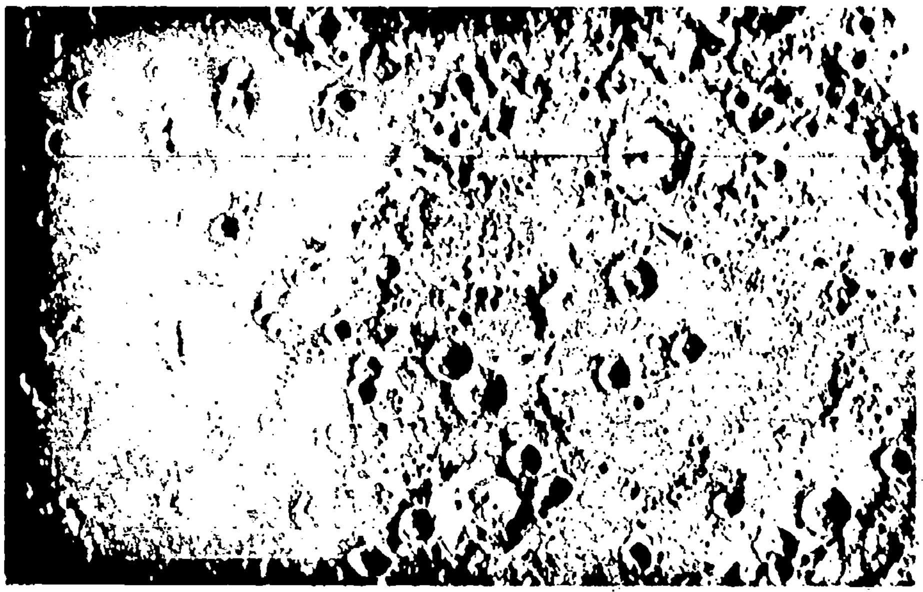


Figure 6

☐5. What do the many small craters in the floor of the large crater in Figure 6 tell you about the relative age of the basin?

Now you will get one last look north at a large section of the lunar surface (Figure 7).

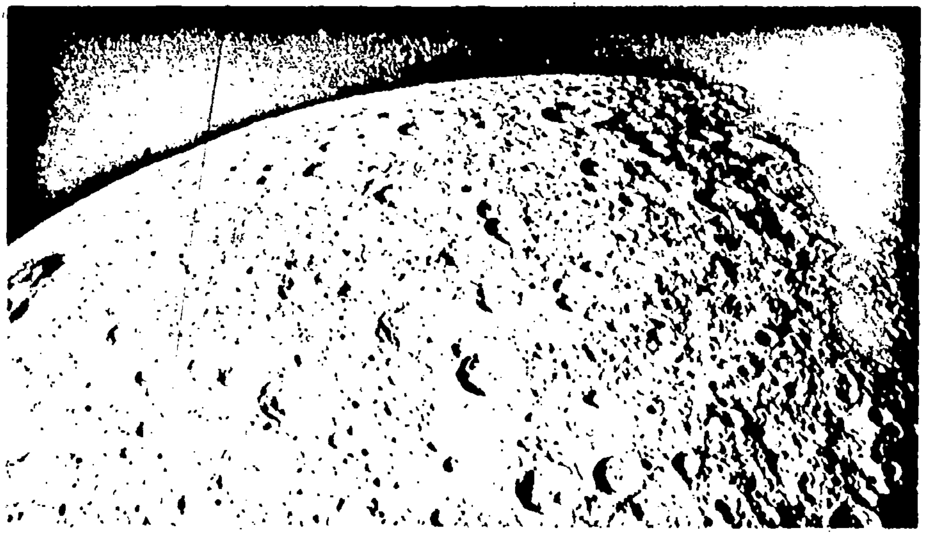
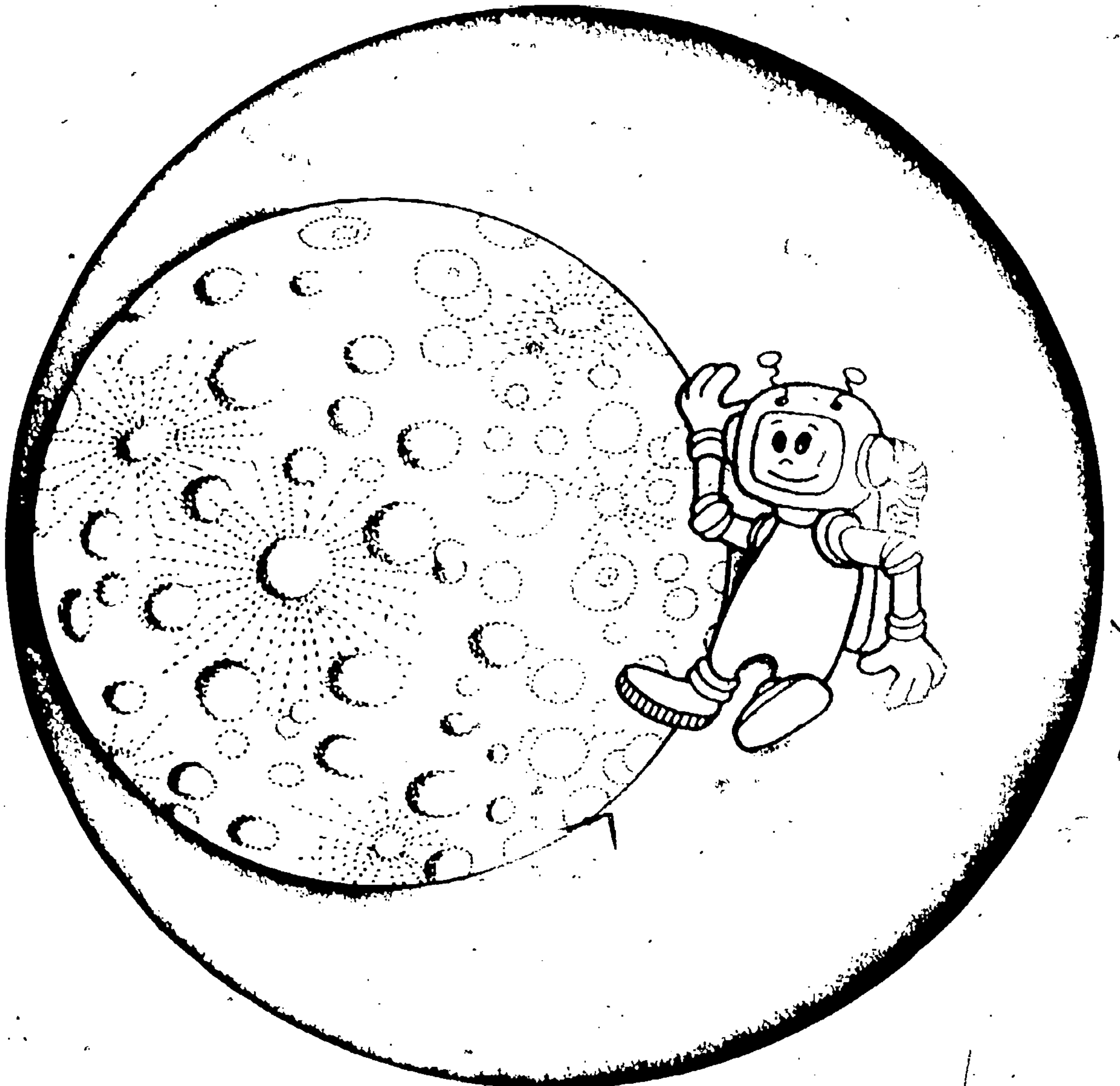


Figure 7

Well, it's time to get back to the moon's near side. You may have found your trip interesting, but the side of the moon never seen from the earth certainly offered no startling surprises. It is much like the near side—perhaps a bit more rugged, with fewer large "seas." The same kinds of features suggest that the same kinds of events have occurred over the entire surface of the moon.



PICTURE CREDITS

T–Top
B–Bottom
L–Left
R–Right

x — NASA 10 — NASA 22 — UPI 34 — NASA 54 — Wide World Photos 55, 56— NASA 57*T* — NASA 57*B* — Mount Wilson & Palomar Observatories 58, 59 — NASA 60*T* — Clay Peters, National Park Service Photo 60*B* — J. R. Eyerman for Life 61*T* — Oregon State Highway Department 61*B* — Australian News & Information Bureau 62*T* — U. S. Atomic Energy Commission 62*B* — National Park Service Photo 63*L* — NASA 63*R* — Dominion Observatory, Ottawa, Canada 69–76 — NASA 78 — U. S. Navy Photo 79 — NASA 82 — NASA 83 — K. Segerstrom from U. Geological Survey 85–98 — NASA 100 — Courtesy ISCS 110-142 — NASA