45 student-centered activities for the planetarium

under ROOF, DOME, SKY

PLANETARY INFORMATION

	MERCURY	VENUS	EARTH	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO	SUN	MOON
Distance (A.U.)	0.387	0.723	1.000	1.524	5.204	9.581	19.117	30.116	39.518		
Diameter (Km.)	4680	12,200	12,742	6,648	139,500	116,340	47,500	44,800	6,000		
Diameter (Mi.)	3000	7,600	7,927	4,200	88,700	75,100	30,900	33,000	3,600	865,384	2159
Diameter Earth=1	0.37	0.95	1.00	0.52	10.95	9.13	3.73	3.52	0.47	109	
Mass Earth=1	0.054	0.81	1.00	0.11	317.4	95.2	14.6	17.6	?	332,960	0.012
Volume Earth=1	0.06	0.86	1.00	0.15	1,318	736	50	42	.12	1,300,000	0.02
Period of Rotation	$59^{d}.4$	243^{d}	$23^{h}56^{m}$	$24^{h}37^{m}$	$9^{h}50^{m}$	$10^{h}14^{m}$	$10^{h}49^{m}$	16^{h}	$6^{d}.4$	$24^{d}16^{h}$	
Sidereal Period	88^{d}	225^{d}	$365^{d}.25$	$1^{y}321^{d}$	$11^{y}314^{d}$	$29^{y}168^{d}$	$84^{y}\ ^{d}$	$164^{y}288^{d}$	$248^{y}157^{d}$		$27^{d}.33$
Surface Gravity Earth=1	0.36	0.90	1.00	0.38	2.65	1.14	1.07	1.00	0.30	28.0	0.16
Inclination of Equator to Orbit			23°27'	25°12'	3°7'	26°45'	98°0'	29°			
Inclination of Equator to Ecliptic	7°0'	3°24'		1°51'	1°18'	2°30'	0°46'	1°47'	17°9'		5°9'
Known Moons	0	0	1	2	12	10	5	2	0		
Max. Vel. Mi./Sec.	29.7	21.7	18.5	15.0	8.1	6.0	4.2	3.4	2.9		.63
Albedo	0.06	0.76	0.36	0.16	0.73	0.76	0.93	0.84	0.15		0.07
Maximum Visual Magnitude	-1.9	-4.4		-2.8	-2.5	-0.2	+5.7	+7.8	+14.9	-26.7	-12.6
Maximum Surface Temp. (°F)	640	800	140	50	-215	-240	-280	-300	-370	10,000	250
Symbol	☿	♀	●	♂	♃	♄	⛢	♆	♇	☉	☾
Density	5.46	5.21	5.52	3.94	1.33	0.69	1.7	1.63	5.5	1.41	3.33

under
ROOF, DOME and SKY

45 Student-Centered Activities

developed in a

Cooperative College School Science Program

proposed by

The Middle Atlantic Planetarium Society

and

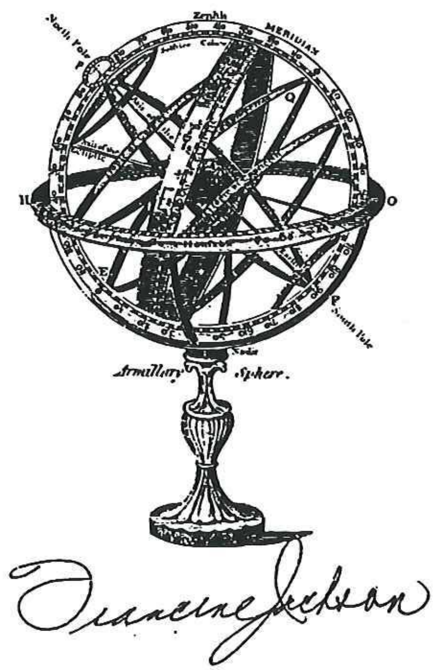
The University of Maryland

in cooperation with

associated school systems

and funded by the

National Science Foundation



Printed in the United States of America

FROM DREAM TO REALITY

In the past decade there has been a tremendous influx of planetariums into our educational society. With the aid of National Defense Education Act (NDEA) funds, many of these instruments found their way into local school systems across the country. Unfortunately, a lack of trained personnel and a dearth of established lesson plans existed and many of the new instruments were not used to their fullest potential.

As the number of installations grew, several "planetarium organizations" were formed in various regions of the United States. The primary goal of each of these organizations was the improvement of planetarium education. One of these organizations, the Middle Atlantic Planetarium Society (MAPS), was a pioneer in this area. During a MAPS meeting, held in March 1968 in Washington, D.C., it was brought to the attention of the membership that planetarium lesson plans that would complement the new science curriculum projects were very much needed. The Earth Science Curriculum Project (ESCP) in particular, had been swamped with requests for planetarium-related materials. The MAPS organization formed a Curriculum Committee to address itself to this task. In July 1968, a committee of seven members met at the Pequea Valley Intermediate School in Kinzers, Pennsylvania and a four-page report of "selected investigations" was published; no lessons or lesson plans--just "selected investigations". This was a start. However, the most important accomplishment of the committee was to come to the realization that the development of planetarium lessons would be a truly monumental task.

In October of 1968, the MAPS committee met again in Rochester, New York, and encountered more complexities. William Chronister, the chairman of the committee, and Russell Blake, who was then president of MAPS, did not give up. Realizing that help was needed, Dr. Marjorie Gardner from the Science Teaching Center at the University of Maryland, was approached and she consented to aid the organization. With her help and the assistance of the National Science Foundation, the Cooperative College-School Science (CCSS) Program had its inception.

The CCSS program consisted of a 1970 summer phase of six weeks and four weekend meetings during the 1970-71 academic year. Thirty participants, all planetarium directors, from eight mid-eastern states and the District of Columbia began work at the University of Maryland. The specific objectives of this summer phase were outlined as follows: 1) to provide planetarium teachers with experience and training in using the process-centered, inquiry approach exemplified in the ESCP program, <u>Investigating the Earth</u>, and related materials; 2) to strengthen the academic background of the planetarium teacher in astronomy and other related earth-space disciplines; 3) to develop lessons and methodology necessary for the effective utilization of the planetarium classroom as a supporting agent in implementing new programs in science as they are introduced into the participant's respective school districts; 4) to experiment with "ask-and-do" planetarium programs as contrasted with "show-and-tell"; 5) and to encompass disciplines such as geophysics, geography, and meteorology for planetarium presentation.

These objectives were accomplished with the aid of: 1) lecture-demonstrations by outstanding scientists or planetarium specialists; 2) laboratory investigations and discussion periods; 3) field trips to observatories, NASA centers and other places of value; 4) work sessions to develop planetarium lessons utilizing new ideas, content, media and the investigative approach.

At the end of the summer well over one hundred inquiry-oriented lessons had been written. It was decided that at least five of the best lessons would be tested by each participant during the academic year phase of the program. Records of student and classroom teacher response were kept to form a basis for revision.

The academic year sessions were hosted and conducted by four different participants in their home planetariums, thereby permitting a practical demonstration of what can be done with a variety of equipment. The individual creativity at each planetarium not only stimulated enthusiasm, but also sparked new ideas and served as an excellent setting for retesting and revising lessons. The weekend meetings permitted the observation of a lesson as it was presented to students. A critique was held after the presentation of each lesson and necessary revisions were considered. The academic year phase proved to be a successful and necessary part of the program. Two of the lessons tested during the 1970-71 year were selected for publication by MAPS.

This, however, was not the end of the program. Acting on the belief that the "inquiry-oriented" approach is a suitable and effective method of instruction, MAPS continued its efforts during the summer of 1971 and the 1971-72 school year. The CCSS program was expanded to include fifteen classroom teachers who represented the various science curriculum projects including Time, Space and Matter (TSM), Introductory Physical Science (IPS), Elementary Science Study (ESS), Science-A Process Approach (AAAS), Harvard Project Physics (HPP), and Physical Science Study Committee Physics (PSSC). The selected teachers worked in teams with fifteen planetarium directors. This ensured the interaction necessary to develop the type of program that would be useful to the classroom teacher.

During the second phase of the program the planetarium directors and classroom teachers directed their discussions separately to some of the problems that are inherent in planetarium education. Although it came as no surprise that scheduling headed the list of problems, it was interesting to note that many of the areas discussed were mirror images of each other. Both groups agreed that scheduling was the most arduous task. On the one hand, the teachers could not predict when they would reach a particular unit that enabled them to utilize the planetarium. On the other hand, the planetarium directors had to prepare their schedules in advance since planetarium facilities serve the entire student body. The question of preparation and planning received attention in both meetings. For example, the teachers expressed concern over the fact that they had no part in planning the planetarium lesson, and the planetarium directors agreed it would be helpful if time were allotted to sit down with the classroom teacher for planning purposes. Both groups had reached the conclusion that more time spent in advance preparation and correlation of material would help alleviate the problem of a planetarium lesson that had little relevance to the classroom discussion.

As a result of these discussions, the group decided that the need for the adoption of a standard format for the various planetarium lessons was imperative. It was recognized that the development of a consistent format would require a clear statement of the purpose of each lesson, as well as the objectives to be accomplished. This in turn required a definition of the background and preparation needed on the part of the student, the materials necessary for the lesson, and a feedback mechanism to evaluate the effectiveness of the lesson.

Using the new format as a guide, the participants devoted the first four weeks of the summer program to the development of new lessons to be incorporated into the classroom curriculum. These lessons were then modified and correlated with the lessons that had been developed during the previous summer.

In the last two weeks of the summer the final drafts were edited. This was accomplished by dividing the participants into four work groups. Each group included staff members, planetarium directors, and classroom teachers.

Once again, during the 1971-72 academic year, the participants tested and evaluated the lessons that had been written. A small production committee was selected to work during the summer of 1972 to put the lessons into final form for publication and dissemination.

The entire Middle Atlantic Planetarium Society joins in thanking those who helped to make this experimental program possible. Any pioneering organization sincerely appreciates the cooperation of experienced leaders in giving their time, talent, and effort; and the members of our society are especially indebted to these dedicated professionals. We invite planetarium directors and interested classroom teachers everywhere to utilize our work and to inform us of your own and your students' response to it.

John Richardson
President of MAPS

Contributors

CONNECTICUT

Trumbull Board of Education

* Louis A. Prosek - 1970-71
  Hillcrest Junior High School
  Trumbull, Connecticut

DISTRICT OF COLUMBIA

Washington, D.C., Public School System

* Lucille M. Howerton - 1970-71
  Cardoza High School Planetarium
  Washington, D.C.

MARYLAND

Cecil County Public School System

Lora Chamblee - 1971-72
North East High School
North East, Maryland

* Phillip Cottrill - 1970-72
  Elkton High School
  Elkton, Maryland

Frederick County Public Schools

John E. Geist - 1971-72
West Frederick High School
Frederick, Maryland

* Charles O. Lambert - 1970-72
  ESSL-So. Frederick Elementary School
  Frederick, Maryland

Garrett County Board of Education

* Paul S. Frank, Jr. - 1970-72
  Garrett County Resource Center
  Oakland, Maryland

Jean T. Grose - 1971-72
Southern Junior High School
Oakland, Maryland

Harford County Board of Education

* Dr. Norman J. Dean - 1970-71
  Bel Air Planetarium
  Bel Air, Maryland

MARYLAND (continued)

* Gregory M. Lauck - 1970-72
  Aberdeen Planetarium
  Aberdeen, Maryland

Prince George's County Public Schools

* Paul A. Boston - 1971-72
  Prince George's County Planetarium
  Bladensburg, Maryland

* Margaret K. Noble - 1970-71
  Prince George's County Planetarium
  Bladensburg, Maryland

Frederick M. Stutz - 1971-72
Roger B. Taney Junior High School
Camp Springs, Maryland

Washington County Board of Education

Cynthia Gist - Summer 1971
Washington County Public Schools
Hagerstown, Maryland

* William W. Kenney - 1971-72
  Washington County Space Science Center
  Hagerstown, Maryland

MASSACHUSETTS

Alice G. Wallace Planetarium, Fitchburg

* W. Russell Blake - 1970-72
  Alice G. Wallace Planetarium
  Fitchburg, Massachusetts

Patrick M. Mesiti - 1971-72
Alice G. Wallace Planetarium
Fitchburg, Massachusetts

Mark Andreason, Artist
Alice G. Wallace Planetarium
Fitchburg, Massachusetts

NEW JERSEY

Madison Township Public School System

* Russell J. Heyde - 1970-71
  Madison Township Schools
  Madison, New Jersey

---

*Planetarium Director

Contributors

NEW YORK

Half Hollow Hills Public School System

* Peter F. Connors - 1970-72
Half Hollows Hills School
Dix Mills, New York

Ronald P. Vieira - 1971-72
Half Hollows Hills School
Dix Mills, New York

Williamsville Public School System

* Robert Rust - 1970-71
Williamsville High School
Williamsville, New York

NORTH CAROLINA

Salisbury City Public School System

* William W. Suggs - 1970-72
Catawba College
Salisbury, North Carolina

Judith Welker - Summer, 1971
Salisbury City Schools
Salisbury, North Carolina

PENNSYLVANIA

Central Bucks Public School System

George Kocher
Central Bucks High School East
Buckingham, Pennsylvania

* Thomas C. Stec - 1970-72
Central Bucks Planetarium
Buckingham, Pennsylvania

East Penn Public School System

* Donald C. Herring - 1970-72
East Penn School District
Emmaus, Pennsylvania

Paul M. Smith - 1971-72
Emmaus Junior High School
Emmaus, Pennsylvania

*Planetarium Director

PENNSYLVANIA (continued)

Gateway Public School District

* Dennis R. Hillen - 1970-72
Gateway High School
Monroeville, Pennsylvania

James A. Ola - 1971-72
Monroeville Junior High School
Monroeville, Pennsylvania

Keystone Oaks Public School District

Ian S. Smith - 1971-72
Keystone Oaks High School
Pittsburg, Pennsylvania

* Larry L. Whaley - 1970-72
Keystone Oaks High School
Pittsburg, Pennsylvania

Lower Moreland Township School District

* John F. Richardson - 1970-72
Lower Moreland School District
Huntingdon Valley, Pennsylvania

Thomas Wittkamp - 1971-72
Lower Moreland Intermediate School
Huntingdon Valley, Pennsylvania

Pequea Valley Public School District

* William Chronister - 1970-71
Pequea Valley Planetarium
Kinzers, Pennsylvania

Upper Dublin Township Public School District

* Arthur Pierce - 1970-71
Sandy Run Junior High School
Dresher, Pennsylvania

VIRGINIA

Fairfax County Public School System

* Julius Cohn - 1970-71
Falls Church Planetarium
Fairfax, Virginia

* Lee Ann A. Hennig - 1970-72
Fort Hunt Planetarium
Fairfax, Virginia

Contributors

VIRGINIA (continued)

Jack L. Lewis - 1971-72
Hayfield Secondary School
Fairfax, Virginia

John I. Melone, Jr. - 1971-72
Thomas Jefferson High School
Fairfax, Virginia

* Walter H. Tenschert - 1970-72
Thomas Jefferson Planetarium
Fairfax, Virginia

* Chris G. Vaganos - 1970-72
Hayfield Planetarium
Fairfax, Virginia

Alexandria Public School System

* Jo Torpy - 1970-71
T. C. Williams High School
Alexandria, Virginia

WEST VIRGINIA

Kanawha County Public School System

* Robert A. Gardner - 1970-71
Children's Museum & Planetarium
Charleston, West Virginia

CCSS STAFF

Dr. Marjorie Gardner
Director - 1970-72
Science Teaching Center
University of Maryland
College Park, Maryland

Dr. John A. Maccini
Assoc. Director - 1970-71
Director - Summer 1971
Science Teaching Center
University of Maryland
College Park, Maryland

Russell Blake
Workshop Director - 1970-72
Alice G. Wallace Planetarium
1000 John Fitch Highway
Fitchburg, Massachusetts

*Planetarium Director

CCSS STAFF (continued)

Gail Griffith
Laboratory Instructor - 1970-71
Geology Department
University of North Dakota
Grand Forks, North Dakota

Dr. Donat Wentzel
Consultant - Summer 1971
Astronomy Department
University of Maryland
College Park, Maryland

Mary Alice Andes
Project Secretary - 1970-72
Science Teaching Center
University of Maryland
College Park, Maryland

Susan Lerner
Administrative Assistant - Summer 1971
Science Teaching Center
University of Maryland
College Park, Maryland

PUBLICATION TEAM

Director:

Dr. Marjorie Gardner

MAPS Coordinators:

W. Russell Blake
Lee Ann Hennig
John Richardson

Editor:

Mary Brodinsky
Old Saybrook, Connecticut

Production Coordinator:

Roger Tatum
Science Teaching Center
University of Maryland

Illustrator:

Cecilia Fletcher
Atholton High School
Howard County, Maryland

TABLE OF CONTENTS

GUIDE TO USE

This collection of learning activities has been designed for two equally important purposes: to help planetarium directors and classroom teachers work together in integrating classroom and planetarium experiences, and to involve students in active inquiry in the planetarium.

Each activity offered is actually an activity unit, or module. It starts in the classroom, proceeds further in the planetarium, and continues back in the classroom. For an individual student, an activity may not conclude until weeks later when, outdoors, he completes an independent study requiring collection of data on the apparent motion of the nighttime stars.

Throughout these activities, the student is the chief investigator. He does not go to the planetarium to see a "program" nor to "sit and look." He uses the planetarium pointer, the planetarium sextant; he invariably has a data sheet, pencil, pen light, clipboard so that he may collect data on what he observes.

The planetarium director and classroom teacher must work closely together in implementing each activity module. This must be done in keeping with the needs of each group.

Change and adapt as necessary, but remember that one need of every student is to be his own man, his own seeker of knowledge and truth.

To be "with it," we have tried to develop specific behavioral objectives for all activity modules. In most instances, the objectives have worked out--so well, in fact, that we think behavioral objectives may be the ticket for getting where we want to go with students. Even though all of the objectives may not meet strict definitions set up for behavioral or performance objectives, they will be of help in evaluating student learning and the success of the activity (let us know your results).

The following outline will help you use each activity:

INTRODUCTION	A statement of the purpose and content of the activity. This sets the tone of the student investigations to come and briefly describes them. For most activities, planetarium procedures will require about an hour; for others, double sessions or several sessions may need to be arranged. The introduction will alert you to extra time required.
STUDENT PREPARATION	Grade level: Specifies whether the activity is basically elementary or secondary level (but there is an extensive gray area between the two). Content background: Indicates the science knowledge and skills needed by the student prior to the planetarium experience unless these will be specifically introduced in the classroom activities described. Occasionally included here, or in the introduction, are suggestions for linking the activity with various science programs, such as Harvard Project Physics (HPP), Earth Science Curriculum Project (ESCP), etc.

FACTS AND CONCEPTS Statements of the major ideas that are developed as well as certain well-established facts about the universe that are valuable for permanent retention.

OBJECTIVES The first objective for each activity is the primary or terminal behavioral change the student should be able to demonstrate as a result of the activity. The additional objectives are either supportive or "spin-off" objectives. Supportive objectives are those the student should be able to achieve to meet the terminal objective; while "spin-off" objectives include those he <u>may</u> accomplish as a result of meeting the terminal objective. If a student achieves the terminal objective, but does not accomplish the additional objectives listed, he has succeeded. For him, the lesson may be considered a success.

MATERIALS Classroom: a listing of the items necessary for the classroom phases of the activity (both pre- and post-planetarium), except for standard classroom items. If certain materials or equipment are commercially produced, the source will be given here or later in a resource section.

Planetarium: a listing of materials and equipment necessary for the planetarium phase of the activity, other than standard projection equipment assumed to be available in every school planetarium.

PROCEDURES <u>In the Classroom</u>

Instructions for carrying out activities to be conducted in the classroom before the planetarium investigation. These activities review necessary content background, introduce new concepts as required, stimulate interest, and set the stage for the planetarium experiences. Unless these activities are completed by students, the planetarium investigation will have little meaning or relevancy for them. In all instances, the teacher should expand these activities as appropriate and necessary for the group.

<u>In the Planetarium</u>

This phase of the activity is designed to be inquiry-oriented, action-filled, and student-centered. The procedural instructions are given in chronological order. The planetarium director through his own teaching approach and teaching personality can enhance this phase. This part of the activity is not meant to stand alone or to be finite in itself; but in partnership with the classroom phases of the activity, it is designed to bring about measurable behavioral growth on the part of students.

Follow-Up Activities

It is through activities back in the classroom that the student will analyze his planetarium experiences and integrate his new learning into his repertoire of knowledge and skills. The success of the preceding classroom and planetarium activities are dependent on the effectiveness of the follow-up.

EVALUATION SUGGESTIONS — Some suggestions for evaluating learning and achievement of objectives are set for each activity. The suggestions may be expanded by the classroom teacher and planetarium director in keeping with the objectives of the activity. (This represents a big step forward in planetarium education, where previously little effort has been directed toward evaluating either student learning or the success of planetarium lessons.)

VOCABULARY — Words not in the students' everyday vocabulary which are essential for communicating about the ideas of the activity; common words used in new ways in the context of the particular topic.

SUGGESTED RESOURCES — Listed are related readings in textbooks, reference books, periodicals--with page numbers given; also maps, visuals, and other teaching and learning aids. Addresses of publishers and manufacturers are given in bibliographies in the appendix.

DATA SHEETS — Where the activity calls for data sheets, observation sheets, evaluation sheets, etc., these are provided at the end of the activity. Any sheets designed for student use may be extracted from this book and duplicated in class supply. In some instances, special types of graph paper are offered which may be duplicated in quantity.

APPENDICES In addition to bibliographies, an appendix offers a variety of tables, charts, and "how to make it" suggestions that will be generally useful. The directions for student-made hand sextants, astrolabes, spectroscopes, etc., will be found here.

The activities offered are divided by content into seven categories. Within each section, activities for elementary level precede those for secondary level (but remember the gray area). Thus only generally are activities presented in order of difficulty. Within elementary and secondary levels, activities are presented alphabetically by title. Each is designed to stand on its own feet as to time of presentation, provided students have the content background specified and that the classroom phases of the activity are carried through.

Because our two purposes in developing these activities were to integrate classroom and planetarium instruction and to propel the student into the role of active inquirer or learner, we hope you will keep these purposes in mind as you use these lessons.

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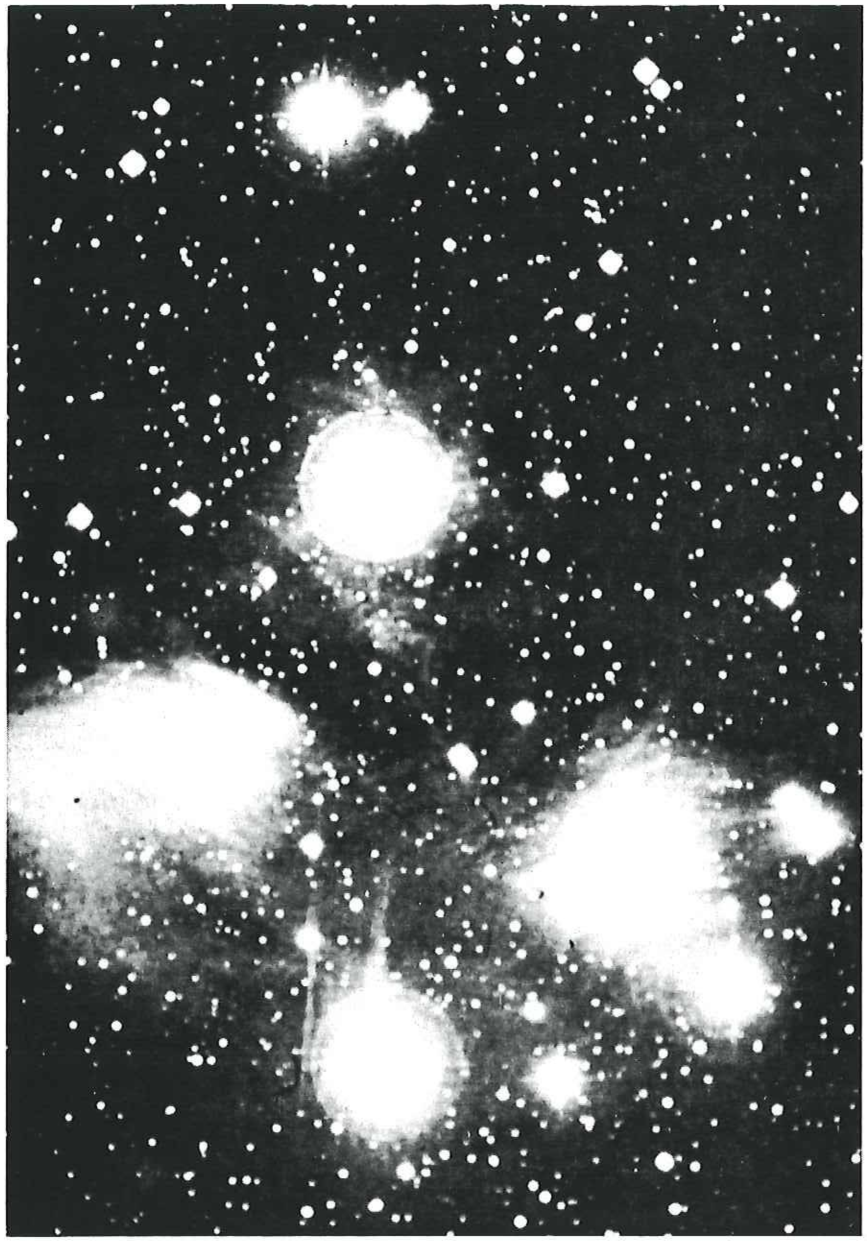
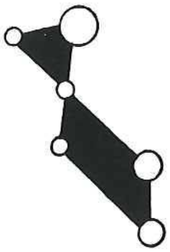


WHAT A WONDERFUL AND AMAZING SCHEME HAVE WE HERE OF THE MAGNIFICENT VASTNESS OF THE UNIVERSE! SO MANY SUNS, SO MANY EARTHS...!

- Christianus Huygens,
  New Conjectures Concerning the Planetary Worlds, Their Inhabitants and Productions.

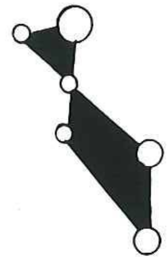


Of Stars and Constellations

In ancient times men proposed that the stars were jewels embedded in a crystal sphere surrounding the earth...dazzling gems dangling from a celestial drapery...holes in the astral framework through which one could see the other side of the universe. A child's first exposure to the wonders of creation may come on that first beautiful evening when he becomes aware of the shining lights in the sky.

The learning activities in this section offer a student the opportunity to investigate the stars in a variety of ways. His accomplishment in identifying a constellation, locating the North Star for the first time--or even realizing that the stars appear to move across the sky through the night--will be a personal triumph.

The stars hold many secrets. By studying their characteristics, the student will gain an understanding and appreciation of how the scientist explores the cosmology of the universe through the investigation of stellar properties and the processes of stellar evolution.



ARE THESE STARS OUT TONIGHT?

If a student is to become truly interested in the stars, he must be able to locate the ones he seeks as he looks up at the myriad of stars in the night sky. By learning to use a star chart in the planetarium--a controlled model of the real sky--students can develop skills to use star charts out of doors and competence in identifying stars and constellations.

STUDENT PREPARATION

Grade level: elementary
Content background: Students should be familiar with stick figures and lined geometric drawings as outlines of star groups (constellations).

FACTS AND CONCEPTS

A representation of the real sky is provided by a star chart. Thus a star chart may be used as a tool for locating stars in the sky.

OBJECTIVES

- The student will be able to use star charts with some degree of proficiency in locating stars both in the planetarium and in the real sky.
- The student will be able to identify specific stars in the night sky for any specific date with the aid of a star chart.
- Using a star chart, the student will be able to locate bright reference stars for the purpose of finding and identifying constellations.

MATERIALS

Classroom: star finder construction materials, one set per student (see Appendix); overhead projector, and transparency material for star finder pattern.

Planetarium: star finders; pencils and pen lights.

PROCEDURES

In the Classroom

1. The teacher should duplicate or have printed enough patterns for star finders for each student to assemble one. The instructions for assembling and using the star finder are provided with the pattern in the Appendix.

2. Using an overhead projector with a transparency of the star finder students are using, point out and/or demonstrate the following:

    1. Time and date
    2. Proper orientation
    3. Position of observer
    4. Cardinal or compass points
    5. Certain bright reference stars
    6. Asterisms and constellations in which these stars are found (point out by name)

    Help children get well acquainted with four or more major constellations to be visible in the night sky on date of planetarium visit.

In the Planetarium

1. Set planetarium for evening of visit.

2. Distribute star finders to the pupils who made them and one pen light to every two students; explain the necessity of working together with one student holding the pen light and the other working with the star finder.

3. Let the planetarium sun set and help students orient themselves and the star finder with respect to planetarium compass points (N, E, S, W). Bring the stars up so that the brightest ones are visible.

4. Students should set their star finders by turning the star disk until the date printed on the disk is set to correspond with the time of observing. Face south and hold the star finder face down overhead in such a manner that the stars can be read and the north of the finder points towards the north pole. Continue holding the finder in position

overhead and use the flashlight to locate the stars which match those in the sky. The finder is designed for latitudes 30° N through 50° N, but is useful at any northern mid-latitude.

5. Ask the students to match in name and location a few of the brightest stars on the dome with those on the star finders. These stars will serve as reference stars.

6. After dimming the room light enough for more stars to be seen, ask the students to use their star finders as above to identify a constellation and/or star as you point it out on the dome.

7. After the above step is accomplished to your satisfaction, turn the cove lights down and let students observe the "real sky." Ask them to verify their identification of the reference stars from the other stars surrounding them. As students do this, they will need to identify the constellation or asterism in which the star is located. Let students use the pointer to outline constellations on the dome.

8. Sum up the planetarium experience with a discussion of the value of a star finder and the usefulness of a few bright reference stars.

Follow-Up Activities

1. Each student should take his star finder home and use it to locate in the nighttime sky the asterisms and constellations he observed in the planetarium. Or:

2. Plan a night observation session when students will use the star finder to locate objects in the real sky. (For a star party, incorporate activities for parents.)

3. Ask several students to make a comparative study of other types of star charts and to use one or more of them. They should report results to the class.

4. Assign charts of various types to other students, with the request that they locate five stars in the sky at night and later report on their star-gazing experiences.

EVALUATION SUGGESTIONS

Point to several specific stars in the planetarium and ask students to locate them on their star finders, designating each with a circle and number.

Point to a constellation or asterism (one or several) and ask students to locate it on their star finders, marking it with a circle.

Evaluate each student on his performance in the post activities.

List several stars and constellations by name and ask students to use their star finders to determine the month each star and constellation would be visible at 10:00 p.m. and to name the general area of the sky in which the star would appear.

VOCABULARY

cardinal points   asterism   constellation
compass points

SUGGESTED RESOURCES

Joseph, Lippincott, _Point to the Star_, pp. 7-79.
Martin, Menzel, _The Friendly Stars_, pp. 5-138.
Read, W. Maxwell, _Patterns in the Sky_, pp. 25-121.
Rey, _Find the Constellations_, pp. 5-72.

"Mean Places of Stars," _The American Ephemeris and Nautical Almanac_.
MacRae, "The Brightest Stars," _The Observer's Handbook_.
Lovi, "Rambling Through (the) Skies," _Sky and Telescope_, centerfold.

NOTE

For star finder referred to in activity, see Appendix.

HOW BRIGHT ARE THE STARS ?

Most children will have observed on clear, dark nights that some stars shine more brightly than others. In the activity below, pupils will be challenged to consider how much brighter some stars appear than others and to devise a scale for specifying degrees of brightness. As they work with the equipment provided, they will gain both appreciation of, and experience in, the collection and interpretation of scientific data.

STUDENT PREPARATION
Grade level: elementary
Content background: some familiarity with stars and constellations (it will be best if each student can identify several stars in the planetarium sky by name).

FACTS AND CONCEPTS
As viewed from Earth, stars display different degrees of brightness. The brightness we see is not the actual brightness; it is an apparent brightness.

OBJECTIVE
With the aid of a simple optical photometer, the student will be able to formulate a scale of apparent brightness for the planetarium stars.

MATERIALS
Classroom: star chart; <u>Observer's Handbook</u> or copy of the magnitude scale from a star atlas.

Planetarium: brightness scalers for use in planetarium (see picture and directions at end of activity); paper, pencils, pen lights.

PROCEDURES
<u>In the Classroom</u>

1. Discuss names and shapes of major constellations and differences in

the brightness of stars.

2. Ask students to consider how the brightness of stars, as seen from the earth, might be measured.

In the Planetarium

1. Light the dome with stars at less than full brightness.

2. Ask students to identify some stars and constellations and to point out characteristics of certain stars. Introduce some if necessary.

3. When brightness and color have been identified as characteristics of stars, ask students to organize into groups of two or three. Distribute the scaling equipment. Ask each group to examine the equipment and use it in devising a scale for magnitude--apparent brightness. (Students should be warned about fingerprints interfering with the efficiency of the material.)

4. After the scales have been devised, ask the class how stars in the Little Dipper might be classified according to various scales developed.

5. Point out several stars and have the class scale them according to one of the systems.

6. Ask students to determine if there is a brightness distribution pattern in the planetarium sky.

7. Evaluate (see suggestions below).

Follow-Up Activities

1. Let students take the scaling materials home and scale the brightness of stars in the nighttime sky. Are differences comparable to those on the planetarium dome?

2. Ask students to compare their scales of brightness with the accepted scale of apparent brightness in the Observer's Handbook. (The actual brightness for each star may be found under "absolute brightness" in the Observer's Handbook.)

3. Discuss, and suggest for individual reading, possible explanations of the difference in stellar brightness.

4. Discuss apparent brightness (apparent magnitude) in contrast to actual brightness (luminosity), if appropriate to academic level.

5. Suggest that students use the scalers to study and compare the brightness of lights of different colors.

EVALUATION SUGGESTIONS

Point to several stars on the planetarium dome and ask students to rate them according to their scales. (The students must submit their scales as well as their ratings.)

Ask students to determine the order of brightness for the stars in the Little Dipper according to their scales. This can be asked for either the stars in the planetarium or for stars in the night sky.

VOCABULARY

brightness
magnitude
apparent brightness
scale

SUGGESTED RESOURCES

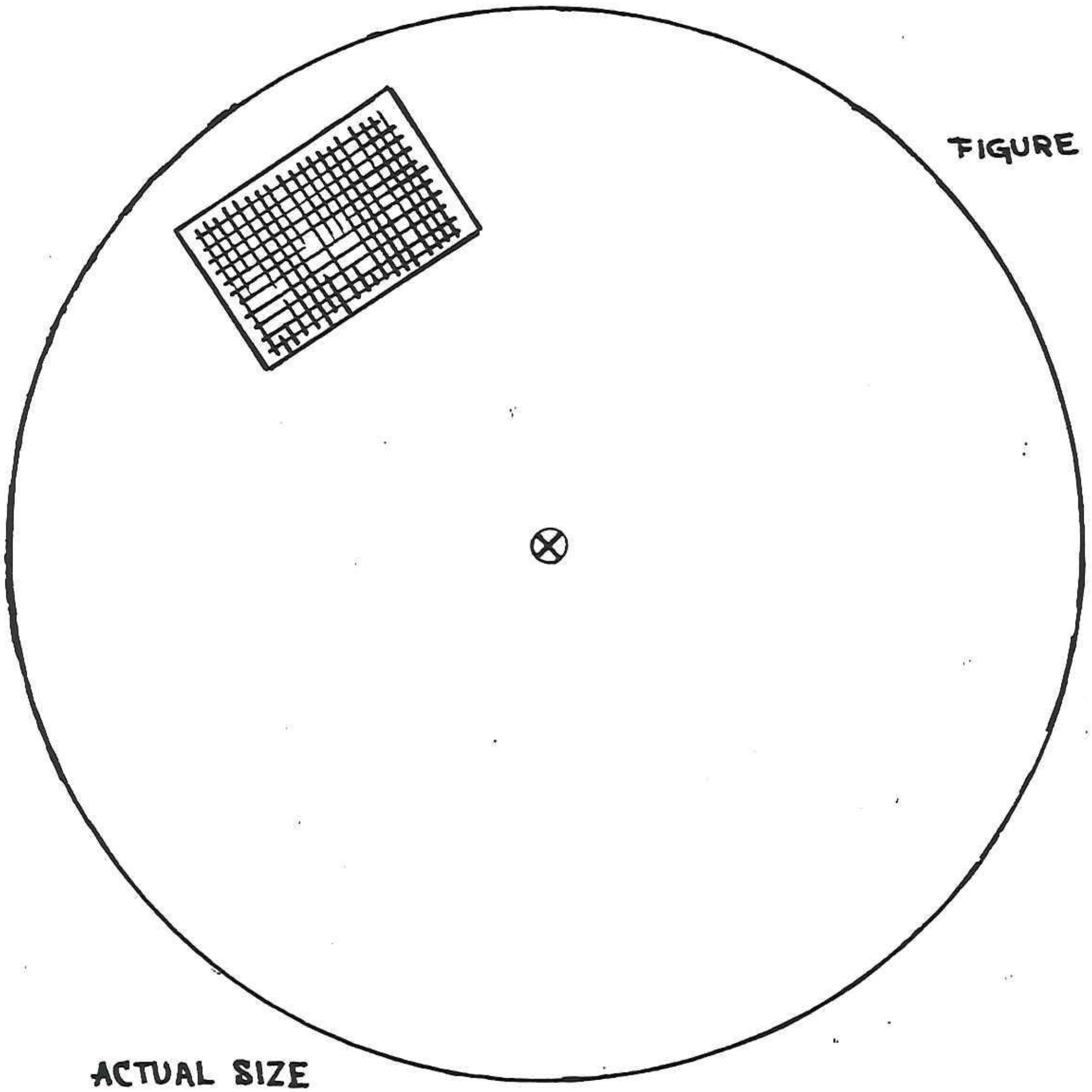
Abell, Exploration of the Universe, pp. 628, 342-352.
Gallant, The ABC's of Astronomy, pp. 85.
Wallenquist, Dictionary of Astronomical Terms, pp. 140-141.
MacRae, Donald, A., "The Brightest Stars," The Observer's Handbook.

NOTE

For brightness scaler diagram and instructions, see following pages.

BRIGHTNESS SCALER--Pattern for Part A and Directions

FIGURE 1



ACTUAL SIZE

Duplicate on manilla paper and cut out, or cut and paste on lightweight cardboard--Figures 1 and 3 (see next page). Cut out area shown in gray.

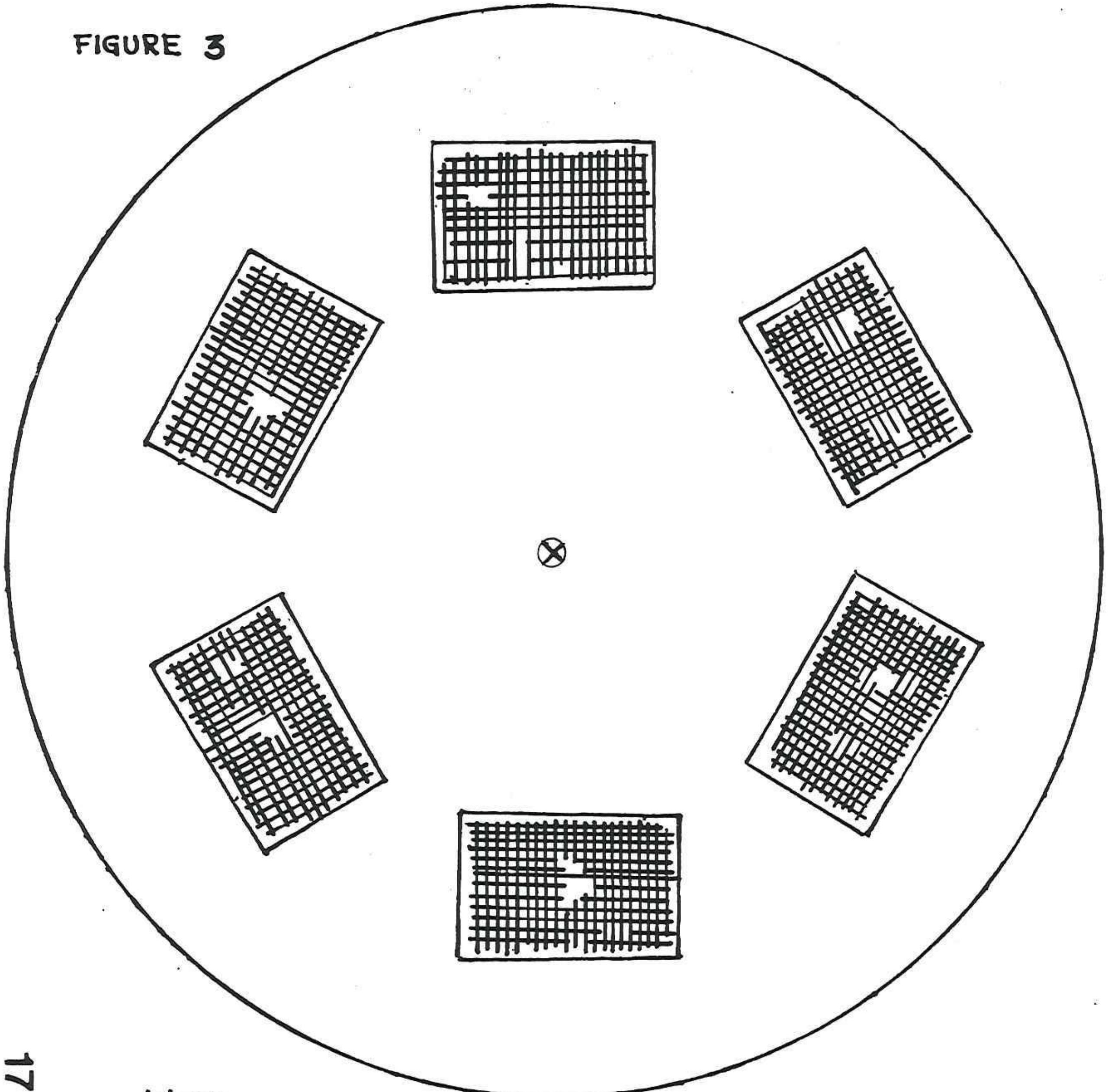
Affix with brad on top of Part B of Brightness Scaler.

This wheel should be free to turn.

Tape filters in respective order to back of the wheel as shown in Figure 2. Use a brad and put Figure 1 on top.

BRIGHTNESS SCALER--Pattern for Part B and Directions

FIGURE 3

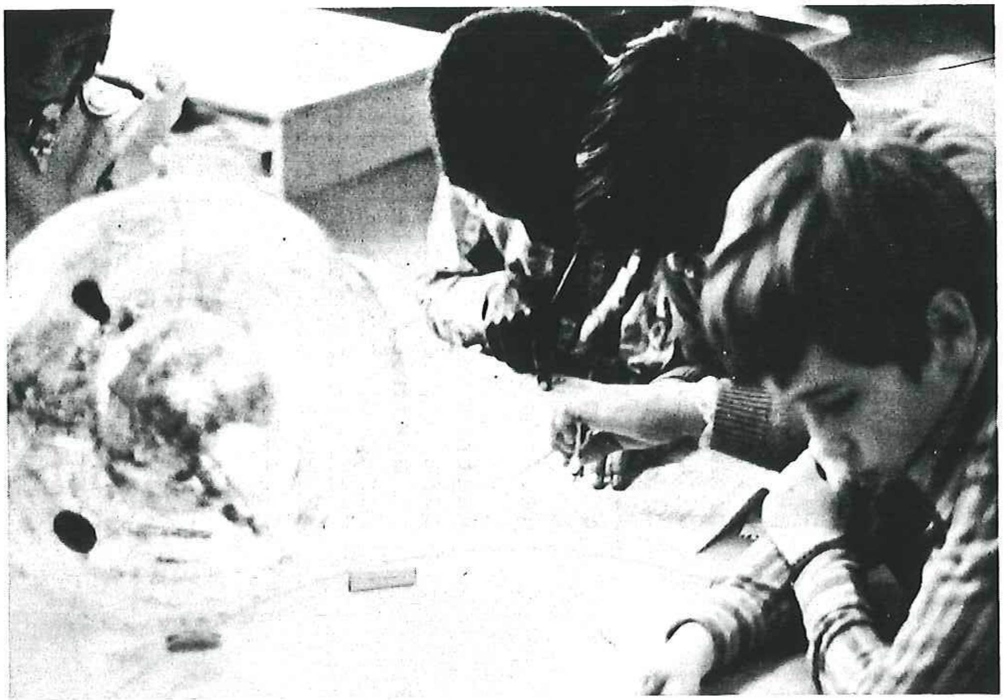


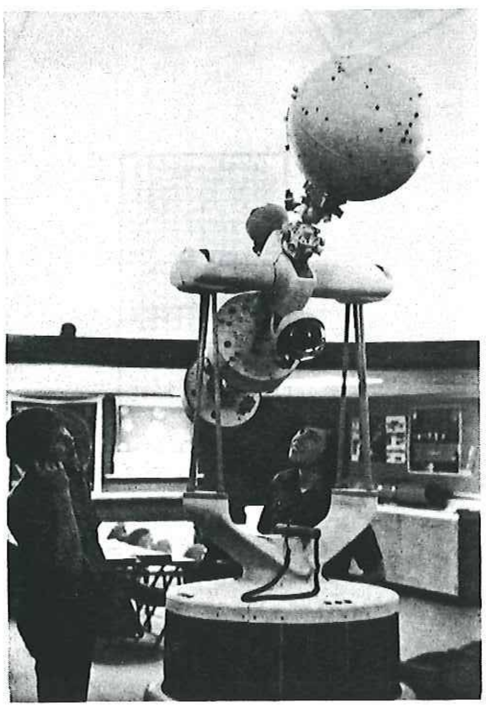
ACTUAL SIZE

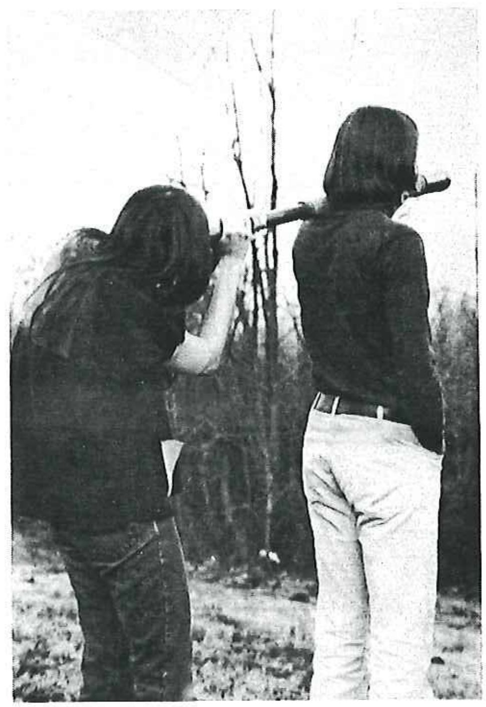
To make filters (negatives), photograph gray cardboard using black and white film (35 mm slides) at different exposures (F stops). Then experiment selecting the negatives most appropriate for differentiating between magnitude classes in your planetarium sky. Note: when sending film to developer, ask that all negatives be returned; otherwise you will get nothing.

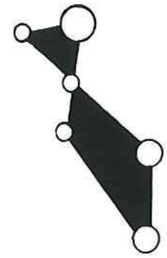
Another way to make filters is to take a photo print scaler and put it against the lens of a camera for each graduation of the scaler. Then photograph a bright light through each graduation of the scaler.

FIGURE 2









LOCATING THE BIG DIPPER

Children will start feeling at home with the stars and will become interested in observing them further when they realize that they can easily find the Big Dipper on a clear night. The Big Dipper, in turn, will help them locate a very important star for finding their way, Polaris. The Dipper finder to be made in this activity will tell them in what general region of the north sky to look for the Big Dipper at any hour of the night throughout the year. As they use it they will see how the Dipper appears to move around the Pole Star. The planetarium substitutes for the night sky to validate the use of the Dipper finder; the night sky is used to confirm the planetarium experience.

STUDENT PREPARATION	Grade level: elementary Content background: some familiarity with Big Dipper and its shape; understanding of the earth's rotation.
FACTS AND CONCEPTS	The Big Dipper appears to move in the sky from hour to hour. The Big Dipper appears to change its position from month to month. The pointer stars in the Big Dipper point toward the North Star (Polaris).
OBJECTIVES	The student will be able to use the Dipper finder to locate the position of the Big Dipper at selected hours and months of the year. The student will be able to locate the North Star (Polaris).

MATERIALS Classroom: Pattern for Dipper finder and accompanying directions for constructing and using it (see Dipper finder pattern at end of activity); brad, rubber cement, scissors.

Planetarium: Dipper finders made in classroom; pen light, pencils and paper.

PROCEDURES In the Classroom

1. Review rotation of the earth, shape of Big Dipper, and the usefulness of this star configuration in finding the North Star and cardinal points.

2. Ask students to construct the Dipper finder, using the materials given them.

3. Let students practice setting and orienting the Dipper finder for various dates and hours of night until they become familiar with its operation.

In the Planetarium

1. Preset the planetarium for the date of the visit and for one hour after sunset.

2. With cove lights up, ask students to set their Dipper finders for the date and time of the planetarium setting and determine the approximate region of the north sky where the Big Dipper will be found.

3. With the students, identify cardinal points, horizon, and zenith. (At upper elementary levels, also identify the meridian and discuss the meaning of upper and lower culmination positions.)

4. Activate the stars, lowering cove lights until the Big and Little Dippers are visible (but maintain as much room illumination as possible). Each student should verify his predicted orientation of the Big Dipper with its position in the planetarium sky. Ask students to observe the position of the North Star (ask them this again in connection with all later observations).

5. Using diurnal motion, advance the sky two or three hours at a time through a 24-hour period. Before each advancement, students should reset their Dipper finders for the

correct time and make a prediction on the Dipper's location. Following each advancement they should observe the position of the Dipper in relation to their prediction and to the horizon, zenith, and other stars (at upper elementary levels, include upper and lower culmination positions).

6. Using annual motion and the ecliptic--and the same inquiry procedures as above--show the position of the sun by season and the position of the Dipper in the evening sky on the same date.

Follow-Up Activities

1. Each student should take his Dipper finder home and use it to locate the Dipper and North Star in the night sky.

2. The Dipper finder is large enough to include more stars. Ask students to plot the Little Dipper, Cassiopeia, and Draco on their Dipper finders from the sky at night. On the next school day, they should check their success with a star chart.

3. At upper elementary levels, guide students in using their Dipper finders and the Big Dipper to tell the time of night (see Suggested Resources).

EVALUATION SUGGESTIONS

Show the Big Dipper in four different positions at 9 p.m. on the planetarium dome and ask students to use their Dipper finders to discover the month in which each position would occur. They should record their answers on paper and turn them in.

Evaluate student performance in the post activities, and the understanding they exhibit in using the Dipper finder.

VOCABULARY

Big Dipper   cardinal points   Polaris
horizon   zenith
(At upper elementary levels, also: upper and lower culmination points, meridian)

SUGGESTED RESOURCES

Atkins, The Universe in Motion, text edition 160.
Branley, Experiments in Sky Watching, pp. 81-83.
Engelbriktson, Greenleaf, Let's Explore Outer Space, pp. 24-36 (directions for using the Big Dipper as a clock in the sky).

Joseph, Lippincott, Point to the Stars, pp. 10-13, 44-45.

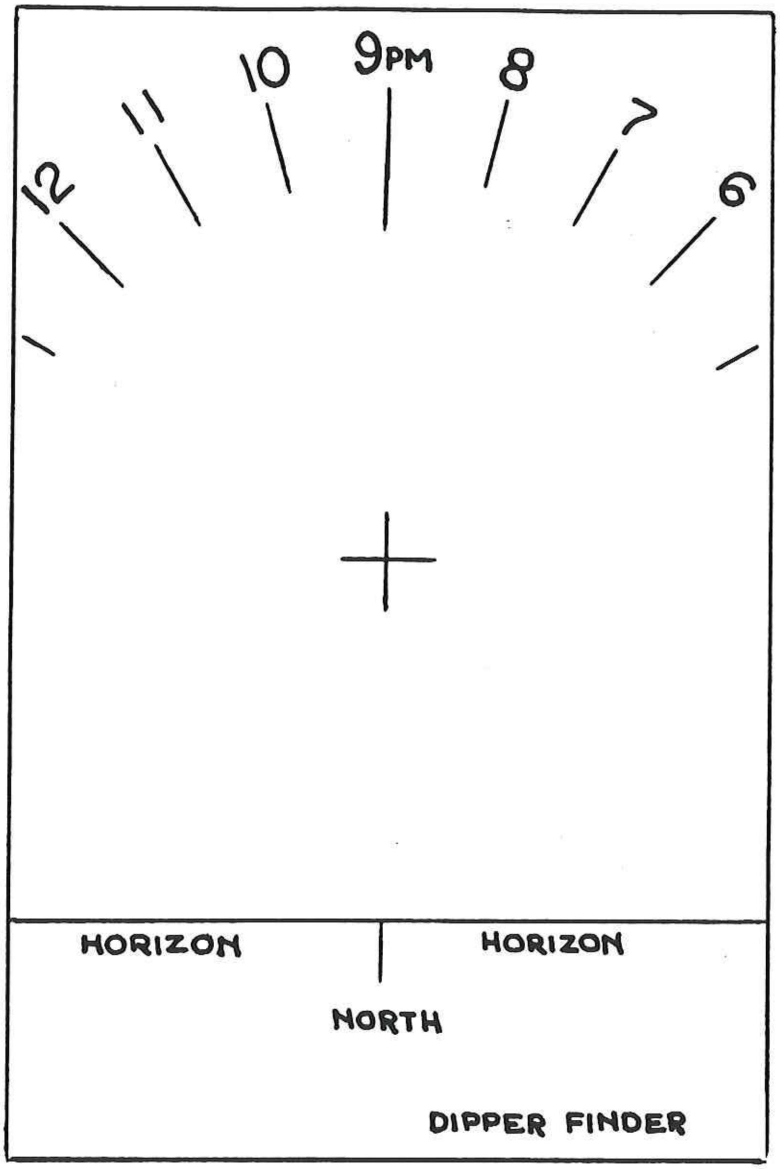
NOTE For Dipper finder pattern used in the activity, see following page.

PATTERN FOR DIPPER FINDER AND INSTRUCTIONS

Construction

1. Cut out the circle and square and paste both on tag board. Trim tag board to exact size of circle and square.

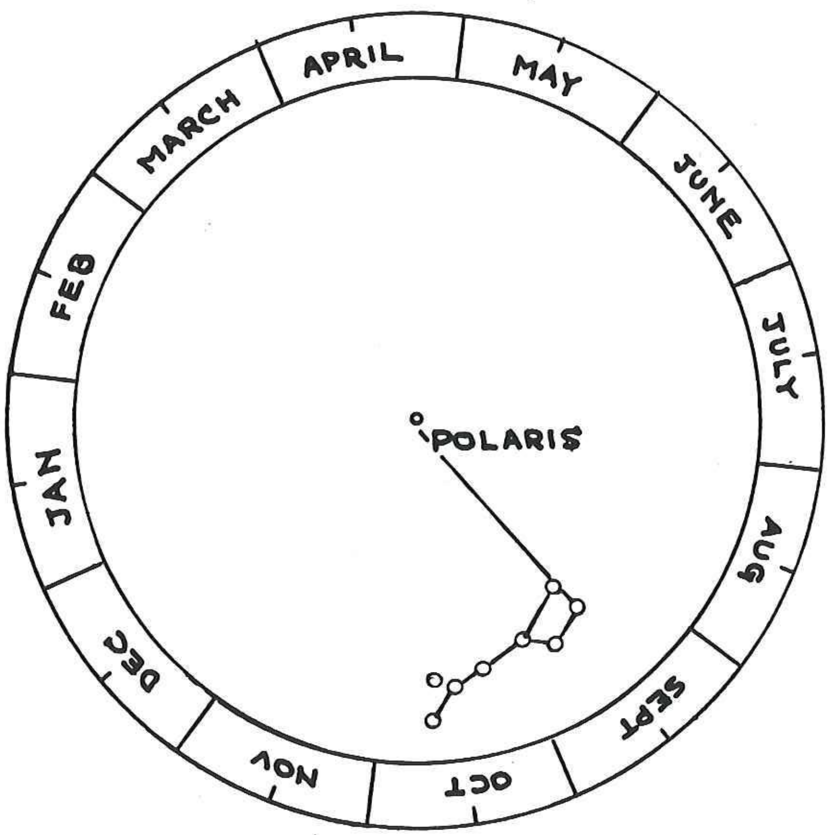
2. Fasten circle to square by putting brad through Polaris.

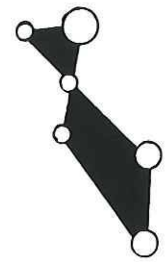


Use

1. Line up the date of observation with the time of observation. For example, if it is 10 p.m. on April 11, turn the month wheel until a point about a third of the way into the space marked "April" is aligned with 10 p.m. on the square card.

2. Hold the card up so that the north horizon on the card corres- ponts with the north horizon in the plane- tarium or real sky.





A VISIT TO THE ZODIAC

Why are particular constellations called constellations of the zodiac and what is significant about them? In the following activity, students will develop answers to these questions as they identify the 12 zodiacal constellations and their positions on the zodiacal belt across the planetarium sky. The ecliptic is introduced, along with an examination of the apparent sun movement that defines it.

STUDENT PREPARATION

Grade level: secondary
Content background: previous introduction to earth rotation and revolution; some familiarity with constellations of the zodiac desirable, but not essential.

FACTS AND CONCEPTS

Because of the revolution of the earth around the sun, the sun appears to move annually through a background path of particular constellations.

Since the orbits of the planets and of the moon are on planes similar to that of Earth, their paths as seen from the earth are in the same belt as that of the sun.

The ancients attached religious significance to celestial objects. Because the sun, moon, and planets traveled through the same belt of stars, the star groups on this belt took on special importance.

OBJECTIVES

- The student will be able to derive the the constellations of the zodiac from his planetarium observations of the yearly movements of the sun and planets and from the monthly motion of the moon.
- The student will be able to locate the

zodiacal belt on a star chart.

- The student will be able to name and depict or describe orally the sign posts (constellations) that comprise the zodiac.

- The student will be able to explain why early man attached special significance to the constellations of the zodiac, "zoo in the sky", which differs among civilizations. "Zodiac" and "zoo" are derived from the same word meaning "animal".

MATERIALS Classroom: orrery, light source, constellation charts; art materials for follow-up activities; star chart for evaluation.

Planetarium: constellation worksheet (see sample at end of activity); pencils, pen lights.

PROCEDURES <u>In the Classroom</u>

1. Using an orrery of the sun and earth, review rotation and revolution with the class.

2. Have the class depict planetary revolution as follows: Place a light source in the center of the room to serve as the sun; ask 12 students to represent constellations and stand in a large circle around it; assign other students appropriate positions in the formation to represent Mercury, Venus, Earth, Mars, Jupiter, Saturn. Ask the "planets" to move around the sun in the direction and at relative speeds appropriate to their celestial counterparts (this will take discussion and referral to a textbook). Call several stops and ask two students to construct a straight line with a string so that it bisects the circle and passes "through" the sun and Earth. Discuss the constellation behind the sun and the constellations and planets that will be visible from Earth in the nighttime sky at each stop. (In repeating the demonstration, add the moon.)

3. Introduce the shapes and names of the 12 constellations behind the sun through the use of constellation charts. Continue with Follow-Up Activity No. 1 if you wish (appropriate either before or after planetarium visit), but in any event, tell students that they will learn more about the significance of these 12 constellations in astronomy when

they visit the planetarium.

In the Planetarium

1. Preset planetarium sun and planets to date of visit. Ask students to observe the movements of the sun and planets--and to remember how they depicted the movements in the classroom--as you use annual and daily motion at the same speed to keep the sun on the meridian. Remind students that this is how planets appear to move in relation to the sun as seen from the Earth. (Explain why they are seeing sun and planets at same time.)

2. Reset instrument to date of visit. Now turn on the stars and repeat the above step. Ask students to notice and identify the constellations that pass in back of the sun and planets.

3. Next turn on the moon and go through one month (keeping the same motion), again asking students to notice and identify star groups in the background.

4. In discussion, emphasize that the constellations behind the sun, planets, and moon were the same constellations. Let a student point out the belt of constellations which moved behind them.

5. Mark the belt by turning on the ecliptic. Introduce the term and the definition.

6. Now repeat Steps 1 and 2 with the ecliptic on. Let students discover that the ecliptic always passes through the center of the sun and that the planets travel very close to the line.

7. Repeat Step 3 with the ecliptic on, so that students can observe the movement of the moon in relation to the ecliptic and learn more about the depth of this belt of constellations.

8. Pass out the constellation worksheets. Using only the stars and ecliptic and daily motion as needed, ask students to observe and name each constellation through which the ecliptic passes (start with the vernal equinox). The name of each constellation and its order in the zodiac can be filled in on worksheets as the discussion goes along.

Follow-Up Activities

1. Ask students to look up the derivation of zodiac (from the Greek word for "animal"). Students who wish might draw original stick figures to represent the objects for which constellations were named.

2. Suggest that each student read and report on at least one myth related to a zodiacal constellation (they may wish to do this for their own particular "signs").

3. Propose that several students make an in-depth study of the religious importance the ancients attached to the sun, planets and moon and the constellations through which they seemed to pass. Both Roman and Greek gods and the deities of the ancient Zoroastrians might be explored. The reports should be presented to the class.

4. Students might cut out figures of the zodical constellations and paste them in order on the inside of a round hatbox. Long skewers can be used for suspending the sun and planets inside for a stationary model of the solar system.

5. Ask pupils to look for the zodiacal constellations in the real sky. Although they can't see the constellation in which the sun is currently appearing, they can make a long-term study which will support planetarium experiences: by noting the rising star group each month at the horizon point directly opposite the setting sun, they will see that these constellations change in sequence, lagging behind the current sign of the zodiac by about six months.

EVALUATION SUGGESTIONS

Give students a star chart and ask them to shade in areas where the paths of the sun, planets, and moon would be found.

Ask students to explain in writing why the ancients, viewing the stars in the sky, attached more importance to the constellations on the zodiacal belt than to others.

Ask students to demonstrate through pictures or models the apparent motion of the sun through the constellations of the zodiac and the earth movement that is actually occurring.

VOCABULARY

constellation   zodiac   zodiacal belt
(names of zodiacal constellations)
ecliptic
mythology   signs of the zodiac   astrology

SUGGESTED RESOURCES

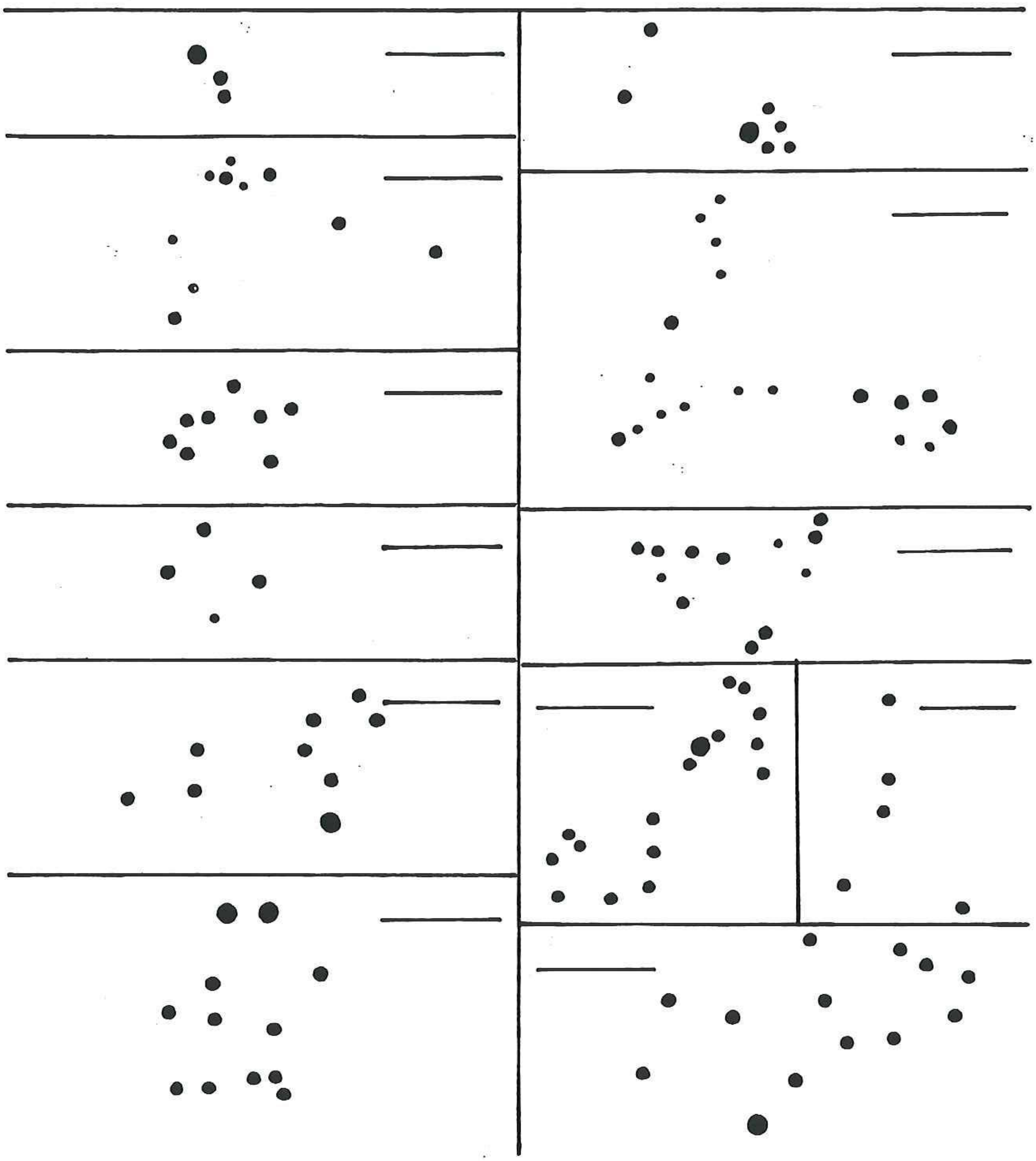
Bergamini, The Universe, pp. 17, 20-21.
Lauber, Look It Up Book of Stars and Planets, p. 123.
Lum, Stars in Our Heaven, pp. 113-203.
Zim, Baker, Stars, pp. 100-101.

NOTE

See following page for worksheet used in planetarium.

CONSTELLATIONS OF THE ZODIAC

Name and number the constellations in order. Draw the stick figures if you wish.



NAMING THE STARS IN CONSTELLATIONS

As students become interested in the stars, they will soon discover that relatively few have proper names. There's Polaris, of course, at the end of the handle in the Little Dipper, Betelgeuse and Rigel in Orion, Pollux and Castor in Gemini. But do the other stars in these configurations have names?

In the activity to follow, students will find out that they, themselves, can often determine the accepted name for the brighter stars in familiar constellations--provided they can distinguish between degrees of brightness and know the beginning of the Greek alphabet.

STUDENT PREPARATION Grade level: secondary
Content background: enough familiarity with constellations to identify several by name and configuration; awareness of differences in stellar brightness; some knowledge of Greek alphabet.

FACTS AND CONCEPTS Orderly and international nomenclature assists in scientific communication. If astronomers throughout the world are to talk about particular stars, the stars need universal names for purposes of identification.

Systems of nomenclature used in science are usually rooted in characteristics which objects (or organisms) possess in common, and differences in these characteristics. An observable characteristic of stars is apparent brightness.

The major system for naming stars in

constellations make use of a letter of the Greek alphabet as a prefix to specify the relative brightness of a star. The Greek prefix is followed by the Latin name of the constellation, with the Latin name appearing in its possessive (genitive) form. Thus the second brightest star in Orion is named:

"β (beta) Orionis"
meaning
(the) second (brightest star) of Orion.

In most systems there are exceptions to rules, and this is particularly true with systems set up to control language with which names are communicated.

OBJECTIVES

- Given an appropriate worksheet and a copy of the Greek alphabet, the student will be able to name certain stars in known constellations.
- The student will be able to state a rule as to how stars are generally named.
- The student will be able to identify the constellation figures observed in this activity.
- The student will be able to list by name and letter the first eight letters of the Greek alphabet.

MATERIALS

Classroom: student study sheets (see end of activity); projector and slide of one of the constellations represented diagrammatically on the study sheet, but not Ursa Major. The slide should show the constellation as it appears in the night sky.

Planetarium: student worksheets (see end of activity), pen lights and pencils; auxiliary projector; slide providing circles or other means for outlining on the dome the constellations represented on worksheets; slides or other means for projecting each constellation alone in its starfield.

PROCEDURES

In the Classroom

1. Project the picture of the constellation, have it identified, and ask students if they can identify any of the stars by proper name. Consider whether there are proper names for all of them.

2. Suggest that the class devise a plan for naming the stars. List methods suggested (perhaps by numbering, using names; or according to color, position, brightness).

3. Let students apply the methods proposed to the stars shown on the screen and decide if the methods are practical.

4. After students discover the problems involved in designing a system for naming stars, distribute the study sheets. Introduce the accepted system for naming stars in constellations and the Greek alphabet.

5. With the class go through the constellation figures by asking students to determine from the Greek letters the scientific name of each star and its order of brightness which its name indicates. Skip the figure of the Big Dipper.

6. Point out that the Big Dipper is an exception. Another system was used in naming its stars. Students should be able to figure out the system (positional order).

<u>In the Planetarium</u>

1. After distributing working materials, turn down cove lights and show star field at full illumination to freshen memories of the star-filled sky. Then turn up cove lights until all stars disappear.

2. Now gradually dim cove lights until only the brightest star can be seen. Continue the dimming until a few more stars appear. Continue further until students recognize that a technique is being used to aid in the differentiation between degrees of brightness.

3. Again show the star field at full illumination, with cove lights low and with all constellations represented on students' worksheets visible. Use an auxiliary slide projector to superimpose circles around the six constellations to be examined.

4. Ask the class to name the constellations and enter the names on their worksheets.

5. Turn up the cove lights and then gradually dim them again as in Step 2. At each stop ask students to point out any newly appearing star(s) in each constellation and to name each, if possible. The first star to appear will be alpha, regardless of the constellation. But from then on, the class must keep track of how many other stars have previously appeared in the constellation and/or notice relative brightness before naming the newly appearing star. Continue until you feel

students understand that degrees of brightness serve as the basis for naming stars.

6. Turn off all stars and project on the dome a slide of the real star field of Orion as it appears in nature. Let students take turns pointing to each star in order of brightness and naming it. Although worksheets will provide the Greek alphabet, the distinction between degrees of brightness will be more difficult now without use of the dimming technique--so allow time for discussion and interaction. Suggest that students fill in their worksheets to their own satisfaction as the procedure goes along.

7. Repeat the above for all other constellation figures except Ursa Major. You can use the dimming technique again to solve some differences of opinion, but with Cassiopeia and Leo, you may have to provide some of the correct names. Even with just the slide of the constellation's star field, the dimming technique of increasing and decreasing brightness in the room will help; also compare the real sky photograph of the constellation with its appearance in the planetarium.

8. Project a photograph of Ursa Major with the Big Dipper circled. Ask a student to use a pointer as he explains how stars are actually named in this configuration, and how they would be named were not the Big Dipper an exception to the general rule.

Follow-Up Activities

1. Let students take new copies of the worksheets home and use it to identify and name constellations and stars in the night sky.

2. Students might investigate how the system for naming stars is extended when a constellation has more stars than the number of letters in the Greek alphabet.

3. Using a brightness scaler (see activity entitled "How Bright Are the Stars") some students might try to determine for themselves the names of stars in other constellations from observations at night.

4. Let students investigate how the constellations and planets received their names.

EVALUATION SUGGESTIONS

Give students diagrams of the constellations studied and a list of their names (or use projection). Ask students to match the names with the constellations.

Use portions of Step 7 under the planetarium procedure for evaluation purposes.

Ask students to state in writing a rule for naming stars in a constellation.

Ask students to list the first eight letters of the Greek alphabet.

VOCABULARY

Orion, Cassiopeia, Triangulum, Leo, Ursa Major, Ursa Minor, brightness, apparent brightness, magnitude, alpha, beta, gamma, delta, epsilon, zeta, eta, theta

SUGGESTED RESOURCES

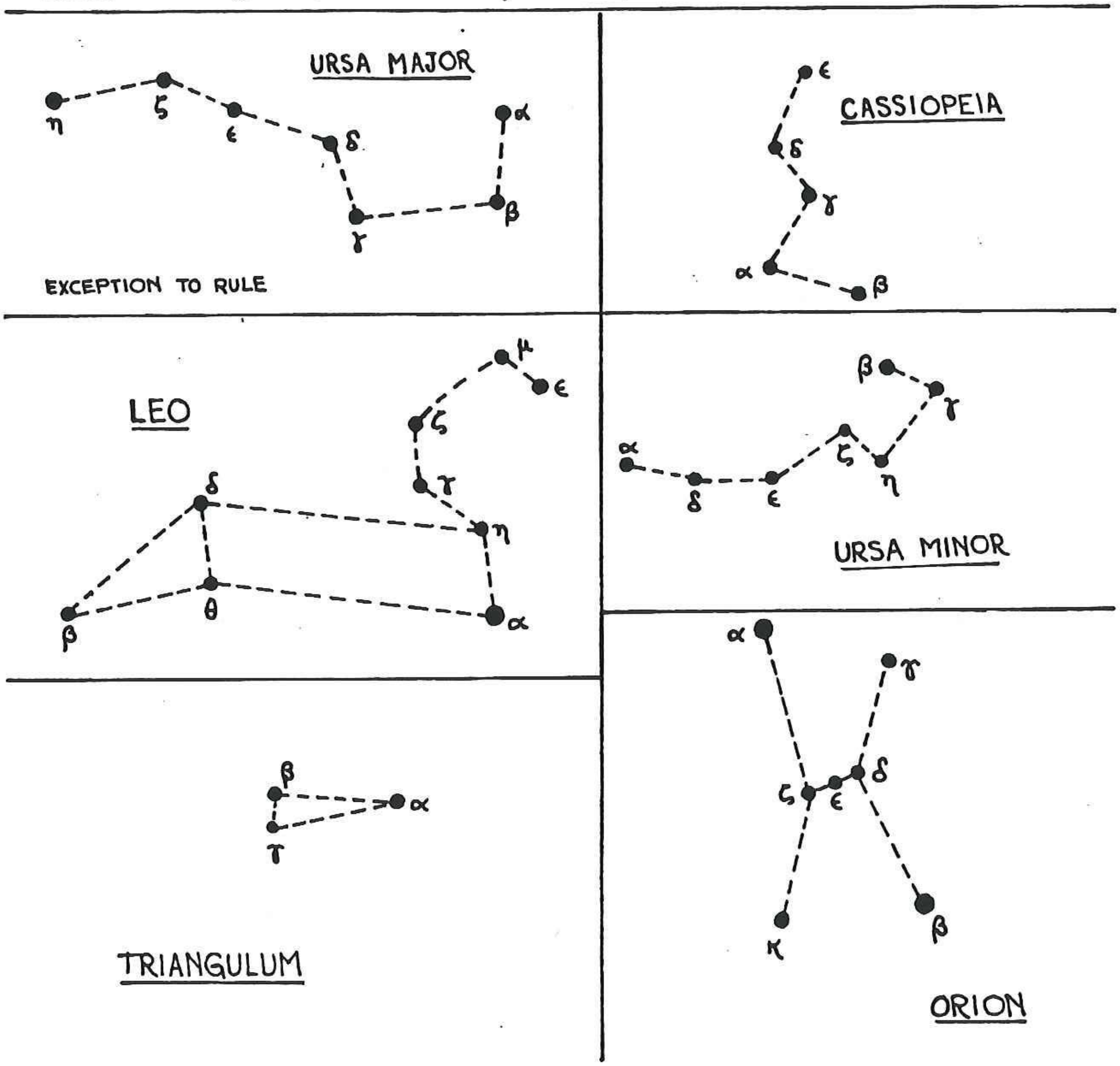
Degani, Astronomy Made Simple, pp. 13-41.
Joseph, Lippincott, Point to the Stars, pp. 24-25.
Martin, Menzel, The Friendly Stars, pp. 10-16.

NOTE

The study sheet and worksheet used in this activity are shown on the two following pages.

STAR NOMENCLATURE STUDY SHEET
GREEK ALPHABET

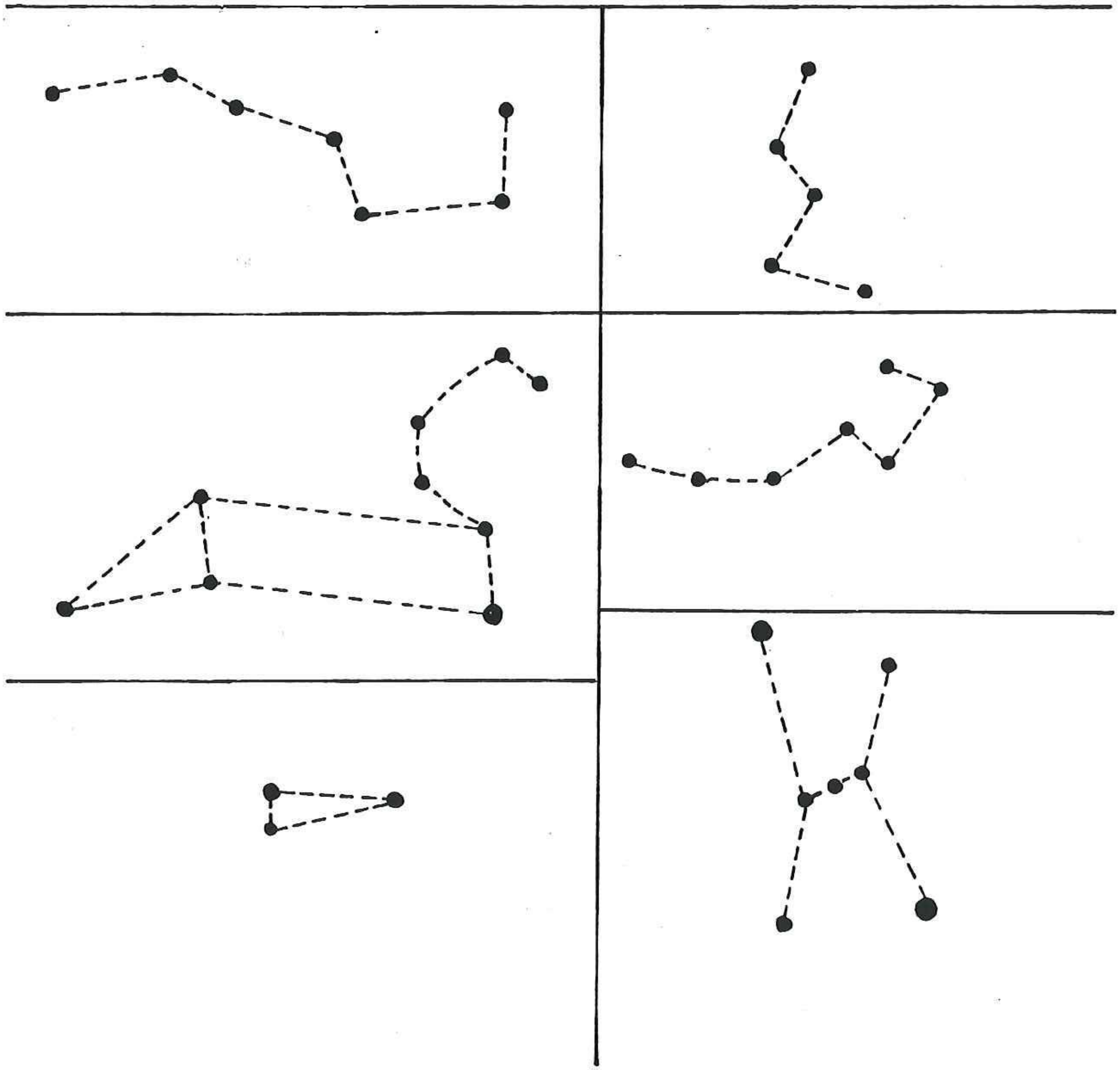
ALPHA	α	ETA	η	NU	ν	TAU	τ
BETA	β	THETA	θ	XI	ξ	UPSILON	υ
GAMMA	γ	IOTA	ι	OMICRON	ο	PHI	φ
DELTA	δ	KAPPA	κ	PI	π	CHI	χ
EPSILON	ε	LAMBDA	λ	RHO	ρ	PSI	ψ
ZETA	ζ	MU	μ	SIGMA	σ	OMEGA	ω

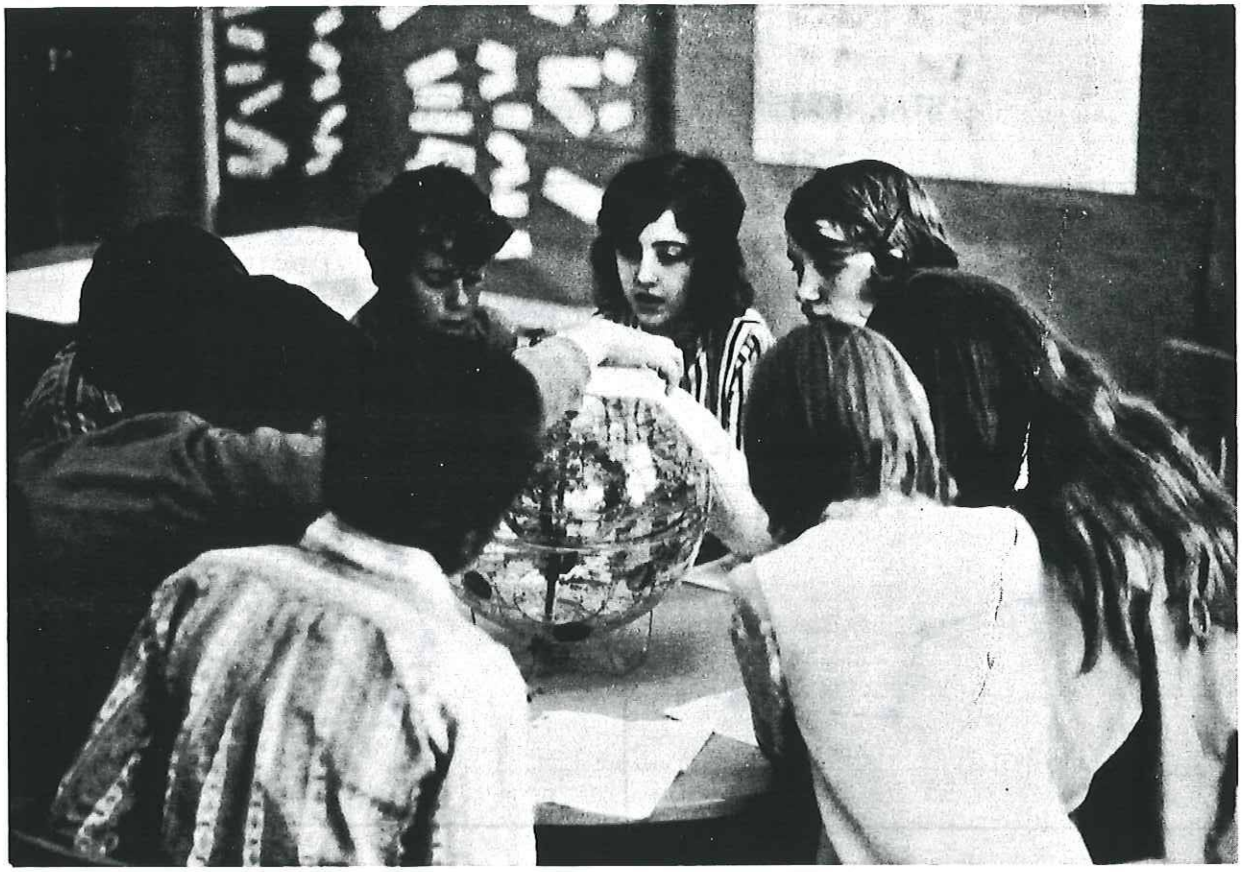


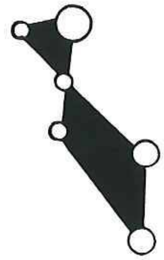
STAR NOMENCLATURE WORKSHEETS

GREEK ALPHABET

ALPHA	α	ETA	η	NU	ν	TAU	τ
BETA	β	THETA	θ	XI	ξ	UPSILON	υ
GAMMA	γ	IOTA	ι	OMICRON	ο	PHI	φ
DELTA	δ	KAPPA	κ	PI	π	CHI	χ
EPSILON	ε	LAMBDA	λ	RHO	ρ	PSI	ψ
ZETA	ς	MU	μ	SIGMA	σ	OMEGA	ω







OBSERVING THE SKY AROUND THE WORLD

In the social studies, students learn that man's way of living is related to his geographical location. Cultures at similar latitudes usually have certain similarities, while those at different latitudes have certain differences. These similarities and differences are reflected in legends from around the world. Moreover, the sky that people see around the world--from latitude to latitude--differs.

In the activity below, students observe in the planetarium the simulated night sky at mid-latitudes, the equator, and the North Pole--and relate what they see to age-old tales about the constellations.

STUDENT PREPARATION

Grade level: secondary
Content background: understanding of seasonal effects on various latitudes; some knowledge of cultural geography of Arctic, temperate, and equatorial regions; familiarity with stick figures as outlines of constellations; understanding of degrees of latitude and longitude.

FACTS AND CONCEPTS

The sky does not appear the same from different latitudes on earth.

The altitude of the North Star above the horizon as seen in the northern hemisphere denotes the latitude of the observer.

The sky appears the same for all longitudes at any given latitude.

At the equator, visible stars, including the sun, appear to rise and set; at the poles, visible stars, with the exception of the sun, appear neither to rise nor set, but to move in paths, parallel to the horizon.

OBJECTIVES

- The student will be able to identify locations on earth from which the sky appears to be the same and locations from which the sky appears to be different.
- The student will be able to identify the North Star and use it to determine his latitude.
- The student will be able to correlate apparent stellar motion with polar, equatorial, and mid-latitude regions.

MATERIALS

Classroom: world maps and globe; art materials for making relief maps; constellation figures; light source, such as filmstrip projector; books containing star legends from different regions (see Suggested Resources).

Planetarium: geocentric earth projector; 3 data sheets per student (see end of activity); pencils, pen lights, notepad, portable pointer.

PROCEDURES

In planning this activity, the classroom and planetarium teachers should select constellations and accompanying legends to emphasize. Base choices on constellations that will be visible on date of planetarium visit and constellations about which tales vary according to the latitude of area of origin.

<u>In the Classroom</u>

1. Ask each student to study and report briefly on the physical geography of a region near the North Pole, the equator, and in the mid-latitudes. Let some students construct topographical or relief maps for areas at these latitudes.

2. Discuss how physical geography, including latitude, affects living habits and the cultural heritage of people. Use the topographical maps students made to emphasize that there are factors in addition to latitude that affect temperature.

3. Using a light source and globe, review the angle of the sun at each season with respect to the various geographic regions of the poles, equator, and mid-latitudes. Also have the students graph temperature variations for

these regions by seasons.

4. With a world map or globe at hand, ask the class to point out major cities, countries, or civilizations that lie at approximately the same latitudes (include equatorial and polar regions).

5. Show some figures of constellations. As a homework assignment, ask students to search for legends about constellations and to find out, if possible, the country of their origin. The students should be ready to tell the tales in the planetarium.

<u>In the Planetarium</u>

1. Preset planetarium for evening sky, date of visit, and set the sun and let planets, moon and stars appear. Ask students to point out (with portable pointer of flashlight type) some constellation and tell a legend about it that originated in the mid-latitudes (Greek and Roman tales qualify). If time permits, repeat for other seasons to introduce additional constellations and tales.

2. Distribute data sheets. Using the same setting and the meridian, ask students to plot the altitude of the North Star.

3. Verify that the North Star is 90° from the equator. To do so, dim the stars, retain the meridian and illuminate the geocentric earth which has been preset with home position at the zenith. Have students count the degrees from home position (at the zenith) to the earth's equator; next, the degrees from home position to the geocentric earth's pole (the sum of the two numbers should equal 90°); then, the degrees from the equator to the geocentric earth's pole. Also have students count the degrees from the horizon to the North Star (this number must be the same as the number of latitude degrees from home position to the equator).

4. With the meridian and geocentric earth dimly illuminated, turn the stars to full brightness and go through several complete daily rotations. Ask students to observe whether new stars appear with each complete rotation and if there is a pattern in the apparent movement of the stars across the sky. They should describe or diagram the pattern. Certain stars do not rise and set but circle the North Star while other stars do rise and set at mid-latitudes.

5. Tell the legend of Cassiopeia emphasizing her position with respect to the North Star as the earth rotates. Also analyze the legend for clues to the culture, heritage

and scientific knowledge of the civilization in which the legend originated.

6. Encourage students to speculate on which stars of those they observe at their home latitude and longitude would be seen at different longitudes but at the same latitude. Then "move" students due west 90° by rotating the geocentric earth from west to east (do this manually if necessary). Activate daily motion and ask students to observe for constellations not seen before and for the general pattern of apparent star movement. "Travel" another 90° west and ask that the same observations be repeated.

7. Suggest that students speculate on what would happen if the latitude were changed but if longitude remained the same. Would the same stars and the same pattern of star movement be seen?

8. Optional activity: to settle the above question, use the geocentric earth and "travel" with the students first to the equator and then to the North Pole. In each case, change the star projector and geocentric earth appropriately for the latitude. For both the equator and North Pole, you might proceed generally as for home latitude, having students:

   a. Plot on a new data sheet the sun's noon position for the beginning of each season at all three latitudes, poles, equator and mid-latitudes. (This activity may already been done in the seasons planetarium lesson). Correlate the angle of the sun's rays with temperature, length of day and its effect on the culture and life style of civilization at these latitudes.

   b. Identify constellations for various seasons and tell tales about them which originate at the latitude (you will need to help out with tales from Africa and the Far North); several weeks prior to this lesson write to the Bureau of Indian Affairs in Washington, D.C. for publications that may be available on the legends, mythology and star lore of various tribes and cultures such as the Eskimo, Navajo, etc.

   c. Plot the altitude of the North Star with respect to the horizon and zenith for each new latitude region--poles, equator, and mid-latitudes. Also observe and describe and/or diagram the apparent motion of the stars with respect to the North Star and horizon for each latitude region.

      (1) Help the students devise a name for the apparent motion of the stars at the poles and equator.

Explain:
(a) Circumpolar--derived from the Latin circum meaning around, and polaris meaning pole.
(b) Equatorial--derived from the Latin aequabilis aequare, meaning to make equal.

(2) Ask students to determine the length of daylight as seen at the various regions by observing several rotational periods at each position on the earth.

d. Observe any newly appearing constellations and the apparent pattern of star movement during several daily rotations--and describe or diagram the pattern.

While at the North Pole, if there is time, ask the class to determine what months they would, or would not, see the sun. Then using annual motion and the ecliptic, let the sun travel along to the 21st of each month. Once at the 21st, travel through one complete daily rotation so that students may observe when and if the sun will rise or set.

Return to home latitude and show the sky as it will appear that night, reviewing particular constellations and suggesting that students look for them in the evening sky.

Follow-Up Activities

1. Ask students to report on the constellations seen in the night sky since the planetarium visit. Have they noticed the altitude of the sun at noon and is this position in accord with the data they collected in the planetarium?

2. Suggest that students review their data on the sun which shows its altitude at the beginning of each season at the mid-latitudes, the equator, and North Pole. Then they should check annual temperatures of cities or towns at similar latitudes and prepare a general statement about the relationship of latitude to temperature.

3. Distribute to the students copies of star legends. Ask that they read them and find

clues (either cultural or more directly geographic) to the latitude of the area in which the tale originated.

EVALUATION SUGGESTIONS

Give students the altitude of the North Star and ask them to determine the latitude. Then, using a globe or world map, they should identify cities where the North Star would appear at that altitude and where the sky would appear the same.

Give students a latitude (or altitude of the sun at noon through the seasons) and ask students to generalize about the climate and life style of the people living at that location.

Given photographs of long exposure star trails taken at the zenith for each latitude studied, ask students to identify the general latitude regions of poles, equator, and mid-latitudes from the apparent diurnal motion of the stars.

VOCABULARY

latitude	meridian	longitude
star altitude	constellation	star lore
	North Star/Polaris	

(names of constellations stressed in activity)

SUGGESTED RESOURCES

Brandwein et al., Principles and Practices in the Teaching of the Social Sciences, Concepts and Values, Level II, pp. 90-107.
Joseph, Lippincott, Point to the Stars, pp. 44-45.
Rey, Find the Constellations, pp. 6-7, 26-27, 30-33.
Zim, Baker, Stars, pp. 54-61.

For star lore, see the following books:

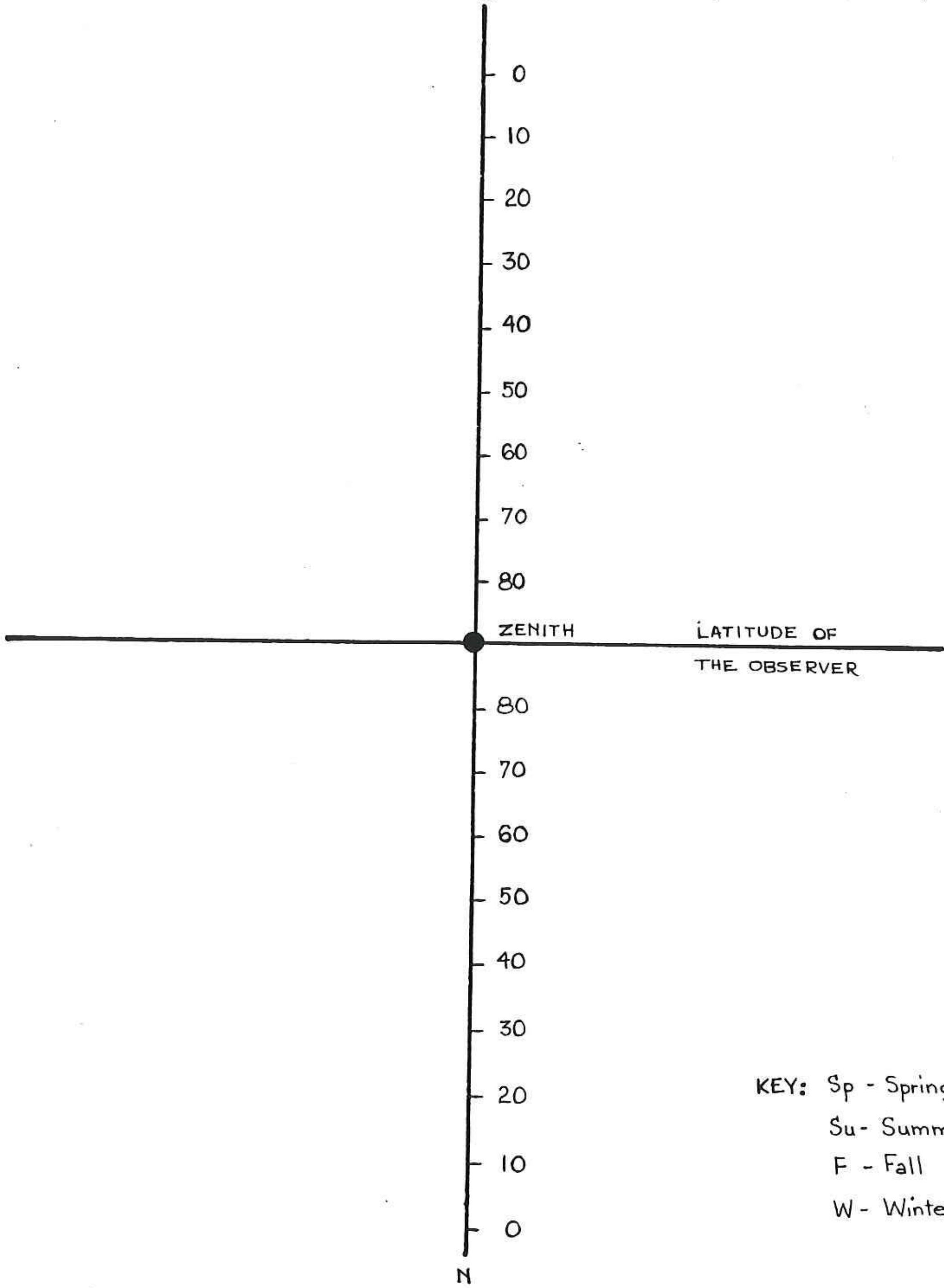
Allen, Star Names: Their Lore and Meaning.
Belting, The Moon Is a Crystal Ball: Unfamiliar Legends of the Stars.
Elgin, The First Book of Mythology: Greek-Roman.
Fisher, Stories California Indians Told.
Gringhuis, Giants, Dragons and Gods: Constellations and Their Folklore.
Lum, The Stars in Our Heaven: Myths and Fables.
White, The Golden Treasury of Myths and Legends.

NOTE

For data sheet used in activity, see following page.

ALTITUDE DATA SHEET

PLACE ____________________
(Indicate either home latitude, equator or North Pole)



KEY: Sp - Spring
Su - Summer
F - Fall
W - Winter

RECEIVING SPACE MESSAGES VIA RADIO

It's difficult for most students to visualize the manner in which a radio telescope "sees" into space. This activity will help them. In it, they will receive and plot, in a simulated situation, radio emissions from the Milky Way. The planetarium makes an ideal setting for this investigation.

STUDENT PREPARATION

Grade level: secondary
Content background: knowledge of the electromagnetic spectrum and of the position of radio wavelengths.

FACTS AND CONCEPTS

Many celestial bodies emit radio waves.

Radio emissions from space can be received by radio telescopes.

A radio contour map can be constructed by plotting the different intensities of radio emissions.

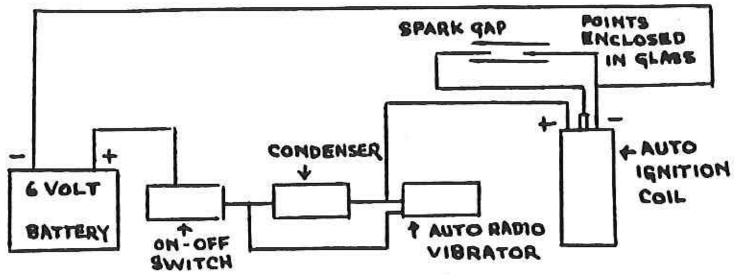
OBJECTIVES

- The student will be able to demonstrate a knowledge of the fundamentals of radio astronomy by plotting and interpreting a radio contour map.
- From simulated galactic radio transmissions, the student will plot a radio intensity map of the Milky Way.
- The student will be able to identify the string emission areas on a radio contour map.
- The student will be able to compare the procedures in this activity with the manner in which a radio telescope

receives, amplifies,and records radio emissions.

MATERIALS Classroom: set of graphs similar to read-outs from a radio telescope for use in follow-up work (see pages following activity).

Planetarium: three radio transmitting sources of different intensity--these are arranged, in advance of the students' arrival, above the dome along the Milky Way. In placing them, experiment so that the receivers to be used will differentiate the three sources. Construction.



Note: to vary intensity of source the distance between the points within the transmitter may be adjusted.

You will also need in the planetarium: an inexpensive AM radio receiver with earplugs for each student; 8" x 10" transparencies of the Milky Way galaxy (available from Palomar, Yerkes); 35mm slides of radio contour maps with corresponding 35mm optical photographs from major radio astronomy observatories (Greenbank, Jodrell Bank, Arecibo); constellation worksheets (see last page of activity); colored pencils (three colors); pen lights.

PROCEDURES <u>In the Classroom</u>

It is assumed that this activity would be scheduled at a time the class is studying the stars and the electromagnetic spectrum. Otherwise general review and discussion will be needed.

<u>In the Planetarium</u>

1. Let students meet initially in a room adjacent to the planetarium for instruction in use of the receivers. Have a radio source operating so that students can learn to turn the receiver

on and off and gain an understanding of the directional nature of the receivers.

2. After assembling students in the planetarium, turn on the stars at a setting where Cygnus, Leo, Aquila and Scorpius will be visible. Then turn up the cove lights to wash out the Milky Way.

3. Distribute the worksheets and ask students to locate on the dome the four constellations.

4. Now ask them to turn on their receivers and check for sounds from the planetarium dome. They should check for sounds of different intensities and try to determine the area of the dome from which each is coming.

5. Direct students to shade in their worksheets to indicate the area of the dome that is emitting each intensity, using different colored pencils for the high, medium, and low.

6. Lower cove lights in order for students to see the Milky Way. Ask them to relate their plottings on the worksheet to what they see in the planetarium sky and to shade in the Milky Way on the worksheet.

7. Emphasize that the Milky Way is a strong radio emitter because of the concentrations of nebulae, not only because of stellar concentrations. You might also mention Pulsars as radio emitters.

8. Explain (or ask students to explain) how this planetarium activity has simulated radio astronomy.

9. In conclusion show slides of the Milky Way galaxy and of radio contour maps, along with the corresponding optical photographs.

Follow-Up Activities

Guide students in constructing a radio map of the Milky Way from graphs similar to readouts from a radio telescope. For work with the graphs offered at the end of this activity, offer these instructions:

1. Cut a strip of paper to the dimensions specified by each scan.

2. Color the strip to indicate intensity as noted on the graph. Use a new color every 100°K up to 600°K. Then change every 300°K.

3. Align and paste the strips in order on a sheet of paper, beginning with scan No. 1 on the left. To align, mark

each strip in the center and line up the center points.

The resulting mosaic should show areas of intensity in the Milky Way, clearly indicating the spiral arms and galactic center. This activity as a follow-up to that in the planetarium will make radio astronomy much clearer to students.

EVALUATION SUGGESTIONS

Results of the follow-up activity can be used, or students might be given similar "read-outs" and asked to make the construction.

VOCABULARY

radio astronomy
radio emitter
electromagnetic spectrum
radio receiver
radio emissions
string emission areas
galaxy
nebula
pulsars
radio contour
scan
read-out
(names of nebulae mentioned in planetarium)
(names of radio astronomy observatories mentioned)

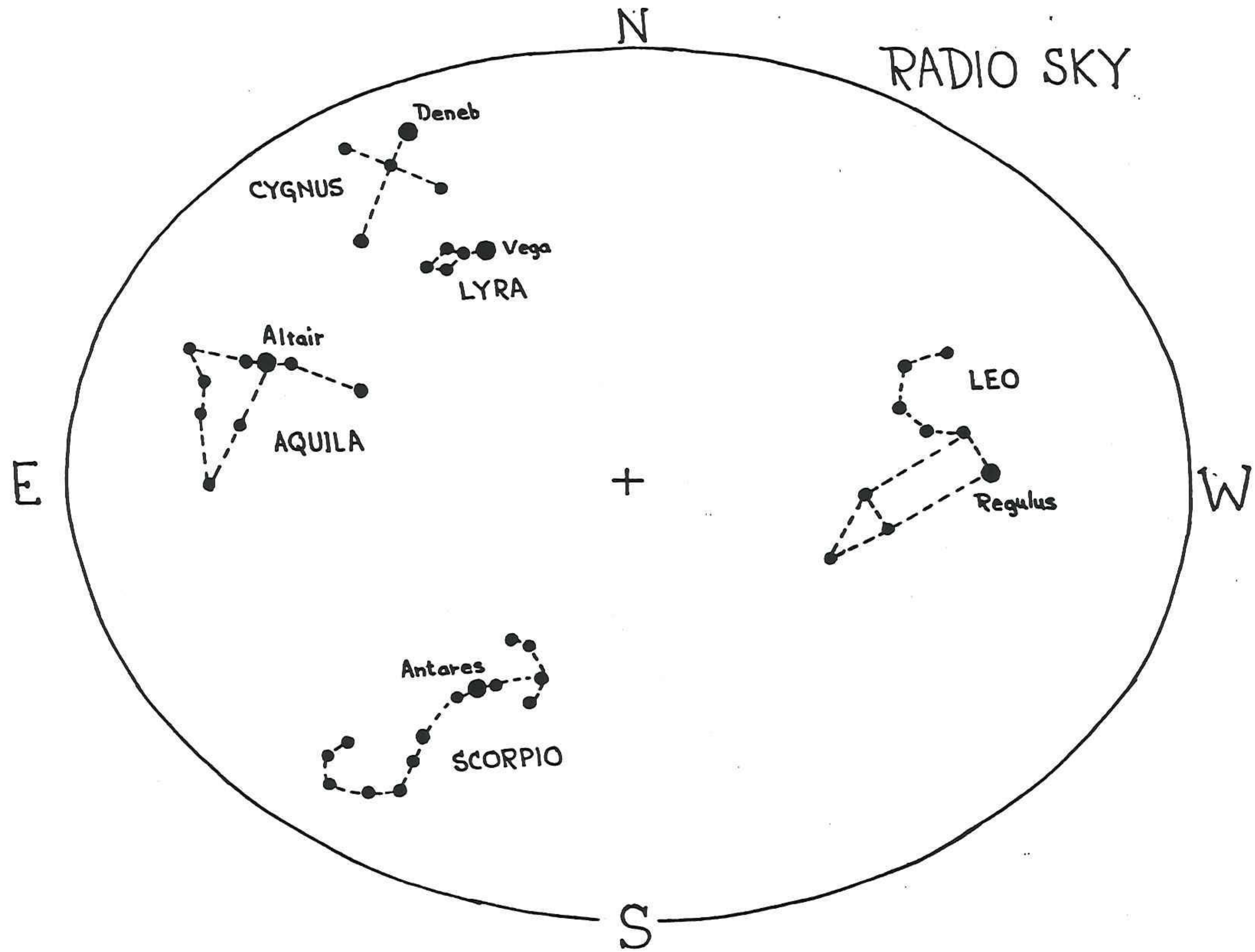
SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 164-167.
Bergamini, The Universe, pp. 38-40.
Kraus, John D., Radio Astronomy, New York, McGraw-Hill Book Co., 1966.
Ronan, Man Probes the Universe, pp. 78-81, 120-123.

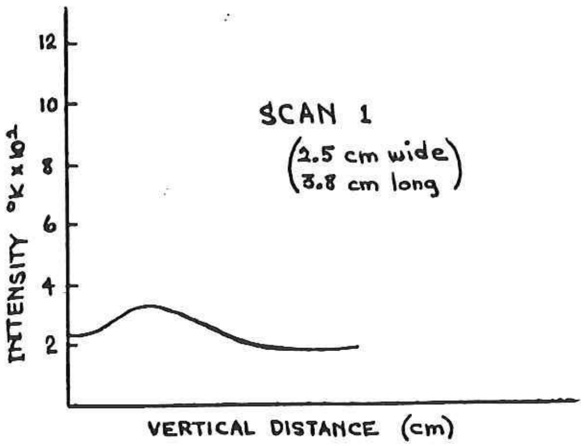
NOTE

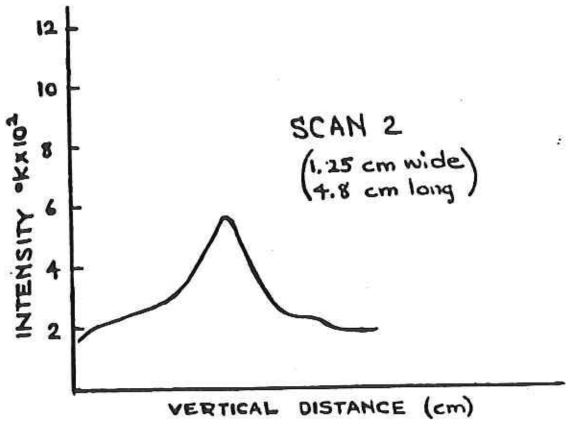
For constellation worksheet and graphs used in activity, see following pages.

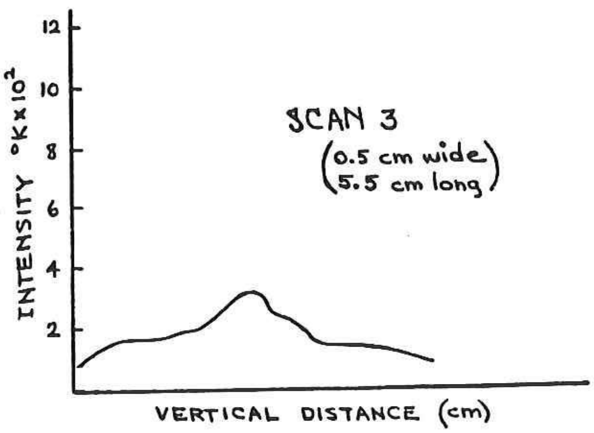
RADIO SKY

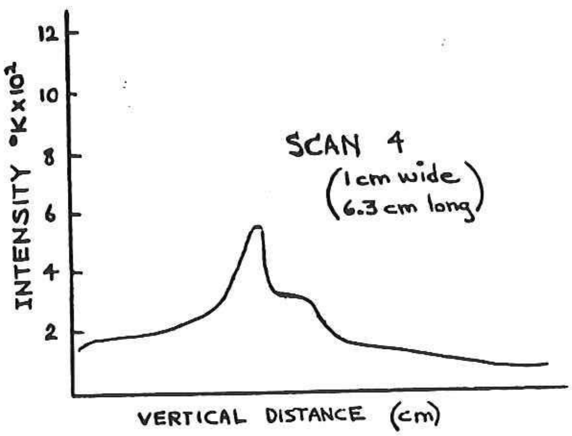

N
S
E
W
Deneb
CYGNUS
Vega
LYRA
Altair
AQUILA
LEO
Regulus
Antares
SCORPIO

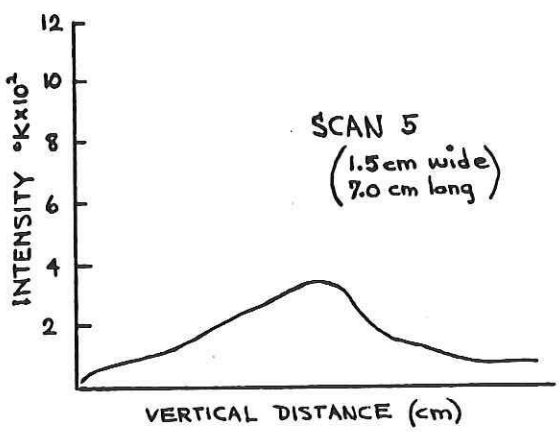
SCAN DATA SHEETS



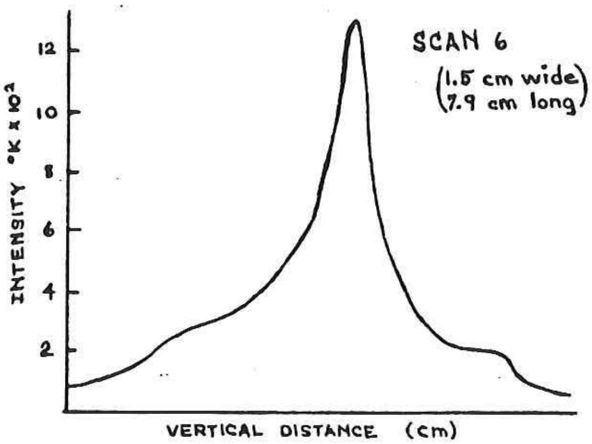


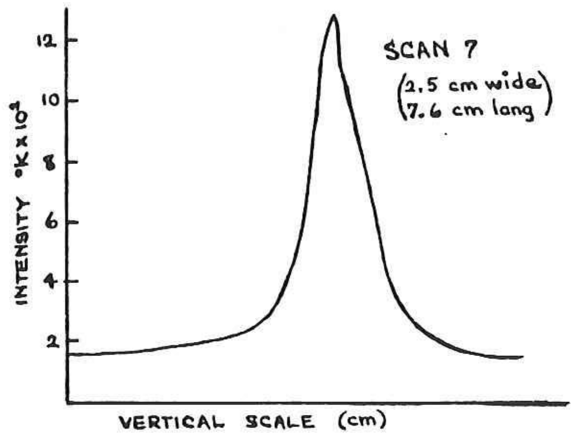


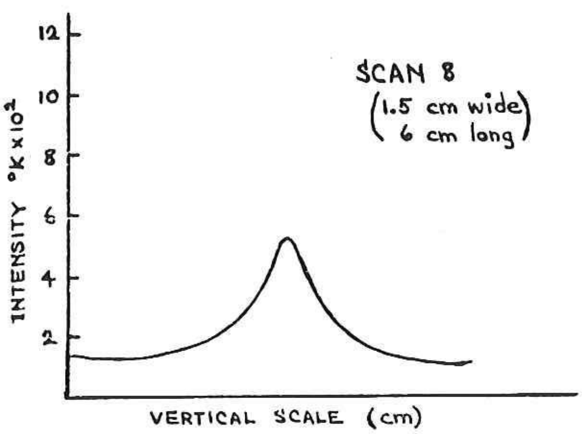


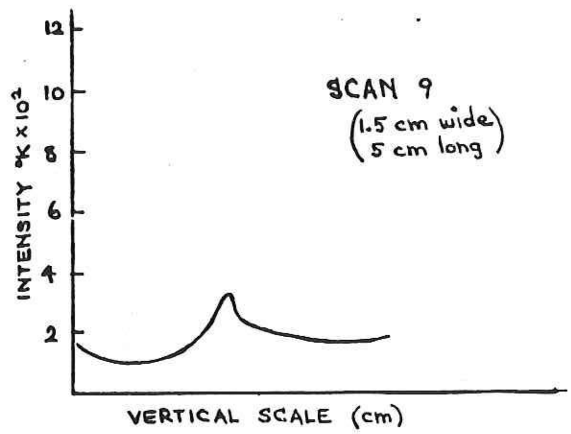


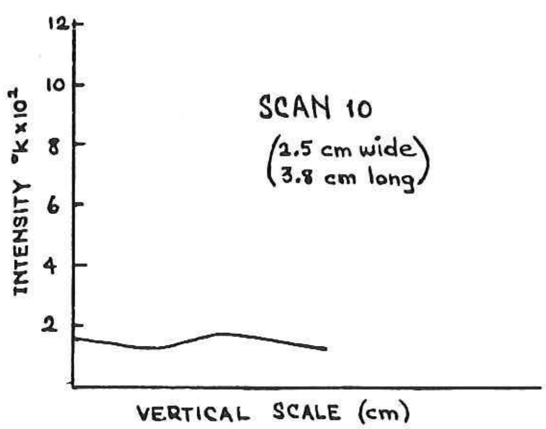
SCAN DATA SHEETS

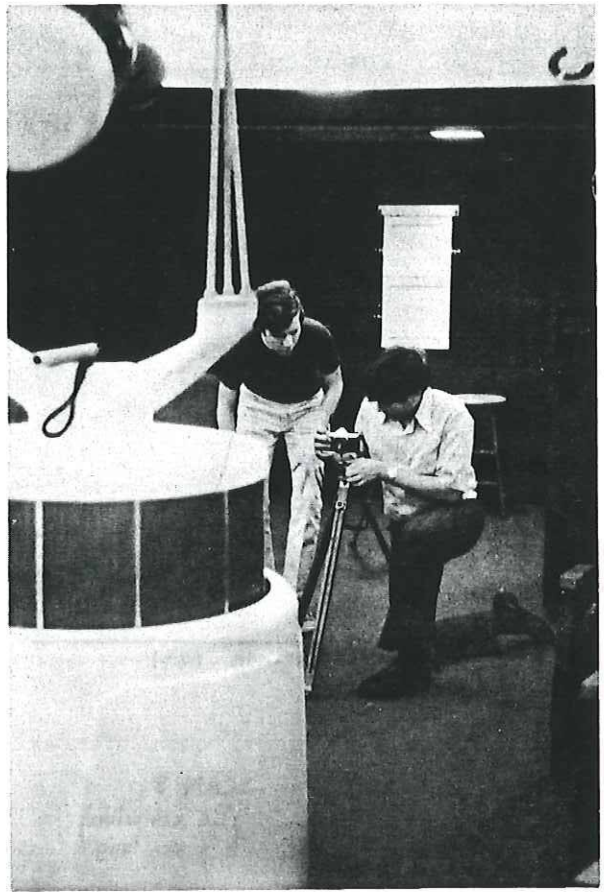












SKY PHOTOGRAPHY WITH A POLAROID

Photography has become one of modern astronomy's most useful tools. In this activity, students will use simple processes to duplicate the techniques through which pictures of the nighttime sky are made and studied. In doing so, they may not only learn to appreciate the particular techniques, but may develop a greater understanding and appreciation of scientific methodology in general. Since the planetarium permits re-creation of the nighttime sky during school hours, it is an ideal facility to use for the activity.

STUDENT PREPARATION

Grade level: secondary
Content background: familiarity with prominent stars and constellations of the season at hand; familiarity with the concept of morning and evening stars (planets) and with the apparent motions of stars and planets; ability to use a star chart (helpful but not essential).

FACTS AND CONCEPTS

Photography is a useful tool in accurately recording celestial phenomena.

Interpretation of photographic records has brought discoveries which would otherwise have gone unnoticed because of man's visual limitations.

Astrophotography poses special problems not normally encountered in photographic work.

OBJECTIVES

Utilizing knowledge gained in the planetarium, the student will be able to produce photographs of (1) circumpolar star trails, (2) star trails in the region of the celestial equator, (3) prominent constellations, and (4) one of the visible planets.

- The student will be able to propose techniques for determining exposure data needed for photographing the real nighttime sky.

- The student will be able to explain the special problems of astrophotography and list solutions.

- The student will be able to operate the camera equipment and produce satisfactory pictures of the planetarium sky.

- The student will be able to interpret data from photographs taken of celestial objects and events.

MATERIALS

Classroom only: star chart; orrery (sun and planet model); black cardboard or posterboard, white paint; daylight film packs; pen lights, globe.

Both classroom and planetarium: tripod and Polaroid 210 camera with time exposure control (or use stop watch)--one of each for every two or three students; at least one motor driven equatorial mount with camera attached directly to the mount or to the telescope.

Planetarium only: Polaroid film ASA 2000 (two packs per camera). Additional packs may be needed for follow-up activities.

PROCEDURES

<u>In the Classroom</u>

1. Using a star chart, familiarize students with the stars and constellations that will be visible in the evening sky on the date of the planetarium visit. They should study the star positions on the chart with respect to N, S, E, W, the horizon, zenith, and North Star.

2. Give basic instruction on the use and care of the Polaroid camera. Then provide practice in its use through the following preparatory activity:

    a. Cover the bulletin board with black poster board and paint on it, as accurately as possible, the stars of the season.

    b. Place the orrery (Trippensee type) about one foot in front of the starry backdrop.

If necessary, illuminate the backdrop so that it will not be overpowered by the size and/or brilliance (if electrified) of the orrery.

c. Ask students to photograph the above set-up by positioning their cameras in direct line with the orrery.

d. Move each planet 180° from its previous position on the orrery. Have students photograph the set-up again.

e. Now students should compare the photographs, particularly noticing the positions of the planets among the background stars. They should see that some planets not only appear in a different background constellation, but also on opposite sides of the sun.

In the Planetarium

1. With the planetarium darkened and set for night sky, date of visit (no motion), give a team of students a camera and tripod and ask them to photograph a given constellation as a trial project.

2. Discuss reasons with the class for the success or failure of the try-out. The idea of time exposure and the need for a timing device will come from the discussion.

3. Give all teams similar equipment (and timing devices, unless cameras are equipped with them) and ask them to photograph the same constellation. On this trial, advance daily motion very slowly. Let students discuss results and reasons for the star trails in the pictures. When they are assured that star trails are a normal outcome when time exposures are taken of the stars, discuss for what purposes star trails might be examined. Suggest an appropriate exposure time for the work to follow. (This may be from 2 to 6 minutes using the camera and film suggested; the best time is arrived at by trial and error and depends on dome size, light source, projector, etc.)

4. Now ask student groups to photograph different portions of the sky, with at least one group photographing the circumpolar area. View photos and discuss differences in star trail shapes, leading to how the shapes might be used to identify sky areas.

5. Suggest that students think of ways to eliminate star trails in astrophotography. Two suggestions may be offered: short exposures on high-speed film or a means of guiding the camera. Give at least one group of students a clock-drive equatorial mount and allow them to discover

the method of using it to produce trail-free photographs. (Note: the speed of daily motion needs to be the same as that of the clock-drive mount.) Discuss the method so that other groups may use the equipment properly. Note: the students may find that it is almost impossible to reproduce a trail-free photo in the planetarium because of the comparative speed of the planetarium drive and the position of the equatorial mount.

6. Using annual motion, the planets, and the sun (the latter dimly lighted), ask students to photograph several positions of the planets. These positions should include once when a planet is to the east of the sun and once when the same planet is to the west of the sun. Another trail-free photo might be taken of the planets as annual motion is used: this time turn off the sun and turn on the stars. (With the camera following the planet, the stars will appear as trails on the photograph.)

7. Next using daily motion (annual motion off), the planets, and the sun, ask students to photograph (trail-free) a planet on the east side of the sun, with the sun 5° to 10° above the western horizon; and another planet on the west side of the sun, with the sun 5° to 10° above the eastern horizon. (For "effect," students might try to get the designations for East and West and a little of the cove edge in the picture.) This experience will help students understand that a planet seen on the east side of the sun will set after the sun, and thus is an evening planet; while a planet that sets before the sun will rise before the sun, and thus is a morning planet.

8. Save time toward the end to instruct students in the identification of constellations, planets, and bright stars as an aid to further work in astrophotography.

Follow-Up Activities

1. First ask students to compare their planetarium photographs of constellations and stars with the star charts to verify their identifications.

2. Now comes the most important part of the activity: issue student groups cameras, tripods, stop watches, and film and ask them to transfer their experiences to outdoor photography for (1) circumpolar star trails, (2) equatorial star trails (3) prominent constellations, (4) one visible planet. Additionally, the equatorial mount might be issued to one team for experiments with long-exposure photography. Some students, if interested, might be encouraged to photograph a planet at the same hour every night for several weeks to measure its apparent motion.

3. Arrange pen lights in a random position so that the lights resemble stars. Then ask students to photograph the fixed lights, with the camera placed on the motor-driven mount. Compare results with the star trail photos taken in the planetarium. If possible, reverse the direction of motion of the motor-driven mount and again ask students to photograph the pen light set-up. Ask students to compare the direction of the trails with the previous photographs.

4. Using their star trail photos and the real sky photos, students should explain and demonstrate with a globe the direction the earth is turning to produce star trails as shown in the photographs.

5. Ask students to photograph, using high-speed color film and varying time exposures, constellations and star trails in the real sky. The students should keep an accurate record of the time of exposure for each shot, so that they can compare the length of the trail with the time of exposure.

6. After students have related the length of trails to the length of exposure, suggest that they try to devise a method of determining the rotational period of the earth. This will be fun and challenging for advanced students.

7. Suggest some reading and reports: for example, on special problems of astrophotography; on ways the photographic process has revolutionized astronomy.

EVALUATION SUGGESTIONS

The performance of students in the follow-up activities provides the best basis for evaluation.

Give students photographs of star trails of various constellations and have students identify the constellations.

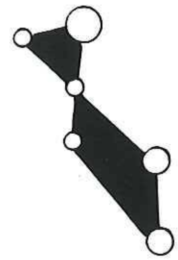
Give students a series of photographs of star trails (all taken with the same camera) and the exposure time for one of the photos. Ask students to determine the approximate length of exposure time for the others.

VOCABULARY circumpolar polar axis declination axis morning planet evening planet (names of constellations emphasized in activity) exposure star trails guided photograph equatorial mount clock-drive

SUGGESTED RESOURCES

Mayall, Robert R. and Margaret W.; Sky Shooting: Photography for Amateur Astronomers; Dover Publications, Inc., N.Y. 1971.

Sussman, Aaron; Amateur Photographer's Handbook, T. Y. Crowell Co., N.Y. 1971.



SPECTRA: FINGERPRINTS OF THE STARS

Analysis of spectra has become one of man's best means for knowing the stars. Using spectroscopy, astronomers have discovered color-temperature relationships, compositional characteristics, distance and motion phenomena, and stellar evolutionary sequences.

In this activity, students will be introduced to the basic techniques of spectroscopy, to the types of spectra emitted by stars, and to ways stellar spectra are used to derive information. There will be emphasis on the techniques--why they work and the need for them. The planetarium makes an excellent setting for contrasting the information that can be discovered from visual observation of the stars with the information that can be discovered through spectroscopy.

The complete activity will probably take two or three classroom/laboratory periods before the planetarium visit, two or three planetarium sessions, and two periods for follow-up purposes.

STUDENT PREPARATION

Grade level: secondary

Content background: previous lessons on stars, including apparent magnitude, luminosity; preferably ability to locate stars by coordinates; familiarity with white light as a mixture of colors ranging from red to violet; understanding that light of different wavelengths is responsible for different colors; some familiarity with chemical elements; ability to use simple spectroscopes or diffraction grating desirable.

FACTS AND CONCEPTS

Analysis of stellar spectra provides us with detailed information related to the temperature, luminosity, and chemical composition of stars.

Stars and other illuminating bodies produce three kinds of spectra depending on their inherent characteristics and those of the transmitting medium. The types are: the continuous spectrum, the emission or bright line spectrum, and the absorption or dark line spectrum.

There exists a relationship between bright line and dark line spectra in that the position of the emission lines of the bright line spectrum corresponds to the positions of the dark lines of the absorption spectrum for the same material.

Stars can be classified by taking into account the similarities and differences in their spectra.

OBJECTIVES

- Given slides of unknown spectra, the student will be able to describe the type--continuous, bright line, or dark line.
- The student will be able to use a simple spectroscope to observe the three types of spectra as evidenced through a pictorial record of his observations.
- The student will be able to estimate the apparent magnitude and color of certain selected stars.
- Shown photographs of the spectra of certain stars, the student will be able to determine their spectral class to within one class.

MATERIALS

Both classroom and planetarium: student-made spectroscopes; worksheet A and colored pencils; non-frosted incandescent bulb; slide projector; rheostat or Variac with calibrations; apparatus for demonstrating relationship between color and temperature. (If only a noncalibrated rheostat or Variac is available, put a paper plate around the knob and mark calibrations degrees on plate using a protractor.)

Classroom only: materials for making spectroscopes, diffraction grating; slides and/or pictures of continuous, dark line, and bright line spectra; materials for student flame tests, including a platinum or wire loop with a handle, alcohol lamp or other heat source, table salt and lithium, copper, and potassium salts; Observer's Handbook. Materials needed for follow-up and evaluation are noted in Procedures.

Planetarium only: Worksheets B, C, and D; pen lights; slide for projecting a thin strip of light; nichrome wire; sheets of colored cellophane or plastic; gas emission tubes for some of the gases shown on Worksheet C and power source; table offering data on 20 brightest stars; opaque projector; D. Van Nystrom spectra chart; slides and/or pictures of stellar spectra; listing, for projection, showing simplified stellar spectral sequence.

Note: All worksheets are shown on pages following this activity; tables for the 20 brightest and 20 nearest stars are in the Appendix; directions for constructing all student- and teacher-made apparatus are in the Appendix; the sources of specific readings, exercises, and audiovisual materials referred to are listed in Suggested Resources at the end of the activity.

PROCEDURES

In the Classroom

1. Provide materials and instructions for students to make their own spectroscopes, perhaps including the diffraction grating. Let students explore how to use the materials and why they work. Emphasize that every spectroscope must have a narrow slit to keep the rays from scattering and to parallel them with the diffraction grating.

2. Illuminate a nonfrosted incandescent bulb and ask students to observe it through their scopes. Using colored pencils, they should record as closely as possible what they see. Since color shading will be difficult to reproduce, they should also describe their observations.

3. Ask students to compare their work with a commercially produced slide or picture of spectra which includes the continuous spectrum. Stress the type of spectrum (continuous). Also discuss other means which permit observation of the continuous spectrum, such as prisms and certain atmospheric conditions.

4. Let students view the incandescent bulb again through the spectroscope, then vary its brilliance with a calibrated rheostat. As one student records the calibrations for each reduction in brilliance, other students should observe through their scopes and record changes in the spectrum. (The spectrum will still be continuous and that of white light, but will appear to fade in the violet, blue, and green end as brilliance is reduced.)

5. When the above data is collected, ask students to plot it on a bar graph, with color along the vertical (red at bottom, violet at top) and with degrees of light drop along the horizontal.

6. Next let students derive the relationship between temperature and color through use of the calibrated rheostat and the apparatus designed for this purpose shown in the Appendix. After they learn to use the equipment, let one student operate it while others observe and record temperature changes as brilliance of the light is reduced by the rheostat settings used in Step 4. After the data is collected, they should use temperature to replace light drop along the horizontal of the bar graph plotted in Step 5, being sure to retain the color as previously plotted.

7. To introduce the relationship between different chemical vapors and colors, let students work in small groups to carry out flame tests with table salt, lithium, copper, and potassium salts. Direct them to dip the wire loop into the salt until it sticks to the wire (dampen the wire a bit first and the salt will stick better), then to place the wire into the top edge of the flame so that the salt burns. They should observe for color and record results. If four students work together, they can take turns manipulating the materials, viewing the flame through a spectroscope, viewing it without optical aid, and recording data.

8. To start developing the concept that stars, including the sun, produce spectra, ask students to use their scopes to view sunlight (looking off to the side of the sun). You might also suggest that they notice on a bright clear day whether they can observe the spectrum by just looking up at the sky--not directly at the sun. At times they should be able to see the spectrum because the sun's light is scattered by the atmosphere.

9. As homework and to give the students a start on planetarium work, distribute Worksheet A and ask them to use a star chart and data tables in the <u>Observer's</u>

Handbook to fill in three columns for the 10 stars listed--the columns for right ascension, declination, and absolute magnitude. Note that the other columns will be used in the planetarium. The students should bring Worksheet A to the planetarium with them.

In the Planetarium

1. Distribute Worksheet B, turn on the stars and coordinate system. Direct students to find each of the 10 stars on the list, using the coordinates they filled in on Worksheet A, and to complete the columns for visual magnitude and visual color on Worksheet B. Offer assistance if needed identifying the stars and use motion as necessary to keep stars visible in the sky.

2. Remind students of the relationships between temperature and color that they observed in the classroom. Now they should observe as you use a piece of nichrome wire electrified through a rheostat and increase the temperature by increasing the electrical current through it. Since students also found in the classroom activity that color was related to temperature, they can next fill in the approximate temperature column of Worksheet B in terms of "hot", "average", and "cool", basing their approximations on visual color of the stars.

3. Turn class attention to Worksheet A, pointing out that students still have no data for the column's absolute magnitude, absolute color, and temperature in degrees K. Light the planetarium stars again and discuss the situation, stressing that visual observation does not reveal precise information. This may lead to the idea that spectral analysis offers precise information.

4. Now review the continuous spectrum, projecting one on the dome. To do so, project a slide containing a slit--or the light from your planetarium pointer--through a prism. (In either case, experiment in advance to get the spectrum where you want it.) Ask students to describe and classify the type of spectrum.

5. Distribute Worksheet C. Then put a 25-watt nonfrosted incandescent light on the rim of the dome. Darken the planetarium and ask students to view the light through their spectroscopes. They should then use colored pencils to record their observations in the area of Worksheet C designated "continuous spectrum." (Keep the bulb in position and use it for comparative purposes in the next two steps.)

6. To introduce dark line spectra, place sheets of cellophane of various colors one at a time in front of another incandescent bulb. For each, ask students to observe the light with their spectroscopes. Discuss observations. When dark bands are identified, have the class record the dark bands in the continuous spectrum drawn in Step 5.

7. To introduce bright line spectra, remind students of the flame tests conducted in the laboratory. Then using the gas emission tubes, but not identifying the contents, ask students to observe through their spectroscopes as you demonstrate. For each sample A through C (you may wish to add more), they should use colored pencils to record in the appropriate sample area of Worksheet C the bright lines observed.

8. Discuss the three types of spectra that have been observed--continuous; dark line or absorption; bright line or emission.

9. Distribute Worksheet D. Ask students to compare their lines on Worksheet C with the spectral lines on Worksheet D and to try to match the bright line spectra they recorded with the known spectra for the elements shown on the new worksheet. Can they identify the gases that were in the emission tubes? A student might point out that Worksheet D shows only dark lines (a limitation of simple printing processes) while his Worksheet C shows bright line spectra. This is true, but explain that the lines are in the same place for the same element or material of the same composition. Verify this by distributing, or showing sections of, the D. Van Nystrom spectra chart. Let students convert Worksheet D to color, showing the continuous spectrum and perhaps using color symbols to indicate bright lines for the samples identified.

10. Return attention to Worksheet B and distribute the data table for the 20 brightest stars. Ask students to check the visual color they entered for Vega and Sirius, for Aldebaran and Arcturus, and for Antares and Betelgeuse against letter designations for these stars under "Spectral Class" on the data sheet. Discuss colors the letter designations may indicate. Then explain that major spectral classifications are designated O, B, A, F, G, K, M in a sequence that indicates both absolute color and absolute temperature since these two properties are directly related. Now show with an opaque projector, or distribute a list, of the major spectral classes, temperature range, and color (omit subclasses).

11. At this point you may find it desirable to repeat Step 6 of the classroom activities to confirm the relationship

between temperature and color. (You might explain, too, that the reason the letter designations for spectral class are not in precise alphabetical order is that the system was set up prior to later discoveries pertaining to this relationship.)

12. Ask students to use the data table and Worksheet B to fill in the "Absolute Color" column of Worksheet A by inserting the letter symbol for spectral class and adding the visual (apparent) color in parentheses. Explain that numbers following the letter symbol indicate subclasses. At the same time, students can insert temperature in degrees Kelvin in the temperature column, using figures on the data sheet.

13. Using commercially available spectra slides of various stars (as those of Tersh Co.), verify the activities in the above step. You might also show on an opaque projector a spectra plate of the stars once published in Sky and Telescope (see Suggested Resources). After each slide or photograph of spectra is shown, discuss the spectral class of the star and point out the star on the dome.

14. In concluding this series of planetarium activities, turn on the stars and turn off all other lights. Ask students to look through their spectroscopes at the brightest star they can see. The students may be disappointed, but they need to remember that the planetarium sky is projected with a man-made light source and that filters give the stars their visual colors. Discuss the problems of using spectroscopy on the planetarium sky.

Follow-Up Activities

1. Ask for some research reports on the use of spectroscopy by today's astronomers.

2. If at all possible, present the spectral classification laboratory exercise noted in Suggested Resources.

3. Ask students to experiment with their spectroscopes in direct observation of nighttime stars and to report results.

4. Arrange a night viewing session in which students can view the stars through a telescope. Cover the telescope objective with a diffraction grating so that students can observe stellar spectra. (For best results, use a diffraction grating with 25,000 lines/square inch. Sheets of diffraction grating needed for this purpose are commercially available from Edmund Scientific Co.)

5. Some students might place a piece of diffraction grating over the lens of a camera and photograph the stars, experimenting with exposure times and types of color film. They should then compare their results with the known spectra of stars. (The students will discover that some film is more sensitive to blues, other film more sensitive to reds.)

6. Ask all students to plot in ink luminosity and temperature for the 20 brightest stars, using the data table and plotting luminosity on the vertical scale and temperature on the horizontal scale. On the same graph, they should plot in another color luminosity and temperature of the 20 nearest stars (data table also in Appendix). They should then compare the sun with the other stars in terms of average, below average, or above average temperature and luminosity.

7. At this point, class work can go directly into study of the H-R diagram and stellar evolution (see next activity in this collection). Concurrently, however, students might enjoy the color investigations which follow.

8. Color Investigations: Suggest reading "What Color Do You Really See?" by Z. V. Harvalik (note Suggested Resources). Propose the following investigations with all results to be explained in terms of wavelengths of the continuous spectrum: (a) view a white sheet of paper, then view it through cellophane of various colors; (b) view marks of various colors on a white sheet of paper as seen through cellophane of various colors; (c) view objects of different colors in different colors of light and under fluorescent and mercury vapor light.

EVALUATION SUGGESTIONS

Give students examples of unknown spectra and ask them to identify the type--continuous, bright line, dark line.

Adapt some of the classroom and planetarium activities for evaluation purposes.

Ask students to match examples of stellar spectra with major spectral classifications, and/or predominate color, approximate temperature.

Use the skill students exhibit in use of a spectroscope as one basis of evaluation.

VOCABULARY

wavelengths, spectral analysis, continuous spectrum, spectra, spectrum, diffraction, absorption spectrum, spectroscopy, spectroscope, diffraction grating, dark line spectra, bright line spectra, stellar spectral classes, emission spectrum

SUGGESTED RESOURCES

Abell, Exploration of the Universe, 1st ed., pp. 156-161 and 366-379; 2nd ed., pp. 202-206 and 406-418. Page 467 has color photograph of the spectra of Pleiades and Hyades.

Bergamini, The Universe, pp. 46-51, 118-121, 180-181.

Huffer, Trinklein, Runge, An Introduction to Astronomy, pp. 245-253.

Investigating the Earth, ESCP, p. 146 and pp. 526-531.

Metcalfe, et al., Modern Chemistry, pp. 344-348.

Trinklein, Huffer, Modern Space Science, pp. 351-366.

Harvalik, Z. V., "What Color Do You Really See?", The Physics Teacher, Sept. 1967. (Reprints available.)

"Spectral Classifications: Laboratory Exercise 2," Laboratory Exercises in Astronomy, Sky Publishing Corp. (Exercise reprinted from Sky and Telescope, Aug. 1964, p. 80.) Exercise offers a spectra plate of the stars.

"The Color Tree," booklet available from Inter-Chemical Corp., 64 W. 44th St., N.Y., N.Y. 10036.

NOTE

See following pages for Worksheets A, B, C, D; see Appendix for data tables on 20 brightest and 20 nearest stars and for details on apparatus and student- and teacher-made equipment used in activity.

WORKSHEET A

NAME	CONSTELLATION	ABSOLUTE MAGNITUDE	SPECTRAL CLASS (COLOR)	R.A.	DEC.	TEMPERATURE (IN DEGREES K)
Vega	Lyra					
Rigel	Orion					
Aldebaran	Taurus					
Arcturus	Boötes					
Sirius	Canis Major					
Antares	Scorpius					
Pollux	Gemini					
Procyon	Canis Major					
Spica	Virgo					
Betelgeuse	Orion					

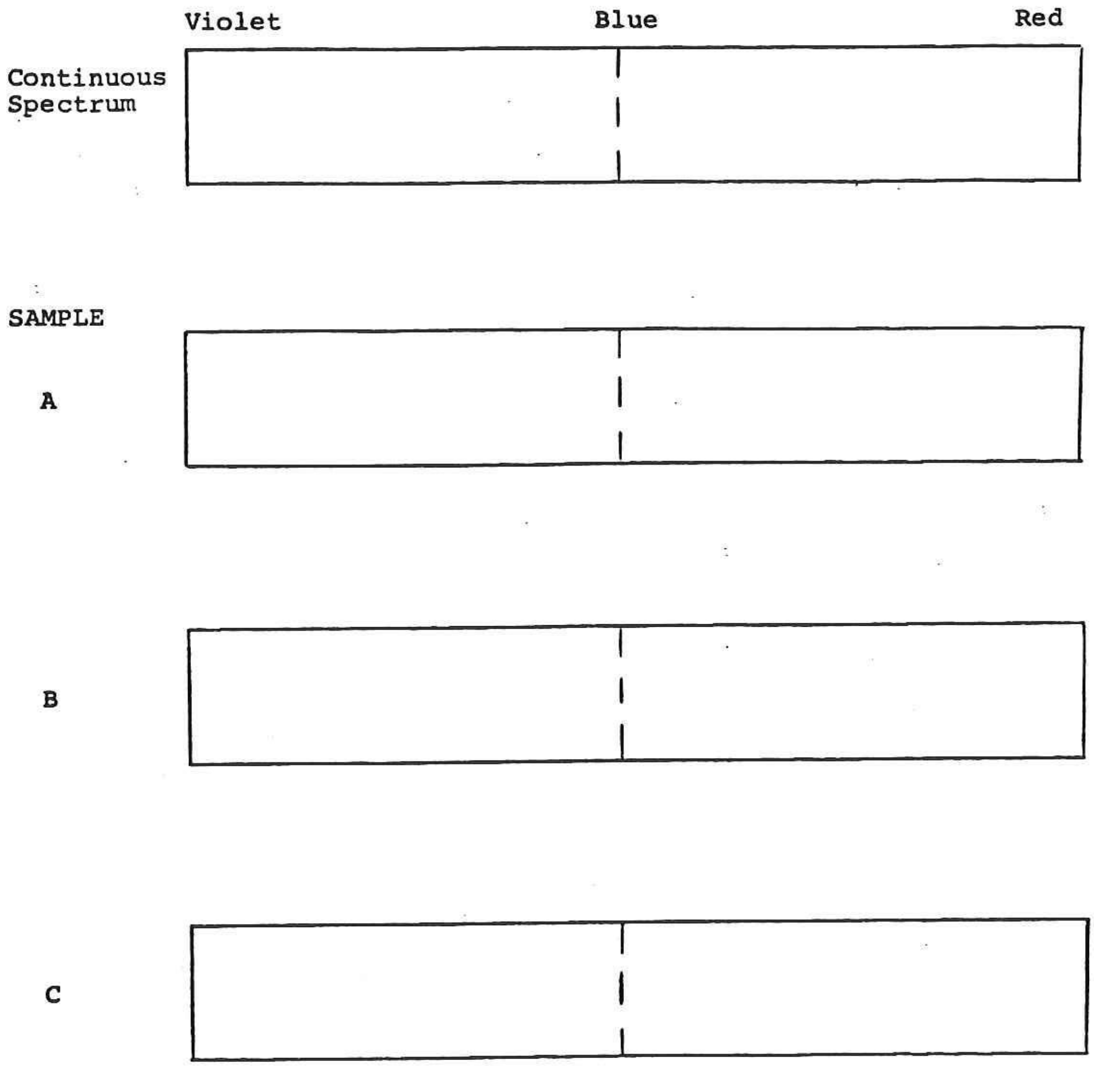
WORKSHEET B

NAME	FOUND IN CONSTELLATION	VISUAL MAGNITUDE*	VISUAL COLOR	APPROXIMATE TEMPERATURE**
Vega	Lyra			
Rigel	Orion			
Aldebaran	Taurus			
Arcturus	Boötes			
Sirius	Canis Major			
Antares	Scorpius			
Pollux	Gemini			
Procyon	Canis Minor			
Spica	Virgo			
Betelgeuse	Orion		Orange-Red	

*Use 1 for the brightest star.

**Indicate in terms of "hot", "average", and "cool".

WORKSHEET C

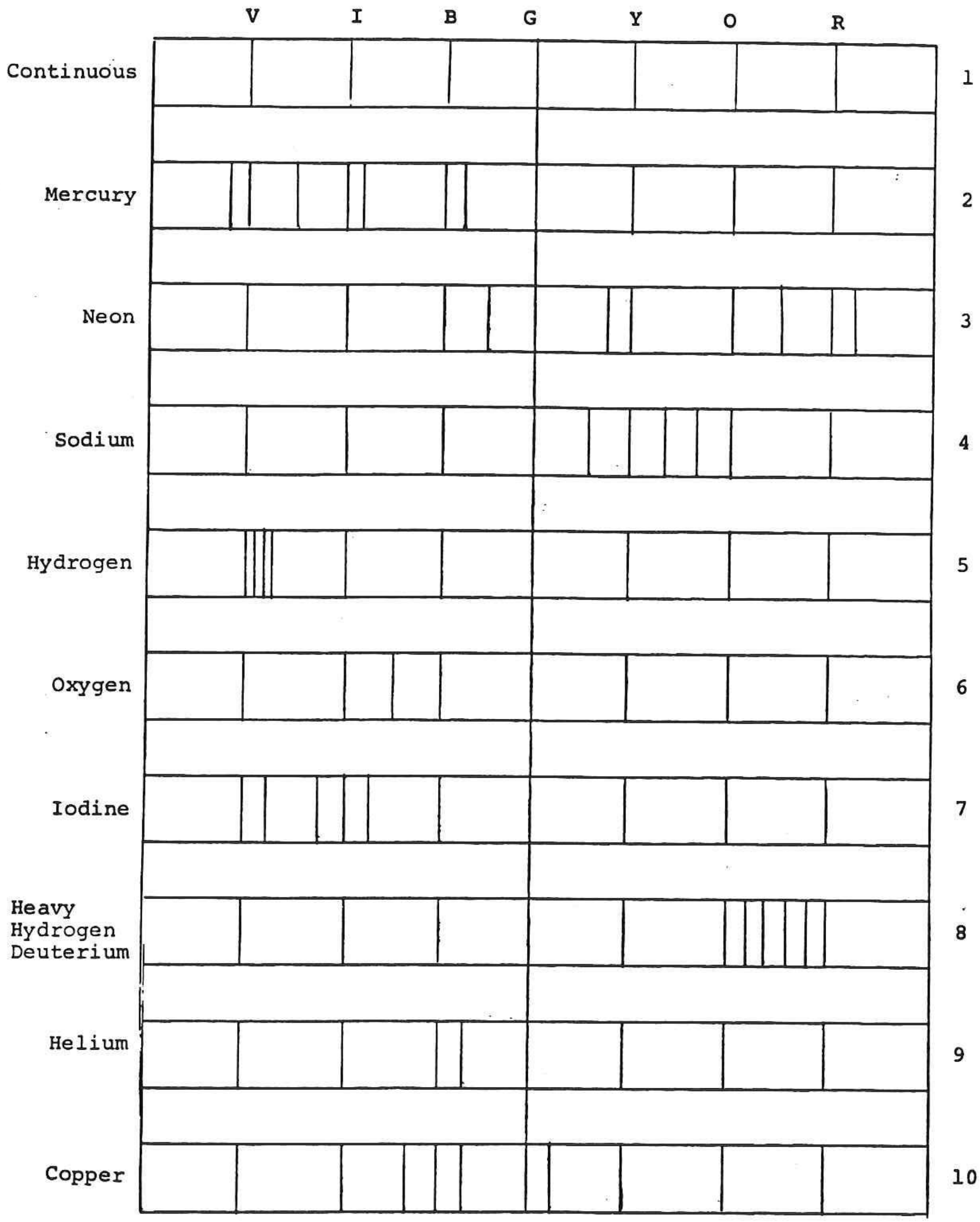


Directions

When asked to do so,

1. Use colored pencils to record continuous spectrum as observed.
2. Record dark lines as observed in space marked "continuous spectrum".
3. Record bright lines in space marked "sample" for each unknown gas.

WORKSHEET D


V
I
B
G
Y
O
R
Continuous
1
Mercury
2
Neon
3
Sodium
4
Hydrogen
5
Oxygen
6
Iodine
7
Heavy Hydrogen Deuterium
8
Helium
9
Copper
10

USING THE H-R DIAGRAM

Stars have been grouped and classified in both random and ordered selection in attempts to understand the relationships of one star to another. Students will investigate the stellar mosaic of the planetarium sky for any relationships or correlations that exist visually. These visual aspects will then be compared with the absolute data of star luminosity, temperature, and spectral classes as obtained by instrumentation and as illustrated in the H-R diagram. The evolution of a star will be simulated in the planetarium--and students will see how the absolute characteristics of stars have revealed the general sequence of stellar evolution.

STUDENT PREPARATION

Grade level: secondary
Content background: familiarity with the relationship of color to stellar temperature, with the various types of spectra--dark line, continuous, bright line--and with the spectra of various chemical elements.

This activity would be especially appropriate for use with Chapters 24 and 25 of <u>Investigating the Earth</u> or with physics or chemistry lessons where the atomic fusion process and applied spectra are being considered. It is recommended as a follow-up to the preceding activity in this collection, "Spectra: Fingerprints of the Stars."

FACTS AND CONCEPTS

Luminosity, temperature, and spectral classes of stars have a direct relationship to each other and to the evolution of a star. The relationship graphed in terms of these units is called the H-R diagram.

The main sequence region of the H-R diagram is where the greatest portion of the lifetime of a star is spent.

When a star changes its temperature and luminosity as a result of consumption of its nuclear fuel, the star will leave its position on the main sequence of the H-R diagram to become a red giant and eventually a white dwarf.

OBJECTIVES

- The student will be able to group the stars into an ordered selection based, first, on visual magnitude (brightness) and visual color; and secondly, on absolute magnitude (luminosity), temperature, and spectral class (color); he will also be able to describe diagrammatically or verbally the evolutionary cycle a star goes through from its birth (nebulae) to its death (black dwarf).

- Given temperature and luminosity data, the student will be able to plot an H-R diagram.

- The student will be able to interpret the H-R diagram in order to classify stars as main sequence, red giant, or white dwarf.

- Observing the evolution of a star as depicted through projection, the student will be able to plot the star's life history on an H-R diagram.

MATERIALS

Classroom: Worksheet A, H-R diagram (see pages following activity); spectra strips made from spectra charts of the chemical elements; hand spectroscopes (or diffraction gratings), ordinary light bulb and fluorescent light tube; materials with which to make and suspend from the ceiling the display described below:

Cut out circles of various sizes and colors from construction paper to depict orders of stars in the H-R diagram. Use colors in the visible spectrum as appropriate to represent temperature and let size of the circles represent luminosity. Diameters ranging from 2 to 16 cm are useful for depicting luminosity from 10^{-3} to 10^{4}. The display should be made and suspended by the teacher before the class session.

Planetarium: per student, two copies of Worksheet B (see pages following activity) and H-R diagram; pencils, colored pencils, pen lights; "evolution of a star" projector. Note: if the last is not available, you can project a series of slides of stars which together represent the changes which occur during stellar evolution.

PROCEDURES

In the Classroom

Upon seeing the ceiling display, students will ask questions. Don't explain it--just ask the students to make an ordered selection of the circles, using any relationships they can find, and to record their selection and its basis.

1. Distribute the spectra strips and ask students to try to order them with reference to lines. Discussion of similarities and differences will provide suggestions: dark lines, bright lines, absence of lines, continuous color.

2. For further review of spectra, distribute the hand spectroscopes and illuminate the ordinary light bulb and fluorescent tube. Call for descriptions and comparisons as students view the spectrum of each. Then ask students to look at the sky, as close to the sun as possible but not directly at it. They should compare that spectrum with the others.

3. Introduce the question: How could spectra assist us in the classification and study of stars? Lead from there into a discussion of how the students ordered the circles suspended from the ceiling.

4. When color and size have been identified as variables in the display, distribute copies of Worksheet A and ask students to put points on the graph to represent each circle. Each student should do the measuring for himself and record results on his own worksheet.

5. Encourage each student to look for a pattern in his own graph.

6. Pass out copies of the H-R diagram and suggest comparisons with the graph. Continue with a discussion of the symbolism

used in ceiling display.

7. Tell students that the H-R diagram will be investigated further in the planetarium when they go there to learn about life history of the stars.

In the Planetarium

1. Preset planetarium sky for midwinter. Ask students to plot on copies of Worksheet B the apparent visual order of the following stars by color and brightness as you point them out: Capella, Rigel, Procyon, Betelgeuse, Aldebaran.

2. Pointing to the same stars again and giving for each its absolute brightness and color (spectra class), ask students to replot each star on a second copy of Worksheet B. (Note: You'll find a table giving temperature, luminosity, and other data for the 20 brightest stars in the Appendix.)

3. Students now should overlay the two copies of Worksheet B to compare the visual plot and the absolute plot for each star. They then should consider possible reasons for the differences, which can be arrived at by deduction.

4. Activate the "evolution of a star" projector lamp (but not the iris) and/or color wheel motor. Ask the class to discuss and classify changes observed according to the H-R diagram.

5. Ask students to plot on the H-R diagram the changes of a star during its life history as you proceed through the entire evolution of a star from the main sequence to dwarf stage. They should plot with colored pencils to represent changes in color.

6. Point to several bright stars and give data for them. Ask students to locate the stars in the planetarium sky and to discuss their respective positions on the H-R diagram.

Follow-Up Activities

1. As homework, assign a night sky observation, asking students to plot the apparent order of 20 or more stars by color and brightness on a copy of Worksheet B. They should label the plots of known stars by name.

2. Ask some students to make a comparative study showing relationships between the spectra of various stars and flame tests for chemical elements. Note: directions for flame tests are given in the preceding activity, titled "Spectra: Fingerprints of the Stars."

3. Assign to other students various first and second magnitude stars, with the request that they locate them in terms of where the star is in its evolutionary cycle (red giant, white dwarf, etc.)

4. Expand discussion of stellar evolution by researching information on variable stars, novae, supernovae, pulsars, black holes.

EVALUATION SUGGESTIONS

The diagrams students made in the planetarium will provide excellent basis for evaluation.

Any written test covering the activity should require interpretation of an H-R diagram or flow-chart on stellar evolution. To demonstrate interpretation, students could be asked to fill in missing parts of the diagram or flow-chart.

VOCABULARY

apparent magnitude
absolute magnitude
spectra
brightness
luminosity
H-R diagram
stellar evolution
nebulae
white dwarf
red giant
black dwarf
main sequence
(names of stars emphasized in the activity)

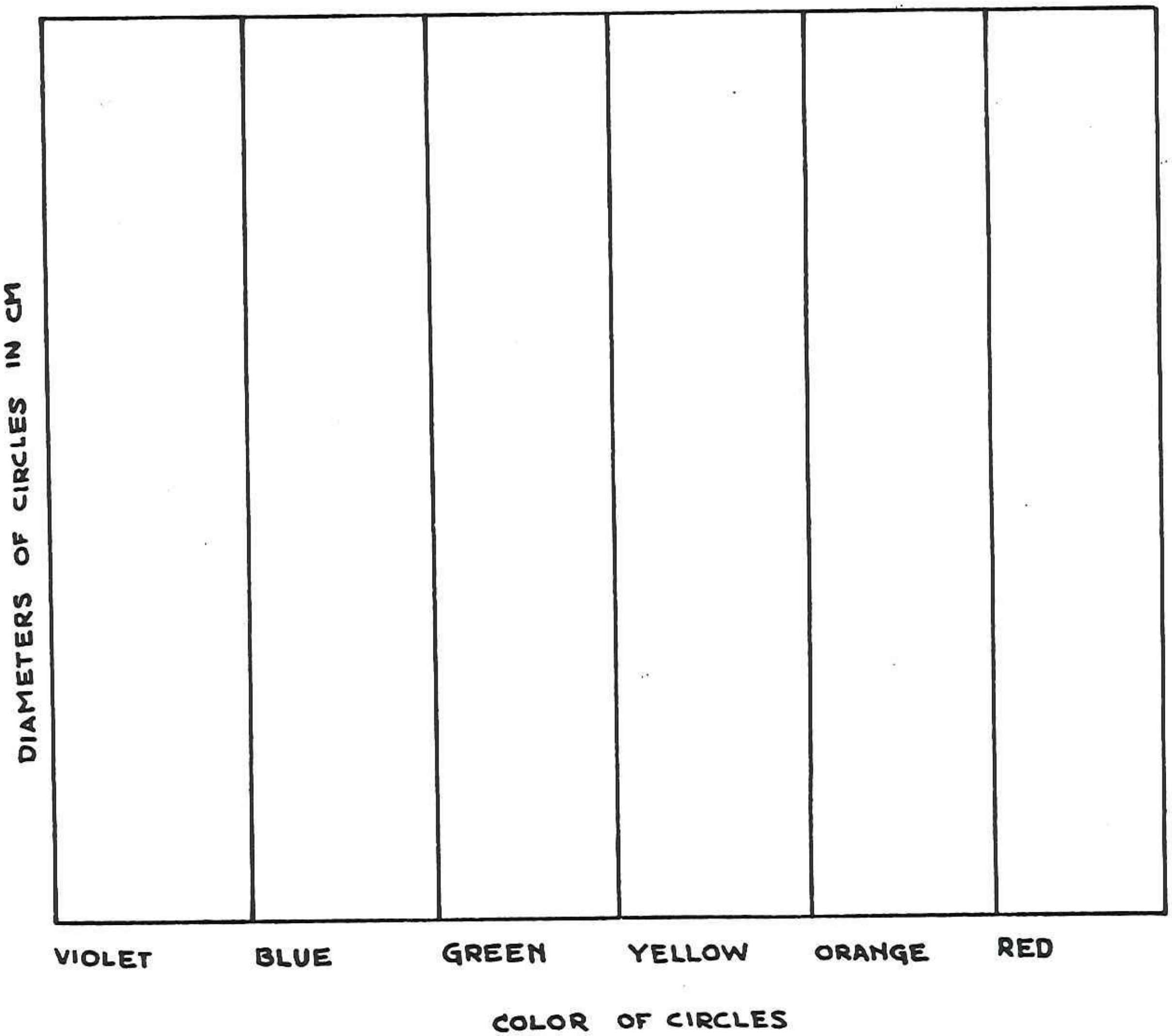
SUGGESTED RESOURCES

Abell, Exploration of the Universe, 2nd Edition, pp. 537-593.
Taylor, The New Physics, pp. 238-258.
Wyatt, Principles of Astronomy, pp. 325-327, 354-355.
Investigating the Earth, ESCP, pp. 529-543.

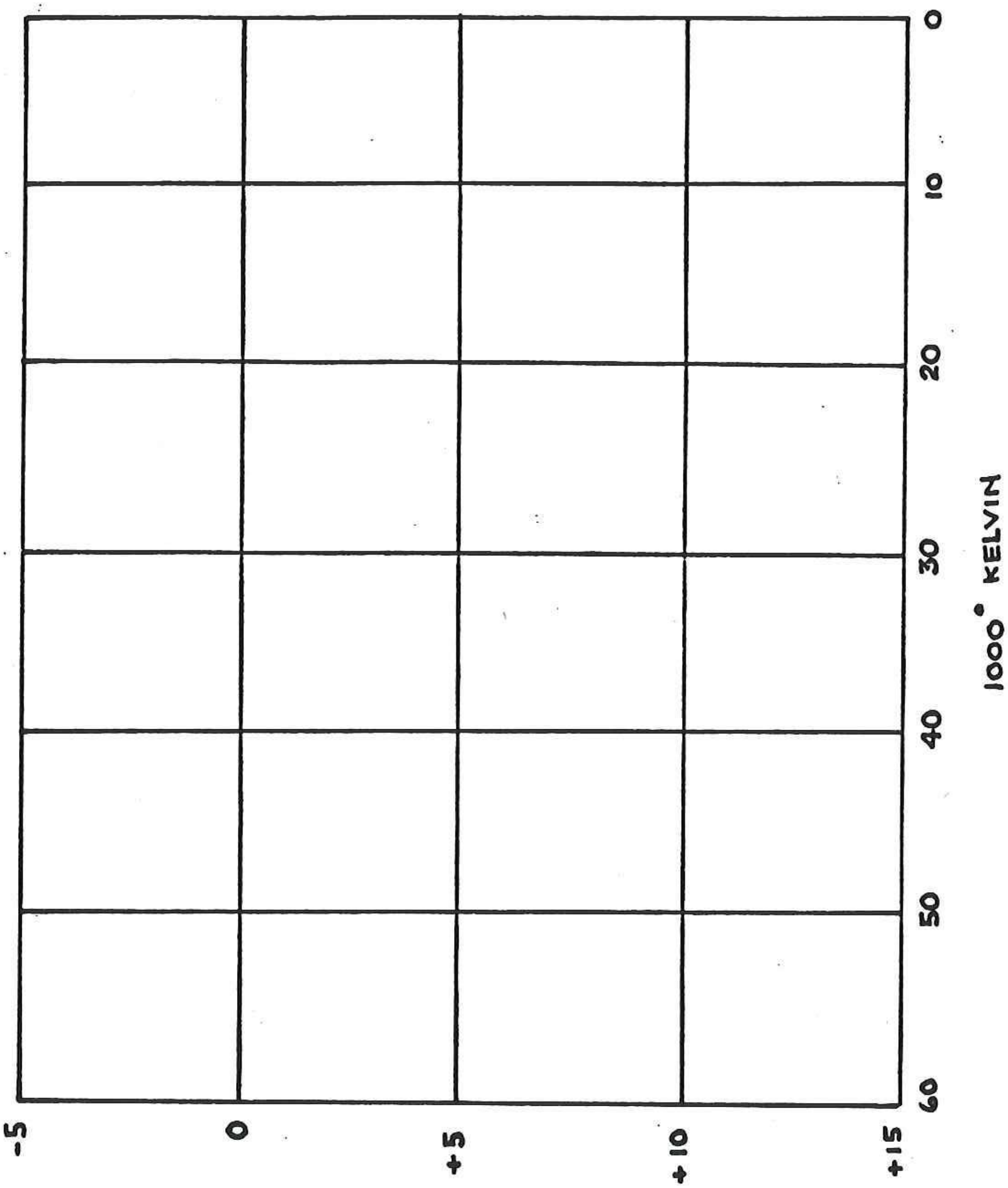
NOTE

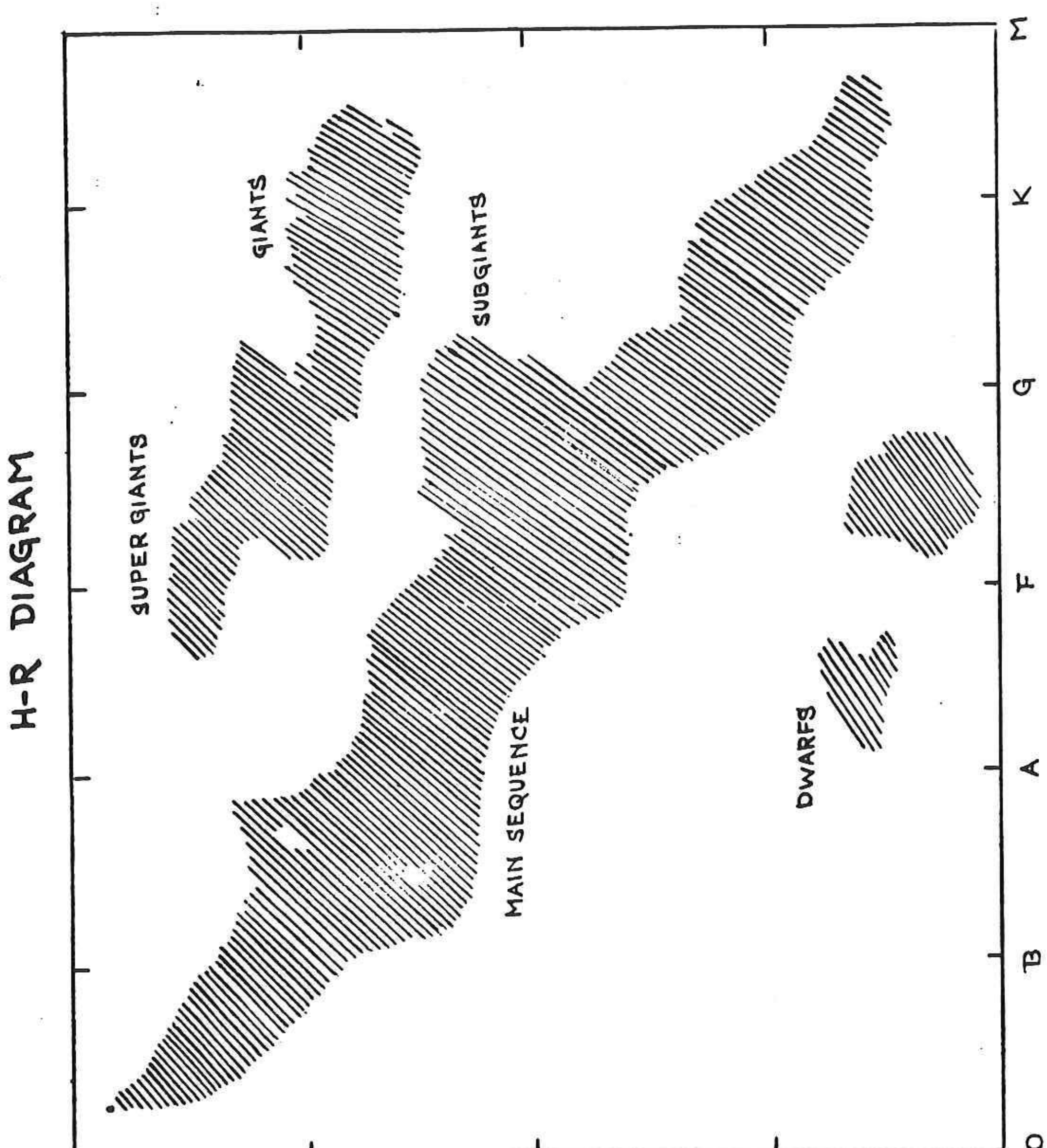
See following pages for Worksheets A and B and H-R diagram. The two worksheets and the H-R diagram have been designed so that they may be overlaid for comparative purposes (use light-weight paper in reproducing). For table giving data on the 20 brightest stars, see Appendix.

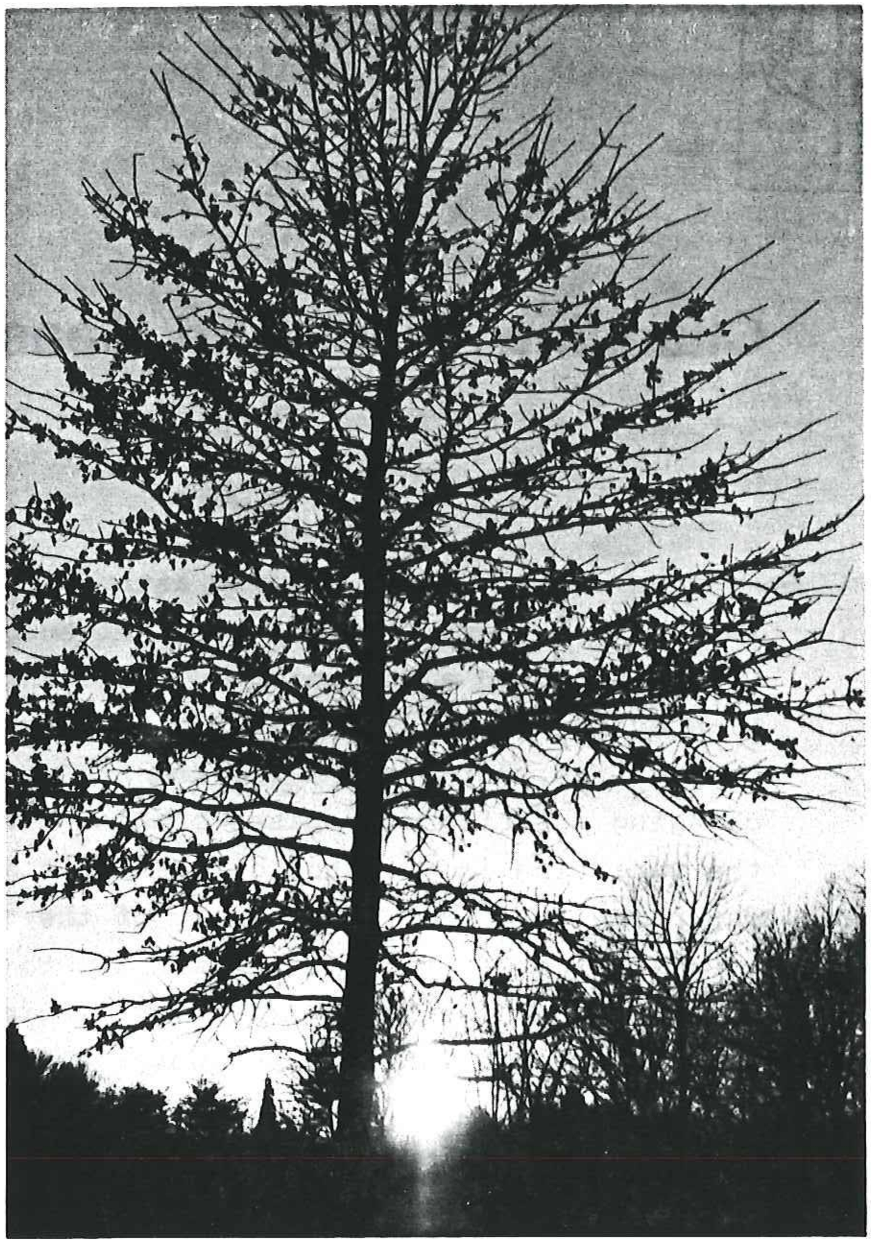
WORKSHEET A


DIAMETERS OF CIRCLES IN CM
VIOLET
BLUE
GREEN
YELLOW
ORANGE
RED
COLOR OF CIRCLES

WORKSHEET B

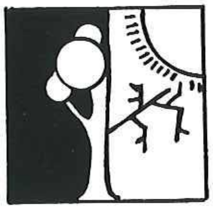



H-R DIAGRAM
SUPER GIANTS
GIANTS
SUBGIANTS
MAIN SEQUENCE
DWARFS
-5
0
+5
+10
+15
O
B
A
F
G
K
M



FOR HE IT WAS WHO SCATTERED O'ER THE SKY
THE SHINING STARS, AND FIXED THEM WHERE THEY ARE-
PROVIDED CONSTELLATIONS THROUGH THE YEAR,
TO MARK THE SEASONS IN THEIR CHANGELESS COURSE.

- Aratus



Changing Time and Seasons

No other area of ancient astronomy was more important to early man than that of seasons and time. Nature provided a convenient way for man to measure time by using celestial objects. The rising and setting of the sun dictated day and night. The moon's changing position and phases ordered the month. And the variation in altitude of the sun's path in the sky determined the year as a result of the cycle of seasons.

To exist on this earth, man had to fit his daily habits into these natural periods of time--his farming, his hunting, his animal husbandry. All of these things were (and most still are) essential to his life, and all involved a time factor.

These activities dealing with time and seasons explore the basic causes and effects which the earth's rotation and revolution produce. By investigating the early methods of timekeeping, the student will gain an understanding of our present system of time zones and the reasons we need a uniform scale worldwide. An extension of the study of time will lead into activities related to the seasonal periods the earth experiences and the effect of the sun on our environment.

DETERMINING A.M. AND P.M.

Through the ages, the sun has been one of the controlling factors in the cultural and intellectual development of mankind. Its presence or absence in the sky governed the daily life of early man--his working, his eating, his sleeping--to the extent that he regarded it as a powerful deity. Today the sun still remains our timekeeper.

As children view the movements of the planetarium sun, they will see how the sun determines the basic divisions of the day and, generally, the time.

STUDENT PREPARATION

Grade level: elementary
Content background: ability to tell time; understanding of cardinal points; knowledge of earth's rotation; (preferably) prior familiarity with clock arithmetic.

FACTS AND CONCEPTS

The terms a.m. and p.m. are time designations derived from the sun's apparent positions east or west of the local meridian.

The sun appears to move east to west across the sky due to the earth's rotation.

The local meridian is an imaginary line running from the north point through the zenith to the south point for any observer's horizon.

OBJECTIVES

The student will be able to describe verbally, or through demonstration or drawings, the sun's apparent daily path across the sky and will be able to relate this path to the local time and meridian.

The student will be able to define a.m. and p.m. in terms of the sun.

The student will be able to identify the general time of day with respect to the sun's apparent position in the sky.

MATERIALS

Classroom: sticks to use as gnomons; materials for making clock dials that may be used in planetarium--preferably, black cardboard, white or luminous paint, white construction paper for clock hands, brad (see clock pattern at end of activity).

Planetarium: clock dials made in classroom; paper, pencils, pen lights; auxiliary projector and slides which simply say:

A.M.	P.M.
ANTE MERIDIAN	POST MERIDIAN

PROCEDURES

In the Classroom

1. Check on the children's understanding of cardinal points.

2. Take the children outside where they can point out where the sun rises and then let them determine other directions from this general reference point.

3. While outside, have a stick placed in the ground and ask children to determine the length and direction of its shadow. The stick should be left there until at least the same time the next day. In the meantime the length and direction of the shadow should be determined and recorded at least once at noon, once as late as possible in the afternoon, once as early as possible in the morning. The class should discuss the data--and the relationship of the location of the sun to the direction and length of the shadow. Also discuss what causes the sun to seem to move (Earth's rotation).

4. Ask each student to construct a cardboard clock dial according to instructions (see page following activity).

Discuss when a day officially starts (12 midnight) and the number of hours in a full day. Also review clock arithmetic ("If you come to school at 9 o'clock and go home at 3:00, how many hours are you in school?")

5. Collect the pupils' clocks, telling the children that they will be needed during the planetarium visit.

In the Planetarium

1. Set the planetarium for the latitude of the observer for early morning on the first day of spring. As the stars fade out, let the sun rise and ask students to determine cardinal points.

2. Ask, as the sun rises, whether it is morning or afternoon in the planetarium.

3. Continue slowly with daily motion, stopping at intervals and asking the same question until planetarium time approaches 11 a.m. Then turn on the meridian.

4. Explain the meridian as the local meridian, an imaginary north-south line that runs through the point directly overhead of the observer--that is, through the observer's zenith.

5. Project the a.m. slide on the SE portion of the dome and explain the meaning of a.m.--"ante (before) meridian."

6. Continue daily motion, stop on the meridian, and ask what time it is now.

7. Proceed with daily motion, stopping about 2 p.m. to ask, "Now what part of the day is it? [Afternoon] Why?" Then project the p.m. slide on the SW portion of the dome and explain the meaning of p.m.--"post (after) meridian."

8. After continuing with daily motion, ask pupils where the sun will set. Confirm their predictions by completing the planetarium day.

9. Briefly return the sun to the noon position and let the children determine whether that position is a.m., p.m., or neither. Discuss.

10. Distribute the clock dials made in the classroom to pupils who made them. Now place the sun at sunrise and ask children to set their clocks (time to depend on time of sunrise, date of planetarium visit).

11. Use daily motion and stop every hour so that children may move the hands of their clocks to correspond with the sun. After discussion at "noon," continue in the same way until sunset.

12. At sunset, ask each pupil to determine (by counting or computation) the number of hours of daylight that day. Then they should predict (by counting or computation) the number of hours of darkness on the forthcoming night. Children should turn in their papers.

13. In concluding planetarium activities, discuss again what makes the sun seem to move across the sky.

Follow-Up Activities

1. Further outdoor activities are in order. Let children relate the position of the sun to a.m. and p.m. and to the time. They should also relate the length and direction of shadows to the time of day.

2. The children can check the time of sunrise and sunset from observations and determine the number of hours of daylight and darkness.

3. If children wish, let them make a drawing of the position of the sun with the respect to their activities at various times of day.

EVALUATION SUGGESTIONS

Children's determination of the hours of daylight and darkness at the end of the planetarium visit will serve as one means of evaluation.

Ask children to describe verbally or through demonstration the apparent path of the sun through the sky.

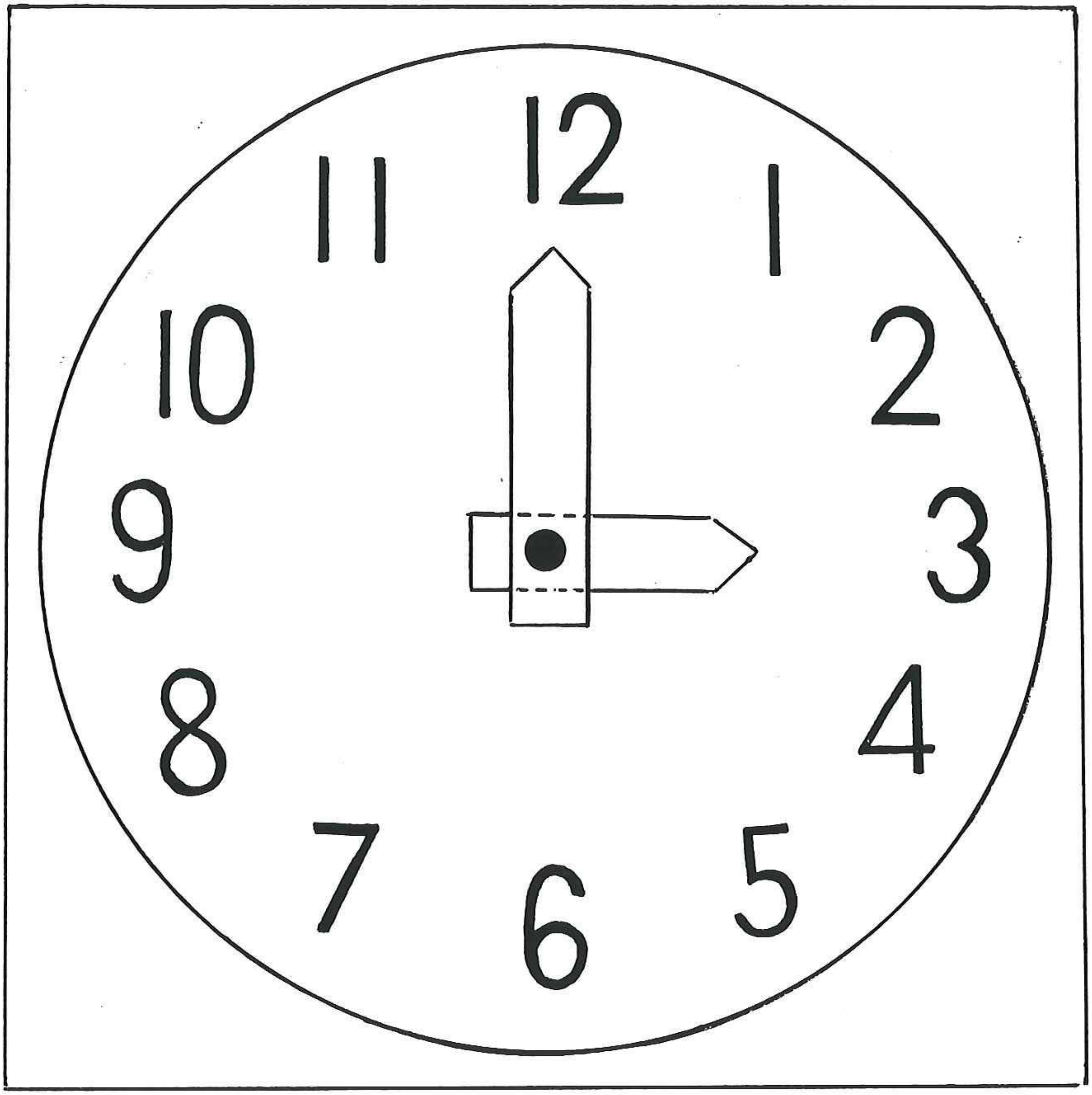
The pupils may be asked to make a diagram illustrating a.m. and p.m. with respect to their observations of the sun's daily motions.

VOCABULARY

a.m.		p.m.
ante meridian	noon	post meridian
meridian	zenith	horizon

SUGGESTED RESOURCES
Bendick, The First Book of Time, pp. 26-29.
Tannenbaum, Stillman, Understanding Time, pp. 110-111.

NOTE See pattern for clock dial on following page.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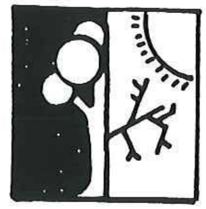


LET'S MEASURE TIME

By using the heavens to keep track of time, prehistoric man set a pattern that fit in with later efforts to record historical and scientific observations.

To record meaningful scientific data, accurate time units had to be established and standardized. One or more naturally occurring, easily observable, cyclic phenomena were needed; periodic motions of heavenly bodies--sun, moon, and stars--served this purpose.

In this activity, students will explore the idea of "time"--what it is, how it can be measured--as they examine the motions of the planetarium sun and moon and consider how their counterparts in the sky have given us three of our basic time units.

STUDENT PREPARATION	Grade level: elementary Content background: familiarity with rotation, revolution; basic mathematics skills--addition, subtraction; prior experiences with clock arithmetic.
FACTS AND CONCEPTS	Time is the interval between two successive events. The apparent cyclic movements of celestial bodies may be used to establish intervals of time. Such cyclic movements include those of the moon, sun, stars, and planets.
OBJECTIVES	The student will be able to suggest a definition for the word "time" from observations of periodic motions. The student will be able to suggest different methods or instruments to measure time.

Students will be able to recognize and list units of time.

MATERIALS

Classroom: for follow-up activities--pendulum, metronome, record player, stop watch, photoelectric timer, other devices for establishing time intervals.

Planetarium: strobe light or equivalent.

PROCEDURES

In the Classroom

1. Ask students to put their heads down on their desks and, when they feel that one minute has elapsed, to raise their hands. Keep a record of the time when hands are raised. Discuss differences in students' estimates of "one minute."

2. Continue by asking how the children made their estimates. (By counting? How else might they have made an estimate? (By tapping finger? Blinking eyes? By counting pulse beat?) Ask what students were measuring with these motions. (Emphasize that they were measuring the time interval between when a minute started and a minute stopped.)

3. Tell the students that they will investigate time more deeply in the planetarium and that in the meantime, they might continue to consider what time is.

4. If the children need practice solving problems involving addition and subtraction in clock arithmetic, it should be provided.

In the Planetarium

1. You can introduce the idea of time units by asking "What time is it?" The answer will probably imply a unit, which you can point out.

2. In the lighted planetarium, turn on the strobe light at set frequency, asking students to observe and estimate the time interval for 10 flashes.

3. In the darkened planetarium, turn on the strobe light at the same set frequency. Again students should estimate the time interval for 10 flashes.

4. Pose the question: "How can we determine if the time intervals were the same?" Try out some of the ideas suggested (perhaps students will count, record pulse, make some kind of "periodic motion). If and when you wish, point out that the intervals for the 10 flashes, and between the flashes, were the same in both instances.

5. Discussion will bring out the need for a precise way to measure time--for an observable, periodically recurring, or cyclic, motion or other phenomenon that may be used to establish a time unit. Let students set up desirable criteria.

6. Continue into the usefulness of the apparent motions of heavenly bodies for establishing time units by showing three periodic celestial motions used for measuring time (show each long enough to demonstrate the recurring cycle):

   a. Apparent daily motion of the sun--the basis of our day. Discuss the cycle, the unit, the subunits.

   b. Phasing of the moon--the historic basis of the month. Run annual motion through one month, discuss the cycle, but hold further discussion until later. (Use daily motion as necessary to keep the moon in the visible sky.)

   c. Apparent annual motion of the sun--the basis of the year. Discuss the cycle, the unit, the subunits.

7. Students should now determine the interrelationships of the three cyclic motions. In the discussion, it will be brought out that the lunar cycle is out of phase with the cycles of the sun (lunar and solar calendars may be investigated and compared during follow-up activities).

8. In conclusion, ask students to distinguish between

the actual motions and apparent motions depicted in the planetarium sky.

Follow-Up Activities

1. Return to the discussion of the question "What is time?" and let students propose definitions.

2. List on the board all time units students can think of and discuss the basis or bases of each one (cyclic celestial motions or other). Some units, as week, may need to be checked through reading.

3. Offer such materials as a pendulum, metronome, stop watch, record player, and suggest that students determine ways to measure small units of time. Let students suggest and construct other devices for measuring small units; let them investigate also the use of a sundial and shadow stick.

4. It can be brought out that for man's convenience, it would be best if the largest unit of time were equally divisible by all of the smaller units--a convenience that the lunar/solar cycles do not offer and that the two solar cycles miss by a small fraction. This discussion will lead naturally into class or individual study of the problems involved in calendar construction--and various calendars, past and present.

EVALUATION SUGGESTIONS

Ask students to write a definition of time.

Have students explain the relationship between our customary units of time (second, minute, hour, day, etc.) and the periodic motion each is based on.

Give students a list of our customary units of time and ask them to compute equivalents in smaller or larger units.

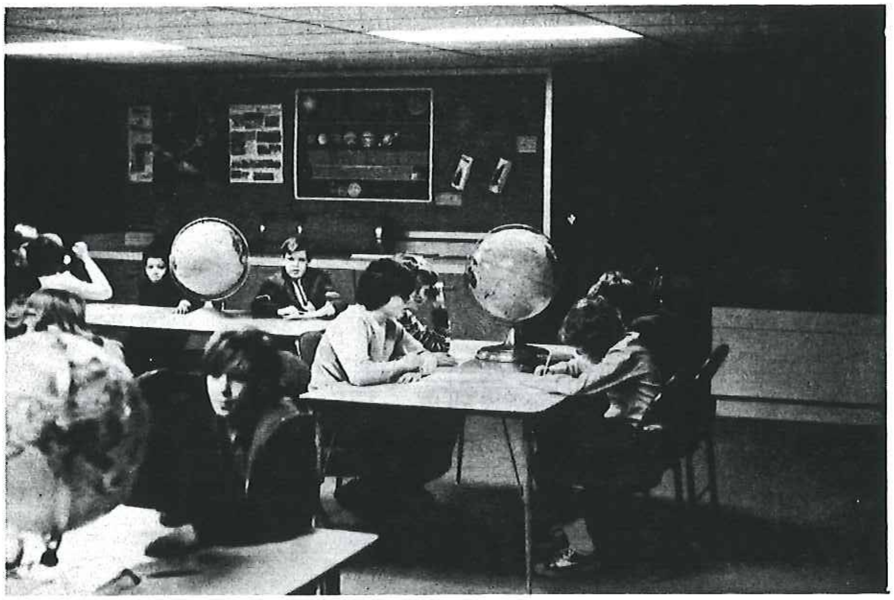
The follow-up activities also may be used as a basis for evaluation.

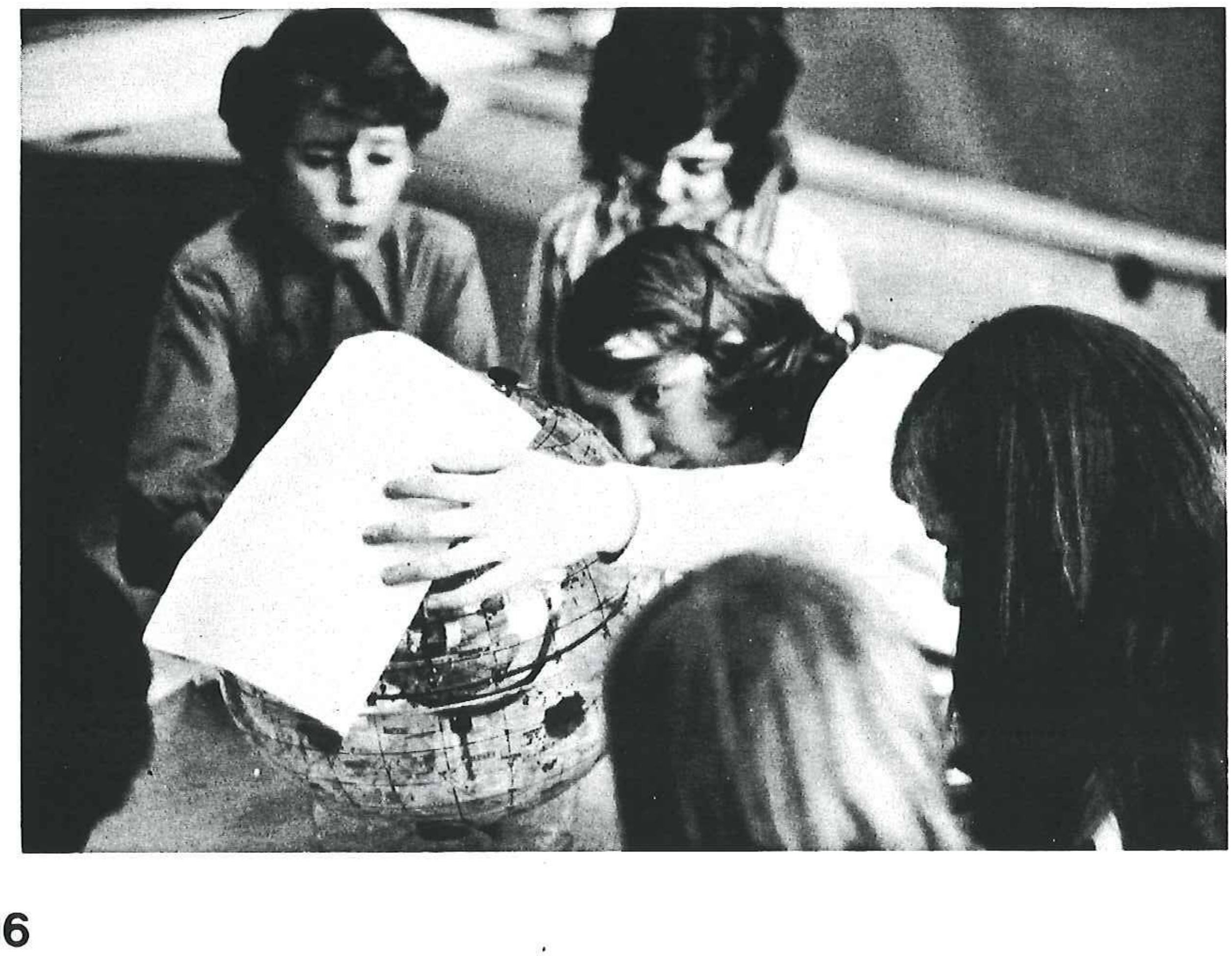
VOCABULARY

interval	time unit	period
	cyclic	
apparent motion		actual motion
	out of phase	

SUGGESTED RESOURCES

Bell,Thelma,The Riddle of Time, pp. 11-26.
Harrison, Sun, Earth, Time, and Man, pp. 1-21.
Keedy, Jameson, Johnson, Exploring Modern Mathematics, pp. 13-31.





LOCATING THE TROPIC PARALLELS

All world maps show lines to represent the tropics of Capricorn and Cancer. From the proximity of the lines to the equator, and because they represent the boundaries of the so-called "torrid zone," students usually associate "tropic" with "hot," but originally the word had no such meaning.

Students will learn that the tropics are parallels which mark the "turning" of the sun in its annual journey around the earth as seen by man. In the planetarium, they will compare the earthbound view of the sun's diurnal paths on the solstices with space-bound views of the same phenomena as represented by a spot of light shining on a slowly rotating glob.

STUDENT PREPARATION	Grade level: elementary Content background: familiarity with rotation, revolution, inclination of the earth's axis; working knowledge of measurement of latitude in degrees; (preferably) prior lessons on causes of the seasons.
FACTS AND CONCEPTS	The daily rotation of the earth makes the sun appear to move across the sky each day. Because of the inclination of Earth's equator to its plane of orbit, the diurnal path of the sun varies from day to day through the year. The diurnal paths of the sun at their southern and northern extremes determine the tropics of Capricorn and Cancer.

OBJECTIVES

Using an earth-sun model, a student will be able to demonstrate the locations of the tropic parallels and explain what determines them.

Given suitable materials for measuring degrees and the inclination of the axis of any planet in the solar system, a student will be able to draw the planet's southern and northern tropics on a diagram or model of the planet.

MATERIALS

Classroom: earth globe; orrery or other aid for demonstrating earth rotation and revolution; for follow-up activities and evaluation--point light source, styrofoam spheres and other materials which students can use for planet-sun models; materials for measuring degrees of latitude.

Planetarium: geocentric earth projector; chalk globe and chalk; slide projector and slide for projecting point of light; materials to measure degrees on chalk globe.

PROCEDURES

In the Classroom

1. Review with the class rotation, revolution, and the tilt of the earth's axis.

2. Reinforce the idea that an extension of the earth's axis at the north pole points toward the North Star.

3. Discuss latitude and longitude and their measurement in degrees, referring to lines designating latitude on maps and globes as parallels. Let students locate the tropic parallels of Capricorn and Cancer on a world map and check, through measurement, the distance of the tropics in degrees from the equator.

In the Planetarium

1. Set the sun for local noon, vernal equinox. Place a chalk globe on the rim of the planetarium chamber, orienting it so that its axis, tilted 23½°, points in the direction of an imagined North Star. Using a slide projector (positioned at center of room) and slide, project a small point of light on the equator at the vernal equinox to simulate the direct rays of the sun.

2. Discuss with the group the representations on the planetarium dome and on the chalk globe: students have a view on the planetarium dome of the sun on the vernal equinox as seen from Earth; on the chalk globe they have the same view as seen from space.

3. Turn on the geocentric earth projector, letting students find home location. Keeping the sun stationary on the dome, slowly go through one daily rotation with the geocentric earth. Ask: What appears to happen to the sun? What path would it appear to take from Earth?

4. Now have one student hold the globe so that its north axis continues to point to the imagined North Star and so that the beam from the slide projector is still perpendicular to the equator. Another student should hold a piece of chalk loosely over the dot of "sunlight," while a third student slowly rotates the globe, not disturbing its orientation. If the globe and chalk are held carefully, the chalk should inscribe a circle around the earth. Let students identify the circle--it is the equator.

5. Reset the planetarium sun for the summer solstice; ask a student to move the chalk globe 90° counter-clockwise around the rim of the planetarium dome, keeping the globe's orientation. Adjust the projector to light up a point 23½° above the equator. Discuss change of planetarium and globe setting--including the earth motion represented in the 90° movement of the globe. Slowly rotate the geocentric earth again, asking students to observe the daily path of the sun. Then repeat the chalk globe procedure previously described. Discuss the diurnal path of the sun as observed on the planetarium dome as our view of the sun's path on the <u>summer solstice</u>; discuss the line inscribed 23½° above the equator on the chalk globe as the <u>tropic of Cancer</u>. (Let students use a string to measure in degrees its distance from the equator.)

6. Reset planetarium sun to autumnal equinox, have the chalk globe moved another 90° counterclockwise, and repeat procedures with the geocentric earth and chalk globe as carried out for the vernal equinox.

7. Reset the planetarium sun for the winter solstice. Have the chalk globe moved 90° counterclockwise as before, resetting the projector to light up a point 23½° below the equator. Repeat procedures with the geocentric earth and chalk globe, discussing the sun's path as observed on the planetarium dome as the <u>winter solstice</u> and the line inscribed on the chalk globe as

the tropic of Capricorn. Again measure the distance of the tropic parallel from the equator.

8. Discuss observations with the group and ask students to explain the relationship of the two tropics to the tilt of the earth's axis.

Follow-Up Activities

1. Ask students to find out why the parallels at $23\frac{1}{2}°$ above and below the equator are called tropics. (They will find a brief etymology in any standard dictionary.)

2. Students should investigate why the proper names for the tropics are Cancer and Capricorn--and why the names were more appropriate once than now. (Further activities may lead into a study of precession--if so, you may wish to adapt the activity on precession in this publication.)

EVALUATION SUGGESTIONS

Ask students to use an earth-sun model to explain the relationship of the southern and northern extremes of the diurnal path of the sun to the inclination of the earth's axis.

Providing the materials needed, ask students to locate and draw the equator and tropics.

Providing the materials needed and giving students the inclination of another planet, ask them to locate and draw the planet's equator and tropic parallels.

VOCABULARY

parallel
equator tropic
rotation axis revolution
tropic of Capricorn tropic of Cancer
solstice latitude
equinox

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 100-105.
Jacobson, Lauby, Konicek, The Sun, Seasons, and Climate, pp. 86-90.
Wyatt, Principles of Astronomy, pp. 52-56.

SUNRISE, SUNSET AND THE SEASONS

Does the sun always rise due east? Does it always set due west? Most students are unsure of the facts and many of them have misconceptions.

Students will observe, measure, and interpret the apparent positions of the sun at sunrise, noon, and sunset on four key days of the year. In one planetarium session, the students can collect data that will permit them to evaluate quantitatively the annual changes in the sun's position and to examine the significance of these changes in relation to seasons.

STUDENT PREPARATION

Grade level: secondary
Content background: basic understanding of rotation, revolution, inclination of the earth's axis; working knowledge of longitude and latitude and of the measurement of altitude and azimuth in degrees.

FACTS AND CONCEPTS

The earth's equator and the earth's orbit are not in the same plane. The difference between these planes is the same as the inclination of the earth's axis--about 23.5°.

Both the inclination of the earth's axis and revolution bring about the seasons; neither could bring about the seasons alone.

OBJECTIVES

- The student will be able to explain or demonstrate why the earth has seasons.
- The student will be able to compare the seasons in the northern and southern hemispheres.

- The student will be able to differentiate between the vernal equinox, the summer solstice, the autumnal equinox, and the winter solstice.

- The student will be able to give the approximate date of the first day of each season.

- The student will be able to plot on a celestial globe the apparent path of the sun on the first day of each season.

- The student will be able to compare the relative number of hours that the sun is visible on the first day of each season.

MATERIALS Classroom: earth globe, light source, celestial globe; for Follow-Up Activities--small clear plastic spheres and marking pencils, shadow stick.

Planetarium: degree markings around base of dome; Sunset/Sunrise Observation Data Sheet (see end of activity); ecliptic projector (optional); pencils, pen lights, sections of string.

PROCEDURES <u>In the Classroom</u>

1. Use an earth globe and light source to review basic ideas about rotation, revolution, and inclination of the earth's axis.

2. Discuss measurement of earth in degrees of longitude and latitude, and the measurement of altitude and azimuth in degrees.

3. Ask students for observations on the location of the sun as it rises and sets. If disagreements ensue, tell the class that they will be settled in the planetarium.

<u>In the Planetarium</u>

Setting: Place sun on vernal equinox for sunrise, local latitude.

1. After orienting students to cardinal points, distribute Sunrise/Sunset

Observation Data Sheets and other working materials. Tell students that the sheets will be used to record observations of the path of the sun through the sky on four days of the year. They will put a dot at the sunrise, noon, and sunset positions; then they will connect the three dots with a smooth curve.

2. Turn on the sun and meridian, announcing the date March 21. Ask students to note the degree markings around the base of the planetarium dome. Let them plot sunrise and check to be sure they understand how to transfer positions on the planetarium dome to the graphic representations. To record azimuth on the graph, they should mark a string in the units shown at the bottom of the worksheet and use the string to measure arcs. (For noon position, they may read altitude from the meridian.) After procedures are clear, use daily motion, stopping at noon and at sunset for further measuring and recording.

3. In turn, show diurnal motion on the summer solstice, autumnal equinox, and winter solstice--announcing each date and stopping the sun at sunrise, noon, and sunset so that students may collect data.

4. After the plotting is completed the following questions might be discussed:

   a. Did the sun move through the sky the same way each day?

   b. Did the sun always rise due east and set due west?

   c. Did the sun reach the same altitude each noon?

   d. Was the sun in the sky for the same length of time each day? (Let students determine from measuring diurnal paths plotted on graphs.)

   e. What causes these differences?

   f. Would these differences occur if the earth were not tilted? Would these differences occur if the earth did not revolve around the sun?

   g. How would the changes you observed in the sun's position bring about seasons on earth?

5. Discuss how the sun's path would appear to an observer at the north pole and equator. If time,

show the apparent paths of the sun from these latitudes on days of an equinox and the solstices so that students may compare local views with views from these places.

Follow-Up Activities

1. Ask students to transfer the data from the Observation Data Sheet completed in the planetarium to clear plastic globes.

2. Suggest that students experiment with a shadow stick.

3. Discuss such questions as: How would the sun's apparent path on the first day of each season differ if the axis of the earth were tilted more? If it were tilted less? How would these changes affect the seasons? If the earth revolved faster or slower would this affect the seasons?

4. Suggest that students prepare a "Fact Sheet" on the seasons. They should be able to assemble, for themselves, most of the facts listed on the Fact Sheets presented as an example at the end of this activity. (Certain facts on the sheets are necessarily filled in locally--blanks have been left.)

EVALUATION SUGGESTIONS

Ask students to describe in writing and in diagram the causes of the seasons.

You can use the Observation Data Sheet and the first follow-up activity as criteria for evaluation.

You can ask fact questions based on planetarium observations, such as: What is the maximum number of degrees that the sun moves away from true east and true west at our latitude? What is the maximum number of degrees that the noontime sun is above the southern horizon at our latitude?

VOCABULARY

vernal equinox
zenith
autumnal equinox
summer/winter solstice
altitude
annual motion
azimuth
diurnal motion
celestial equator

SUGGESTED RESOURCES

Abell, _Exploration of the Universe_, pp. 100-105.
Investigating the Earth, ESCP, pp. 92-97.

NOTE

See following pages for Sunrise/Sunset Observation Data Sheet and for Fact Sheets on the Seasons

FACT SHEETS ON THE SEASONS

NOTE: Below are examples of the facts students might collect during the activity. Certain facts are necessarily local. Blanks have been left to point up their availability during the course of the lesson.

What causes the seasons?

1. The earth's axis, therefore the plane of the earth's equator, is inclined about 23.5° from the plane of the earth's orbit. This creates a difference between the plane of the earth's equator and the apparent annual path of the sun, called the ecliptic. The difference is called the obliquity of the ecliptic.

2. The obliquity of the ecliptic, along with the fact that the earth revolves about the sun, is responsible for the seasons.

3. The result is that the northern hemisphere is inclined toward the sun from about March 21 to September 23 and away from the sun from about September 23 to March 21. In the southern hemisphere it is just the reverse.

Daylight and darkness on the first day of each season

1. March 21 is usually the vernal equinox, the first day of spring. The sun appears in the direction of the celestial equator, and every place on earth receives 12 hours of sunlight and 12 hours of night. Equinox means "equal night."

2. June 21 is usually the summer solstice, the first day of summer. Solstice comes from a Latin word meaning to "stand still." On this day, the sun has traveled as far north of the celestial equator in its apparent path as it will go. A typical town in the United States receives about 14 to 15 hours of light on this day. The sun appears high in the sky and therefore is more effective in heating the earth.

3. September 23 is usually the autumnal equinox, the first day of fall. On this day the sun appears in the direction of the celestial equator and again days and nights are equal in length.

4. December 22 is usually the winter solstice, the first day of winter. The sun appears fairly low in the sky even at noon, and therefore does not heat the northern hemisphere as effectively as in the summer. A typical city in the United States receives only about nine or ten hours of sunlight.

Sunrise, sunset on the first day of each season

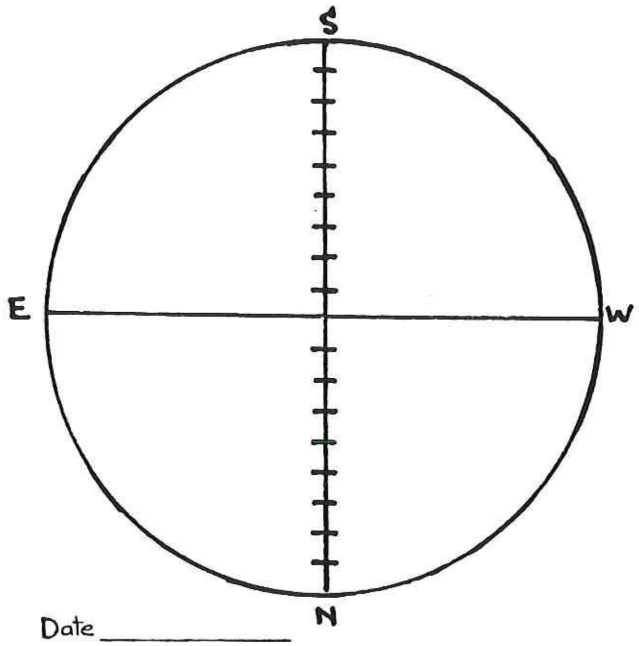
1. On the first day of spring, the sun appears to rise in the east and to set in the west. It's altitude at noon varies with latitude. At our latitude it is ____ degrees. At the equator the sun appears to rise due east and to set due west; it is on the zenith at noon.

2. On the first day of summer at our latitude the sun appears to rise ____ degrees north of east and to set ____ degrees north of west. It reaches a noon altitude of ____ degrees. To a person at latitude 23.5° north, the sun is overhead at noon. This latitude is called the tropic of Cancer.

3. On the first day of fall, the sun again appears to rise in the east and set in the west, and to move across the sky in exactly the same manner as it does on the first day of spring. It reaches the same altitude at noon.

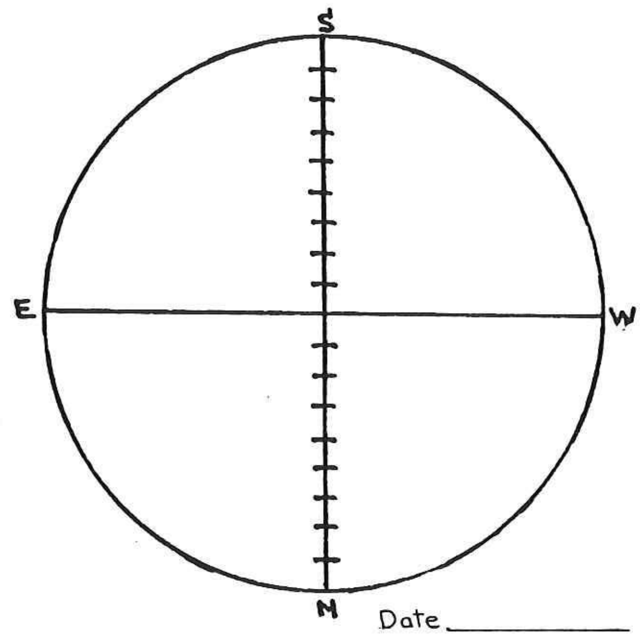
4. On the first day of winter at our latitude the sun appears to rise ____ degrees south of east and to set ____ degrees south of west. Its altitude is ____ degrees at noon. To a person at latitude 23.5° south, the sun is overhead at noon. This latitude is called the tropic of Capricorn.

SUNRISE/SUNSET OBSERVATION DATA SHEET



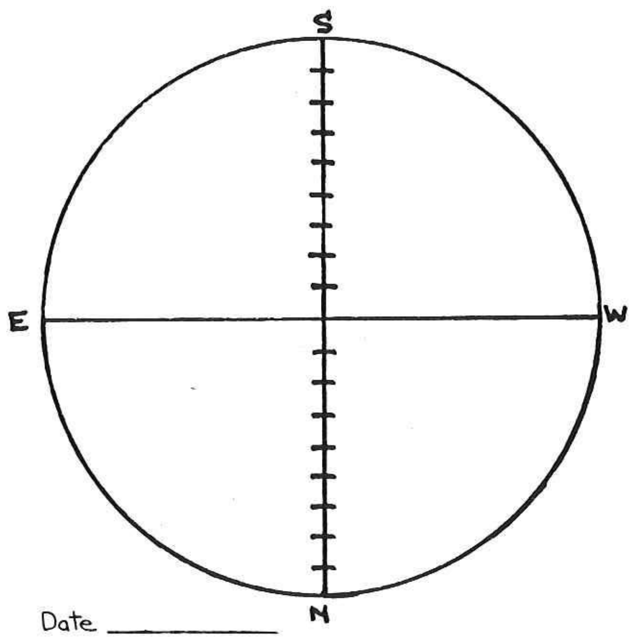
Date ____________

Vernal Equinox, first day of spring



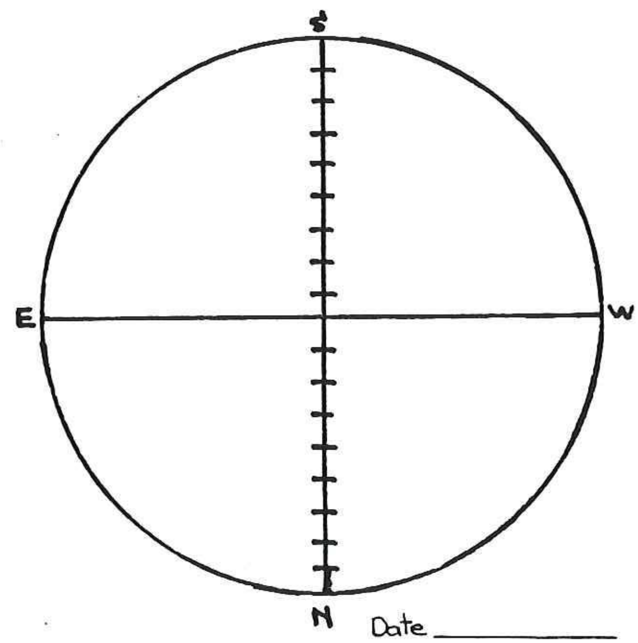
Date ____________

Summer Solstice, first day of summer



Date ____________

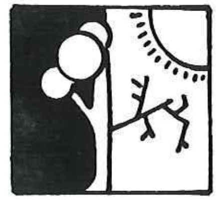
Autumnal Equinox, first day of fall



Date ____________

Winter Solstice, first day of winter

UNITS IN 10° FOR MEASURING AZIMUTH



TIME AROUND THE WORLD

The measurement of time appeared to be under control after the discovery that the pendulum could be used for time-keeping. But in the nineteenth century, faster modes of transportation and communication brought an urgency for synchronization of clocks throughout the world on the basis of a standardized time.

This activity will help students grasp the relationship of standard time to mean solar time and longitude. In the planetarium, the student will see the sun shining directly on the longitude of Greenwich and will be able to count the degrees and hours of time difference between that longitude and his own.

STUDENT PREPARATION

Grade level: secondary

Content background: working knowledge of longitude and measurement of longitude in degrees: (preferably) prior lesson on different kinds of time--apparent solar time, local mean time.

FACTS AND CONCEPTS

Time and location are related because the earth rotates 360° in 24 hours--equal to 15° in one hour. This accommodated the establishment of 24 time zones around the world.

Since the earth is a sphere, an arbitrary starting point had to be designated for time measurement. The longitude of Greenwich, England, was designated as the starting point. The meridian on the opposite side of the earth, at 180°, was designated as the longitude for change of date.

Any position on Earth is directly related to the hour angle from the Greenwich meridian.

Time zone boundaries deviate from longitudinal meridians for man's convenience.

OBJECTIVES

- The student will be able to determine his longitude on Earth using the difference between Greenwich apparent solar time and local apparent solar time.

- Given Greenwich mean time and local mean time, the student will be able to calculate local longitude.

- Given Greenwich mean time and local longitude, the student will be able to calculate local mean time.

- Given local mean time, date, and local longitude, the student will be able to calculate local mean time and date for any other given longitude.

MATERIALS

Classroom: world map; world map and/or U.S. map showing time zones; earth globe; pinpoint light source (such as slide projector with pinhole slide); protractor or string for measuring degrees on globe (optional).

Planetarium: geocentric earth projector--mark longitude and latitude on geocentric earth with narrow tape (1/8" to 1/16" wide) or grease pencil at 15° intervals; world maps for reference; paper, pencils, pen lights.

PROCEDURES

<u>In the Classroom</u>

1. Using a world map, review longitude and latitude with the class, particularly noting the prime meridian passing through Greenwich, England, and its designation as the starting point for the measurement of both longitude and time.

2. Using a world map and/or U.S. map showing time zones, ask students to estimate the number of degrees per zone. They may do this from the meridians shown on the map or by transferring the zones to a globe and using suitable techniques and materials for degree measurement. Due to irregularities in time zone boundaries, the number of degrees may be difficult to determine--but students who remember that there are 360° around a sphere will come to the conclusion that time zones are set up in units of 15° to accommodate 24 hourly changes in time.

3. Now, one student, using a point light source and a globe, should shine a point of light directly on Greenwich, England. Another student should mark the 0° meridian with the current date and time (the direct rays of the light indicate that it is noon in Greenwich). He should then mark meridians, westward, at 15° intervals by time and date. At the 180° meridian it will be 12 o'clock midnight, and he will need to decide whether to set the date ahead or back.

4. Discuss the meridians that have just been marked as standard meridians running through the center of each time zone. Discuss the time in each zone as standard time, the local mean time along the standard meridian. (See definitions at end of activity for explanations to draw on in discussing apparent solar time, mean solar time, standard time.)

In the Planetarium

Presetting: Set the geocentric earth so that the meridian passes through local longitude (see note immediately below). Set the sun on the vernal equinox at noon, Greenwich mean time. Note: If local longitude is more than 90°W, preset the planetarium and change projection as necessary for the activity.

1. Let students locate themselves in relation to the geocentric earth and meridian. Then they should note and discuss the prime meridian, the location of the sun, and the time along the Greenwich meridian as represented by the setting.

2. Run daily motion until the sun is on the local meridian, showing changes in the sun's position. Then stop the sun.

3. Ask students to determine (read) as accurately as possible from the coordinate lines on the geocentric earth the number of hours between their local meridian and the Greenwich meridian.

4. Discuss the distance in degrees that the mean sun moves in 24 hours (360°). Then ask students to calculate the hourly rate of movement in degrees (15° per hour).

5. Using the hourly rate of movement of the mean sun and the number of hours between their local meridian and the Greenwich meridian, the students now should determine their local longitude.

6. Next they should determine from the geocentric earth coordinates the number of degrees and the number of hours difference between the Greenwich meridian and the standard meridian of their time zone. Let them also determine how many new time zones would be entered on a trip from their home location to Greenwich.

7. Ask the students to discuss, offering sample problems and solutions, the following questions:

   a. How would you find local longitude if given Greenwich mean time and local mean time?

   b. How would you calculate your local mean time if you knew Greenwich mean time and your local longitude?

   c. How would you calculate the local mean time and the date of any given longitude if you knew, either for your own or any other location, the local longitude, local mean time, and the date?

As students offer explanations, sample problems, and solutions, let them use your pointer to point to locations on the dome for illustrative purposes. World maps may be used for reference.

Follow-Up Activities

1. Let students explore the history of the establishment of time zones throughout the United States and the world.

2. Suggest that they look into other kinds of time established for man's convenience (daylight savings time, war time during the Second World War).

3. Give problems for solution of the type discussed in the planetarium.

4. Offer problems of a practical nature, using settings involving travel, radio and TV broadcasts, long distance telephone calls.

EVALUATION SUGGESTIONS Evaluation may be based on the problems given in the follow-up activities.

VOCABULARY

hour angle
prime meridian
longitude Greenwich mean time
local apparent solar time
standard meridian standard time
local mean time
International Date Line time zone

SUGGESTED RESOURCES Namowitz, Stone, Earth Science, pp. 422-429.
Ramsey, Burckley, Modern Earth Science, pp. 117-120.
Investigating the Earth, pp. 95-99.

Overhead Projectuals: Buehrig, Eleanor B., "United States Time Zones, Science-25W."

NOTE See following page for definitions of kinds of time.

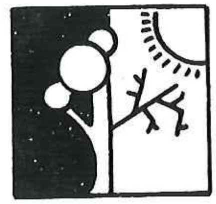
KINDS OF TIME

Apparent solar time--the hour angle of the sun at any given longitude on any given date. When the sun crosses the observer's meridian, it is noon, apparent solar time. Sundials give apparent solar time; clocks would need to be reset each day to do so because the length of the solar day varies through the year.

Local mean time is based on a mean sun--a fictitious sun or point in the sky--which moves uniformly through the year to the east along the celestial equator. It is noon, local mean time, when the mean sun crosses the observer's meridian. Knowing the longitude of a given locality and Greenwich mean time, local mean time can be computed.

Greenwich mean time is the local mean time of the meridian that runs through Greenwich, England--the arbitrary point used to establish 0° longitude. This meridian is used as the starting point for time measurement.

Standard time is a system of time measurement set up to accommodate communication about time. It is the local mean time on the meridian that runs through the center of the time zone. It is noon, standard time, at any given locality in a given time zone when it is noon, local mean time, on the standard meridian for that zone.



TIME BY THE SUN AND BY THE STARS

Through the centuries man's activities have been regulated by the apparent motions of the sun, and to a lesser degree by those of the moon and stars. The length of a day is firmly fixed in men's minds as being 24 hours. However, a day can be measured and defined in at least three ways.

Students will develop definitions of an apparent solar day, mean solar day, and sidereal day from observations in the planetarium.

STUDENT PREPARATION

Grade level: secondary
Content background: familiarity with apparent daily and annual motion of the sun; familiarity with idea of celestial globe and ability to use equatorial coordinate system.

Note: The activity might be timed for use with Investigations 5 or 9 in _Time, Space, and Matter_; Chapters 4 or 17 in _Investigating the Earth_; Chapter 5 of Unit 2 in the Harvard Project Physics program.

FACTS AND CONCEPTS

A day may be defined as the time interval between two successive crossings of the celestial meridian by a celestial reference object.

An apparent solar day may be defined as the interval between two successive crossings of the celestial meridian by the sun, with the center of the sun used for measurement purposes.

The length of an apparent solar day varies due to the variation in the speed of Earth in its revolution about the sun and to the inclination of the ecliptic to the celestial equator.

A mean solar day may be defined as the interval between two successive crossings of the celestial meridian by the mean sun--an imaginary sun that moves with uniform velocity along the celestial equator. A mean solar day is 24 hours--the average length of an apparent solar day.

A sidereal day may be defined as the interval between two successive crossings of the celestial meridian by a star. The length of a sidereal day is 23 hours, 56 minutes, 4 seconds.

OBJECTIVES

- The student will be able to differentiate verbally or in some written form between the apparent solar day, mean solar day, and sidereal day.
- The student will be able to list two celestial objects that could be used to measure the length of a day other than the sun.
- The student will be able to compare the length of an apparent solar day, the mean solar day, and the sidereal day.

MATERIALS

Classroom: globe, light source; celestial globe with earth inside; (optional) orrery; styrofoam balls, clear plastic spheres, other objects for earth-sun-celestial sphere models.

Planetarium: note pads, pen lights, pencils.

PROCEDURES

<u>In the Classroom</u>

1. Using a celestial globe with an earth globe inside, review with the class celestial coordinates as an extension of earth coordinates.

2. Using the same globe, guide students in the discovery that celestial coordinates appear fixed to the star background, not to locations on earth.

3. Using models (orrery, celestial globe, other), help students grow in familiarity with the terms <u>celestial meridian</u>, <u>celestial equator</u>, <u>ecliptic</u>.

In the Planetarium

Presetting: Place both the sun and a prominent star on the meridian for noon.

1. Before any objects are shown in the planetarium sky, ask the class how the ancients might have determined the beginning and end of one day. Allow students to discuss their own ideas, but try to guide them to the concept of using two successive crossings of the celestial meridian by a celestial reference object.

2. Discuss, letting students decide, what celestial reference objects might be used. Sun, stars, moon, planets may be suggested.

3. At this point, dim the lights and turn on the sun and stars.

4. Ask students the relative distance of the sun and the star on the meridian. Make sure that they realize the sun is very close to Earth compared with the star.

5. Run daily motion for a rotational period. When the sun and star are below the horizon, turn annual motion to full speed and off again in one continuous motion. (You need to practice this so that the sun will end up slightly to the east of the meridian when the period is completed.) Ask students to assume that the slight difference which is noted in the sun's and star's position in relation to the meridian is 4 minutes of an arc. Ask: On that basis, what would be the length of a sidereal day compared with an apparent solar day? (23 hours, 56 minutes, 4 seconds has been determined as the length of a sidereal day.)

6. Adapt procedures of Step 5 so that students may make observations at different times of year.

7. On the basis of their observations, students should suggest possible causes for the differences between the sidereal day and the apparent solar day, and between one apparent solar day and another. (If the role of the earth's revolution is not forthcoming, arrange for students to "act out" all motions observed in the planetarium sky.)

Follow-Up Activities

1. Ask students, "What might be the basis of the 24 hour day as we know it?" Guide the group to a definition of the mean solar day.

2. Suggest that students construct a model to demonstrate

the motions observed in the planetarium, using styrofoam balls and/or other materials.

3. Propose to students that they time the intervals between transits of the celestial meridian by stars in the real sky. (Let students plan their own projects as to proper procedure. They must use a fixed object--chimney, telephone pole--for reference in observing a transit; and they must not only stand in the same spot, but keep the same posture.)

4. Discuss possibilities of using celestial objects other than the stars and sun for determining the length of a day. The discussion may lead into the motions and apparent motions of the moon and planets, and the difficulty and/or impracticality of their use as reference objects.

EVALUATION SUGGESTIONS

Ask students to describe in a form of their own choosing the difference between an apparent solar day, mean solar day, and sidereal day.

Ask students to list the types of celestial objects that might be used to determine the length of a day.

You can evaluate investigative skills developed in the activity through the plans students make for determining the length of a day using reference objects in the real sky.

VOCABULARY

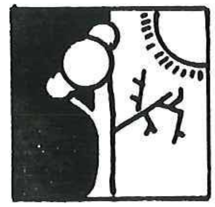
apparent solar day
mean solar day
mean sun
celestial equator
celestial meridian
ecliptic
sidereal day

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 108-113.
Branley, The Earth, pp. 63-67.
Harrison, Sun, Earth, Time, and Man, pp. 152-155.
Investigating the Earth, ESCP, Chapters 5, 9.
Harvard Project Physics text, Chapter 5, Unit 2.
Huffer, Trinklein, Bunge, An Introduction to Astronomy, pp. 127-129.
Time, Space, and Matter, Chapters 4, 17.

Filmstrip (35 mm): Measuring Time by the Sun and Stars, 60 frames, color.

Encyclopaedia Britannica Films, Inc., #11125; 1966.
Film (16 mm): Mystery of Stonehenge, 57 minutes, color,
McGraw Hill Book Co., #684001, 1968.



TWILIGHT: HOW LONG DOES IT LAST

Perhaps students have observed that at times, or in certain locations, darkness comes faster than usual after sunset--or that twilight seems to last longer.

Many variables enter into determining the duration of twilight--among them atmospheric conditions, time of year and latitude of the observer. Two of these variables, latitude and season, can be examined by students employing data gathered in the planetarium and using the Pythagorean Theorem.

STUDENT PREPARATION

Grade level: secondary
Content background: understanding of earth motions and their effect on apparent sun motions; ability to apply the Pythagorean Theorem to practical problems.

FACTS AND CONCEPTS

Twilight is sunlight scattered by particles in the upper atmosphere and reflected back to earth at locations where the sun has set or where it has not yet risen.

Assuming a uniform atmospheric condition, twilight ends (no reflected light from the sun can be detected) when the sun sinks 18° below the horizon.

The length of time it takes the sun to sink 18° below the horizon depends on the angle of the plane of the sun's path to the plane of the horizon.

Latitude and season affect the angle of the sun's path in relation to the horizon.

The period of pre-dawn light prior to sunrise is comparable in every respect to the period of twilight.

OBJECTIVES Given latitude and season, the student will be able to compute the duration of twilight.

Offered a suitable planetarium demonstration, the student will be able to collect data on the angle of the sun's path in relation to the horizon at various latitudes and at various times of year.

MATERIALS Classroom: celestial globe and/or other materials for review of earth motions and sun's apparent daily and annual paths; optional for calculation portion of activity--slide rule or square root table.

Planetarium: Twilight Data Sheets, pencils, pen lights; yardstick (may be used in determining degrees below horizon); roll of large paper for use as described below under Planetarium Procedures).

PROCEDURES <u>In the Classroom</u>

1. Discuss with the class relationships between earth's rotation and theoretical and practical definitions of day and night: night, in theory, comes when the sun sets; but for all practical purposes it comes when it gets dark.

2. Let students offer explanations as to why there is light before sunrise and after sunset although the sun is below the horizon. (The scattering and reflection of light by particles in the upper atmosphere should be pinpointed as its cause.)

3. Ask how long twilight lasts--and let students give estimates. (You can expect responses to be studded with if's, and's, and but's.) Tell students that on a clear day under uniform (average) atmospheric conditions, astronomers have determined that no light from the sun can be detected after it sinks 18° below the horizon--and that is the end of "astronomical twilight." Then ask how long in minutes it would take the sun to sink 18° below the horizon--or to rise 18° above it.

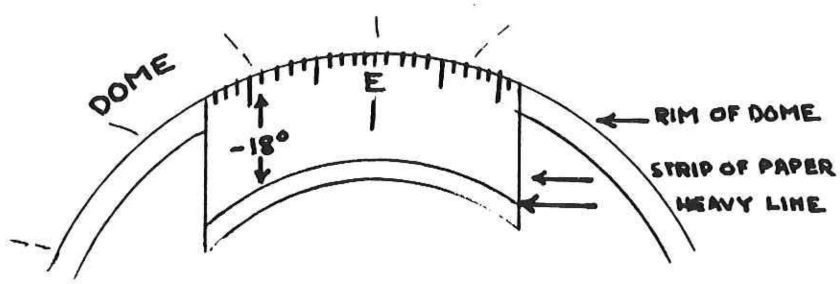
4. Some students may come up with almost an immediate answer: Since the earth rotates

at the rate of 15° per hour, the sun will rise or sink at that rate--therefore, twilight will last 1 hour, 12 minutes. The answer may be considered correct for the equator; but suggest that students consider, prior to the planetarium visit, the sun's apparent path at home latitude.

Note: During the course of the class discussion, review concepts related to rotation, revolution, and axial inclination if you sense this is needed. With groups that have not had fairly recent experience applying the Pythagorean Theorem and finding square root, also review the mathematical understandings and operations that will be required in the Follow-Up Activities.

In the Planetarium

Preparation: Attach to the rim of the dome at planetarium east an oversize strip of paper. It must extend along the dome for as many degrees of azimuth as will accommodate the collection of data for local latitude described in the activity; it must extend below the dome for at least 20 degrees. Degrees azimuth should be marked on the strip and a conspicuous line near the bottom should indicate -18° altitude, as pictured below.



Presetting: Set the planetarium and sun (with cut-offs removed) for home latitude, vernal equinox, prior to sunrise. The upper limb of the sun should be at least 20° below the horizon.

1. Turn on sun, and discuss the setting with students including the date, latitude, and the "x-ray eyes" that would be needed to observe the sun below the horizon. Let students estimate (or measure) its position in degrees below the horizon, asking how many more degrees it will need to rise before morning twilight starts.

2. Distribute Twilight Data Sheets. Then using daily motion, allow the sun to rise until the upper limb reaches the mark indicating -18° altitude on the sheet. Ask students to determine the azimuth of the sun at this altitude and to record results in degrees in the appropriate space on the data sheet.

3. Continue daily motion until the upper limb of the sun reaches the horizon. Ask students to determine and record the azimuth of the sun again.

4. Repeat the same planetarium demonstration described in Steps 2 and 3 for local latitude on the summer solstice, autumnal equinox, and winter solstice, and a date between an equinox and solstice. In each instance, the students should again determine and record the azimuth of the sun at -18° altitude and as it reaches the horizon.

5. Repeat the planetarium demonstration for one equinox and both solstices for latitudes 0° and 90°N.

6. Hold treatment of the data for the next class session, but suggest that students consider in the meantime how geometry might assist them in determining the duration of twilight for the various instances observed. A portion of the strip of paper used at the planetarium rim should be preserved for classroom use.)

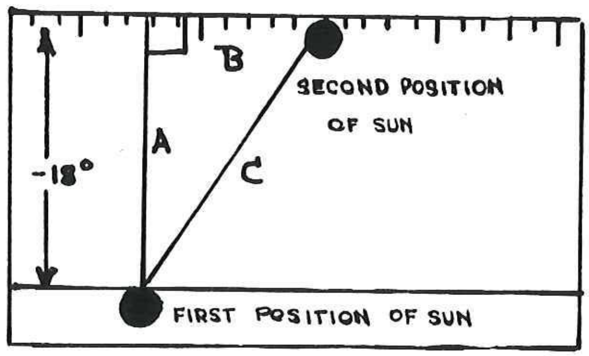
Follow-Up Activities

1. Ask for ideas on how the data collected in the planetarium might be treated mathematically to determine how long twilight lasts. From discussion and suggestions, sort out the following ideas for display on the board, using a section from the strip of paper used in the planetarium when appropriate:

   Known facts: Twilight is that period of time when the morning sun is between the horizon and 18° below the horizon. The earth revolves at the rate of 15° per hour, or 1° in 4 minutes. Therefore it follows that the sun transverses 18° of altitude during the period of twilight. This will require 1 hour and 12 minutes when the sun travels at an angle perpendicular to the horizon.

   Problem: When the sun's daily path is not perpendicular to the horizon, how many degrees of combined altitude -azimuth must it cross and how long will this take?

Solution: The Pythagorean Theorem tells us that in the figure below $A^2 + B^2 = C^2$.



Let A = degrees of altitude that sun crosses during twilight; know to be 18°

Let B = change of azimuth in degrees between beginning and end of twilight (data available for each observation on student data sheets); in the example below, the change of azimuth is 12°.

Let C = distance in degrees of combined altitude-azimuth traveled by sun.

Substituting known values for degrees and applying the theorem,

$$18^2 + 12^2 = C^2$$

computing, $324 + 124 = 468$

therefore, C = 468 or approximately 21.6°.

Knowing that the sun travels at the rate of 1° in 4 minutes, the duration of twilight in the given example is found to be approximately 1 hour, 26 minutes.

2. Ask students to calculate the duration of twilight for the observations made in the planetarium and insert the figures requested in the last three columns of the data sheet.

3. To conclude classwork, help the group correlate and sum up effects of the seasons and latitude on the duration of twilight. Discuss how students might estimate its duration given latitude and season.

4. Suggest independent reading and investigations on twilight: for example, on the difference between

astronomical, nautical, and civil twilight (and the reasons for these various definitions); on local twilight (does its duration in the real sky uphold planetarium observations?)

EVALUATION SUGGESTIONS — The data sheet will provide criteria for evaluation; however further examples should be presented in written form for both solution and explanation of why the procedures used are appropriate.

VOCABULARY

twilight
azimuth altitude
latitude reflection
limb of sun

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 104-105.
Harrison, Sun, Earth, Time, and Man, pp. 76-113.
"Times of Rising and Setting of the Sun and Moon," The Observer's Handbooks.

"Sunrise and Twilight--Sunset and Twilight," American Ephemeris and Nautical Almanac.

NOTE See following page for Twilight Data Sheet.

TWILIGHT DATA SHEET

		Data Collected in Planetarium		Calculations Made in Classroom		
		AZIMUTH OF SUN AT START OF TWILIGHT	AZIMUTH OF SUN AT SUNRISE	CHANGE IN AZIMUTH	SUN'S TWILIGHT PATH IN DEGREES	TWILIGHT DURATION
HOME LATITUDE:	Vernal Equinox					
	Summer Solstice					
	Autumnal Equinox					
	Winter Solstice					
	Interim Date:					
EQUATOR - 0°	Equinox					
	Summer Solstice					
	Winter Solstice					
OPTIONAL NORTH POLE - 90°N	Equinox					
	Summer Solstice					
	Winter Solstice					

WHAT'S YOUR LOCAL MEAN TIME

Students will be introduced to the curiously shaped object that appears in the middle of the Pacific Ocean on many globes--the analemma. They will meet it through constructing one themselves from observations of the sun through the year at noon, local mean time, in the planetarium. The plotting will take one planetarium session, compared with a year were it to be done from observations of the real sun.

Making an analemma and analyzing its construction will provide excellent review and reinforcement of most basic concepts about earth motions, apparent sun motions, and the use of the latter for telling time.

STUDENT PREPARATION

Grade level: secondary

Content background: knowledge of inclination of the earth's axis and understanding that the sun as viewed from earth follows the ecliptic instead of the celestial equator; knowledge of the ellipticity of the earth's orbit and understanding of its effect on orbital velocity; familiarity with apparent solar time and local mean time.

FACTS AND CONCEPTS

The length of an apparent solar day varies due to the obliquity of the ecliptic and to variations in the orbital velocity of the earth.

Although differences in the length of an apparent solar day compared with the mean solar day are small, these differences mount up from day to day at certain times of year to create much larger differences between local mean time and apparent solar time.

An analemma is a graph which shows the amount of time by which the sun runs ahead or behind the mean sun for every day of the year. The graph also shows the sun's declination.

OBJECTIVES

- The student will be able to use an analemma to (a) determine the latitude where the sun would be seen at the zenith during a given month; (b) convert apparent solar time to local mean time.

- The student will be able to demonstrate, using diagrams or models, why the sun is never at the zenith in latitudes north of 23.5°N or south of 23.5°S.

- The student will be able to explain why the sun usually is not on the meridian at noon, local mean time.

MATERIALS

Classroom: materials for earth-sun models; (optional) materials for construction of an ellipse; for Follow-Up Activities--reference books containing an analemma and a graph of the equation of time through the year.

Planetarium: timetable of the heavens or good analemma for determining planetarium settings; Analemma Data Sheet, pencils.

PROCEDURES

<u>In the Classroom</u>

It is assumed that students will engage in this activity during or following study of apparent sun motions and the measurement of time. Learning experiences prior to the planetarium visit should include:

1. Consideration of the varying length of the solar day through the year and its causes.

2. Construction of an ellipse; consideration of the effect of an elliptical orbit on orbital speed, and of the effect varying orbital speeds would have on the intervals between meridian crossings of the sun as viewed from earth.

3. Examination of what is meant by an apparent solar day and mean solar day; apparent solar time and mean solar time.

In the Planetarium

Planetarium setting: The sun will be shown in its apparent position at home latitude at noon, local mean time, for the 21st of each month, March through one year. The minutes that the sun will be set fast or slow (west or east) of the local meridian on each date must be obtained from a good analemma or from a timetable of the heavens (see Suggested Resources). To place the sun at the desired position, move in annual motion to the desired date and use daily motion to place it properly for noon, local mean time.

1. With the meridian and coordinates on, show the sun at noon, local mean time, vernal equinox, home latitude. Discuss the setting with students, giving them the date and local mean time. Encourage them to imagine a mean sun on the meridian at the celestial equator. Ask the declination of the "real" sun and whether it is running fast or slow according to local mean time.

2. Distribute Analemma Data Sheet. Ask each student to plot the position of the sun, using the coordinates, according to declination and the number of minutes the sun is running fast or slow. Check to be sure students understand what is represented along each axis of the graph and that the zero point for both axes is in the center of the graph.

3. Position sun for the 21st of April, again asking students to plot the position of the sun. Continue until data has been collected for 12 months.

4. Now students should connect the points on their graphs with a smooth curve and examine the figure constructed. Ask such questions as: (a) at what latitude is the sun at the zenith on September 23? On December 23? (b) in what months is the sun running slow? Fast? On what dates is apparent solar time almost the same as local mean time?

Follow-Up Activities

1. From data collected in the planetarium, students should graph the difference between apparent solar time and mean solar time (the equation of time) against months through the year, putting months on the horizontal axis and minutes fast or slow on the vertical axis.

2. Let students check the analemma made in the planetarium and the graph of the equation of time throughout the year against graphs to be found in reference books, evaluating their own for accuracy.

3. Suggest that students do further reading on the equation of time to compare the quantitative effects of the obliquity of the ecliptic and of the varying speeds of the earth in orbit on the length of the apparent solar day, and on the resulting differences in apparent solar time and mean solar time.

4. Encourage students who wish to construct an analemma, as a long-term project, through indirect observations of the real sun. (Directions for using gnomons or reflections cast by the sun for construction of analemmas will be found in resource books on science projects.)

EVALUATION SUGGESTIONS

Offer questions through which students will be required to use the analemma constructed in the planetarium to determine latitudes where the sun would be seen at the zenith at various times of year, and to find local mean time, given the apparent position of the sun.

Ask students to explain through means of their choosing why the sun is rarely on the meridian at noon, local mean time.

VOCABULARY

analemma
local mean time
apparent solar time
obliquity of ecliptic
eccentricity of orbit

SUGGESTED RESOURCES

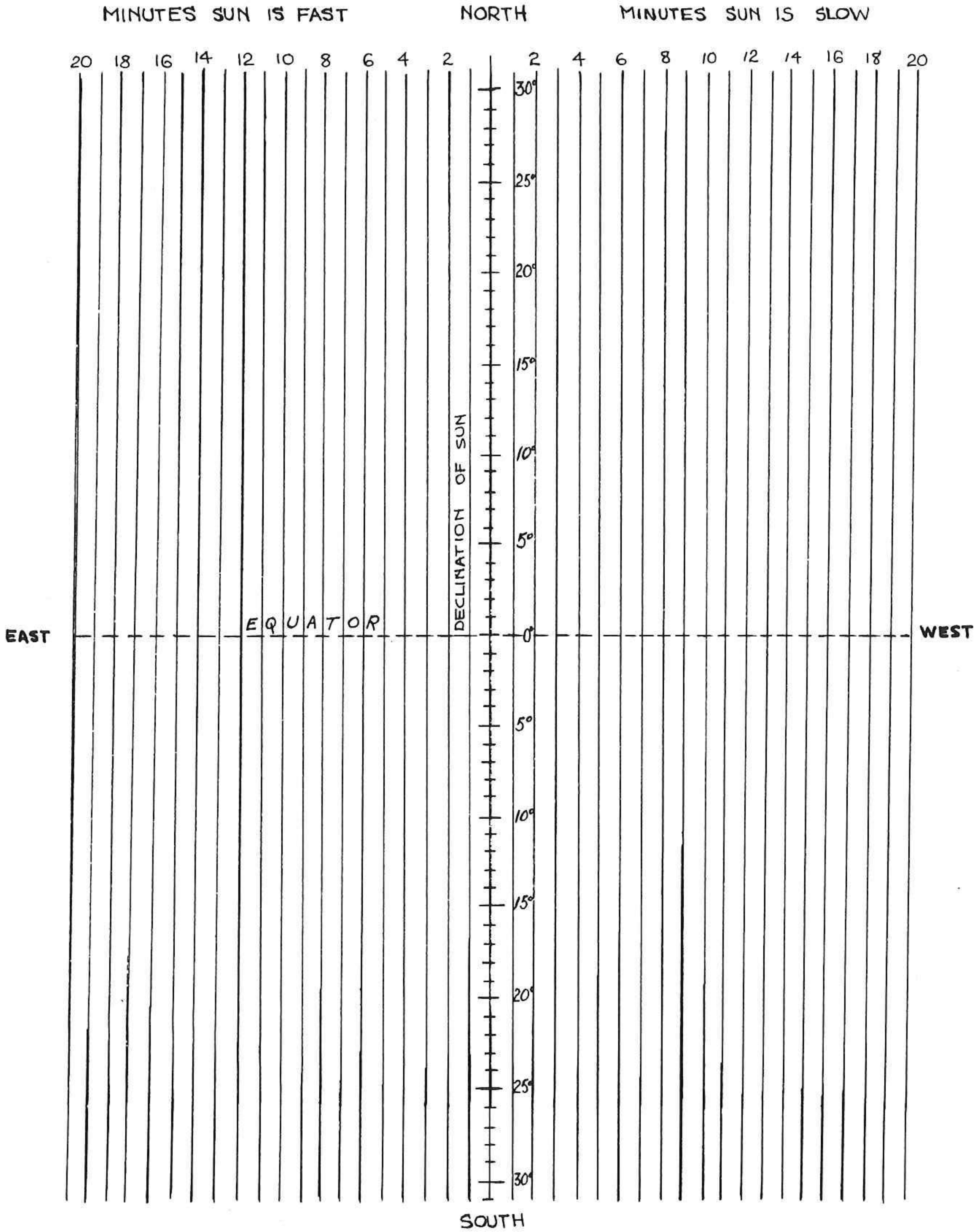
Abell, Exploration of the Universe, pp. 111-114.
Branley, Experiments in Sky Watching, pp. 21-25.
Harrison, Sun, Earth, Time and Man, pp. 157-159.
Strahler, The Earth Sciences, p. 48 (for analemma.)

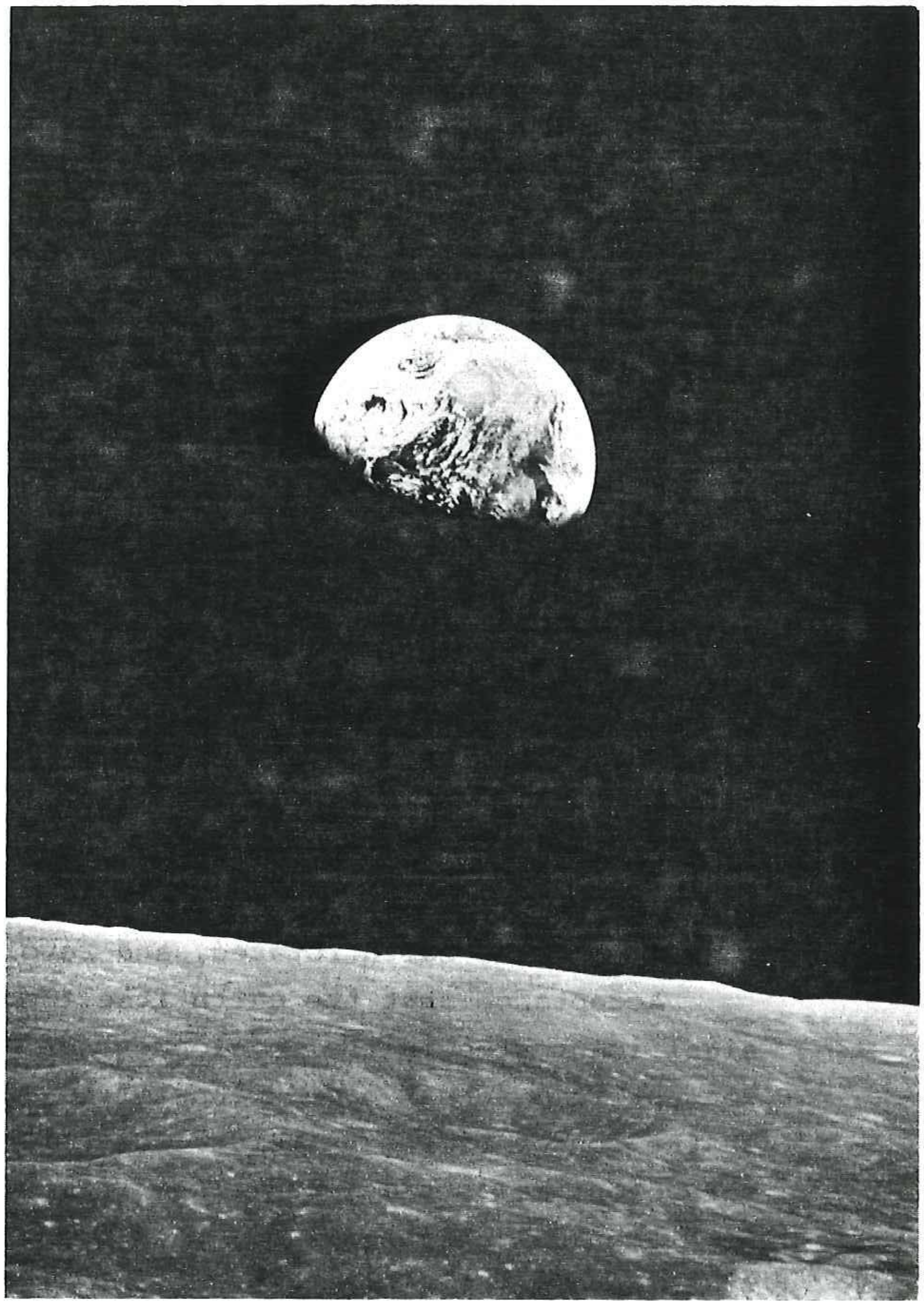
Graphic Time Table of the Heavens, Watson, Paul S., Maryland Academy of Sciences, Baltimore. Published annually. (Recommended for obtaining planetarium settings used in activity.)

NOTE

See following page for Analemma Data Sheet.

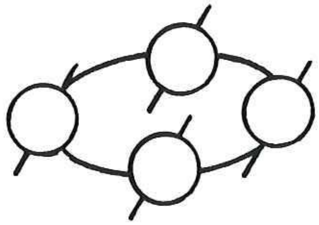
ANALEMMA DATA SHEET





TO SEE THE EARTH AS IT TRULY IS, SMALL AND BLUE AND BEAUTIFUL IN THAT ETERNAL SILENCE WHERE IT FLOATS, IS TO SEE OURSELVES AS RIDERS ON THE EARTH TOGETHER, BROTHERS ON THAT BRIGHT LOVELINESS IN THE ETERNAL COLD--BROTHERS WHO KNOW NOW THAT THEY ARE TRULY BROTHERS.

- *Archibald MacLeish*
This Island Earth, NASA Sp- 250

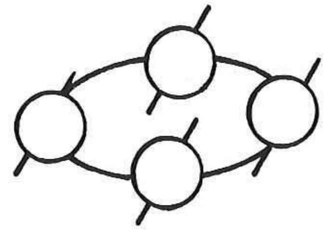


Earth and Its Motions

Observations of the celestial sphere reveal that the stars, the planets, the sun, and the moon appear to change their positions in the sky. Early in recorded history, man reasoned--logically, he thought--that these extraterrestrial objects were orbiting the earth. To consider that the earth moved was deemed heresy. As late as the Seventeenth Century, the great Galileo was found guilty of intellectually defying God when he supported the Copernican theory that the earth rotated, and revolved around the sun.

Acceptance that the earth itself moves marked a significant step in the development of astronomy. This concept removed our proud planet from its hallowed pedestal at the center of the universe, which it had occupied throughout man's time, and placed Earth in perspective with the rest of the solar system.

The activities in this section allow the student to investigate motions the earth experiences--rotation, revolution, precession--and to become aware of the effects they have on our lives and on what we see in the sky.



EARTH'S ROTATION: NIGHT AND DAY

Children observe the difference between day and night at a tender age--indeed this is the first astronomical observation that they make. However, it is hard for a young child to comprehend what causes the daily cycle of daylight and darkness since his own eyes tell him that each day the sun rises, moves across the sky, and sets--then the dark comes.

In the following activity, the phenomenon of daylight and darkness, and the earth movement responsible for it, are introduced through manipulative materials and a simulated 24-hour sky watch in the planetarium. Throughout the lesson there is emphasis on the idea of apparent motion.

STUDENT PREPARATION

Grade level: elementary
Content background: familiarity with cardinal points; understanding that the earth is a sphere far away in space from the sun; (preferably) prior introduction to the fact that the earth rotates.

FACTS AND CONCEPTS

As the earth rotates, the sun illuminates different areas on the earth.

The apparent daily motion of the sun and stars across the sky is a result of the earth's rotation.

OBJECTIVES

- Using a model of the earth and sun, the student will be able to demonstrate the cause of day and night.
- The student will be able to describe orally, or draw a picture depicting the daily motions of the sun and stars as observed in the planetarium.

ø The student will be able to explain why the sun and stars are not visible for an entire 24-hour day.

MATERIALS

Classroom: shadow sticks, ruler, compass, earth globe; for evaluation and follow-up activities--materials for demonstrating day-night effect, such as styrofoam balls to represent earth and sun, plastic hemispheres and marking pencil, light source, orrery; NASA photos of earth.

Planetarium: rotating globe, light source, figure of child cut from cardboard; film loop showing movie taken of passing scenery from inside a moving school bus (a simple 8-mm movie, homemade, will be fine); projector.

PROCEDURES

In the Classroom

1. Ask the children to suggest various things that can be seen only in the day or at night. Lead them to natural phenomena visible only in light or in darkness--sun, clouds, rainbows, shadows; stars, moon.

2. Explore with the group relationships between the sun and shadows. Start with questions such as: Are shadows longer at certain times of day? Are shadows in different positions at certain times of day? Then arrange for the group to examine the shadows cast by a shadow stick during the course of a school day to establish the relationship between length of the shadow and its position and the time of day and the position of the sun. The objects casting the shadows and the shadows should be measured and the direction of the sun and shadow established with the aid of a compass.

3. Guide the children in using the data collected to write a set of generalizations and to describe the daily path that the sun seems to make.

4. Discuss with the group what happens to shadows as the sun sets. Suggest that they observe their own shadows in the evening as the sun sinks below the horizon.

5. Check on the children's understanding of cardinal points, of the spherical shape of the earth, and on their prior knowledge about rotation. For example, let them find

an object in the room the shape of a sphere and use it to demonstrate what is meant by "rotating." (Depending on the group, one or more of these ideas may need to be developed further before the planetarium visit.)

In the Planetarium

1. With the cove lights still on, ask the children to look up at the dome and pretend that they are sitting outdoors looking up at the sky. Tell them to be ready to describe their observation in terms of what they imagine is happening as they look at the sky. Then very slowly (a) dim cove lights to complete blackness, letting the stars shine forth; (b) in five to 10 seconds, gradually brighten cove lights, (c) pause, as before, and repeat (a) and (b).

2. Discuss what children imagined was happening. Press for responses until all of them have identified the simulated day-night sequence.

3. Set up a rotating earth globe at a level where everyone can see it. Discuss what it represents and let various children identify familiar areas and points (include North Pole, South Pole, equator, and hometown). At approximately home location, attach a cardboard paperdoll (large enough for all children to see) upright to the globe. Explain that the figure represents a child sitting on the lawn.

4. Simulate sunrise to show when the nighttime stars disappear. Ask "Why don't we see the stars in the daytime?" and discuss.

5. Suggest that children observe the sunset that night, trying to remember that they are on a rotating earth, and think about the direction the earth is actually turning.

Follow-Up Activity

1. Discuss personal experiences children may have had with apparent motion (as thinking they were moving when sitting in a stationary train and observing a train passing).

2. Review planetarium experiences by asking the children to use various objects to demonstrate the cause of the daily cycle of daylight and darkness.

3. If possible, show and discuss NASA photographs of the earth in space which show areas in light and darkness (and in series establish a proof that the earth rotates).

4. Suggest that students keep a record of the times of daylight and darkness for several weeks or longer.

5. Any project on the times of daylight and darkness will lead directly into investigation of another earth movement--revolution.

EVALUATION SUGGESTIONS

Ask the children to draw a picture showing how the sun moves through the daytime sky or how the stars move through the planetarium sky. They should label directions.

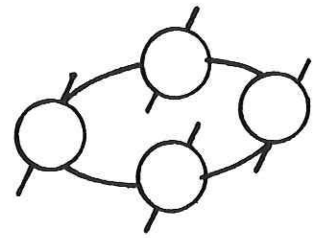
Ask each pupil to draw a picture of the earth and sun, or to use a three-dimensional model, to explain the causes of night and day.

VOCABULARY

shadow   darkness
sphere   rotate/rotation   globe
directions: north/east/south/west
apparent motion   actual motion
horizon

SUGGESTED RESOURCES

Bendick, The First Book of Time, pp. 19-25.
Freeman, Mae & Ira, The Sun, the Moon, and the Stars, pp. 6-15.
Lewellen, The True Book of Moon, Sun, and Stars, pp. 28-33.
Zim, Baker, Stars, pp. 112-113.



EARTH'S ROTATION: THE CHANGING SKY

A youngster who can explain the apparent daily movement of the sun as an effect of the earth's rotation may be totally unfamiliar with the fact that the stars seem to move in the sky. Children's observations of the nighttime sky are limited by early bedtimes and, more often than not, by poor conditions for stargazing.

This activity will acquaint students with the diurnal motion of stars as viewed from Earth through "all-night" observations in the planetarium. The students will also explore patterns of star movement, relating these patterns to latitude.

STUDENT PREPARATION

Grade level: elementary
Content background: understanding of cardinal points; understanding that the earth rotates on its axis, making a complete rotation in approximately 24 hours; (preferably) a working knowledge of latitude and longitude.

FACTS AND CONCEPTS

The apparent diurnal motion of the stars is a result of the earth's daily rotation.

The latitude of the observer affects the pattern of star movement that he sees in the sky: (a) if viewed from the mid-latitudes, some stars rise and set; (b) if viewed from the North Pole, the stars neither rise or set, but circle around the North Star; (c) if viewed from the equator, all of the stars rise and set.

The North Star, Polaris, is a point in the sky almost directly above the North Pole. A line to that point can be considered an extension of the earth's axis of rotation.

OBJECTIVES

- Using data collected in the planetarium, the student will be able to explain, demonstrate, or depict graphically the relationship between the apparent diurnal motion of the stars and the earth's rotation.

- Given the pattern of star movement as seen by an observer, the student will be able to determine whether the observer is located at polar, equatorial, or mid-latitudes.

- The student will be able to explain verbally, through demonstration, or drawings why the pattern of star movement changes with latitude.

MATERIALS

Classroom: magnetic compass, earth globe, styrofoam balls, clear plastic hemispheres (ESCP variety), marking pencils, string, photographs of phasing earth (see Suggested Resources); for Follow-Up Activities--photographic equipment and other materials as mentioned in Procedures.

Planetarium: worksheet for plotting star movements (see page following activity), pencils, pen lights; geocentric earth projector.

PROCEDURES

<u>In the Classroom</u>

1. If considered necessary for the group, review cardinal points, using a magnetic compass. Discuss the North Star as a celestial object whose location marks the approximate direction of north.

2. Using an earth globe, review latitude and longitude with the class. Note: If the group needs more background in these ideas, distribute styrofoam spheres, or plastic globes, and guide students in using string and marking pencils to establish intervals of latitude and longitude in degrees--first marking the equator, then the poles and prime meridian.

3. Ask students to use earth globes (or the globes made above) to demonstrate the rotation of the earth. Note the direction students rotate the globe and the axis of rotation, and discuss. Some students may wish to demonstrate the tilt of the axis. (This might be discussed although it has no relation to the concepts or objectives of the particular activity.) Discuss the location of the North Star as a point in the celestial sphere almost directly above the North Pole.

4. Display or project photographs of phasing earth, asking students to observe the shift of the position of the continents with respect to the line of darkness, the earth's terminator. Discuss the photos as proof of the earth's rotation.

<u>In the Planetarium</u>

1. Preset the planetarium for home latitude, night of visit. Orient students to cardinal points and time/place of setting. Show daily motion and ask for observations.

2. When the students comment that the stars are moving, ask them to notice the pattern of movement. Can they find some stars that move in a pattern different from that of other stars?

3. After it is observed and discussed that some stars rise and set, while others do not, distribute the worksheet.

4. Let someone point out the North Star, Polaris. When it is identified, ask students to plot it on Circle A of the worksheet ("View from Home Latitude"). Ask students to notice whether or not Polaris moves "through the night" as you run daily motion.

5. One at a time, point out and identify five or more bright stars (some circumpolar, some equatorial); run daily motion for each group and ask students to plot their movements in Circle A of the worksheet.

6. Suggest that the group try to develop an explanation for the patterns observed. Just encourage students to think--without commenting on their reasoning; observations to come may help them correct their own misjudgments. Then ask the students to speculate as to whether star movement would appear the same at all locations on earth.

7. Tell the group that in the planetarium you can view the stars as seen from almost anywhere on earth, and ask for suggestions as to where, and how far away, the group might "travel" for a look at star movement.

8. Select from suggestions locations as near the North Pole and equators as possible. After a brief "night" at each location, students should first plot on the appropriate circle of the worksheet the position of the North Star and then the movements of five or more bright stars. (If time, repeat for the South Pole and for a mid-latitude in the Southern Hemisphere.)

9. Again ask for an explanation of the daily patterns of star movement. This time, as needed, ask questions to guide development of a sound explanation rooted in the daily rotation of the earth on an axis that points in the direction of the North Star.

10. Ask students to classify patterns of star movement as observed from the earth. Provide appropriate terminology--"circumpolar" for stars that circle the pole star; "equatorial" for the stars that rise and set.

11. With the stars on, project the geocentric earth. Turn on diurnal motion and ask students to observe the apparent motion of the stars with reference to the continents.

12. In summary, ask students to explain the direction the earth rotates on the basis of their observations throughout the planetarium visit.

Follow-Up Activities

1. Suggest that students view the night sky and plot two positions of the Big Dipper at intervals separated by two hours.

2. Review planetarium experiences, getting the class to reconstruct in writing an explanation of the patterns of star movement.

3. Propose that students might make a model to demonstrate apparent star movement. (They might use a clear plastic bowl with stars glued on it for a celestial hemisphere, and a small ball wired inside for the earth.)

4. Some students might be assigned to photograph a star field at intervals of one hour, either in the planetarium or out of doors. Provide them with equipment and directions for the work. They should use the resulting photographs to provide the class with further evidence of the west-to-east rotation of the earth.

5. Advanced students might be asked to investigate and report on the Foucault pendulum as a proof of the earth's rotation.

EVALUATION SUGGESTIONS

The worksheet completed in the planetarium may serve as one basis of evaluation.

Ask each student to prepare a demonstration, model, or pictures which will explain apparent star movement and the different patterns of movement.

Prepare a sheet showing patterns of star movement seen in the nighttime sky by several observers. Ask students to determine the approximate latitude of each observer.

VOCABULARY

axis
rotation
North Pole South Pole
latitude equator longitude
circumpolar stars equatorial stars
(names of stars mentioned)
celestial sphere earth's terminator
apparent/actual motion
Polaris

SUGGESTED RESOURCES

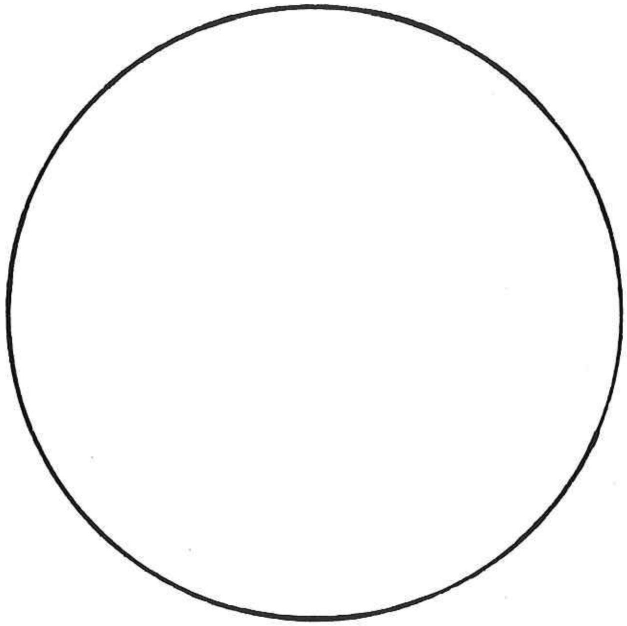
Branley, The Earth, pp. 53-68.
Wyatt, Principles of Astronomy, pp. 34-44.

Phasing moon photographs: NASA photographs, and publications showing reproductions; photographs taken by ATS Satellite.

NOTE

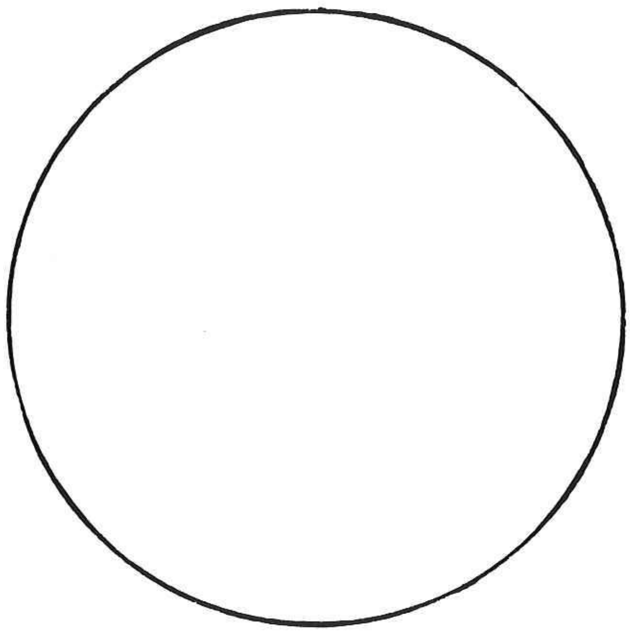
See following page for worksheet used in the activity.

WORKSHEET: DIURNAL STAR MOTION



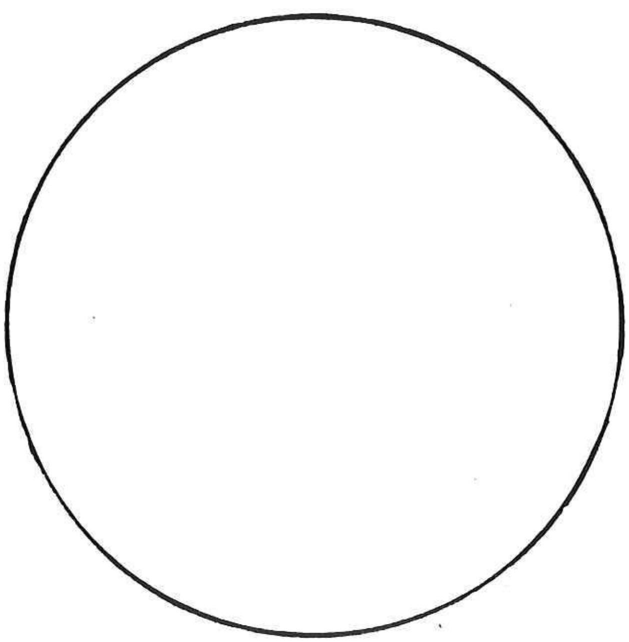
CIRCLE A

VIEW FROM
HOME LATITUDE



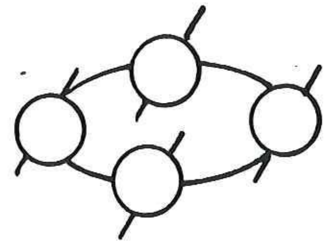
CIRCLE B

VIEW FROM
NORTH POLE



CIRCLE C

VIEW FROM
EQUATOR



LATITUDE AND APPARENT STAR MOVEMENT

Although the spin of the earth accounts for our seeing celestial objects wheel across the sky, their particular routes through the heavens are determined by the position of the observer. Investigating these patterns of apparent star motion, and understanding them, are well within the ken of middle-graders.

In the activity below, the students will observe differences in the daily paths of the stars as viewed at various places on the earth and will relate these differences to latitude. The planetarium instrument, by permitting instantaneous "travel" from one pole to another is essential in providing this type of vicarious experience.

STUDENT PREPARATION	Grade level: elementary Content background: understanding of rotation, angular measurement, latitude and longitude.
FACTS AND CONCEPTS	The apparent motion of the stars resulting from the rotation of the earth varies directly with the latitude of the observer. At the North and South Poles, all stars appear to move along paths parallel to the horizon. At the equator, all stars appear to rise and set at right angles to the horizon. In the mid-latitudes, some stars appear to circle the North Star; others rise and set at various angles to the horizon.

OBJECTIVES

ø Given a pattern of diurnal star motion as seen by an observer, the student will be able to determine his approximate latitude.

ø The student will be able to describe orally, in writing, or with a model the effect of latitude on the apparent pattern of star movement.

MATERIALS

Classroom: earth globe, light source, maps; for Follow-Up Activities and Evaluation--glass flask for use as sky model (pictured in Procedures), marking pencil, colored water, string; celestial globe with movable horizon disk, globe protractor; photographs or diagrams of star tracks.

Planetarium: note pads, pencils, flashlights.

PROCEDURES

In the Classroom

1. Review rotation. Providing an earth globe and flashlight or other light source, ask students to demonstrate and explain the direction of rotation of the earth. Discuss the North Pole as marking one end of the earth's axis of rotation--an axis that extends from the North Pole through the center of the earth to the South Pole.

2. Review latitude and longitude. Giving coordinates, ask students to locate positions on the globe and maps. Be sure to include coordinates for home location, the equator, and the poles.

3. Bring up the question where a person standing at the North Pole would see Polaris. You may get the correct answer ("at the zenith," "90° above," etc.): if you get the direction "north", ask students to think it over. Let confirmation of a correct response await the planetarium visit.

In the Planetarium

1. Set the planetarium for home latitude, night of visit, with cardinal points and stars visible.

2. Ask students to locate and identify Polaris. Turn on the meridian and let them measure its altitude. Then ask the latitude of home location and let students compare the two figures.

3. Start daily motion, slowly, and ask students to observe, suggesting that they sketch observations on their note pads. Call for observations and discuss patterns of movement. (Repeat daily motion unless all students have noticed both circumpolar stars and those that rise and set.)

4. Change the setting to the North Pole, announcing the new location. Again ask students to locate and identify Polaris--and, after turning on the meridian, to measure its altitude. Then ask for the latitude of the North Pole so that the two figures may be compared.

5. Proceed for the North Pole as in Step 3, letting students observe and sketch diurnal motion. In discussion, stress the paths of the stars in relation to the horizon. (Unless it has been observed that star paths are parallel to the horizon, repeat daily motion.)

6. Change the setting to the equator and continue as in Steps 4 and 5. (Repeat daily motion unless students have observed that all of the stars rise and set at right angles to the horizon.)

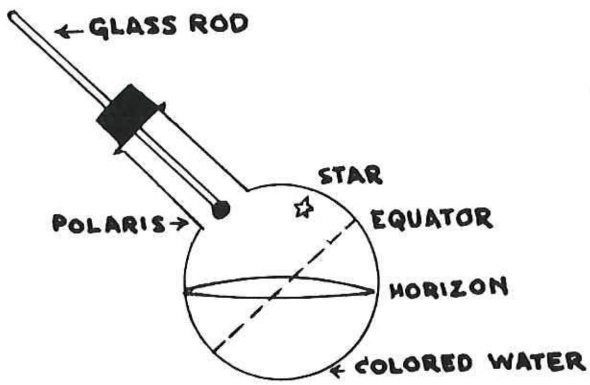
7. Change the setting to any latitude between 0° and 90°, repeating the procedures used before for another test of the direct relationship between the latitude of the observer and both the altitude of Polaris and the pattern of star movement. Again stress the inclination of star paths to the horizon.

8. Repeat for the South Pole (or as near as possible), if time.

Follow-Up Activities

1. Permit students to present their own explanations of the relationships observed in the planetarium, then continue with the following investigations using sky models:

2. To investigate the relationship between the latitude of the observer and the altitude of Polaris, students can use a glass flask, as pictured below, for a sky model.



Ask students to assume a spherical shape for the flask, ignoring the flattened bottom (as has been done in the drawing) and the spout. When the flasks have been readied, discuss the line marking the celestial equator as an extension of the earth's equator; discuss the position of Polaris (center of long cork) as an extension of the earth's axis from the North Pole and the level of the colored water as the horizon line of the observer. First have students establish that the observer sees 180° of the celestial sphere, that the other 180° is below his horizon. Then students should tip the flask at various angles, each time measuring with a string or tape calibrated in degrees for the circumference of the flask the distance from the horizon level to the celestial equator and the distance from the horizon level to Polaris. On the basis that the observer sees 180° of the horizon, the student should be able to develop an informal mathematical proof that the altitude of Polaris equals the latitude of the observer.

3. Discuss the patterns of star movements observed and sketched in the planetarium. Then make available celestial globes containing a movable horizon disk and globe protractors. Ask students to measure and record the parallel paths of the stars in relation to the horizon as the horizon view changes with latitude.

4. After work with the sky models, the students may be able to develop mathematical statements explaining: (a) which stars in the southern celestial hemisphere would never be visible to persons at certain latitudes north of the equator (those whose angular distance from the south celestial pole is less than the observer's latitude); and (b) which stars will be seen by observers at various northern latitudes as circumpolar stars (those whose angular distance from the north celestial pole is less than the observer's latitude).

5. Show the class photographs or diagrams of star trails. Ask students to estimate latitude from the trails. (They should explain the basis of their estimations.)

6. To help students stretch their imaginations--and visualize apparent star movement--ask them how the movement of the stars would appear to an observer at different latitudes (a) if the earth were flat, (b) if the earth didn't rotate, and (c) if the earth revolved at different rates--for example, if it completed one revolution around the sun in the same length of time it makes one complete rotation.

EVALUATION SUGGESTIONS

Steps 2 and 3 of the Follow-up Activities may be used for evaluation purposes.

Ask students to construct a model, using a globe and light source, to illustrate the effects of rotation on the diurnal motion of the stars.

Distribute diagrams of star trails and ask students to identify the general regions of the earth where the patterns would be observed.

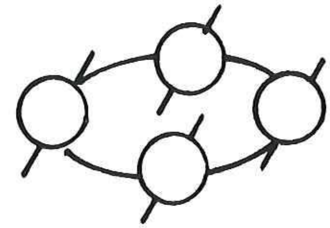
Give students an altitude of the North Star and ask them to determine the latitude (or vice versa).

VOCABULARY

zenith
Polaris
horizon
celestial sphere
celestial equator
circumpolar
NCP/SCP
star trails
apparent motion
diurnal motion
angular distance
altitude

SUGGESTED RESOURCES

Branley, The Earth, pp. 53-68.
Harrison, Sun, Earth, Time and Man, pp. 106-113.



SOLAR ECLIPSES AND REVOLUTION EFFECTS

On the date of a total solar eclipse, astronomers and other scientists gather in the area of totality to make sophisticated studies that can be carried out at no other time. An eclipse also offers students special opportunities for observation and investigation.

A total eclipse of the sun will be presented in the planetarium so that students may observe daytime stars and obtain initial data with which to arrive at certain effects of the earth's revolution.

STUDENT PREPARATION	Grade level: elementary Content background: general knowledge of rotation and diurnal motion, of revolution, and of the cause and effects of eclipses. The activity might follow the one in this book titled "Earth's Rotation: It Makes the Stars Seem to Move All Night"; or it might be used along with Investigation 5 in <u>Time, Space, and Matter</u> (see Suggested Resources).
FACTS AND CONCEPTS	During totality of a solar eclipse, very bright stars may be observed by persons in the area of totality. The stars that appear close to the sun during totality are not visible in the evening sky on the date of totality. The stars that appear close to the sun during totality appear in the night sky six months from the date of totality. Because of the earth's revolution around the sun every 12 months, stars alternately appear every six,

months in the nighttime sky and in the daytime sky, but they are not visible in the daytime sky because of the sun's presence.

OBJECTIVES

- The student will be able to postulate revolution, either orally or in writing, on the basis of his observations of the stars visible during a total solar eclipse and of the stars visible in the nighttime sky that night and at intervals through a year.

- From observing stars visible during a total solar eclipse, the student will be able to determine when these stars will be visible in the nighttime sky.

- From his observations of stars visible during a total solar eclipse and from subsequent observations of stars visible in the night sky, the student will be able to calculate the approximate period of the earth's revolution.

MATERIALS

Classroom: styrofoam spheres and light source; for Follow-Up Activities--celestial globe with small earth globe inside.

Planetarium: eclipse projector (or slide showing total solar eclipse and supplementary projector); Eclipse Data Sheet (see page following activity), pen lights, pencils.

PROCEDURES

<u>In the Classroom</u>

1. Review revolution and the conditions responsible for eclipses. Let students use styrofoam spheres and a light source to simulate the conditions required.

2. Ask students to find the date and location of the last total solar eclipse and the next total solar eclipse.

3. Discuss solar and lunar eclipses that students have seen, including partial eclipses. (Students who may have seen total eclipses close to areas of totality should report observations in detail.)

<u>In the Planetarium</u>

1. Distribute the Eclipse Data Sheets. If possible, use an eclipse projector to show a total solar eclipse. Otherwise, project

a slide of a solar eclipse on the dome. In either instance, simulate conditions for the last total solar eclipse as viewed from within the center line of totality. Call for discussion of the relative positions of the sun, earth, and moon which account for the eclipse.

2. When totality is reached, turn on the stars at minimum brightness so that a few bright stars will be visible. Identify any planets. Ask students to record the positions of five bright stars visible in the southern sky. End eclipse.

3. After simulating sunset, show the stars visible the night of the eclipse. Again use minimum brightness and ask students to record positions of five bright stars in the southern sky on their data sheets.

4. Now the nighttime observations should be repeated at three-month intervals through 12 months. For each date, the students should collect the same data as previously.

5. Students can be told to examine the data and to be ready to discuss it during the next class period.

Follow-Up Activities

1. Ask students to look at the stars plotted during the eclipse and at those plotted the night of the eclipse: Are they the same stars? When it is decided that the stars are different, call for an explanation (rotation).

2. Suggest that students compare the six sets of data collected. They should discover the similarity between the daytime stars plotted during the eclipse and the stars plotted at night six months later (as well as in the nighttime data taken 12 months apart). Ask for explanations.

3. When the earth's revolution is agreed upon as the cause of stars visible during an eclipse appearing in the night sky six months later, you might use a celestial globe with a small earth globe inside to reinforce the concept.

4. Students should now use the dates of the various observations to determine the period of the earth's revolution. (Encourage them to write statements which rely only on the evidence collected.)

5. If a student proposes that the same effects would be observed were the sun revolving around the earth, suggest that he do some reading in reference books and

report on the types of evidence that are accepted as proof of the earth's revolution about the sun.

EVALUATION SUGGESTIONS

Give students a worksheet similar to the one used in the planetarium, but have it already filled with data for an imaginary planet (use another period of revolution). Ask the following questions: (a) Which data from nightly examinations most closely resembles the eclipse data? (b) Why are the stars in the same position at these two times? (c) What is the period of the planet's revolution?

The data collected in the planetarium can also be used for evaluation purposes.

VOCABULARY

eclipse
total eclipse
time of totality
area of totality
solar eclipse
partial eclipse
period of revolution
revolution

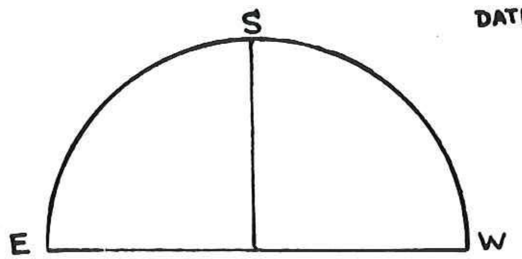
SUGGESTED RESOURCES

<u>Investigating the Earth</u>, ESCP, pp. 84-103.
Namowitz, <u>Stone, Earth Science: The World We Live In</u>, pp. 402-411.
<u>Time, Space, and Matter</u>, Secondary School Science Project, Investigation 5.
Wyatt, <u>Principles of Astronomy</u>, pp. 34-44.
"Eclipses of the Sun and Moon," <u>American Ephemeris and Nautical Almanac</u>.

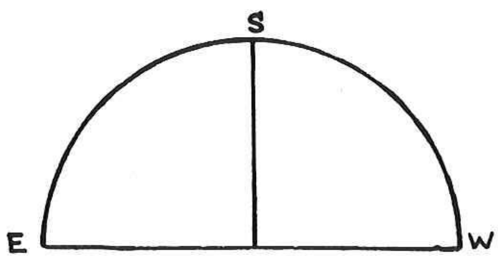
NOTE See following page for Eclipse Data Sheet.

ECLIPSE DATA SHEET

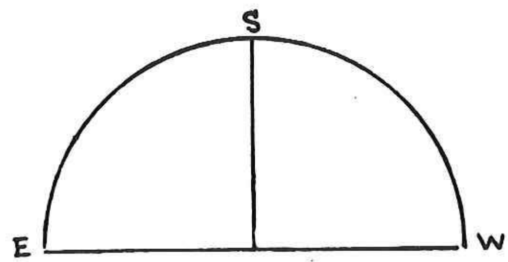
DATE OF ECLIPSE ________



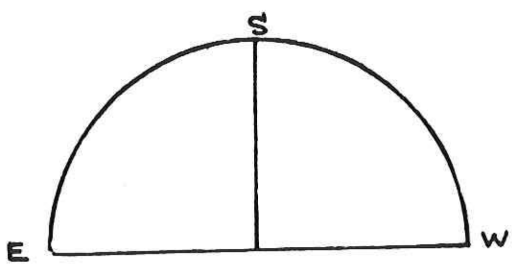
DURING ECLIPSE



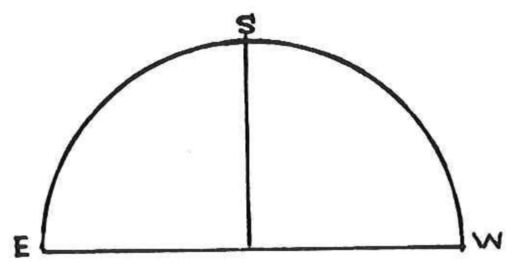
NIGHT OF ECLIPSE



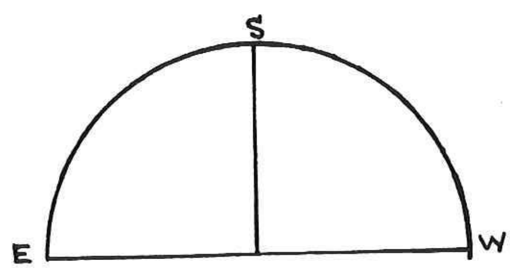
THREE MONTHS LATER



SIX MONTHS LATER

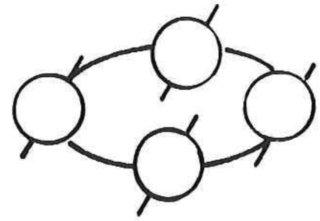


NINE MONTHS LATER



TWELVE MONTHS LATER

DIRECTIONS: FOR EACH TIME MENTIONED, RECORD THE POSITIONS OF FIVE OR MORE OF THE BRIGHTEST STARS OBSERVED IN THE SOUTHERN SKY.



DETERMINING THE SUN'S ANNUAL PATH

Because of popular reference to astrology in song and lore, students become acquainted with the constellations of the zodiac without ever realizing why these constellations were long ago singled out for special homage. In this activity, students will catch up with the ancients, becoming acquainted with the zodiacal constellations as those in that belt of the sky through which the sun seems to pass on its annual journey.

In the planetarium, where the stars behind the sun may be seen, students will plot on a star chart the annual path of the sun--the ecliptic--from month-by-month observations of the sun's position against the star field. There is emphasis on the earth motion (revolution) and the positional relationship (inclination of earth's axis to plane of revolution) which accounts for the path as seen by earthbound man.

STUDENT PREPARATION	Grade level: secondary Content background: understanding of revolution and knowledge of the inclination of the earth's axis in relation to plane of revolution; familiarity with the idea of a celestial sphere; working knowledge of degrees and equatorial coordinate system; (helpful) some familiarity with zodiacal constellations.
FACTS AND CONCEPTS	One effect of the earth's revolution about the sun is the sun's apparent annual path across the sky, called the ecliptic. The ecliptic passes through 12 constellations known as constellations of the zodiac.

The positional relationship of the ecliptic to the celestial equator is defined by the inclination of the Earth's axis with respect to the orbital plane.

OBJECTIVES

- The student will be able to plot the ecliptic on a star map or celestial globe.
- The student will be able to determine and explain the inclination of the earth's axis in relation to the plane of the ecliptic.
- The student will be able to identify the constellations through which the sun appears to move through the year.

MATERIALS

Classroom: earth globe, pinpoint light source; celestial globe; separate charts (large) of the 12 zodiacal constellations; additionally for Follow-Up Activities--object to serve as model sun; protractors; (optional) clear plastic hemispheres, as ESCP variety, and marking pencils.

Planetarium: equatorial star charts not showing ecliptic; note pads, pencils, pen lights.

PROCEDURES

In the Classroom

1. Review revolution and the inclination of the earth's axis. Pairs or small groups of students might be instructed as follows:

   (a) Project a pinpoint light source on an earth globe so that the beam of light shines directly on the equator; next, keeping the rays of light perpendicular to the equator, rotate the globe and, while doing so, circle the globe around the light source. Then in contrast--

   (b) Repeat the general procedure, but tip the globe at an angle of 23½ degrees when lining up the pinpoint light with the equator; keep this angle while rotating the globe and circling it around the light source.

In both of the above procedures, students should observe the path of the beam of light in relation to the equator as the globe completes one orbit.

2. Discuss the path of the beam of light as observed in (b) above as the <u>ecliptic</u>, the annual apparent path of the sun.

3. Using a celestial globe, review concepts of a celestial sphere and of a coordinate system, based on the earth's coordinate system, for designating the location of stars. Tell students that in the planetarium they will examine the ecliptic in relation to the celestial sphere and to the constellations which from Earth are behind the sun each month.

4. Show charts of constellations of the zodiac so that students may become familiar with their names and shapes. Introducing the constellations in order may help students remember them, as well as familiarizing them with their relative positions in the zodiacal belt.

<u>In the Planetarium</u>

1. Turn on the planetarium sky, home latitude, date of visit. After orientation to the setting, ask students to locate and identify the zodiacal constellations visible. Use daily motion so that more may be sighted. Simulate sunrise and fade out the stars.

2. Now, with the sun on the meridian, use annual motion for a brief overview of the sun's annual path through the stars. Ask students which direction the sun seems to move through the star field.

3. Distribute equatorial star charts (these should not show the ecliptic). With the sun on the meridian, run the planetarium instrument through one year, stopping on the 21st of each month for students to:

    (a) Note the constellation in which the sun appears, and

    (b) Plot the sun's position on the star

chart. Briefly turn on the meridian and coordinate system to aid students in accurate plotting.

4. After the plotting is completed, students should be asked to draw a smooth curve through the points marked (or this may be done later in the classroom).

Follow-Up Activities

1. To dramatize the concept that the sun appears to pass annually through a belt of constellations, put charts of the constellations of the zodiac in a circle around the classroom, with equal spacing between each. Position a model sun in the center of the circle. Holding a globe, a student should walk around the model sun in front of the constellations. All students should note which constellation is behind the sun from the vantage point of earth as the globe is moved. They should also observe which constellations would be visible from earth at various times of the year.

2. Ask students to use protractors to determine the positional relationship of the ecliptic to the celestial equator as plotted on the star charts in the planetarium.

3. Use a celestial globe to reinforce ideas of the activity. Or, if you prefer, ask students to transfer the data they collected on the sun's position through the year to clear plastic globes. The students would need to construct the coordinate system first; the plotting should start at the vernal equinox and proceed in the direction of the sun's movement through the stars.

4. Suggest that students use their star charts for the following out-of-door activity: immediately after sunset, draw a north-south line by eye running through the zenith. As soon as possible, locate a zodiacal constellation on the north-south line. Knowing that the sun is approximately 90° west, just below the horizon, determine from the star chart the constellation the sun is in and the approximate date.

EVALUATION SUGGESTIONS

As a test, students may be asked to draw the ecliptic on an equatorial star chart or celestial globe.

Ask students to explain orally, in writing, or through demonstration why the ecliptic does not follow the celestial equator.

Provide students with a sheet listing by month the constellations through which the sun passes. Ask a series of questions such as, "If Virgo appears overhead at midnight, what constellation is the sun in and what month is it?"

Use constellation charts to test memory of constellation shapes and names.

VOCABULARY

zodiac
ecliptic
inclination
inclination of axis
plane of the ecliptic
plane of earth's revolution/orbit
(names of constellations of the zodiac)
zenith   celestial sphere   meridian

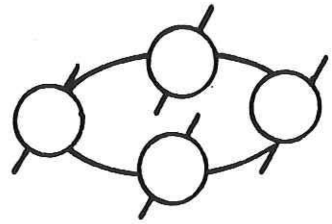
SUGGESTED RESOURCES

Mayall, Wyckoff, The Sky Observer's Guide, pp. 24-25.
Wyler, Ames, The Golden Book of Astronomy, pp. 73.
Wyatt, Principles of Astronomy, pp. 49-50.
Zim, Baker, Stars, pp. 100-101.

Lovi, George, "Rambling Through (the) Skies," Sky and Telescope, centerfold.

Additionally, students particularly interested in lore related to the zodiac might be referred to the books listed under Suggested Resources for the activity "A Visit to the Zodiac" in this publication.


C
D
E
F
G
H
Mizar
Alcor
Megrez
Alkaid



THE ECLIPTIC AND EARTH'S REVOLUTION

Students in high school are aware that the earth annually revolves around the sun and is "tilted on its axis." Even though they assume a causal relationship between these phenomena and the changing positions of heavenly bodies through the year and the seasons, most of them are hard-pressed to offer lucid explanations.

The following activity is designed to clarify the relationships. The students will examine one effect of the two phenomena intensively: the annual apparent path of the sun. In the planetarium, they will observe and record the sun's noontime position on the 21st of each month in relation to the horizon and the celestial equator. Later they will graph and analyze their data, using it to predict the position of the sun on various dates, and dates on which the sun will be observed in particular positions.

STUDENT PREPARATION	Grade level: secondary Content background: knowledge of earth's revolution and inclination of axis; familiarity with the idea of celestial sphere and with the location of celestial objects by the equatorial coordinate system; working knowledge of the measurement of altitude in relation to the horizon.
FACTS AND CONCEPTS	The annual revolution of the earth around the sun and the inclination of the earth's equator to its plane of revolution are responsible for: (a) changes in the position of sun at sunrise, noon, sunset as seen from the earth throughout the year. (b) sun's apparent annual path through the sky--the ecliptic; (c) seasons.

Earth's revolution causes apparent changes in the nighttime sky through the year.

OBJECTIVES

- The student will be able to explain orally or in writing or demonstrate the apparent annual motions of heavenly bodies, including the movement of the sun among the stars.
- The student will be able to use models to demonstrate the earth-sun relationships responsible for the seasons.
- The student will be able to define the ecliptic and determine its location mathematically in relation to the celestial equator.
- Given a date, the student will be able to determine the approximate declination of the sun.
- Given declination of the sun, the student will be able to estimate dates on which that declination would be recorded in the Northern Hemisphere.

MATERIALS

Classroom: earth globes and light source; celestial sphere; for Follow-Up Activities--Graphs A and B, scissors, cellophane tape.

Planetarium: data sheet, pencils, pen lights; (optional) degree markings around planetarium dome.

PROCEDURES

In the Classroom

Review ideas and understandings mentioned under Content Background. You might:

1. Ask students to use a globe and light source to demonstrate diurnal motion, the inclination of the earth's axis, and revolution.

2. Ask them to describe their observations of changes through the year in the position of the sun at sunrise, noon, and sunset. Discuss in terms of altitude and direction.

3. Use an earth and celestial globe to review the concept of a celestial sphere and a celestial coordinate system based on the earth's system for designating the locations of heavenly bodies. Include discussion of <u>declination</u> and <u>right ascension</u> and their notation.

<u>In the Planetarium</u>

1. After turning on the stars (current date, early evening) and orienting students to cardinal points, start diurnal motion and progress through 24 hours, letting the sun rise and set. Discuss apparent daily motion and the position the sun maintained against the background of stars.

2. Return the sun to noon position, current date, with the stars still on. Then to provide a brief overview of annual motion, ask students to note the position of the sun in relation to both the horizon and the background of stars as you use annual and daily motion simultaneously at the same speed and progress through one year at noontime. Students should note the direction the sun seems to move through the star field.

3. Distribute data sheets, turn on the meridian, and repeat, stopping at the 21st of each month. At each stop, students should read and record the altitude of the sun in relation to the horizon. (Note: They should also fill in the space for home latitude.)

4. After discussion of altitude changes, turn on the celestial coordinate system. Ask students to identify the celestial equator and poles and to point out markings indicating right ascension and declination. Now repeat annual motion of the noontime sun, stopping on the 21st of each month for students to determine and record on their data sheets the sun's right ascension and declination. The latter term can be discussed as the sun's altitude in

relation to the celestial equator in contrast with its altitude in relation to the horizon.

5. Observations may now be made of the sun's changing position at sunrise and sunset through the year (manipulate the planetarium instrument as before, keeping the sun on the horizon). Stop at the 21st of various months to permit students to check sunrise/sunset right ascension-declination data with noon data for the same date. Using degree markings around the planetarium dome, the students might also note changes in azimuth at sunrise/sunset through the year.

6. As the above steps proceed, discuss observations and the data being collected. You might ask such questions as: How do annual changes observed in the stars relate to earth motions? What accounts for the changes in the sun's position in relation to the background of stars? How long will it take the sun to return to the same position? What are the maximum and minimum altitudes of the sun and on what dates do these occur? What are the maximum and minimum deviations between the path of the sun and the celestial equator and on what dates do these occur?

7. In conclusion, turn on the ecliptic and discuss it as the annual path of the sun which students have just recorded.

Follow-Up Activities

1. Students should use the data collected in the planetarium (a) to plot on Graph A the altitude of the sun at noon through the year, with dates along the horizontal axis and altitude along the vertical axis; (b) to plot the ecliptic on Graph B, with dates and right ascension along the horizontal axis and declination along the vertical axis. (Note: Remind students to fill in the space for home latitude on Graph A.)

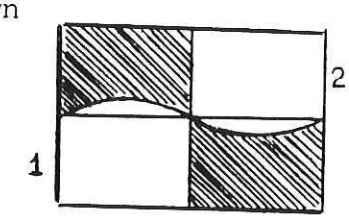
2. Ask students to examine and compare the graphs. Encourage them to find a mathematical relationship between the altitude of the sun at noon and its declination.

3. Let students use (a) Graph A to predict the altitude of the sun at noontime at home and at other latitudes on various dates--and the converse; (b) use Graph B to predict the declination of the sun on various dates, including the equinoxes and solstices--and to predict the date, given declination of the sun.

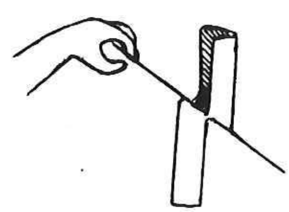
4. (Optional) If students have the necessary background, ask them to describe the curves plotted on Graphs A and B (sine curve). This definition can also be extended to the celestial equator.

5. Students should now cut out Graph B and tape it together. Directions:

   a. Cut out area shown here as shaded. Tape side 1 and side 2 to create the figure shown below. Be careful when cutting not to snip the two unshaded areas apart.



   b. Slide a ruler, as shown, through the figure to observe the plane of the ecliptic in relation to the plane of the celestial equator.



6. Propose that students suggest some "what if" questions for class discussion. (Example: What if the earth's plane of rotation were the same as its plane of orbit--Would this make a difference in the daytime or nighttime sky?)

EVALUATION SUGGESTIONS

Examine students' data sheets and graphs for evaluation purposes.

Let students create and use models to demonstrate what accounts for the apparent movement of heavenly bodies, and the seasons.

Give students a list of dates and ask them to insert the approximate declination of the sun on each date.

Give students declination data and ask them to insert approximate dates.

Ask students to provide a drawing, demonstration or statement explaining the mathematical relationship of the ecliptic to the celestial equator.

VOCABULARY

altitude
axis
inclination of axis
plane of revolution/orbit
diurnal motion   annual motion
equinox   ecliptic   solstice
right ascension   declination
celestial equator
deviation

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 101-105.
Harrison, Sun, Earth, Time and Man, pp. 49-91.
Zim, Baker, Stars, pp. 100-101.
Wyatt, Principles of Astronomy, pp. 49-52.

NOTE See following pages for data sheet and Graphs A and B.

DATA SHEET

NOONTIME POSITION OF SUN THROUGH THE YEAR

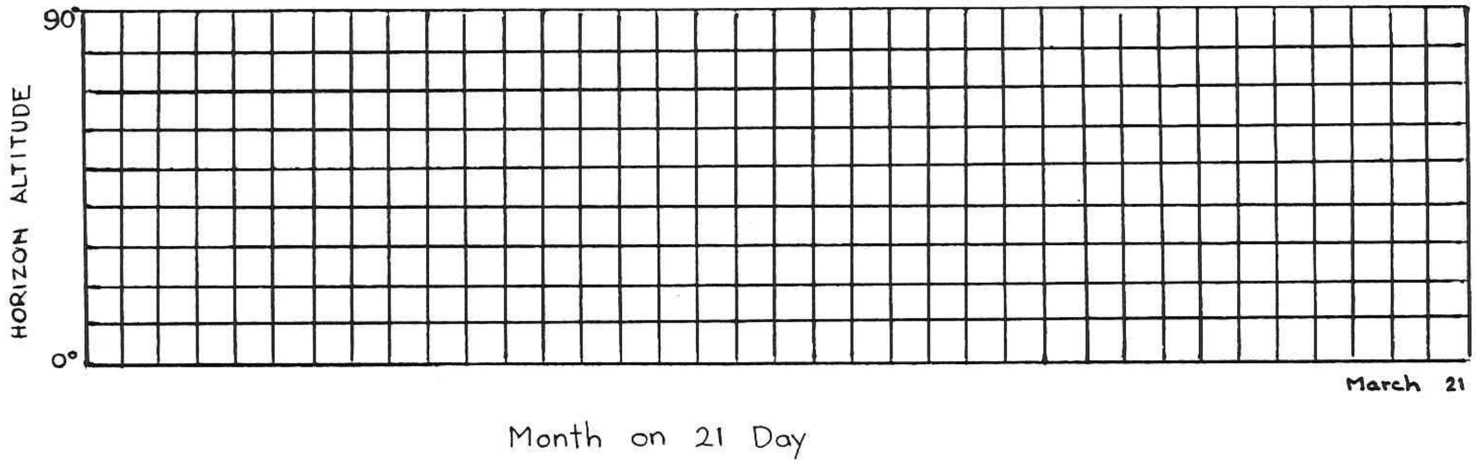
DATE--21st day of each month	ALTITUDE--in relation to horizon	DECLINATION--altitude in relation to celestial equator	RIGHT ASCENSION
MARCH			
APRIL			
MAY			
JUNE			
JULY			
AUGUST			
SEPTEMBER			
OCTOBER			
NOVEMBER			
DECEMBER			
JANUARY			
FEBRUARY			
MARCH			

Home latitude____________

GRAPH A

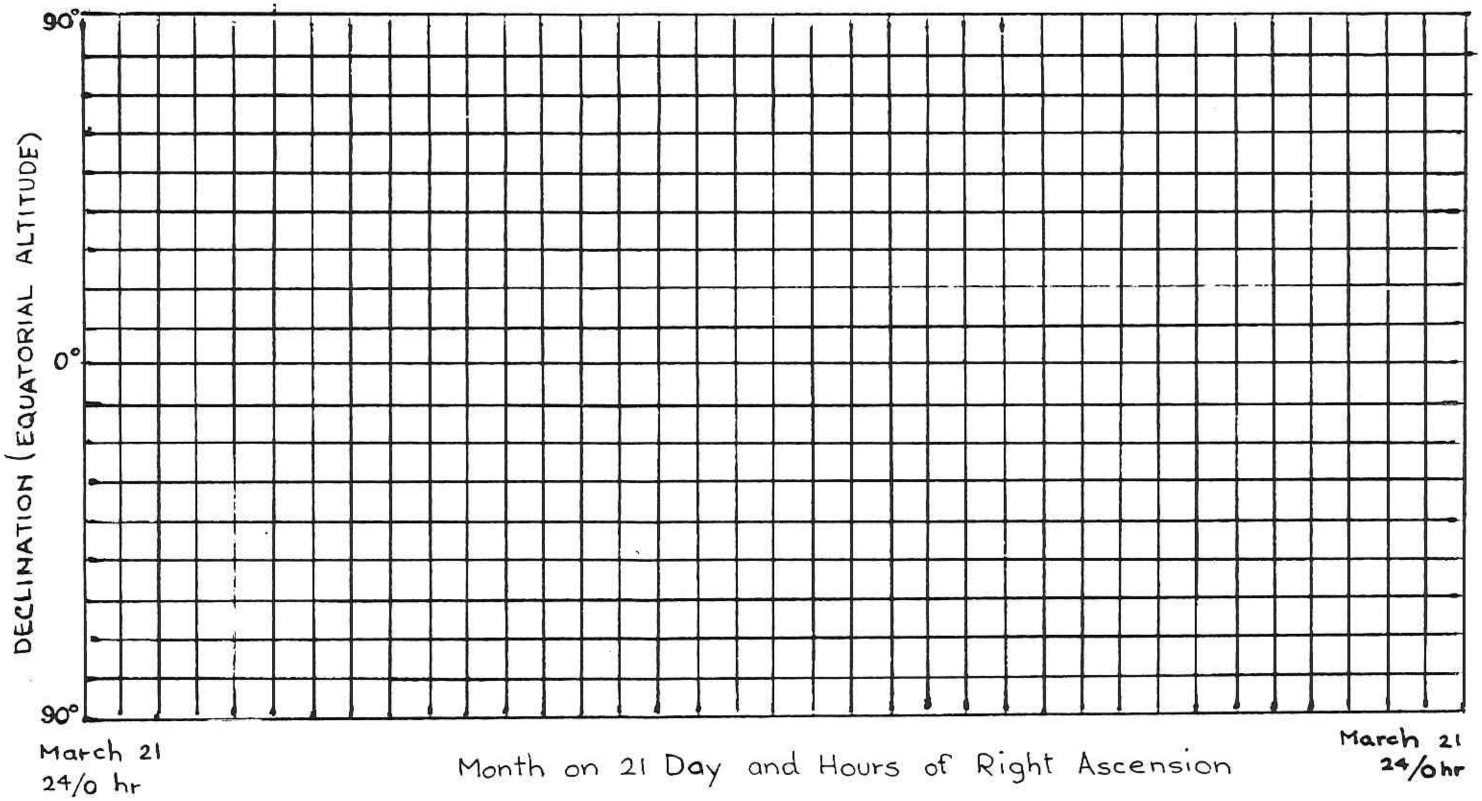
ALTITUDE OF SUN AT NOON THROUGH YEAR

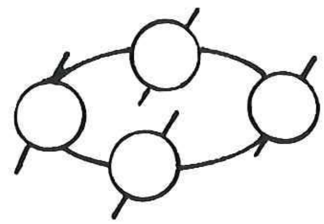
HOME LATITUDE: ______________



GRAPH B

DECLINATION AND RIGHT ASCENSION OF SUN THROUGH YEAR





THE WOBBLE OF THE EARTH'S AXIS

No one can observe the effects of precession in the night-time sky, but the precession cycle--which takes almost 26 milleniums to complete--can be observed and investigated by students in one planetarium session. Most students will find the topic especially interesting--because of the long trips back and forth into time that such a study demands of their imaginations; because of the confusion that a "floating" Polaris lends to their sense of direction; and because of the complications that a backsliding vernal equinox has added to man's measurement of time and his construction of a lasting calendar.

In the planetarium portion of the activity, the students will be permitted to discover the visual effects of precession for themselves. They will observe and graph the changing position of Polaris and observe the constellations of the zodiac creep eastward along the ecliptic to meet the celestial equator.

STUDENT PREPARATION	Grade level: secondary Content background: familiarity with rotation, revolution, idea of celestial sphere, celestial coordinate system, the ecliptic; (helpful) familiarity with zodiacal constellations, prior lessons on time and the seasons.
FACTS AND CONCEPTS	The celestial poles and the celestial equator are not fixed among the stars. Their locations are defined by the earth's rotational axis and equator. Thus their locations change according to a pattern established by a long-term motion of the earth's axis known as precession.

The precession of the earth describes a complete cone approximately every 26,000 years.

This earth motion creates a pattern of changes in the nighttime sky that reoccur in accordance with the cycle.

Observation of the occurrence of the equinoxes earlier in each successive sidereal year and the gradual westward movement of the equinoctial points along the ecliptic are evidence of the change in direction of the earth's axis as it turns around the axis of the ecliptic.

Precession has caused complications for man in the long-term measurement of time and the construction of a lasting calendar.

OBJECTIVES

- The student will be able to chart, describe, and identify long-term changes in star positions which are an effect of precession.
- From data collected in the planetarium, the student will be able to diagram on a star chart the changing position of the north celestial pole during a precession cycle.
- The student will be able to support with data and explanation the saying that the earth "is moving into the Age of Aquarius."

MATERIALS

Classroom: models with which to review rotation and revolution; celestial globe, toy gyroscope (available in toy and variety stores), earth globe, transparent bowl large enough to invert over gyroscope.

Planetarium: geocentric earth projector, precession projector, star charts (north circumpolar and equatorial), graph paper, drawing compasses, pencils, pen lights; grid for projection and supplementary projector. Note: the grid will be projected only over the area of the precession cycle. You can make the transparency by photographing graph paper. It should be made and/or projected so that degrees of the celestial sphere can be approximated from the lines. For this activity remove reference points in planetarium.

PROCEDURES <u>In the Classroom</u>

1. Review rotation and revolution, emphasizing the inclination of the axis of rotation to the plane of revolution. Encourage students to use models in giving explanations.

2. Using a celestial globe, review the location of celestial objects by the equatorial coordinate system. The ecliptic and its location should also be noted and the constellations through which it passes. Also ask students to locate stars and constellations in the north circumpolar region.

3. Ask what star is approximately over the earth's axis and whether this star always has been and always will be there. More knowledgeable students may offer comments on the shifting position of Polaris, but confirmation of such replies can await planetarium experience.

4. Use the toy gyroscope to demonstrate gyroscopic motion. Explain the motion as a spin about an axis which holds the axis in position until an outside force changes it. Observing the gyroscope, students should discover that the outside force of friction on the spinning wheel (caused by the air) slows the wheel, and that this change in speed changes the inclination of the vertical axis. Demonstrate what happens when a force is applied (touch gyroscope with finger) around the horizontal axis: the force causes the horizontal axis to turn (precess) around the vertical axis. Next apply a force to the vertical axis and let students observe precession around the horizontal axis.

5. Now place an earth globe next to the gyroscope on the table. Spin both in the same direction (east to west, as determined by the globe), with their vertical axes perpendicular to the table. Ask students to discuss analogies offered in the demonstration. Then incline the vertical axes of both at an angle of about 23° and repeat.

6. Use the gyroscope and the transparent bowl together for another demonstration. In preparation, invert the bowl over the gyro-

scope after setting it spinning with its vertical axis inclined 23°. Mark the level on the bowl that represents an extension of the gyroscope's vertical axis. At this level glue three very small paper disks (made with a paper hole punch) an equal distance apart around the bowl. For the demonstration, set the gyroscope in motion with its vertical axis inclined as above. Place the transparent bowl over it so that the axis of the gyroscope points to one of the paper disks (stars). As the gyroscope spins, ask students to observe the change in direction of its vertical axis with respect to the paper disks.

7. Ask whether the rotation of the earth, like that of a spinning top, might be slowing down. The students may be asked to read up on this topic--and about precession in general--either prior to, or following, the planetarium visit.

<u>In the Planetarium</u>

1. Turn on the night sky (early evening, date of visit). Orient students to the setting by asking them to locate Polaris. Then project the geocentric earth so that students may examine the location of Polaris in relation to the polar axis. Use the meridian or a projected north point to aid in precise location of the north celestial pole.

2. Show daily and then annual motion so that students may review the visual effects of rotation and revolution separately. The group should be alerted to observe the northern region of the sky particularly.

3. Next, without informing the students what you are showing but simply asking them to observe the northern region of the sky and to be ready to describe observations, (a) run daily motion once, then precess until the North Star is 10° off the north celestial pole, (b) run daily motion a second time, then precess 10°, (c) run daily motion a third time, then precess another 10°.

4. Ask students to describe and identify, if possible, the motions observed. Continue as in Step 3 until a motion not caused by the earth's rotation is described. When you are satisfied that most students have observed the visual effect of precession, again use the geocentric earth and the meridian or a projected north point to draw attention to the new position of Polaris in relation to the polar axis.

5. Precess to Vega. Again ask students to check the location of Polaris and the polar axis. Let a student use a star chart to identify for the class the new "north star."

6. Precess to Thuban, then precess to Polaris, completing the cycle, checking the location of Polaris and the polar axis, and identifying the "north star" at each stop.

7. After discussion of the precession cycle and the earth motion responsible for the star movements observed, distribute graph paper and drawing compasses. Project a grid over the area of the precession cycle and show precession for a full cycle again, making six or more stops. At each stop, students should plot the position of Polaris. Direct them to use the same number of lines on their graph paper as show on the projected grid and, after finishing, to connect the points with a smooth curve. They should also indicate direction of movement (clockwise, counterclockwise).

8. When the observed movement of Polaris has been plotted, give students instructions for numbering the lines (numbering must conform with the number of degrees the grid covers on the dome). Then ask students to find the diameter of the precession cycle in degrees of the celestial sphere. They should write down the figure (47°) for consideration later in the classroom.

9. Now students should observe the equatorial region of the planetarium sky for further effects of precession. With the stars, the coordinates, and the ecliptic on, and with the vernal equinox on the projected meridian, precess. Ask students to observe the crossing of the ecliptic and celestial equator (vernal equinox) and the constellations through which it passes. Continue for one full cycle and call for observations. Discuss the direction of apparent star movement and the length of time it takes all of the constellations of the zodiac to pass through the vernal equinox.

10. Conclude by letting students relate what they have just observed to both astrology and to the approaching Age of Aquarius and other "ages" past and present.

Follow-Up Activities

1. Using data from the graph completed in the planetarium, students should plot on a star chart the right ascension and declination of the north celestial pole for the precession cycle. They should indicate the direction of motion.

2. At the same time they may fill in on their graphs all other stars the polar point passes through, or very close to, in the precession cycle.

3. Assign reading on precession (if not done earlier) and discuss with students the cause of this earth motion. Bring out in the discussion the relationship between the 47° found as the diameter of the precession cycle and the inclination of the earth's axis to the plane of orbit.

4. Discuss with the class the difference (in degrees) that the precession cycle makes in the position of the stars each year as seen from earth. Then let them compute how long it will be before various stars will be the pole star and how long it will be before the earth enters various "ages." Also suggest that students investigate the resulting complications in the construction of a calendar in which seasons remain constant with dates.

EVALUATION SUGGESTIONS

The graphs and star charts may be collected and utilized for evaluation purposes.

Describe various star motions, giving compass direction and coordinates, and ask students to specify whether the motion results from rotation, revolution, or precession. The students may be allowed to refer to star charts.

Ask questions such as: if the vernal equinox is in the constellation Sagittarius, what century might it be? In approximately how many years will Thuban be the North Star?

Ask students to support with data and explanation the fact that the earth is moving into the Age of Aquarius.

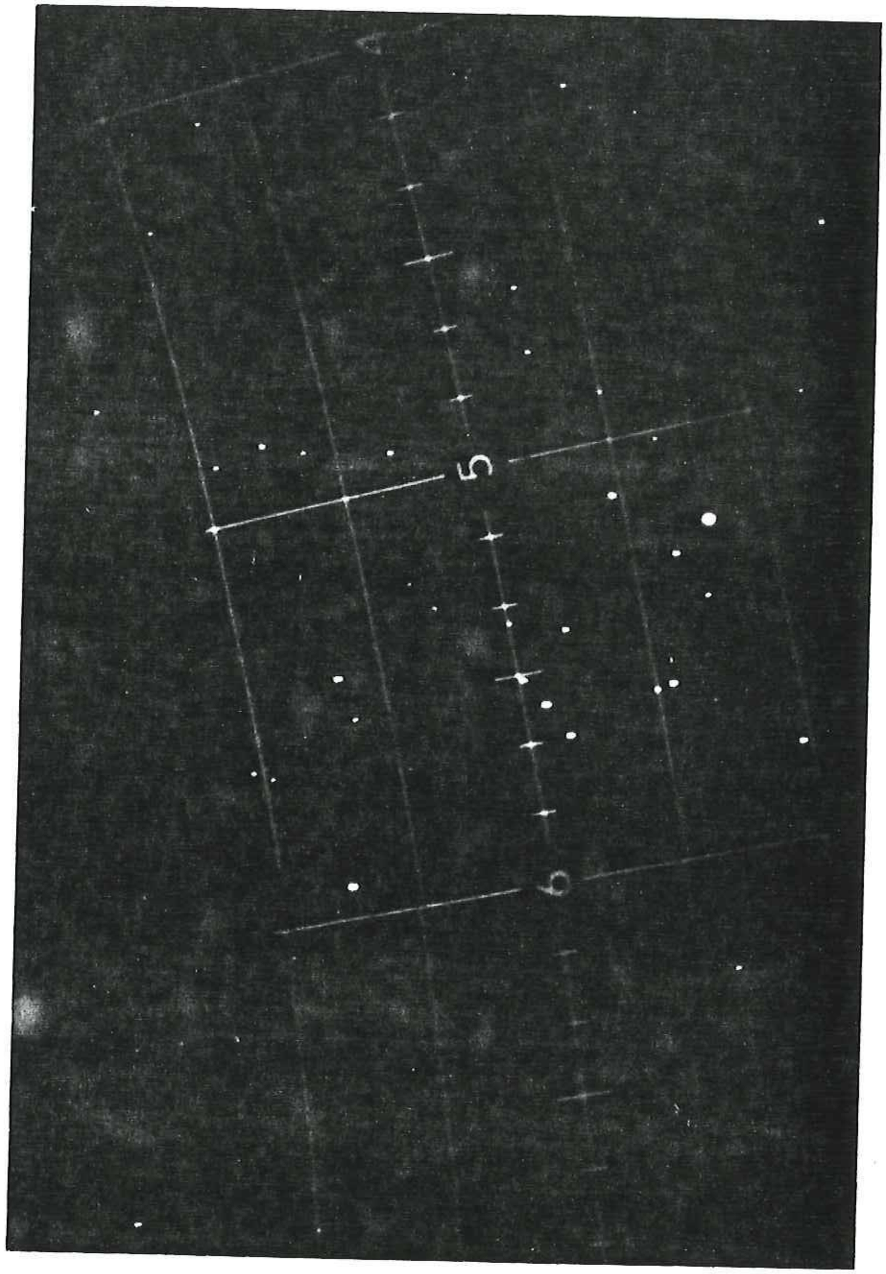
VOCABULARY

ecliptic
precession
precession cycle
right ascension declination
Polaris Vega Thuban
north celestial pole
celestial equator

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 227-233.
Branley, The Earth, pp. 91-97.
Ramsey, et al., Modern Earth Science, pp. 113-114.
Zim, Baker, Stars, pp. 53.

Circumpolar star charts: Sky Publishing Corporation.



THE EARTH IN CIRCLING ROUND THE MOVING SUN,
SEEMS TO GIVE MOTION TO THE NEARER STARS,
BENDING THE TRACKS THEY TRACE ACROSS THE SKY.

— *Aratus*

Celestial Coordinate Systems

Can a student imagine trying to find a person if his address were simply "Anywhere, Earth"? This would be the predicament of astronomers if they wished to communicate about a new discovery in the heavens and had no way of pinpointing precise locations. True, the stars do not move (much)--but the earth turns, and people live in different places. At each moment, each place offers a different view of the stars.

The activities in this section are designed to introduce students to basic coordinate systems which are used to catalogue the positions of celestial objects. The activities also emphasize that certain fundamental characteristics are common to all coordinate systems--whether the coordinates are projected on a world map by a cartographer, transcribed on an abstract figure by a mathematician, or superimposed on a celestial sphere by an astronomer.

SHIFTING ADDRESSES FOR STARS

Although the use of altitude and azimuth for designating the location of stars is limited in astronomy, the basic method used (a Cartesian coordinate system) and the measurement techniques employed are common to more sophisticated methods. Students will acquire skills for determining altitude and azimuth coordinates. Experiences in the planetarium will point up the limitations of these shifting addresses for stars and develop understanding of star movement.

STUDENT PREPARATION

Grade level: secondary
Content background: understanding of ordered pairs and their use in a coordinate system; ability to use longitude-latitude coordinates to find points on a map and globe; understanding of angular measurement and the units used (degrees); preferably acquaintance with a few bright stars.

FACTS AND CONCEPTS

A Cartesian coordinate system can be used for locating points on a plane surface.

A Cartesian coordinate system can be used for locating points on a spherical surface.

Determination of altitude and azimuth constitutes a Cartesian coordinate system for designating temporary locations of celestial objects from any given point on the earth.

OBJECTIVES

- Using a projected hand sextant and degree markings around the base of the planetarium dome, the student will be able to determine and record the altitude and azimuth of selected bright stars in the planetarium sky.

- Given a compass and an astrolabe or hand sextant, the student will be able to determine the altitude-azimuth of the sun in the real sky.

- The student will be able to express altitude and azimuth in conventional terms.

MATERIALS

Classroom: maps and globe; compass--one for every two students; hand sextant and astrolabe--one of both for class purposes, one of either for every two students; eye-safety device. (See Appendix for details on last three items.)

Planetarium: degree markings at 10° intervals around planetarium dome; planetarium sextant projection device (see Appendix); at least one compass (perhaps more) and one regular hand sextant; notepads, pencils, pen lights; data sheet with the following column headings--

STAR DATE TIME ALTITUDE AZIMUTH

Note: make degree markings with strips of white cardboard 1 inch wide and 12 inches long. Tape at 10° intervals around dome. However, if planetarium is oriented with cardinal points, you may prefer that the students use compasses throughout the activity rather than degree markings.

PROCEDURES

<u>In the Classroom</u>

1. Review the use of ordered pairs in determining location. For example, a student may sit in the <u>fourth</u> seat from the left in the <u>third</u> row; Mountain City, Nev., lies close to the <u>116th</u> meridian and <u>42nd</u> parallel.

2. Allow some practice in finding points on a map and globe from

given latitudes and longitudes.

3. Ask students to speculate how a coordinate system might be used to designate the location of a star from any given place at any given moment. Press for the answer that the star will have an elevation in relation to the horizon and a direction in relation to compass points.

4. Explain that "altitude," as used in astronomy, is the angular distance of an object measured on a vertical circle from the horizon through the object and toward the zenith. It ranges from 0° to 90°.

5. Using a compass to illustrate, discuss how compass direction, or azimuth, is located from a fixed reference point (north point). Explain notation: from 0° to 360° around the horizon clockwise from north.

6. Review angular measurement with questions such as, How do you find degrees, given a section of a circle? What use would a surveyor make of a base line to find the elevation of a hill?

7. Distribute compasses, astrolabes, and/or hand sextants (or materials for making one of the latter two instruments) and help students learn to use them properly. They might practice by determining the altitude and azimuth of selected points inside and outside of the classroom. (Note: It is desirable for students to get acquainted with both an astrolabe and hand sextant.)

<u>In the Planetarium</u>

1. After asking students to work in pairs and passing around the materials they will need, dim cove lights and project the planetarium sky (no motion), preset for early evening, date of visit.

2. Determine cardinal points (using compass if planetarium is appropriately oriented), mark on dome, and point out that the horizon is marked at 10° intervals.

3. Ask for suggestions on how to take a good azimuth reading, particularly for stars far above the horizon. A pencil, edge of a sheet of paper, or string with weight attached could be used for lining up horizon degree markings with stars.

4. Point out a bright star and ask several students to determine its altitude from where they are sitting with a regular hand sextant. Discuss their readings with the class and the reason for differences.

5. Project the planetarium sextant, calibrating it with the meridian, and explain use of the projected degrees of altitude. Let students discuss and try out, if possible, the position (center of room) from which a regular hand sextant would need to be used for good accuracy.

6. As you point to several stars, ask the class to determine their azimuth and then altitude, using the projected sextant.

7. Distribute data sheets (described under Materials). Announce the planetarium setting--date and time. Then as you point, one by one, to six bright stars and have them identified by name, ask students to determine their azimuth and, with the aid of the projected sextant, their altitude.

8. Advance daily motion three hours and ask students to repeat the measurements for the same stars. After letting the students locate them (or as many as are still visible), point to them as before so that mistaken identity will not confuse results.

9. Advance daily motion another three hours and repeat Step 8. Then, if time, do this again.

10. Discuss the paths of the six stars in terms of both observations and data. Students will note that (a) some of the stars were in the sky longer than others, (b) each star's location, according to altitude-azimuth coordinates changed--more so for some stars than for others. Some students may also have observed that a star low on the horizon as it crossed the meridian was only in the sky a short time.

11. The above procedure might be repeated for the sun and for the moon.

Follow-Up Activities

1. Give the class three sets of altitude-azimuth coordinates four hours apart for several stars and ask students to visualize and describe their movements across the sky.

2. Give students altitude-azimuth coordinates of specific objects in the room and ask them to use an astrolabe or hand sextant to locate and identify the objects.

3. Discuss the limitations of altitude-azimuth coordinates for designating star location. Suggest some readings and reports to the class on how altitude-azimuth is used in navigation.

4. Making altitude-azimuth determinations in the real sky will be interesting for students and will reinforce concepts of diurnal movements of the sun, moon, and stars as seen from Earth. Suggest that students use an astrolabe or hand sextant and compass to determine the location and movement of objects in the real sky.

EVALUATION SUGGESTIONS

Evaluate student performance on the data sheets developed in the planetarium.

Give students the altitude-azimuth of selected points outside the classroom and ask them to identify the objects located at the points, using a compass and astrolabe or hand sextant.

Ask students to record the position of the sun. That they may do this without danger to their eyes, provide them with eye-safety devices (see Appendix).

VOCABULARY

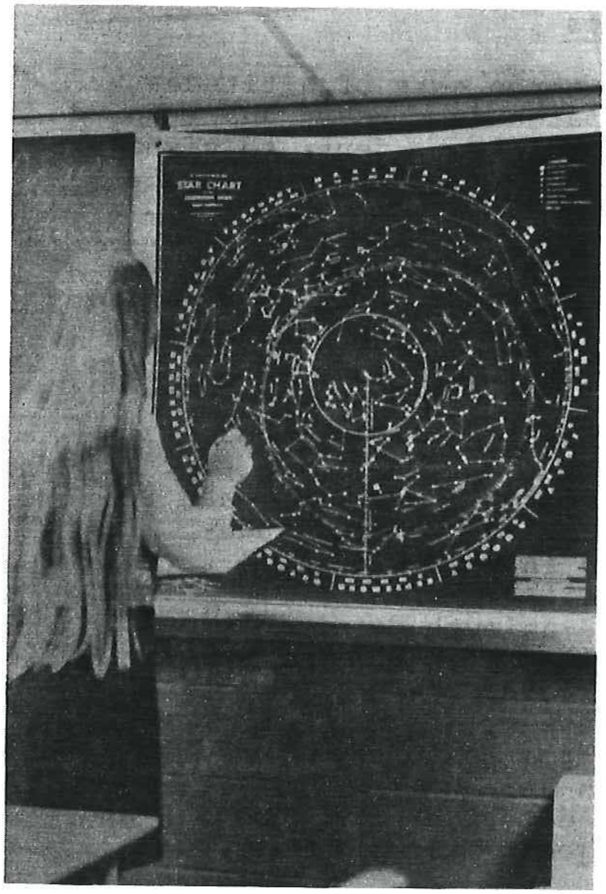
altitude azimuth zenith horizon
longitude latitude
north point
astrolabe sextant base line

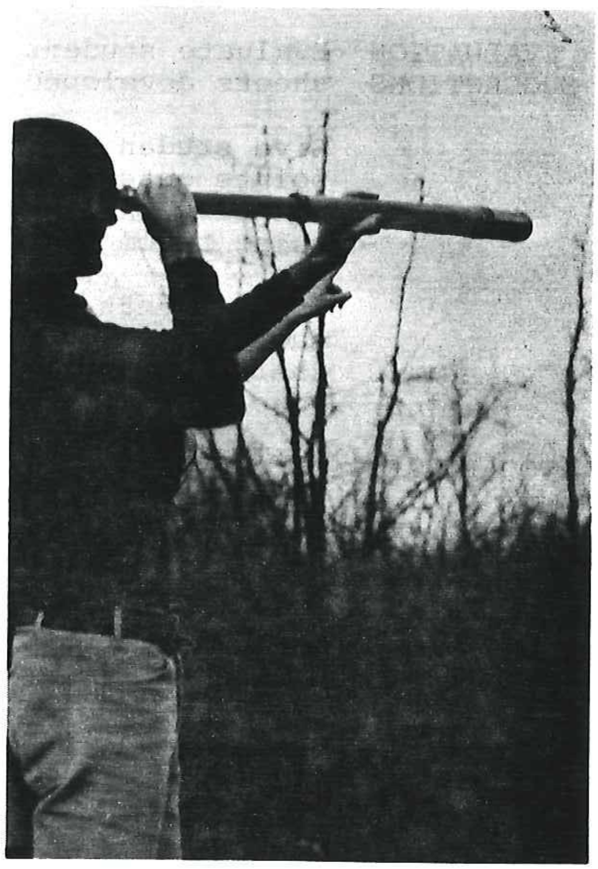
SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 95, 621.
Investigating the Earth, ESCP, pp. 60-68.
Joseph, Lippincott, Point to the Stars, pp. 20-21.

NOTE

For details on student-made planetarium sextant, astrolabes and hand sextant, and eye-safety device, see Appendix.


STAR CHART



PERMANENT ADDRESSES FOR STARS

Although the general location of a star can be designated by its position in a constellation--or locally at a given moment by altitude and azimuth--a universal system is needed that tells precisely where each star is located in relation to others. In this activity, students will be introduced to the equatorial coordinate system, learning how exact positions of stars in relation to a fixed system can be stated and used.

The planetarium provides an excellent setting for developing the concept of a celestial sphere and for demonstrating the equatorial coordinate system as an extension of latitude and longitude coordinates.

STUDENT PREPARATION

Grade level: secondary
Content background: understanding of longitude and latitude; familiarity with altitude and azimuth and how they are determined.

FACTS AND CONCEPTS

The equatorial coordinate system provides a means of defining with fixed values the locations of objects in the sky.

All spherical coordinate systems have the same basic framework.

OBJECTIVES

- Given the necessary information and/or instruments, a student will be able to locate objects in the planetarium or real sky by using the equatorial coordinate system.
- Given equatorial coordinates for the stars in a constellation, the student will be able to plot the constellation on graph paper.

- Given right ascension and declination, a student will be able to locate objects on an equatorial star chart.

MATERIALS Classroom: maps and globes; per student, a small earth globe and clear plastic hemispheres (such as those used in the Earth Science Curriculum Project lessons), pencil for marking on plastic. Additional classroom materials are noted in the Follow-Up Activities and in Evaluation Suggestions.

Planetarium: geocentric earth projector, coordinate projector; slide with list of coordinates of various bright stars and supplementary projector; per student, equatorial star chart, pencil, pen light.

PROCEDURES Note: Although not included below, a review of the use of altitude and azimuth for determining star location--and the limitations of the system--might be incorporated into either the classroom or planetarium work.

In the Classroom

1. Distribute small earth globes and review with students the concept of a spherical coordinate system as illustrated by that of the earth. Include the physical basis (axis of rotation) that defines the fundamental great circle (equator); the poles (ends of axis); small circles with planes parallel to the equator (parallels marking latitude); and the secondary great circles which intersect the poles, including the prime meridian (all used for indicating degree of longitude).

2. Introduce the idea of a celestial sphere--the half globe we see above us, the other half that is below the horizon. As an aid to imagining, distribute clear plastic hemispheres. Ask students to assume that the two hemispheres are placed together to represent the celestial sphere and they, the students, are inside at the center looking out from a very tiny blue Earth.

3. Call for suggestions on a celestial coordinate system that might be appropriate for the celestial sphere. When a system comparable to that used for the earth is suggested, elicit explanation in detail (as in Step 1).

4. Now ask students to fit the plastic hemispheres over the small earth globe and use a marking pencil to extend the earth's coordinates to the celestial sphere. Let them examine results and how they "created" the coordinate system.

5. Tell the class that in the planetarium there will be opportunity to explore the celestial globe and its coordinate system further.

In the Planetarium

1. Start with the geocentric earth set for the North Pole. After orienting students to the setting, use the continents as reference and review the earth's coordinate system.

2. Add the celestial coordinate system (still from North Pole) and discuss it as an extension of the earth's system. Explain lines indicating declination in terms of latitude, noting that the numbering of degrees--known as degrees of declination--is the same as for terrestrial latitude and starts from the celestial equator. Explain lines indicating right ascension in terms of longitude, but emphasize differences: the measurement of degrees is in hours of right ascension from a west to east direction starting at the vernal equinox--the prime meridian of the celestial sphere.

3. Now move the geocentric earth to home location, adding the meridian, and repeat Steps 2 and 3. Discuss similarities and differences between the earth and sky systems.

4. Turn on the stars, set for early evening, date of visit. Identify some bright stars and ask the class to locate them by equatorial coordinates.

5. Now eliminating the geocentric earth, use only the meridian and coordinate system. Start daily motion. As some of the stars located previously reach the meridian, ask again for their location by equatorial coordinates. (You might take this opportunity to ask for comments on the practicality of hour measurement for right ascension and for ideas as to why degrees of "latitude" are called degrees of declination.)

6. Project a list of coordinates of some major stars. Let various students use your pointer to locate them on the dome.

7. Distribute the equatorial star charts and help students get acquainted with the equatorial coordinate system as it looks when reduced to two dimensions. Then ask

students to circle the appropriate stars on the chart as you point out certain stars on the planetarium dome and/or give their coordinates.

8. Point out that although the real sky has no projected grid showing right ascension and declination, that the coordinate system has very practical uses, as the students will see in some later activities.

Follow-Up Activities

1. Guide general discussion on (a) the differences and similarities between the terrestrial coordinate system and the equatorial coordinate system, (b) differences and similarities between azimuth-altitude coordinates and equatorial coordinates.

2. Ask students to suggest how the equatorial coordinate system might be used for locating objects in the real sky. What information would be needed in addition to an equatorial star chart?

3. Suggest that students investigate the telescope as an instrument--not the lens, but how it is set for sighting particular stars.

4. Propose that some students make star maps using equatorial coordinates, offering them directions to be found in "Astronomy--A Resource Guide for Teachers," by R. Lynn Bondurant (see Suggested Resources below).

5. If possible, have an evening session. Set up a telescope and guide students in how to use the setting circles and a conversion table to find selected stars.

6. As a project for individuals, encourage the construction and use of an equatorial coordinate star finder. The one pictured and described (see Appendix) has the same setting circles as a telescope, but only a simple sighting tube.

7. In connection with the two suggestions above, you might consider introducing the concepts of sidereal time, hour angle, etc., so that students could see the methods actually employed by astronomers. For example, you might give the students an object to look for whose right ascension would be such that at the present time it would be below the horizon and not visible. This emphasizes the idea that an observer is usually concerned about where the star is not only in relation to other stars but also with respect to his position and the time of his observation. But a thorough investigation of time as a factor to be contended with would require another planetarium session.

EVALUATION SUGGESTIONS

Ask students to plot a number of objects on a star chart using right ascension and declination.

Give students right ascension and declination and ask them to find the objects on a star chart.

Give students graph paper, ask them to construct the equatorial coordinate system; then give them right ascension and declination for the stars in a prominent constellation, and ask them to plot the stars.

VOCABULARY

pole — equator
axis of rotation
terrestrial coordinate system
great circle
fundamental great circle
secondary great circle
longitude — latitude — prime meridian
parallels
equatorial coordinate system
vernal equinox — declination — right ascension

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 95, 621.
Bondurant, Astronomy: A Resource Guide for Teachers, pp. 44-45 (has directions for making a star map, using equatorial coordinate system).
Investigating the Earth, ESCP, pp. 58-81.
Huffer, Trinklein, Bunge, An Introduction to Astronomy, pp. 86-87.
Ramsey, Burchley, Modern Earth Science, pp. 98-106.
Wyatts, Principles of Astronomy, pp. 68-69.

NOTE

For picture and description of student-made equatorial coordinate star finder, see Appendix.

HIGH NOON: DETERMINING LATITUDE

Since students are generally unaware of the latitude of their own communities, it often comes as a surprise that latitude can be determined by celestial observation and a simple calculation. Students will learn to measure the sun's noon position with respect to the horizon and use the results to find local latitude. Understandings which underlie the calculation are developed through inquiry procedures in the planetarium.

STUDENT PREPARATION

Grade level: secondary
Content background: lessons on rotation, revolution, seasons, terrestrial and equatorial coordinate systems--preferably including planetarium visits during which students have observed and recorded the apparent annual path of the sun through the sky.

FACTS AND CONCEPTS

As an observer changes his latitude on earth, the celestial equator changes its altitude relative to the zenith and horizon.

The latitude of an observer can be calculated by measuring the sun's noon altitude after determining the time of year and declination of the sun from a reference.

OBJECTIVES

- The student will be able to calculate latitude from the sun's noon position after determining the necessary information.

- The student will be able to furnish evidence to support the concept that the sun has a predictable apparent path across the sky.

- Using the proper instruments, the student will be able to measure the altitude of the sun in the planetarium or real sky.

MATERIALS

Classroom: celestial globe with small earth globe inside; astrolabes--or materials for making them (see Appendix); eye-safety device (also in Appendix).

Planetarium: geocentric earth, projector; coordinate projector; pencils, pen lights, note pads; data sheets with columns headed:

DATE	ALTITUDE OF SUN	DECLINATION

PROCEDURES

In the Classroom

1. Review topics mentioned under Student Preparation, using concrete objects. A celestial globe with a small earth globe inside will be appropriate for reviewing the concepts of a celestial sphere and of an equatorial coordinate system based on the terrestrial system. This teaching aid will also be excellent for developing or reinforcing the idea that as you change latitude on the earth, the celestial equator changes its altitude relative to the zenith and horizon.

2. Introduce or review the measurement of altitude. If this is the first time students have been asked to measure altitude, they should make their own instruments and practice measuring the altitude of various objects in the classroom.

In the Planetarium

1. Preset the planetarium sun to local latitude, vernal equinox, at noon. After orienting students to cardinal points, announce the time of "day," and ask students the azimuth of the sun. Then turn on the meridian and ask them to read its altitude.

2. Eliminating the sun temporarily, turn on the geocentric earth and coordinate projector. Ask students to observe the position of the celestial equator in relation to the zenith. You might discuss in what position, relative to the zenith and horizon,

the sun would be seen at noon on the vernal equinox by people in various areas of the world.

3. Distribute data sheets. Now using only the coordinate projector and the meridian, show the sun again at vernal equinox, local latitude, noon. Ask students to reread and write down the altitude from the meridian on the data sheet, noting the date, and to use the coordinate system to find and record the sun's declination.

4. Continue by using annual motion, keeping the sun on the meridian, and stopping on the 21st of each month for one year so that students may collect data for 12 months. (Check around to see that students are recording declination properly, using negative numbers to indicate declination south of the celestial equator.)

5. When columns for altitude and declination have been completed, suggest that students look at the two sets of data and examine them for a pattern. (All students will probably notice that changes in altitude are accompanied by changes in declination; most will recognize that the pattern of changes as recorded undergoes an alteration following dates of the equinoxes and solstices; probably quite a number of students will either know, or sense, a direct relationship--and this will no doubt be reflected in the "accuracy" with which they read the projected coordinates.) Discuss patterns observed, letting students express them in their own words.

6. Now return with the sun to the 21st of one month. Ask the class to tell you the month, using the data previously collected and getting the group to agree on the most accurate reading for altitude and declination. Ask each student to look at the agreed-upon data carefully and to try to develop an equation for determining local latitude.

7. After checking around to see how students are doing and giving time for independent discovery, let students present their equations for class discussion. Then using an opaque projector, present

   $$\text{Latitude} = 90° - (\text{altitude} - \text{declination}),$$

   which students may or may not have been expressing clearly. Ask students to test out the equation several times with the data collected. Note whether they are doing the operations correctly.

8. Reset the planetarium sun for another selected latitude, asking students to read and record on a fresh sheet of paper the sun's altitude and declination and to use these measurements to determine the latitude. Repeat for several additional latitudes.

Follow-Up Activities

1. Immediately following the planetarium visit, the class should examine graphically the mathematics of the equation for latitude. In presenting the following elucidation, let students make as many suggestions as possible.

   Start with Figure 1 below in which O is the observer, Z the zenith, and CE the celestial equator.

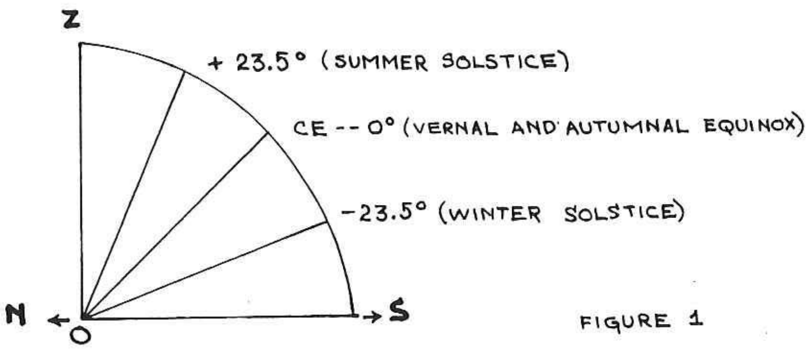


FIGURE 1

   The distance from the celestial equator to the zenith of the observer is equal to the observer's latitude. Therefore, angle ZOCE = latitude. But the sun is located at CE only on dates of the vernal and autumnal equinoxes. At other times it shifts from CE (0°) to +23.5° on June 21 to -23.5° on December 21. To determine latitude by the sun, you must return the sun mathematically to the equator by a correction factor--the sun's declination.

   Show Figure 2, with months on the x-axis and declination on the y-axis, for an examination of the correction factor.

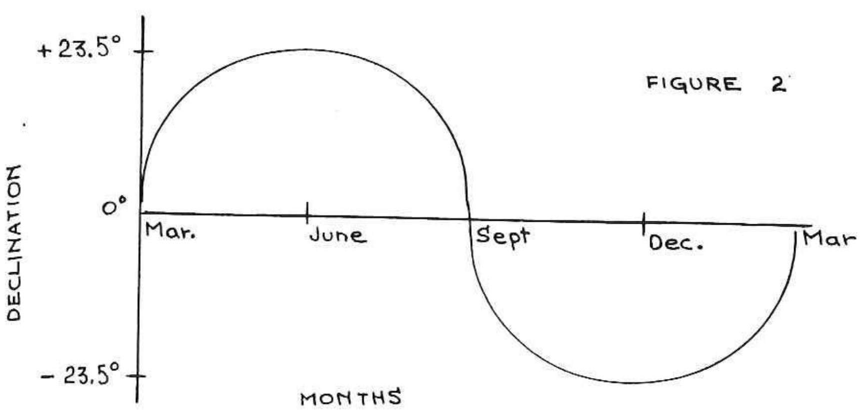


FIGURE 2

The correction factor, declination, may be easily determined as shown above after plotting the annual path of the sun with respect to the celestial equator. (For the development, students can provide declination data from their planetarium data sheets.)

2. By using the equation for latitude, students can now find the latitude for any location, given altitude and declination of the sun at noon. Offer some problems.

3. By using Figures 1 and 2, students may solve for latitude of any location, given the data and altitude of the sun at noon. You might let students suggest problems for class solution.

4. Propose that students use their astrolabes and determine other equipment/information they will need to find local latitude by measuring the altitude of the sun at noon. Let them suggest how they will determine noon, according to the sun. Warn against direct viewing of the sun while taking measurements and equip students with suitable eye-safety devices.

EVALUATION SUGGESTIONS

Check and evaluate the results of student work during the last step of the planetarium activities.

Note how competently each student solves the problems offered.

Ask students to write a paragraph supporting the idea that the sun appears to move in a predictable annual path.

VOCABULARY

celestial sphere
celestial equator
equatorial coordinate system
latitude
zenith
altitude
declination
meridian
equinox
solstice

SUGGESTED RESOURCES

Ramsey, Burckley, Modern Earth Science, pp. 102-103.
Huffer, Trinklein, Bunge, An Introduction to Astronomy, pp. 123-125.
Investigating the Earth, ESCP, pp. 63-65.

NOTE

For student-made astrolabes and eye-safety device for viewing the sun, see Appendix.

USING ECLIPTIC COORDINATES

Depending on the purpose of an astronomical investigation, the location of celestial objects is specified in different ways. Although the altitude-azimuth and equatorial coordinate systems are the most commonly used, astronomers often prefer ecliptic coordinates for studies of planetary positions and orbits.

In this activity, students will examine the ecliptic system and use it in the planetarium to locate stars.

STUDENT PREPARATION

Grade level: secondary
Content background: familiarity with altitude-azimuth and equatorial coordinate systems; understanding of the ecliptic as the apparent annual path of the sun.

FACTS AND CONCEPTS

The ecliptic coordinate system is based on the apparent annual path of the sun through the sky.

The annual path of the sun appears to form a great circle in the sky, called the ecliptic, which is inclined to the celestial equator by an angle of about 23.5°. This angle is called the obliquity of the ecliptic.

The north and south ecliptic poles are points 90° away from all points on the plane of the ecliptic.

The vernal equinox is the point where the sun in its annual journey appears to cross the celestial equator going north. The comparable point of crossing going south is the autumnal equinox.

OBJECTIVES

- The student will be able to describe verbally, graphically, with a model, or in some written form the ecliptic coordinate system.
- The student will be able to transfer positional data from the equatorial system to the ecliptic system, given devices for measurement.

MATERIALS

Classroom: celestial globe, scale for measuring angles on globe, string, marking pencil.

Planetarium: coordinate projector, planetarium sextant projector (see Appendix); pencils, pen lights; Ecliptic Coordinate Data Sheet (see page following activity).

PROCEDURES

In the Classroom

1. Review the ecliptic, asking students to describe what it is and its location in relation to the celestial equator. Define its angle of inclination (23.5°) as the obliquity of the ecliptic.

2. Give each group of students a celestial globe, a suitable protractor for measuring angles on it, a string, and marking pencil. Ask them to mark the string at 10° intervals appropriate to the globe.

3. First students should locate the ecliptic and measure the angle of its inclination to the celestial equator, noting and naming the points of crossing.

4. Ask students how an ecliptic coordinate system might be developed (and see if they relate this idea to the equatorial coordinate system). When the suggestion is made that the ecliptic poles will lie 90° from the ecliptic, the students should be directed to locate and mark these points on the globe. Ask them to note the coordinates of the ecliptic poles in the equatorial coordinate system. (The NEP lies in the constellation Draco at about right ascension 18 hours and declination +66.5°; the SEP lies in the constellation Dorado.)

5. Ask how ecliptic latitude might be determined (see note on terminology in Vocabulary section). Let groups develop the system. All that needs to be done is to draw a great

circle (or great half circle) which passes through both poles of the ecliptic and to mark this line in degrees. Emphasize that this great circle will be perpendicular to the ecliptic because any great circle drawn through the two poles of another great circle will intersect it at right angles. Confirm that notation for latitude in the ecliptic system is the same as in the equatorial coordinate system, with latitudes north of the ecliptic designated as plus (+) and latitudes south of the ecliptic designated as minus (-).

6. Ask how ecliptic longitude might be measured. Confirm that it is measured eastward for 360° along the ecliptic from the vernal equinox, pointing out that the units used are degrees (not hours of right ascension as in the equatorial coordinate system). As students might expect, the vernal equinox is assigned the coordinates 0°-0°.

7. Give the equatorial coordinates of several stars and ask groups to locate them and to determine their ecliptic coordinates. Students can proceed by (a) locating the star by equatorial coordinates, (b) stretching the scaled string through the poles of the ecliptic so that it passes through the star--thus determining the latitude, and (c) using degree markings--or the scaled string--around the ecliptic to determine longitude.

<u>In the Planetarium</u>

1. Project the star field and coordinate system. Ask a student to explain to the class how the grid is used.

2. Point out several bright stars. Ask the class to determine their right ascension and declination.

3. Distribute data sheets. Ask each student to fill in equatorial coordinates for the first six locations mentioned (vernal and autumnal equinoxes, summer and winter solstices, north and south celestial poles).

4. Turn on the ecliptic. Discuss the ecliptic coordinate system--its basis, location of the poles, and notation.

5. Project the meridian and planetarium sextant to provide a grid for ecliptic coordinates. Discuss the grid. Then ask students to determine the right ascension and declination of the north and south ecliptic poles, plus the ecliptic coordinates for the other six locations mentioned.

6. Give students the equatorial coordinates of several

bright stars and ask them to determine their ecliptic coordinates, entering both sets of data on the data sheet.

Follow-Up Activities

1. Discuss various coordinate systems, the components they have in common, and their similarities and differences.

2. Ask students to report on the origin and uses of the various coordinate systems for specifying star location.

EVALUATION SUGGESTIONS

Ask students to describe orally, in written form, or through use of a model the different coordinate systems used for designating the locations of stars.

Use the completed data sheets as a basis for evaluation.

VOCABULARY

ecliptic
ecliptic coordinate system
ecliptic poles
ecliptic latitude* ecliptic longitude*
obliquity
equatorial coordinate system
celestial equator celestial poles
right ascension declination
solstice equinox

*The terms celestial latitude and celestial longitude as used in the ecliptic coordniate system are giving way to the more modern terms ecliptic latitude and ecliptic longitude.

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 93-98, 478-480, 621-622.
Huffer, Trinklein, Bunge, An Introduction to Astronomy, pp. 81-93.
Wyatt, Principles of Astronomy, pp. 65-70.

NOTE

See following page for Ecliptic Coordinate Data Sheet.

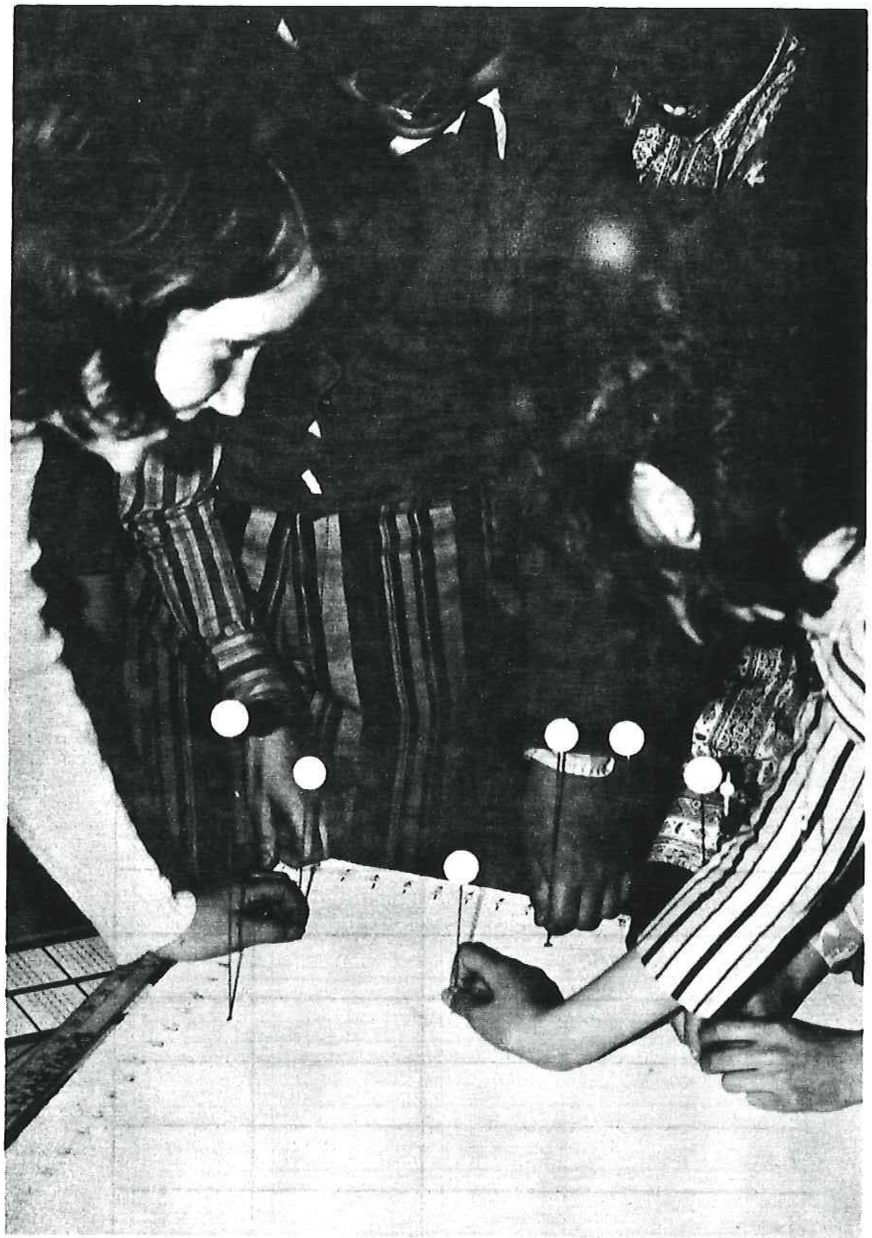
ECLIPTIC COORDINATE DATA SHEET

Sec. 1

LOCATION	EQUATORIAL Dec.	R.A.	ECLIPTIC Long.	Lat.
Vernal equinox				
Autumnal equinox				
Summer solstice				
Winter solstice				
North celestial pole				
South celestial pole				
North ecliptic pole				
South ecliptic pole				

Sec. 2

CELESTIAL OBJECT		
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		



USING GALACTIC COORDINATES

When astronomers study objects deep in the Milky Way and relationships among them, they need a coordinate system based on the galaxy itself, rather than one whose physical basis relates to the earth. As students are introduced to the galactic coordinate system in the activity below, they will use investigative procedures in the planetarium to find the galactic equator and galactic poles. Then, through the use of the planetarium sextant, they will specify the location of stars by galactic coordinates.

The versatility of the planetarium instrument offers excellent opportunity to display the circular shape of the band of the Milky Way--and this will help students grasp the idea that the band marks the central portion of a system (galaxy) of stars.

STUDENT PREPARATION	Grade level: secondary Content background: understanding of, and ability to use, coordinate systems generally and the equatorial coordinate system particularly; some prior study of Milky Way galaxy.
FACTS AND CONCEPTS	The plane of the Milky Way can be used to define a coordinate system by which celestial objects can be located. Every star that can be seen by the naked eye belongs to the Milky Way galaxy.
OBJECTIVES	Given an appropriate device for measurement, the student will be able to locate selected celestial objects by using the galactic coordinate system.

- The student will be able to locate the north and south galactic poles.

- The student will be able to identify the intersection of the galactic plane and the celestial equator.

- Given an appropriate instrument, the student will be able to measure the inclination of the galactic plane to the celestial equator.

- The student will be able to point out constellations or bright stars in the following areas: (a) north and south galactic poles, (b) intersection of galactic plane and celestial equator.

MATERIALS Classroom: earth globe, celestial globe, star chart.

Planetarium: planetarium sextant (see Appendix); degree markings around base of planetarium dome; pen lights, note pads, pencils.

PROCEDURES <u>In the Classroom</u>

1. Use an earth and celestial globe to review the components of coordinate systems.

2. Point out band of the Milky Way on celestial sphere and ask students to describe its appearance in the night sky. Present examples showing that the equatorial coordinate system has limitations for defining the locations of stars deep in space; for example, if astronomers wish to study spacial relationships among objects in the galaxy, they prefer a coordinate system that relates directly to the galaxy.

3. Tell students that in the planetarium they will find out how to locate stars by a galactic coordinate system.

<u>In the Planetarium</u>

1. Turn on the night sky, date of visit. Ask students to point out the Milky Way and to identify the area where the concentration of stars seems to be the highest.

2. Change latitude and rotate (daily motion) for the best view of the concentration. When the concentration is reidentified,

briefly turn on the coordinates, getting students to observe that the concentration is south of the celestial equator in the region of Sagittarius. Ask: Since this appears to be the highest concentration of stars in the Milky Way, what might this indicate? (That it might be the center of the galaxy.)

3. Ask students to notice other areas of concentration in either direction and to observe the extent of the band of light.

4. Manipulate latitude and use daily motion as necessary to place the band of the Milky Way around the horizon. Discuss position of the band in relation to the horizon--that is, the center of the band now lies <u>on</u> the horizon.

5. Project a zenith and the meridian. Ask students to measure the altitude to the zenith (90°). Using latitude motion, rotate the sky 180° so that the other half of the band of the Milky Way appears on the horizon. Again ask the class to determine the degrees from the horizon to the zenith. Discuss what the above observations indicate. (That the band must be in the center of a system, or galaxy, of stars).

6. Ask the class for suggestions on how a galactic coordinate system might be developed for specifying the location of stars in relation to other stars in the galaxy. Elicit that the galactic equator would be in the center of the band, that the galactic poles would lie 90° from all points on the plane of the equator. Students should now recognize that the galactic equator was located around the horizon and that the projected zeniths, 90° from the horizon, marked the north and south galactic poles.

7. Change the sky as necessary and help students locate the galactic poles again. Discuss that the north galactic pole is in Coma Berenices and that the south galactic pole is marked by Sculptor. To verify that the poles are 180° apart, use altitude-azimuth motion as needed to put the galactic equator on the meridian and ask students to measure angular distance between the two poles.

8. Now use the heading on the planetarium instrument to align Sagittarius with the meridian. Then with the class assign to the point marked by Sagittarius 0° galactic latitude and 0° galactic longitude. Students should note that the meridian intersects the galactic equator at the points 0°, 0° and 0°, 180°.

9. With Sagittarius still aligned with the meridian, again place the band of the Milky Way around the horizon. Project the planetarium sextant (or meridian) and ask the class to determine the galactic latitude of several stars. Discuss notation (the north and south galactic poles are assigned +90° and -90°, respectively).

10. Ask for suggestions on measuring galactic longitude. (Simply measure angular distance from the reference point, Sagittarius, all the way around the horizon from 0° to 360°.) Explain that measurements are made clockwise from Sagittarius toward Cygnus. Ask the class to determine the longitude of several stars using the degree markings around the dome.

11. Give the class the galactic coordinates of some bright stars. Ask students to use your pointer to identify the objects in question, as you provide the necessary grid for latitude by projecting the planetarium sextant.

12. As you point out several bright stars, ask each student to determine and write down their galactic coordinates.

13. Discuss with students the stars visible in the planetarium and nighttime sky. Return the planetarium setting to the night sky, date of visit. Emphasize that all the stars we see with the naked eye belong to the Milky Way galaxy and that our position in the galaxy accounts for our particular view of the system.

14. In conclusion, turn on the coordinate system and ask students to observe the band of the Milky Way in relation to the celestial equator. At what angle would the center line of the band intersect the galactic equator? To provide an answer to this question, project the planetarium sextant along the band so that students may determine the inclination of the galactic equator to the celestial equator (about 62°). Then using motion as needed, point out constellations in areas of the intersections so that students, if they wish, may identify these points of crossing in the nighttime sky.

Follow-Up Activities

1. Review various coordinate systems used in astronomy, their derivation and uses.

2. Show and discuss various galactic coordinate charts.

3. Having determined that the plane of the galactic equator is inclined approximately 62° to the celestial equator, students in the class may be able to construct a galaxy map. Suggest that they do so.

4. Suggest that students do research and write reports on the use of galactic coordinates by astronomers.

EVALUATION SUGGESTIONS

Step 12 in the planetarium procedures can serve for evaluation purposes.

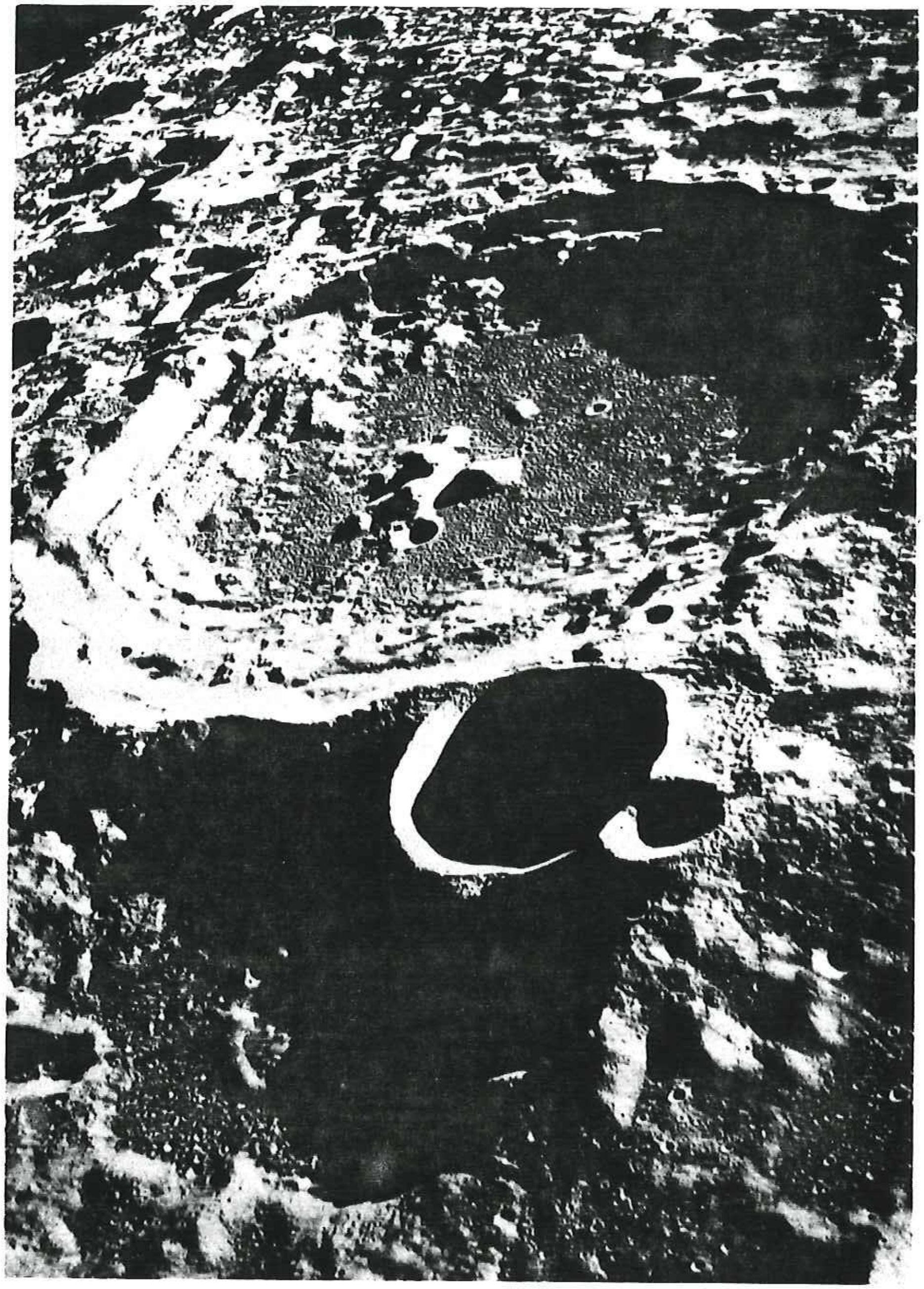
VOCABULARY

Milky Way band of Milky Way galaxy
galactic equator galactic poles
galactic latitude galactic longitude
inclination angular distance
(names of stars and constellations emphasized)

SUGGESTED RESOURCES

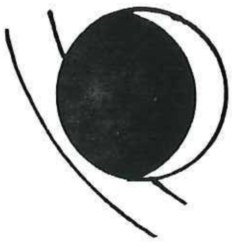
Abell, Exploration of the Universe, pp. 478-480, 621-622.

Wyatt, Principles of Astronomy, 1st Ed., pp. 70, 458; 2nd Ed., pp. 74-75. 560-561.



THE SILVER MOON O'ER BRINEY SEAS PRESIDES,
AND HEAVES HUGE OCEAN WITH ALTERNATE TIDES.

- *Lucan's Pharsalia*
(*Rowe's trans.*)

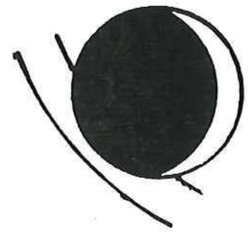


The Moon: Earth's Silvery Orb

The silvery orb that lighted the pathway of early man through the dark night--then thrust him into sheer terror when it eclipsed the sun--has been the symbol of his fascination for the wonders of the universe since time began.

In 1969, the moon took on a greater meaning for Earthlings when the first human being set foot on the lunar surface. The explorations students make must be limited to classroom and planetarium--but these activity excursions can be exciting and worthwhile. By observing Earth's nearest neighbor in space, students will learn about the section of the solar system of which they are a part.

This series of activities allows the students to investigate the relationship of the three most important members of the solar system (from the earth-bound point of view): the earth, sun, and moon. By actively examining moon phases, eclipses, tides, the student will gain an understanding of his portion of the solar system and an appreciation of the importance of systematic observations of celestial objects.



THE MOON AT SUNRISE AND SUNSET

While most young children are aware that the moon seems to change its shape, few of them recognize the cyclic nature of these changes. This activity is planned, first, to help children develop ability to observe and recognize recurring patterns; second, to introduce informally the phases of the moon.

By observing and recording the changing shapes of the moon at sunrise and sunset for a month, outdoors and then in the planetarium, the children will become aware that these changes recur in a consistent pattern and relate to the relative positions of the sun and moon as viewed from earth.

STUDENT PREPARATION

Grade level: elementary
Content background: knowledge of cardinal points; prior lessons on rotation and revolution; understanding that the moon orbits the earth.

FACTS AND CONCEPTS

Due to reflected sunlight, we are able to see the moon.

Over a period of time, the moon appears to change its shape.

The moon appears to change its shape in a pattern that repeats itself.

There is a relationship between the shape of the moon and the position of the moon with respect to the sun as seen from Earth.

OBJECTIVES

- The student will be able to indicate on a diagram the changing positions and shapes of the moon as observed at sunrise.

◐ The student will be able to indicate on a diagram the changing positions and shapes of the moon as observed at sunset.

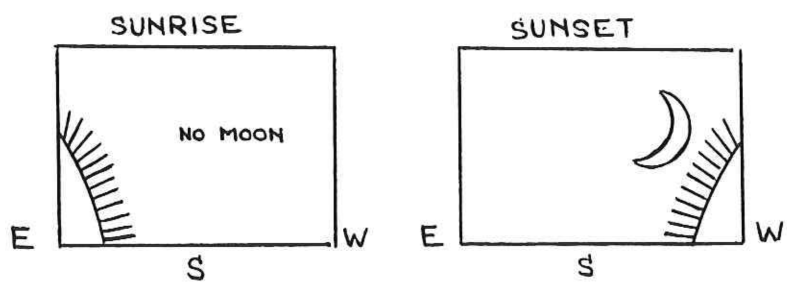
◐ Given one apparent shape of the moon, the student will be able to predict the next shape that will appear.

MATERIALS Classroom: materials to use as sun-earth-moon models; light source, earth globe, aluminum foil; for evaluation--Moonwatch Evaluation Sheet (see end of activity).

Planetarium: sun, moon; Planetarium Moonwatch Data Sheet (four per pupil--see end of activity); pen lights, pencils.

PROCEDURES <u>In the Classroom</u>

1. Starting one month before the planetarium visit, pupils should carry out an outdoor sunrise-sunset moonwatch. Assign pairs of pupils to look for the moon and record in pictures its position and shape (a) as close to sunrise as possible, and (b) at sunset. The class record for each day might be kept as follows, with the record also showing the position of the sun:

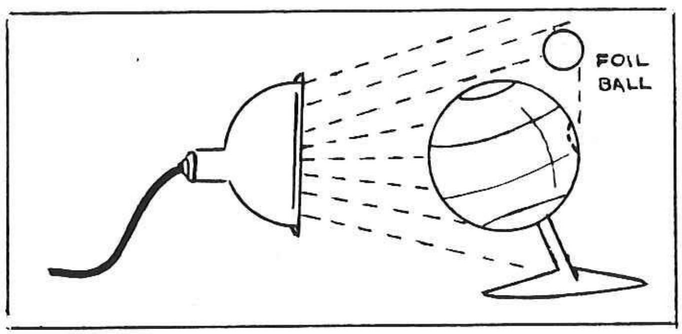


Date: April 20
Notes: No Moon at Sunrise, Clear

If the sky is overcast, or if clear but no moon, these conditions should be entered as "notes." You can discuss cardinal points and zenith in connection with the record.

2. As the moonwatch goes along, pupils should review earth and moon motions, using models. They should discuss the real shape of the moon (spherical) and the way this shape appears to us from the earth (as a disk).

3. The children know that man has been on the moon. The light we see from the moon, therefore, cannot be the same as the light we see from the sun and other stars which are "burning." Ask what accounts for the light from the moon. In explanation for the class, present a simple demonstration of reflection such as shown in the sketch below. The "moon" is a small ball or wad of paper covered as smoothly as possible with aluminum foil.



4. The children should examine what causes the spot of light on the side of the globe opposite the "sun." (Note: the reason for the various shapes of the moon as observed from earth is not the point of this activity, but children who are observing the moon for a month may press for the reason. If so, it can be pursued through a demonstration such as suggested in the activity on phases of the moon in this publication.)

In the Planetarium

Presetting: Set the planetarium sun, moon, and stars for the current lunar cycle, with the moon close to waxing cresent and the sun about to rise.

1. Turn on daily motion allowing the sun to rise. Discuss the setting with pupils, including the cardinal points and date.

2. Distribute Planetarium Moonwatch Data Sheets (four per pupil) . Ask children in what position the sun is at

sunrise relative to cardinal points. When they decide that the sun rises in the eastern sky, ask them to draw the sun in the appropriate position of each picture marked "sunrise" on the four data sheets.

3. Ask, "Can we see the moon on this day at sunrise?" When it is determined that no moon is visible, the children should write "no moon" in the sunrise picture number 1.

4. Use daily motion, permitting the children to view the moon as it rises later in the morning. Then continue daily motion until sunset.

5. At sunset, stop motion, and ask the children in what direction the sun sets. When they decide that the sun sets in the western sky, let them draw the sun in the appropriate position on each picture marked "sunset" on the four data sheets.

6. Now ask the children to record in sunset picture number 1 the position and shape of the moon as they see it in the sky. Check and discuss the shapes drawn, asking children to observe whether the points of the crescent moon are pointed toward or away from the sun.

7. Use annual motion to advance planetarium to first quarter phase, sunrise. Announce new date. Ask children to look for the moon (again, no moon), and make the proper entry in the sunrise picture number 2.

8. Use daily motion (again children will see the moon rise--now later in the day). Stop at sunset. The children are to record the moon's position and shape on sunset picture number 2.

9. Continue as above, alternating annual and daily motion to show the position and shape of the moon at sunrise and sunset for each phase through new moon and asking children to record observations. After new moon, reshow waxing crescent.

10. Discuss the pattern of the changing shapes and positions of the moon, asking the children to recall moon changes observed during the outdoor moonwatch the previous month.

11. You might ask such questions as the following, encouraging children to use their data sheets if they wish in giving answers:

    a. Did the moon appear to change in shape gradually or all at once?

    b. What shape was the moon when it appeared in the western sky at sunset? When it was high in the sky at sunset? When it appeared in the eastern sky at sunset?

c. What shape was the moon when it was in the western sky at sunrise? High in the sky at sunrise? When it appeared in the eastern sky at sunrise?

d. From sunrise to sunset, in what direction did the sun appear to move?

e. How did the moon appear to change its shape and position when you watched it outdoors?

f. What do you think the moon would look like a few days after we last recorded its position and shape? What would be the best place to look for it in the evening sky?

Follow-Up Activities

1. Select a sequence of record sheets from the outdoor moonwatch which illustrate the phases and post them in a row on the board. Underneath post a similar set of pictures selected from the planetarium moonwatch data sheets. Let pupils examine and compare the two sets of pictures.

2. Ask pupils to observe the moon at sunset and sunrise and predict from its location and shape its shape and location four days later.

3. If the lesson has been successful, you can expect the children to want information on the cause of the phases. See the activity which follows.

EVALUATION SUGGESTIONS: Ask children to predict the coming phase of the moon from pictures of the current phase.

Use the Moonwatch Evaluation Sheet provided with this activity.

VOCABULARY

sphere
reflection
rotation orbit revolution
(names of phases of moon as discussed)

SUGGESTED RESOURCES

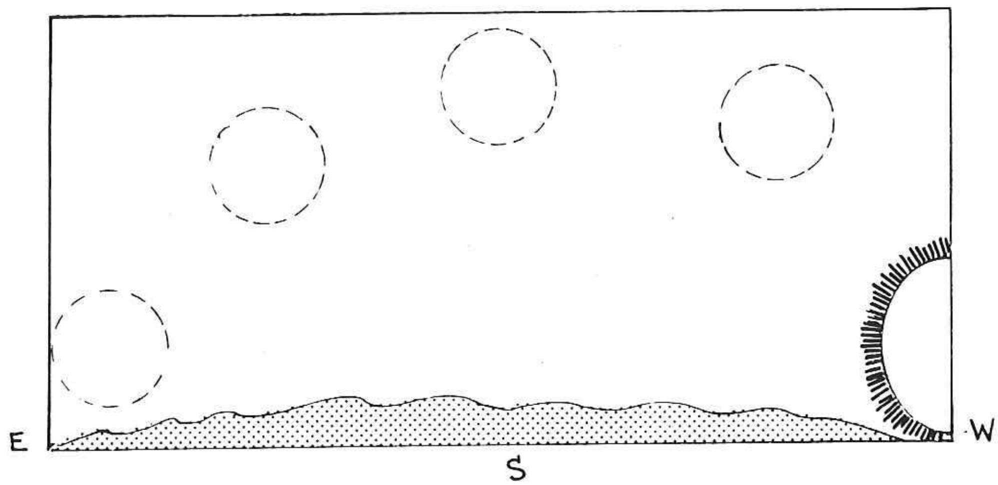
Abell, Exploration of the Universe, pp. 173-174.
Gallant, Exploring the Moon, pp. 56-57.
Jacobson, Lauby, Konicek, The Moon, pp. 4-5, 10-19.

NOTE

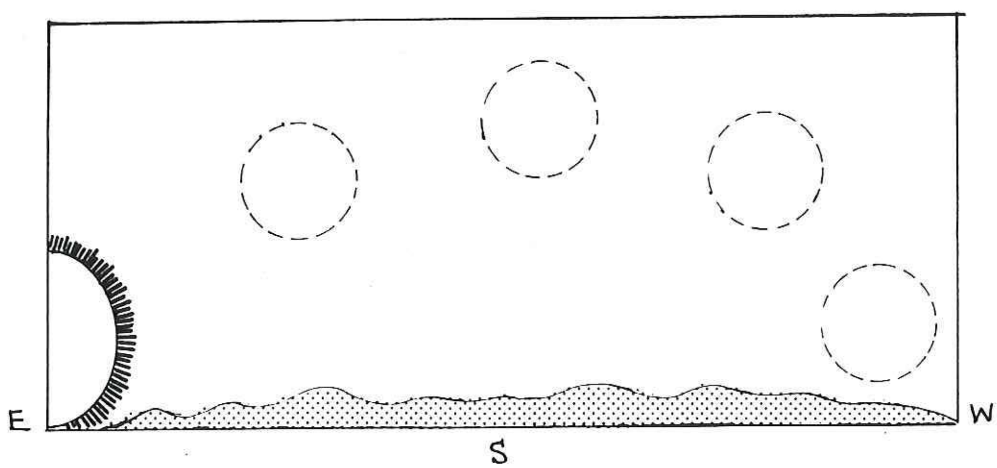
See following pages for Planetarium Moonwatch Data Sheets and Moonwatch Evaluation Sheet.

MOONWATCH EVALUATION SHEET

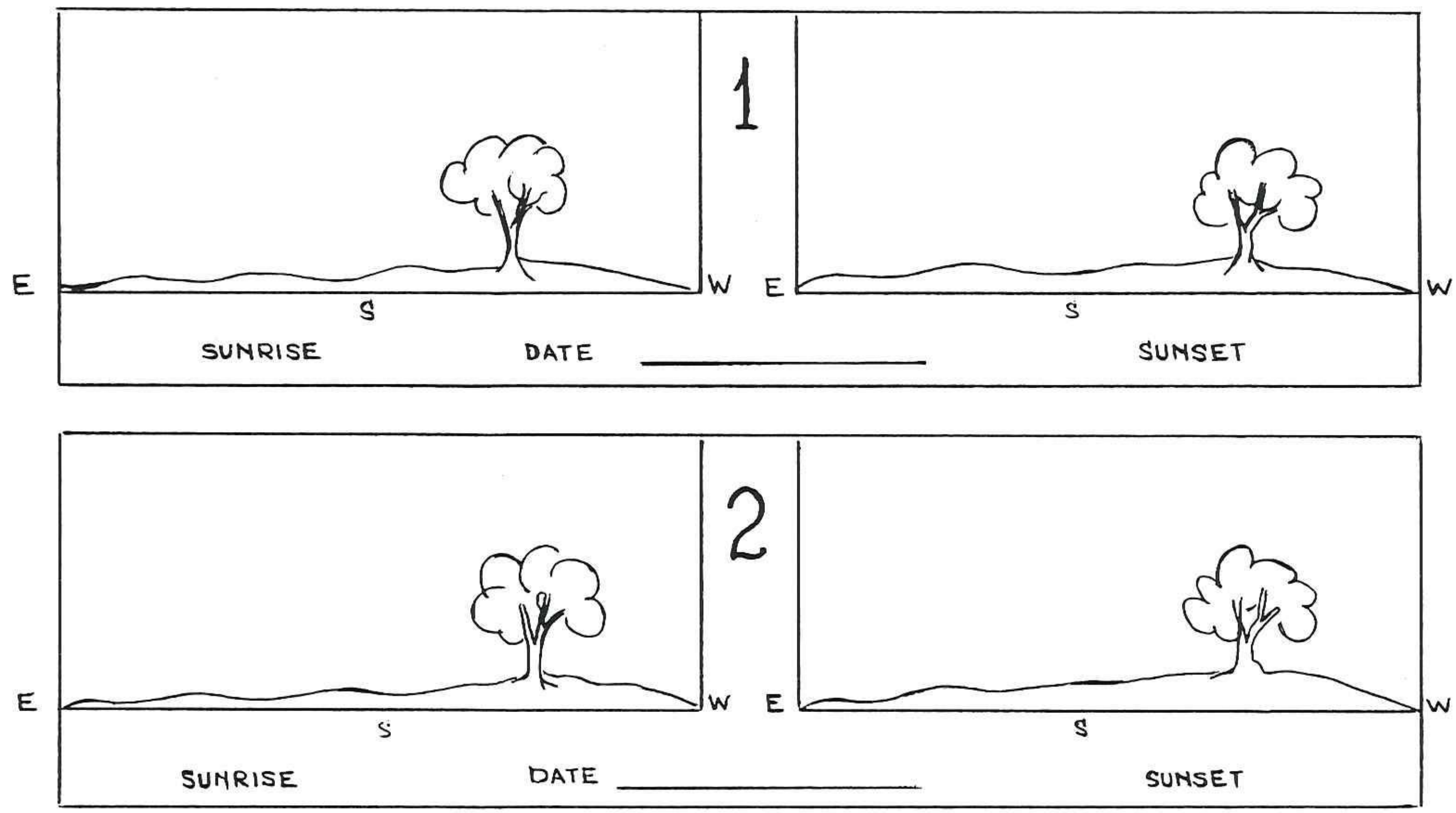
At sunset the moon can be seen at different times of the month in any of the positions shown below. Draw what its shape will look like in each position. Then draw an arrow to show the direction the moon changes its position from day to day during the month.



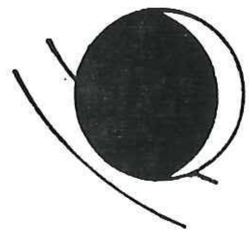
At sunrise the moon can be seen at different times of the month in any of the positions shown below. Draw what its shape will look like in each position. Then draw an arrow to show the direction the moon changes its position from day to day during the month.



PLANETARIUM MOONWATCH DATA SHEET



Directions to be given pupils in recording each observation: (1) draw the sun to show its position in the sky; (2) draw the moon to show its position and shape; (3) if you don't see a moon, write "no moon"; (4) if you see only part of a moon, draw what you see and use a dashed line to show what you think the part that you don't see looks like. NOTE: Except for numbering of picture frames, the other three data sheets are identical. With young children, you may want to use one data sheet per phase to accommodate larger pictures.



THE PHASES OF THE MOON

A youngster may have observed that the moon as viewed from the earth changes in shape regularly and consistently. It will be easy for him to learn the names of the phases, but grasping the sun-earth-moon positional relationships responsible for them will be more difficult for him to achieve.

In the following activity, children are introduced to the phases of the moon through manipulating a moon-phase model in the classroom. Later in the planetarium they observe how the changes in sun-earth-moon positions affect the appearance of the moon in the nighttime and daytime sky. The planetarium instrument gives them opportunity to observe the moon's journey through the stars during the entire lunar month--a convenience that the real sky cannot accommodate.

STUDENT PREPARATION	Grade level: elementary Content background: familiarity with cardinal points, horizon, meridian; prior lessons on rotation, revolution, orbit of the moon around the earth; (preferably) acquaintance with some of the seasonal constellations.
FACTS AND CONCEPTS	During the revolution of the moon about the earth, the relative positions of the sun, earth, and moon change. This causes sunlight to be reflected toward the earth by different portions of the side of the moon facing us. Thus the changing positional relationships of the sun, earth, and moon caused by the moon's orbit about the earth are responsible for the phases of the moon--that is, for the apparent changes in its shape as viewed from earth.

The revolution of the moon about the earth is directly responsible for the changes we view from earth in the moon's position among the stars.

OBJECTIVES

- Given data on the relative positions of the sun, earth, and moon on a particular date, the student will be able to draw and name the moon phase on that date.
- The student will be able to identify the phases of the moon by name and list them in sequence.
- Using a sun-earth-moon model, the student will be able to demonstrate what causes the phases of the moon.

MATERIALS

Classroom: materials for moon-phase models, including large sheets of corrugated cardboard (cut from sides of large cartons), long nails, styrofoam balls, masking tape, light source; constellation charts; for follow-up activities and evaluation--various materials for student-made earth-sun-moon models (paint and more styrofoam balls, large sheets of cardboard, nails); photos of moon phases; NASA photos of Earth phases (if possible).

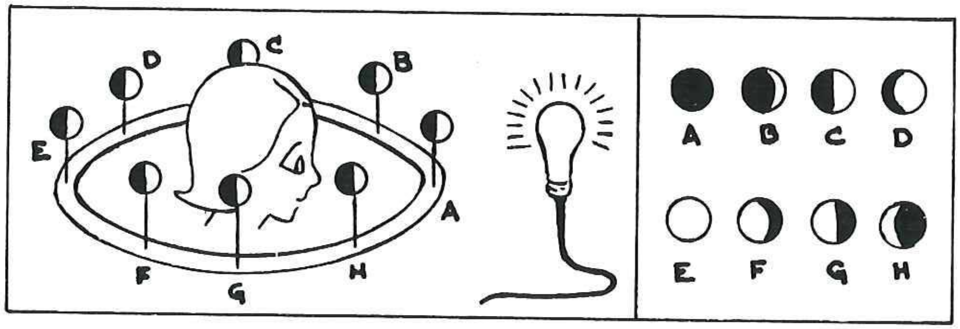
Planetarium: equatorial star charts (see Appendix for a chart that may be reproduced and used); pencils, pen lights.

PROCEDURES

In the Classroom

1. For several weeks before the planetarium visit, students should observe the moon outdoors each night and report on its appearance and position in the sky.

2. Arrange for students to examine causes of the apparent changes in the moon's shape through use of the moon-phase model pictured below. The hoop should be about three feet in diameter and may be cut from the side of a large corrugated box; the styrofoam "moons" can be affixed to nails stuck upright through the bottom of the hoop (tape heads of nails in position). One model should be available for each group of three to five pupils.



Above: How student uses model.
Right: What student sees as he looks directly at each "moon."

3. The student should turn his head and examine the portion of the moon that he sees illuminated by "sunlight" at each position indicated in the sketch. As the activity ensues, names of the phases can be introduced: A--new moon; B--waxing crescent; C--first quarter; D--waxing gibbous; E--full moon; F--waning gibbous; G--third quarter; H--waning crescent.

4. Using constellation charts, review or introduce some of the seasonal constellations visible during month of planetarium visit.

In the Planetarium

Setting: Obtain the necessary information from the Ephemeris so that you may preset the planetarium sun, moon, and stars for the first date of waxing crescent moon during the month of the planetarium visit, and so that later you may show the moon in relation to the star background (and to the sun, when called for) for each of the subsequent seven phases. You will use only annual motion throughout except as indicated while showing waxing crescent and full moon.

Discussion procedure: As the plotting called for below goes along, the class should (a) locate and identify by name the constellation behind the moon, (b) describe the moon's apparent shape in detail, (c) discuss the moon's location in relation to the sun, (d) discuss observations in relation to observations made during the preceding phase, (e) predict what will be observed during the subsequent phase.

1. Turn on the sun and moon, preset to just before sunset on the first date of waxing crescent moon, month of planetarium visit. Orient students to the setting--cardinal points, meridian, date.

2. Distribute equatorial star charts. Activate the sun and moon, letting the sun set and turning on the stars. Incorporating the discussion procedure previously suggested, ask students to draw the shape of the moon as they see it in the proper constellation on the star chart.

3. Using annual motion and announcing the new date, show in turn the moon and stars for the same time of night for the first date of first quarter, waxing gibbous, and full moon. Plotting and discussion continues as before.

4. After showing full moon, use daily motion until the full moon is just above the western horizon. Permit the sun to rise. (Students should note the change in time of day.) Keep the sun and stars on as you use annual motion to show, in turn, waning gibbous, third quarter, and waning crescent. For each of these phases, the students should continue plotting the shape and position of the moon on their star charts.

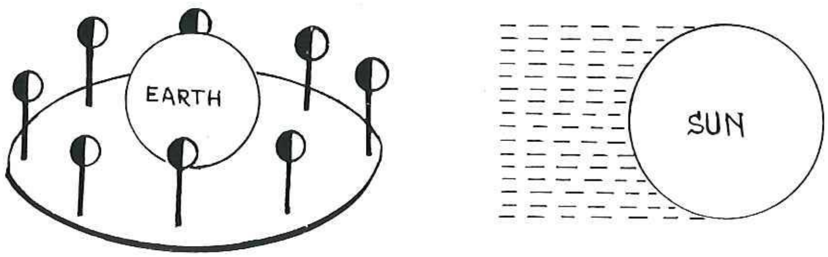
5. After waning crescent, use annual motion to show the change in the moon's position and shape <u>each day</u>, asking students to plot each change, until the <u>last of</u> the crescent disappears into the sun. The students then should mark "new moon" in the appropriate constellation of the star chart.

6. In conclusion discuss such questions as the following: (a) Which direction does the moon appear to shift in the sky? (b) How long does it take the moon to move from one phase to another? (c) How long does it take the moon to complete its eight-phase cycle--a lunar month? (d) Which phases of the moon do you see in the daytime? (e) Which phase of the moon is visible for the longest time in the night sky, beginning after sunset?

<u>Follow-Up Activities</u>

1. Suggest that students devise their own moon-phase models, establishing the positions of the sun and earth as reference points and labeling moon phases as appropriate. Make an assortment of materials available for the purpose or let students collect their own. A simple but effective model such as the one pictured below can be made with paint, styrofoam balls, nails, cardboard, and name tags.

MOON PHASE MODEL



2. If the students have background in the measurement of angles, ask them to measure the angles between the phases, using either the moon-phase model or a model students have made themselves. From angle measurements, the students should determine the number of degrees between each phase and the number of degrees of change in position per day.

3. Make available additional star charts like those used in the planetarium and ask that students plot the moon's shape and position during the following month from observations made outdoors.

4. Present photos of the moon in different phases and ask students to identify the phase.

5. Present NASA photos of Earth phases and discuss the appearance of the earth as viewed from the moon. Compare Earth phases and moon phases.

6. Suggest reading, and provide demonstrations, on the question "Do we always see the same side of the moon?" The rotational period of the moon will need to be explored in resolving this question.

7. Making a vovelle--a medieval device which gives the phase of the moon for any date through the year--would be excellent reinforcement for this activity on phases of the moon.

EVALUATION SUGGESTIONS

Give students information on sun-earth-moon positions for a particular day and ask them to name the phase of the moon on that day and draw its shape.

Show students photos of the moon at random phases and ask them to identify each phase in terms of waxing and waning.

Ask students to show the positions of the earth, sun, and moon for the various moon phases by manipulating a styrofoam sphere representing each of the bodies.

VOCABULARY

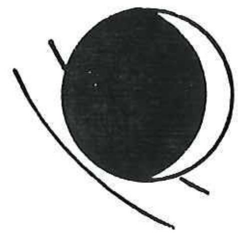
orbit
rotation revolution
waxing lunar month waning
crescent quarter gibbous full
new moon

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 173-174.
Investigating the Earth, ESCP, pp. 482-484.
Lewellen, The True Book of Moon, Sun, and Stars, pp. 18-21.
Sutton, The How and Why Wonder Book of the Moon, p. 11.
Warshofsky, Target Moon, pp. 10-17, 42-44.

NOTE

See Appendix for equatorial star chart which may be used with activity.



CONDITIONS FOR ECLIPSES

Recognizing that the moon orbits the earth, it isn't hard for students to conceive of conditions that give rise to eclipses: When the moon in its orbit comes directly between the sun and the earth, the moon blocks out the rays of the sun, producing a solar eclipse; at the opposite point in the lunar orbit, with the earth directly between the sun and the moon, the earth blocks the sun's rays from the moon, producing a lunar eclipse. But the conditions aren't this simple, as students will concede if asked to ponder why we don't have an eclipse of the sun and moon each month.

In the activity below, students will learn why total eclipses at any given location on earth are rare events. Plotting the orbit of the moon against the ecliptic in the planetarium, they will discover the differences in these planes; plotting the regression of the nodes, they will discover that they can predict eclipses.

STUDENT PREPARATION	Grade level: secondary Content background: familiarity with graphing techniques, with right ascension and declination; understanding of the ecliptic as a plane and of moon phases and their causes.
FACTS AND CONCEPTS	Eclipses occur as a result of one celestial body moving into the shadow cone of another. The moon's orbit and the ecliptic are not coplanar. Eclipses occur when the nodes of the moon's orbit are in alignment with the sun and earth.

OBJECTIVES

- The student will be able to explain verbally or through demonstrations why there is not a lunar and solar eclipse every month.
- The student will be able to demonstrate the relationship between shadows and eclipses.
- The student will be able to explain through demonstration the kinds of eclipses that can occur.
- Given suitable positional data relative to the sun, moon, and earth and to the nodes of the moon's orbit, the student will be able to predict when eclipses will occur.

MATERIALS

Classroom: smoke box, slide projector for use as light source, disk and sphere of same diameter; celestial globe; ecliptic graph paper (available from Sky Publishing Corporation); additionally for follow-up activities and evaluation--assortment of materials for sun-earth-moon-models; <u>Ephemeris</u> or <u>Observer's Handbook</u>.

Planetarium: ecliptic graph paper, notepads, pencils, pen lights. Device for indicating nodal points.

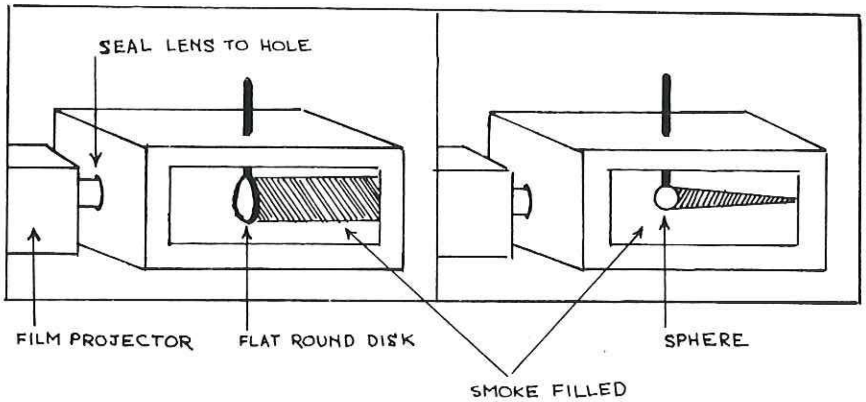
PROCEDURES

<u>In the Classroom</u>

1. Ask a student to diagram for the class the moon's orbit around the earth, indicating the position of the sun. Let another student point out the orbital positions in which an eclipse of the sun and moon could occur. Discuss the phase of the moon as seen from earth at each position, permitting students to consider and discuss why a solar eclipse doesn't occur with each new moon, and a lunar eclipse with each full moon. (The answer, however, can await the planetarium visit.)

2. Let students investigate the shadow created by an eclipse in miniature. Set up a smoke-box laboratory exercise in which students compare and contrast the shadows cast by a disk and by a sphere of the same diameter. Fill the smoke box with smoke or dry-ice vapor, shine a beam of light into one end,

and insert the disk and sphere alternately in a position so as to intersect the beam of light and produce a visible shadow (see sketches below). The students should discuss the nature of the shadows and cone of invisibility.



3. In preparation for the graphing that will be done in the planetarium, review celestial coordinates (right ascension and declination) with the class, using a celestial globe. Also review the ecliptic, emphasizing its plane. Then distribute ecliptic graph paper and instruct students in using it to plot celestial objects by right ascension and declination.

In the Planetarium

1. Preset planetarium sun and moon for the date of visit. Turn on the coordinate system and orient students to the setting.

2. Ask students to collect data on the right ascension and declination of the moon at each phase through one lunar cycle. Use annual motion to proceed from phase to phase, and daily motion as needed to keep the moon in the planetarium sky; turn on the stars as appropriate.

3. When the data is collected, turn on the lights and distribute ecliptic graph paper. Ask students to transfer their data to the graph and plot the moon's orbit.

4. In examining the lunar orbit they have plotted, the students should recognize that it is not exactly identical with the ecliptic. Let them determine its inclination and the points at which it intersects the ecliptic, discussing these positions as the ascending and descending nodes of the lunar orbit.

5. Next, the students will observe and record the regression of the nodes on another sheet of graph paper. That they may do this, turn on the meridian, ecliptic, and coordinates. Then:

a. Place the moon with one node on the meridian and ask students to record right ascension and declination.

b. Using only annual motion, put the moon in orbit and stop it at the exact point of intersection with the ecliptic. Discuss this point as the new node and ask students to plot its right ascension and declination.

c. Continue as above, stopping for collection and recording of data at each node until you feel that students have collected enough information to carry out the next step.

6. From the data plotted on the graph, students should (a) determine how far a node moves in right ascension per month, (b) determine how far it moves in right ascension per year, (c) predict how long it will take the node to return to the same position, completing one regression cycle.

Follow-Up Activities

1. Using the data graphed in the planetarium, the rate of regression of the nodes, and the dates of the last eclipse, students should predict the date of the next eclipse. Then they should check the accuracy of their predictions against information in the Ephemeris or Observer's Handbook.

2. Assign reading and discuss various types of eclipses; how the area of earth experiencing a total eclipse may be determined, and the length of time the sun (moon) will be eclipsed.

3. Suggest that students make a 3-D model of an eclipse (solar or lunar) using styrofoam spheres and light sources. (A particularly effective model can be set up in a smoke box.)

EVALUATION SUGGESTIONS

Ask students to use models to explain why there are not eclipses every month.

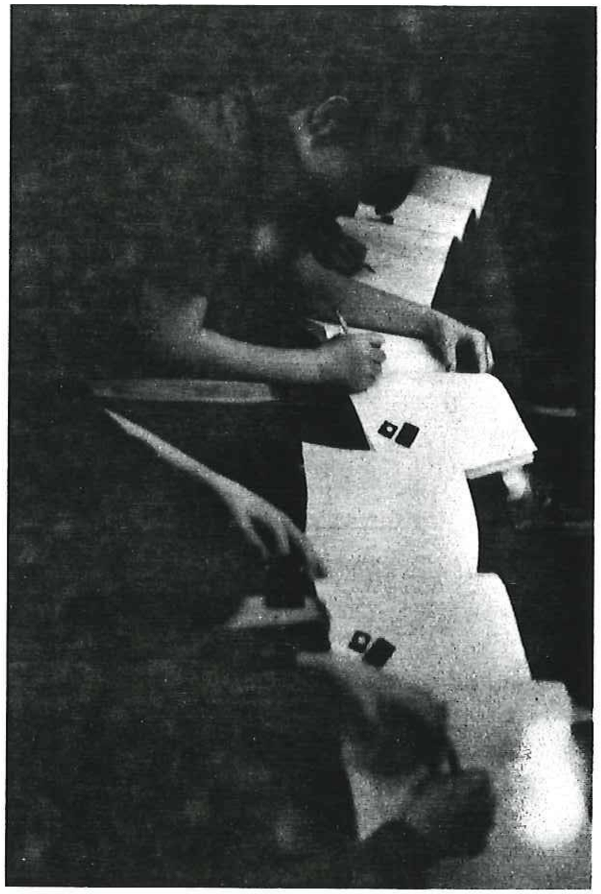
Ask students to list and explain in writing, or demonstrate, the kinds of eclipses that can occur.

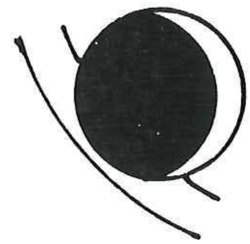
VOCABULARY

node
eclipse
ecliptic
right ascension
declination
total eclipse
partial eclipse
moon phases
shadow
cone of invisibility
regression of nodes

SUGGESTED RESOURCES

Abell, <u>Exploration of the Universe</u>, pp. 195-216.
Branley, <u>The Sun: Star Number One</u>, pp. 111-121.
Brenna, <u>The Moon</u>, pp. 37-39.
Trinklein, Huffer, <u>Modern Space Science</u>, pp. 305-318.
"Eclipses of the Sun and Moon," <u>American Ephemeris and Nautical Almanac</u> 1972, pp. 343-353.
"Eclipses During ...," <u>The Observer's Handbook</u>.





HIGH TIDES/LOW TIDES

As did the early Greeks and Romans, most students today recognize that the tides are "somehow" caused by the moon, but even those students living on the shore do not understand the relationships very clearly.

This activity is designed to study the effects of earth's rotation and the changing positions of the moon relative to the earth and sun upon the height of the waters that lap our shores. The planetarium will provide students with views of the apparent motion of the moon caused by the earth's rotation and of the real movement of the moon in orbit--thus helping them to conceive of the shifting gravitational forces responsible for the repetitive periods of high and low tides, and of spring and neap tides.

STUDENT PREPARATION

Grade level: secondary
Content background: familiarity with the Universal Law of Gravitation; understanding of the relationship between the orbital position of the moon and its phase.

FACTS AND CONCEPTS

The gravitational force of the moon, and to a lesser degree of the sun, are responsible for the tides.

The two daily cycles of high tides and low tides are caused by the changing positions of the moon in relation to the earth as a result of the earth's rotation.

The two monthly cycles of spring tides and neap tides are caused by changes in the relative positions of the sun, earth, and moon which result from the moon's monthly orbit around the earth.

Various other phenomena also influence the time of high tide and low tide, and the height of the tide locally.

OBJECTIVES

◐ Through diagrams and/or verbal explanation, the student will be able to correlate high tides and low tides with the earth's rotational period relative to the moon.

◐ Through diagrams and/or verbal explanation, the student will be able to correlate periods of the highest tides during the month and periods of the lowest tides with relative positions of the sun, earth, and moon.

MATERIALS

Classroom: pictures and/or filmstrips showing differences in seashore landscapes at times of high and low tide (particularly for classes in inland communities); local tide tables (for classes in shore communities); petrie dish, iron filings, strong horseshoe magnet; earth globe and object for use as moon; earth-moon-sun orrery; for follow-up activities--if possible, charts for specific bays or shore areas giving the time of high tide and the height of high tide through a month; graph paper.

Planetarium: geocentric earth projector; moon phase projector or orrery; Moon/Tide Data Sheets (see last page of activity), pencils, pen lights.

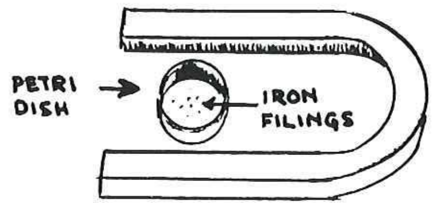
PROCEDURES

<u>In the Classroom</u>

1. Unless students live along the coast, they will have little or no first-hand knowledge of tides. For these students, introductory activities should include examination of pictures showing the dramatic differences high and low tides make in the coastal landscape and discussion of ways the tide affects both man's activities and the ecology of the shore and sea. For students living on the coast, the best introduction may be an examination of local tide tables which give the times of high and low tide. Let them compare the times with the times of two crossings of the local meridian by the moon.

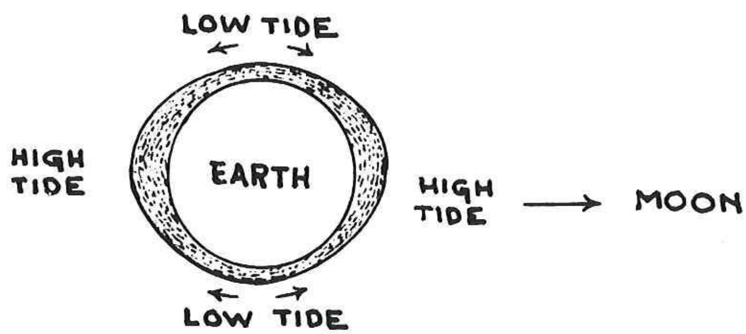
2. When the gravitational pull of the moon is suggested as the cause of the tides, arrange for students to carry out the following

observations: Put iron filings in a petri dish and place a strong horseshoe magnet around it as below; then revolve the petrie dish and observe.

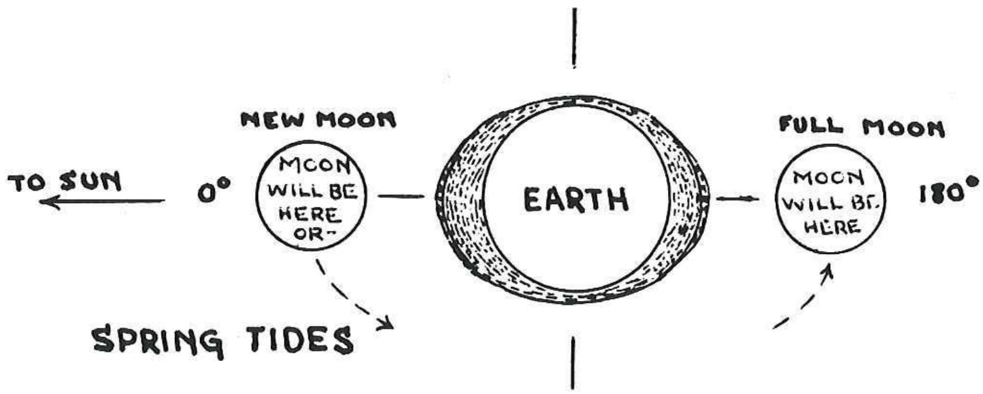


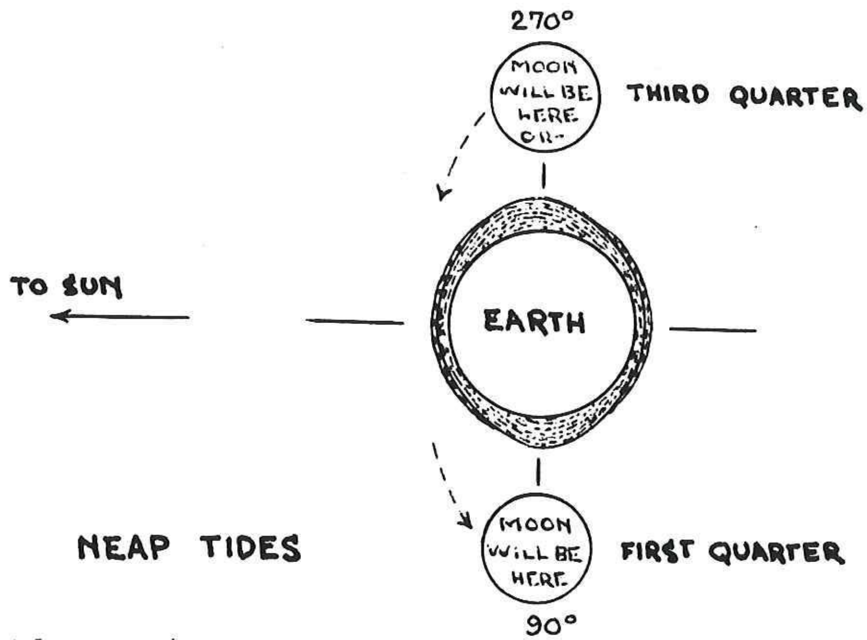
Let students consider ways in which the demonstration provides analogies to the tides.

3. Use an earth globe and a smaller sphere (for the moon) to illustrate how two periods of high and low tides appear to move around the earth as the earth completes one rotation in reference to the moon. Emphasize the period of high tide brought by the strong gravitational pull of the moon as the moon passes the local meridian, and the similar period of high tide at the same location as the moon passes the opposite point in its diurnal path, 180° from the local meridian. A diagram such as the following will help students visualize high and low tides occurring alternately 90° apart around the earth.



4. Using an earth-moon-sun orrery, review with the class the relative positions of the sun, earth, and moon during the monthly lunar orbit. Ask students to consider how the gravitational force of the sun might combine with, or counteract, the gravitational force of the moon to bring periods of particularly high tides or low tides during a lunar month. Diagrams such as the following will be useful in discussing the positional relationships responsible for spring tides and neap tides.





In the Planetarium

1. Preset the planetarium moon for the phase on date of planetarium visit; preset the sun for noon, local solar time. Turn on the sun, moon, meridian and coordinate system. After discussing the setting, use daily motion to progress through time until the moon reaches the meridian. As the motion goes on, the students should count the number of hour lines crossing the meridian, thus determining the approximate time of the next high tide for any coastal area at their longitude. The students should also calculate the approximate number of hours until the next low tide for the area.

2. Turn off the coordinates and turn on the geocentric earth. Ask students what actual coastal areas would be experiencing high and low tides when the moon is on their own local meridian. Rotate the geocentric earth (manually, if necessary), so that students may view the areas experiencing a high tide on the opposite side of the earth.

3. Next, provide students with views of the moon in orbit and resulting changes in the positional relationships of the earth, moon, and sun. To do this, you can use either a moon phase projector or the orrery. If you use the orrery, cover the sun lamp with green cellophane (to represent the earth) and remove all bulbs except Mercury (which will represent the moon). In either case, preset to show the moon in orbit for its current phase, date of visit, and station the planetarium sun appropriately in the sky, keeping it in the same position throughout this and the following steps. First show earth-moon-sun positions for the current moon phase. Ask students where high tides and low tides would be on the earth representation shown on the dome. Then discuss the current phase of the moon, the moon's position in relation to the sun and earth, and whether or not the positional relationships of the current phase would result in a spring tide or a neap tide.

4. Distribute Moon/Tide Data Sheets. Then, beginning with the phase most appropriate for the current date, progress through moon phases (include new moon, first quarter, full moon, third quarter). Stop at each phase so that students may do the diagramming and make the entries called for on the data sheet.

5. In concluding planetarium activities, ask students to summarize the changing gravitational forces responsible for periods of particularly high and low tides during the lunar month.

Follow-Up Activities

1. Students should investigate tidal lag through reading. Encourage discussion of the various phenomena which affect the exact time of high and low tide at all locations and at various locations.

2. If possible, present a table showing the level of high tide above mean water level at a given location through a calendar month. Let students plot the height of high tides against dates, and then correlate the dates with moon phases. (As predicted from observing positional relationships in the planetarium, students will find that the highest tides occur near the dates of the new and full moon, and that the lowest tides occur during the first and third quarters.)

3. Suggest independent reading and reports to the class on locations, such as the Bay of Fundy, which experience exceptionally high tides, and factors which contribute to such phenomena. Some students might report on the evidence of tides in lakes and small bodies of water. Capable and interested students might also report on

research that correlates weather phenomena with moon phasing and tidal changes.

EVALUATION SUGGESTIONS

Provide students with a world map or globe and give them the location of the moon relative to sublunar longitude. Ask them to indicate areas of the earth that would be experiencing periods of high tides and low tides.

Give students tidal drawings indicative of various moon phases and ask them to show on the drawings the positions of the sun and moon that might be responsible. (Or give students positions of the sun and moon relative to the earth, and ask them to provide the tidal drawings.)

You may also use the data sheets prepared in the planetarium as a basis for evaluation.

VOCABULARY

tide
high tide   low tide
spring tide   neap tide
Universal Law of Gravitation
(names of moon phases)
tidal lag   tidal bulge

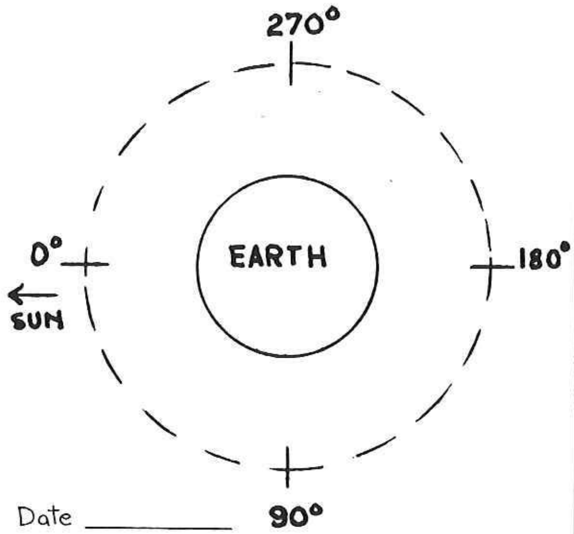
SUGGESTED RESOURCES

Abell, <u>Exploration of the Universe</u>, pp. 217-277.
<u>Investigating the Earth</u>, ESCP, pp. 99-101.
Wyatt, <u>Principles of Astronomy</u>, pp. 125-128.

NOTE See following page for Moon/Tide Data Sheet.

MOON/TIDE DATA SHEET

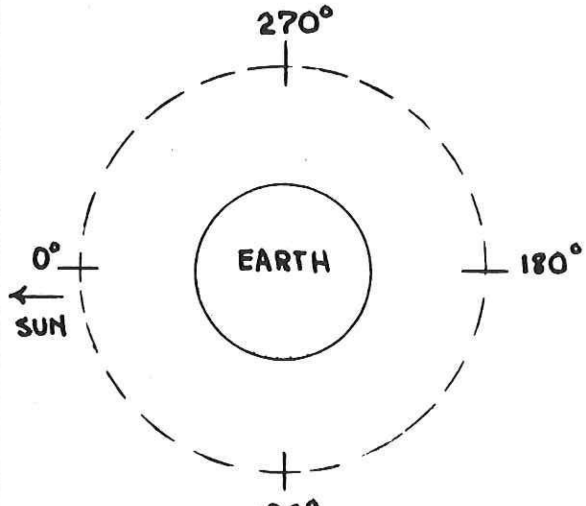
Instructions: Below the dashed lines represent the moon's orbit. When directed to do so, draw in the moon on the specified section to show the sun-earth-moon configuration that you see on the dome. Then depict on the circle representing Earth the areas of high tide and low tide and the type of tide you predict would result from the orbital position of the moon. Also fill in the date, the moon phase, and the name of the tide.



Date ____________
Moon phase _____
Tide ____________

1

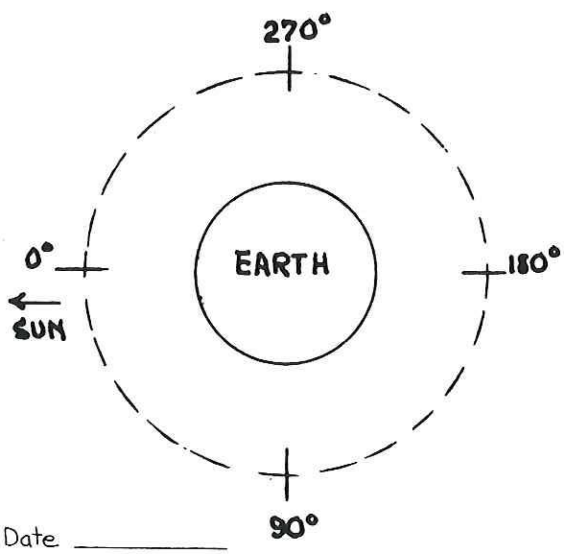
2



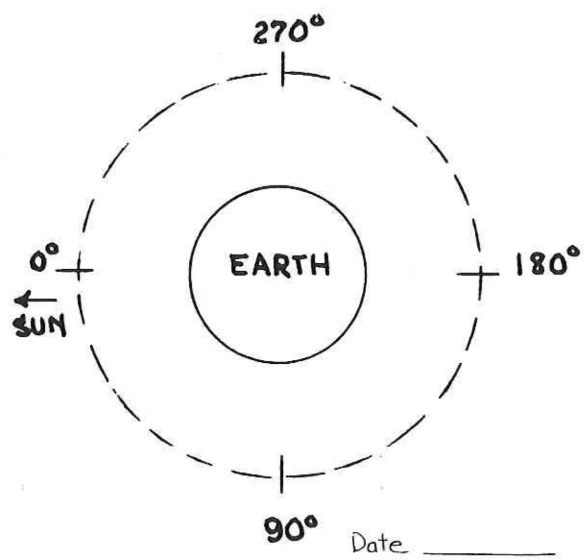
Date ____________
Moon phase _____
Tide ____________

3

4



Date ____________
Moon phase _____
Tide ____________



Date ____________
Moon phase _____
Tide ____________

SOME SAY, HE BID HIS ANGELS TURN ASKANCE
THE POLES OF EARTH TWICE TEN DEGREES OR MORE
FROM THE SUN'S AXLE; THEY WITH LABOR PUSH'D
OBLIQUE THE CENTRIC GLOBE.

- *Milton's Paradise Lost*

Mathematics and Measurements

Mathematics has become linked with all of the sciences, but it has always been linked with the stars. Consider the simplest questions about the star-studded heavens, and it is easy to see why astronomers have always been mathematicians.

In the activities in this section, the students will develop for themselves some answers to questions they may often have wondered about: How many stars do we see in the sky? How far away are the stars? Where was that "shooting star"? Did it come to Earth? Might it be found?

By participating in these activities, the student will discover ways to apply techniques for measuring spheres, distances, and angles to the celestial sphere. And he may extract the important idea that questions about the heavens, the earth, and even his society can be subjected to mathematical tests and solution.

LEARNING ESTIMATION TECHNIQUES

How many stars are in the sky? What child does not wonder about this when he gets a clear, full view of the star-studded heavens. On their first trips to the planetarium, too, children are concerned with "how many." Actuallv, there are fewer clearly visible stars than many children think--a few thousand, but not "millions."

In Part I of this activity, children will estimate the number of stars in the planetarium sky; in Part II, they will estimate the proportions of planetarium stars of different magnitude classes. And in both cases, they will acquire generally useful techniques for estimation.

The activity is appropriate either for classes studying estimation in mathematics or the stars in science. The procedures are divided into two parts so that Part I may be easily extracted for use with younger children. Parts I and II should be used together with middle-graders.

STUDENT PREPARATION Grade level: elementary
Content background: Part I--mathematical operations up to and including multiplication and division by two-digit numbers; Part II--all operations with three-digit numbers and ability to solve simple proportions in the form 3 is to 10 as $\underline{x}$ is to 1,000; prior lesson on apparent stellar brightness (such as provided in "How Bright Are the Stars?" in this publication).

FACTS AND CONCEPTS Part I: (1) It is possible to estimate the number of stars in the planetarium or real sky. (2) The number of stars in the planetarium or real sky can be estimated through a random sampling procedure. (3) This technique can be applied for estimating the number of many types of objects.

Part II: (1) Because of differences in distance and intrinsic brightness, all stars, as viewed from the earth, display different degrees of brightness. (2) The number of planetarium or real stars of different magnitude classes can be estimated through a random sampling technique. (3) The proportion of planetarium or real stars of different magnitude classes can also be estimated through a random sampling technique. (4) These techniques are generally useful for estimating the number and proportion of types of objects within a large population.

OBJECTIVES

Part I: (1) Using the method for estimating large numbers developed in the activity, the student will be able to estimate the number of stars in the planetarium sky. (2) The student will be able to identify other problems to which the same estimation method may be applied and use it to obtain estimates of large numbers.

Part II: Using the method for estimating proportions developed in the activity, the student will be able to estimate the proportions of stars of different magnitude classes in the planetarium sky. (2) Using a brightness scaler, the student will be able to collect data on star magnitude in the planetarium. (3) The student will be able to identify other problems to which the estimation method may be applied and use it to obtain estimates of proportions.

MATERIALS

Classroom: large sheet of posterboard on which a large number of stars (varying in size) have been drawn; for evaluation--large quantity of small beads, glass bowl, set of measuring cups. The beads must be of various colors for Part II.

Planetarium: paper, pencils, pen lights; devices--or materials for constructing devices--through which a fractional portion of the planetarium sky may be viewed. The devices may be clear plastic hemispheres on which fractional portions may be marked with grease pencil. Note: a "window" 10 inches square will enable a student to view approximately 1/50th of a 30-foot dome when held at arm's length. The planetarium director will need to consider the size of the window most desirable for the windows used in evaluation.

Planetarium (Part II only): brightness scaler (see device suggested in "How Bright Are the Stars" in this publication, or adapt a Kodak print scaler).

PROCEDURES

In the Classroom, Part I

1. Briefly hold up for class inspection a large sheet of posterboard on which a large number of stars (varying in size) are drawn. Ask how many stars are shown. Let the children give their estimates and talk about how they arrived at them.

2. Ask for ideas on such simple estimation problems as: How might we estimate the number of third-graders in school if we know that there are four third grades and that each class has about 25 pupils? How might we estimate the number of beans in a quart jar without counting each one?

3. Ask children what methods they think might be used for estimating the total number of stars in the sky--and tell them that this question will be investigated in the planetarium. Suggest that they look at the night sky in the meantime and consider the problem.

In the Classroom, Part II

1. Continue with questions which lead into techniques for estimating proportions. For example: How might you estimate the proportions of red, black, and white beans in a quart jar which has beans of these three colors? How might you estimate the proportions of nine-, ten-, and 11-year-olds among all pupils in all the fifth grades? Discuss suggestions.

2. Ask students whether they think similar procedures might be used to estimate the numbers and proportions of stars of various magnitude classes--and tell the class that these questions also will be investigated in the planetarium.

3. Review previously developed understandings about apparent stellar brightness. The students might look at the night sky and try to conceive of a way that the proportions of "bright, brighter, and brightest" stars could be estimated.

In the Planetarium, Part I

1. After room lights are dimmed and the stars appear, ask students to guess how many stars are in the planetarium sky and to write down their answers on paper.

2. Fade out the stars and project one point of light with the latitude indicator or other single light source. Ask how many stars are in the sky now. When the answer "one" is chorused, inquire how this was discovered. Emphasize that the students used a method for getting the answer even though they used it unconsciously--they observed and counted.

3. Add the inferior planet lights to increase to three the bright points on the dome and ask the two questions asked above. Then add the three superior planets, increasing the total bright points to six, and repeat the questions.

4. Next turn on the star projector to between one-fourth and one-half brightness so that the stars become difficult to count. Again ask students how many stars they see, giving them time to arrive at an answer. In discussion of the methods used in determining the number, some students may express frustration at "having to count so many stars," some may simply guess a large number without a basis for doing so, but some will probably report that they estimated--that is, they counted a portion of the stars and multiplied by a number obtained from thinking about the size of that section of stars in relation to the entire planetarium sky.

5. Draw out the last method in some detail until it is clear that it consists of counting the stars in a fractional portion of the sky and then multiplying by the estimated number of equal portions comprising the entire sky.

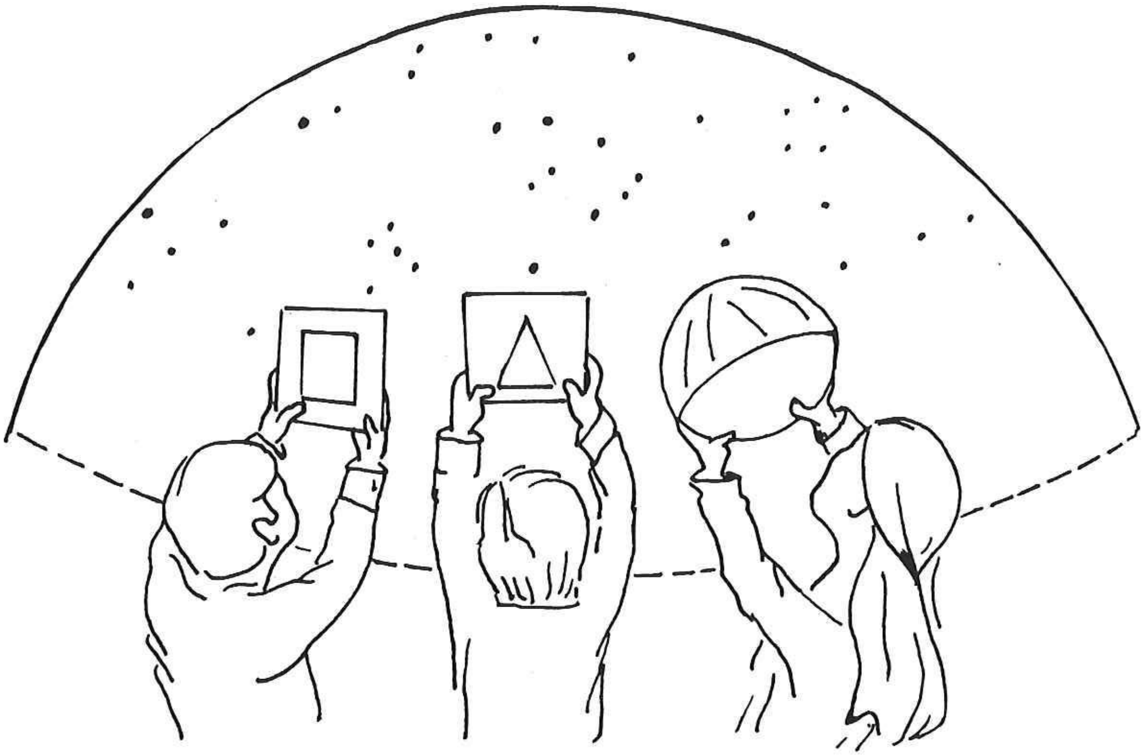
6. Now split the class into small groups and ask each group to find a way to divide the sky into approximately equal sections (see picture) and to:

   a. Count the number of sections.

   b. Count the stars in each of 5 sections chosen from different areas of the sky, write down the number counted in each section, and add these together.

c. To divide the total by 5 to get the average number of stars for the five sections.

d. To multiply the average number of stars by the total number of sections to get an estimate of total number of stars in the planetarium sky.



7. When groups have finished, discuss methods and results--and let students compare the estimates with their original guesses on the number of stars in the planetarium sky. Discuss why it was necessary to count the stars in five sections rather than one.

8. If time, evaluate. Use daily motion to turn the sky at least 30° and ask students individually to estimate the total number of stars using a cardboard window with a 10 square-inch opening. You can tell students that if they hold the card at arm's length, they will view approximately 1/50th of the planetarium sky (see note under Materials). The students should turn in their estimates and working papers.

In the Planetarium, Part II

1. Ask students to observe the characteristics of the stars. Then discuss the variations noted (size, color, brightness) and reasons for variations (temperature, distance).

2. If the students have had previous experience devising a scale for brightness, proceed to Step 3. If not, ask for suggestions on how such a scale might be developed and what type of tool would be useful.

3. Distribute brightness scalers, asking students to devise a scale for use by the class--or to review the scale previously developed. (General agreement on, and understanding of, the scale is important to the rest of the activity.) Let students point out some stars for the class to examine and designate by magnitude according to the class-developed scale.

4. Now ask students to consider how they might estimate how many stars of each magnitude class are in the entire planetarium sky. Although someone may suggest direct counting and scaling of all stars--perhaps dividing the labor among student groups--previous experiences with estimating should bring less onerous methods to mind. A student probably will suggest scaling and counting the stars in several fractional portions of the sky and using the resulting figures to estimate total numbers and the proportions of stars of various magnitude classes.

5. In addition to the brightness scalers, students will need the kind of materials used in Part I to carry through the suggestion. Again let students and working groups discuss methods and problems. Now two pieces of equipment--a device for viewing a fractional portion of the sky and the brightness scaler--will need to be used simultaneously or in close alternation for counting stars of the various magnitudes defined by the scale.

6. Ask working groups to report the methods used and their estimates as to both the total number of stars of each magnitude class and the proportion of stars of each magnitude class. Such reports will provide material for questions through which you can stress the mathematical ideas involved. For example:

   If 2 stars of "second" magnitude are found in an "average" sample representing 1/50th of the celestial hemisphere, how many "second" magnitude stars might be found in the celestial hemisphere? In the entire celestial sphere?

   If 7 stars in the same sample of 20 stars are of "third" magnitude, what is the ratio of "third" magnitude stars to the sample? What is the estimated ratio of "third" magnitude stars to all stars in the planetarium sky?

7. If time, evaluate. Turn the planetarium sky 30° and ask students individually to estimate the numbers and proportions of all stars of various magnitude classes and to turn in their papers.

Follow-Up Activities, Part I

1. Discuss estimates of the number of stars that may be seen at the same time in the planetarium sky. Let students compare their estimates with the actual number (about 675 on a Spitz A3P or A4). It should be noted that only half the visible stars in the celestial sphere--as well as half the stars which may be seen in the planetarium--can be observed at one time; and that the planetarium dome--and the real sky as we observe and think of it--are hemispheres.

2. Ask pupils how the number of visible stars in the nighttime sky might be estimated using the same techniques, encouraging them to imagine and describe types of equipment that would be needed. The students will be interested to know that the number of visible stars, under the best atmospheric conditions, has been estimated as close to 17,000. About 11,000 of these are very faint stars.

3. Discuss other problems in estimation that could be solved using the same technique.

4. Suggest projects in estimating large numbers: for example, estimating the number of leaves in a large pile, the number of blades of grass on the front lawn, the number of single strands of hair on a human head.

Follow-Up Activities, Part II

1. Putting the estimates for the total number of stars of each magnitude class, as obtained either by working groups or individual students, on the board, let students pool the figures and treat them mathematically to get another estimate of the size and proportion of magnitude classes.

2. Discuss the planetarium instrument and its representation of the night sky: there are approximately 1,350 stars in the entire planetarium sky (Spitz A3P or A4) and 17,000 visible stars, under best conditions, in the entire celestial sphere. Let students figure out the proportion of planetarium stars to real stars.

3. Ask students how the techniques used in the planetarium might be used to determine the numbers and proportions of stars of various magnitudes in the real sky. What types of tools would be needed? (If you have any figures

on numbers and proportions, present them to satisfy the desire of some students for "factual information.")

4. Discuss other problems in estimating proportions that could be solved using the same estimation technique.

5. Suggest projects in estimating proportions when large numbers are involved: for example, estimating the proportions of various types of living things in an untended area of lawn, the proportion of various types of shells on a defined seashore area.

EVALUATION SUGGESTIONS

Part I: (1) Evaluate the papers pupils submitted in the planetarium. (2) Provide students with a list of estimation problems, asking them to identify those that might be solved through the method used in the planetarium. (3) Ask students to estimate the total number of small beads in a fish bowl (make a set of measuring cups available).

Part II: (1) Evaluate papers pupils turned in at the end of planetarium activities. (2) Provide a list of estimation problems involving proportion and ask students to identify those that might be solved through the method used in the planetarium. (3) Ask students to estimate the total number of various colored beads in a fish bowl and the proportion of each color (make a set of measuring cups available).

VOCABULARY

I.
estimate
sample sphere hemisphere
representative/fractional sample
population average

II.
scale
apparent brightness
magnitude proportion
random distribution

SUGGESTED RESOURCES

Baker, <u>Dictionary of Mathematics</u>, pp. 520-521.
Bendick, Levin, <u>Mathematics Illustrated Dictionary</u>, pp. 159-160.
Bendick, Levin, <u>Take Shapes, Lines, and Letters</u>, pp. 43-45.
Stein, <u>Fundamentals of Mathematics</u>, pp. 248-251.
<u>The Shapes of Tomorrow</u>, NASA, pp. 16-17.

EXAMINING SPHERES AND SPHERICAL ANGLES

A planetarium is useful in teaching subjects other than science. For example, when students in mathematics classes are being introduced to the ideas of spherical geometry, the planetarium can provide an excellent setting for experiential development of concepts. In the activity below the students use the planetarium dome to refine their own definitions of the properties of spheres and for developing conclusions about spherical angles.

Although designed particularly for mathematics classes, the activity will be equally useful in science. And--as presented in this activity--spherical geometry need not be limited to advanced groups in high school. The concepts and investigative procedure are well within the ken of junior high school students.

STUDENT PREPARATION

Grade level: secondary
Content background: previous experience with the exactitude of definitions in geometry; ability to measure angles on a plane surface.

FACTS AND CONCEPTS

The planes of all great circles of a sphere pass through the sphere's center.

The definitions of the properties of a sphere become more useful when they refer to something in nature.

Figures and angles on a spherical surface pose special measurement problems.

OBJECTIVES

From his observations in the planetarium, the student will be able to formulate verbal and written definitions for the following: sphere, spherical center, great circle, small circle, parallels, axis, equator, meridian, spherical angles. (Note: see definitions at end of activity.)

The student will be able to support or refute the premise that the sum of the interior angles of a spherical triangle is equal to or greater than 180°.

MATERIALS Classroom: for each group of three students--listing of the nine terms to be defined; several styrofoam balls and instrument to cut them with; two clear plastic hemispheres that fit together; length of string, one bead, cellophane tape, grease pencil.

Planetarium: plastic spheres and list of definitions prepared by students in the classroom; chalkboard and (if possible), ultraviolet chalk; folding six-foot ruler (fluorescent, phosphorescent or painted white); planetarium projection, sextant; pencils, pen lights, paper.

PROCEDURES

In the Classroom

1. Give each group of three students the materials listed under "classroom" above. They are to use the materials as aids in developing definitions of the nine terms.

2. Suggest that they suspend the bead in the center of a sphere. They can do this by using string, cellophane tape, and the two plastic hemispheres.

3. The students should also cut up the styrofoams balls for purposes of exploring the terms. Then they can use grease pencil to illustrate the terms on the plastic sphere.

4. With their own model of each term in front of them, the students should write a definition for each term.

In the Planetarium

1. When the students come to the planetarium, they should bring their definitions and models of the celestial sphere. Take up each term in order (sphere, spherical center, great circle, small circle, parallels, axis, equator, meridian, spherical angle) and ask students to present definitions.

2. Turn on the stars, asking the group to look at the sky and to consider it in relation to the plastic sphere with the small bead inside. Ask what the small bead represents (the earth) and help students see that one point on the bead represents the location from which they are viewing the night sky.

3. Go through each term, using planetarium effects to illustrate it (use meridian, coordinates, ecliptic, motion, etc., as needed). Pause after each demonstration for discussion and to let students refine their written definitions. As the class agrees on the best definition, you might write it on a chalkboard with ultraviolet chalk.

4. Play back planetarium effects, asking students to identify what is being illustrated. (At any time students might identify the horizon as a great circle.)

5. Turn attention to the definition of a spherical angle and illustrate one on the dome. To clarify a point often misunderstood about angles, use a six-foot folding ruler. Show students how the ruler can be bent to show any angle; discuss how extending the legs of the ruler doesn't affect the size of the angle.

6. Let students view and identify spherical angles between the ecliptic and horizon, ecliptic and celestial equator, ecliptic and meridian, celestial equator and horizon, etc.

7. Discuss the measurement of spherical angles in the planetarium sky. Then turn on the planetarium sextant so that the angles mentioned above may be measured. (To check accuracy of the hand sextant, use the meridian.

8. Construct a triangle on the chalkboard and review the triangle as defined in plane geometry. Then, using the astronomical triangle projector (or a projected triangle), show construction of a spherical triangle.

9. Students should measure the interior angles of the triangle above to draw conclusions concerning the sum of the interior angles of a spherical triangle.

10. In conclusion, cut up a large styrofoam ball to show the three dimensions of a spherical triangle.

<u>Follow-Up Activities</u>

1. Offer problems in spherical geometry appropriate to the activity.

2. Discuss constellations as being three-dimensional. The students might make a three-dimensional constellation model, using the directions provided with the activity on parallax in this publication. (In making the model, students will be using a spherical triangle determined by parallax.)

3. Let students investigate the procedures Eratosthenes used to measure the circumference of the earth. If another trip to the planetarium can be scheduled, the sun at noon may be shown for both the latitudes of Alexandria and Syene, and students may use spherical geometry to calculate the circumference of the earth in the same way that Erastosthenes did.

EVALUATION SUGGESTION — Evaluation may be based on the definitions developed by students.

VOCABULARY — (The nine terms developed in the activity).

SUGGESTED RESOURCES

Abell, <u>Exploration of the Universe</u>, pp. 93-99.
Baker, <u>Dictionary of Mathematics</u>, pp. 282-283.
Bernhard, Bennett, Rice, <u>New Handbook of the Heavens</u>, pp. 195-197.
<u>Investigating the Earth</u>, ESCP, pp. 64-66 (see for method used by Erastosthenes in measuring circumference of earth).
<u>The Shapes of Tomorrow</u>, NASA, pp. 25-26.

NOTE — See following page for definitions.

SPHERICAL GEOMETRY: DEFINITIONS

The following are examples of acceptable definitions that might be developed by students in the foregoing activity.

Sphere: Any round solid figure having the surface equally distant from the center at all points.

Spherical center: A fixed point from which all points on the surface of a round solid figure are equidistant.

Great circle: A circle of a sphere whose plane passes through the center of the sphere.

Small circle: Any circle of a sphere whose plane does not pass through the center of the sphere.

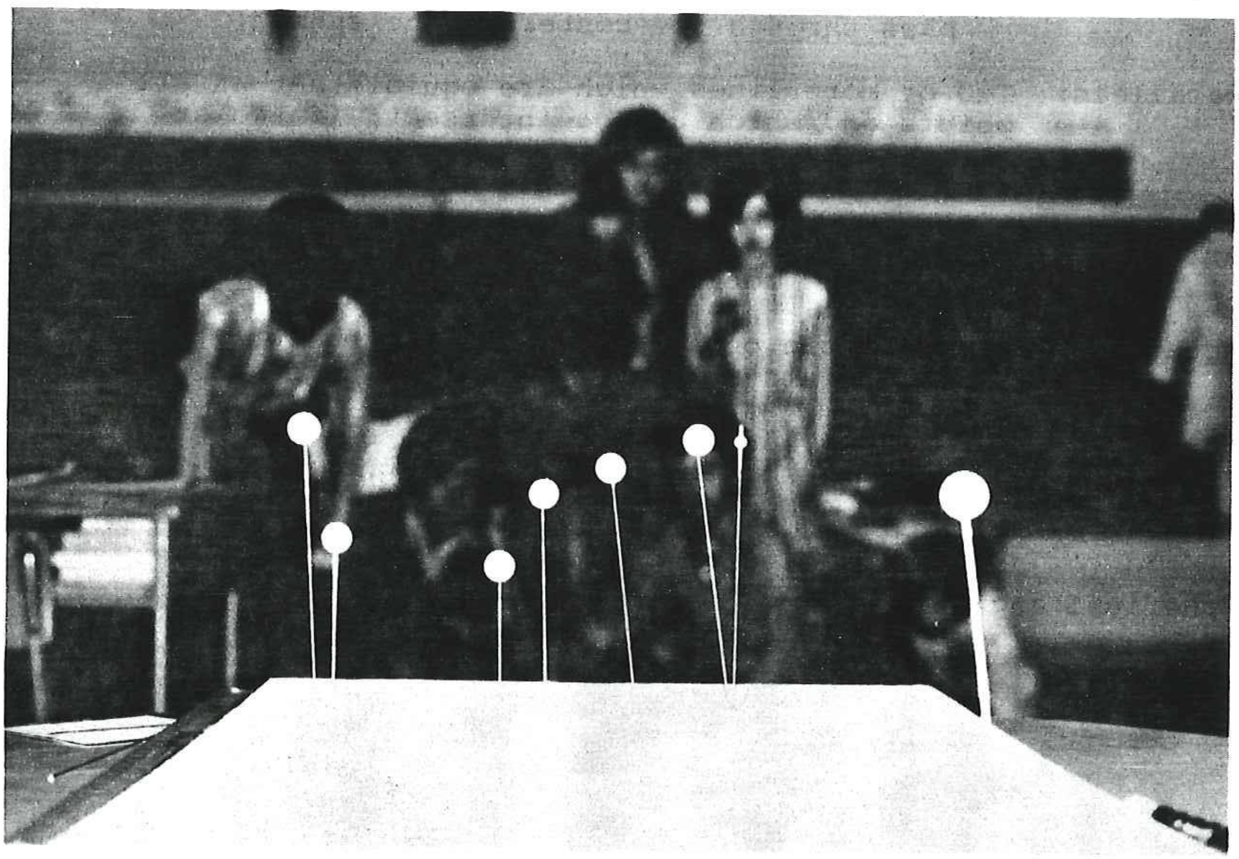
Parallels: Two or more lines which are equidistant at all points and which do not intersect; if two or more planes which intersect a sphere are equidistant, the planes are parallel.

Axis: An imaginary or real line or point about which an object or sphere rotates.

Equator: A great circle on a sphere which is equidistant from the points at either end of an axis.

Meridian: An imaginary line extending from pole to pole which crosses the equator at a right angle; all great circles which contain the axis as their diameter.

Spherical angle: The angle established by the intersection of two great circles.



STEERING BY THE STARS

In the era of radar and computers, it may come as a shock to students that navigators of ships and planes still use the stars as a basic reference system for determining locations and headings. Why? "The stars are dependable," explained one airline pilot. "Once you get above the clouds at night, they're always there and nothing ever goes wrong with them."

In the following activity, students will use the planetarium stars to learn the basic principles involved in celestial navigation.

STUDENT PREPARATION

Grade level: secondary
Content background: understanding of celestial sphere; familiarity with right ascension and declination; prior lesson sidereal time; working knowledge of use of protractor and tools for measuring altitude and azimuth.

FACTS AND CONCEPTS

The positions of the stars, along with sidereal time, can be used to determine an observer's exact position on the earth.

OBJECTIVES

- Using the stars as reference objects, the student will be able to determine his position on earth.
- The student will be able to determine altitude and azimuth.
- The student will be able to plot the navigational triangle on a world map.
- The student will be able to determine a heading.

MATERIALS Classroom: world map, earth globe, celestial globe, coordinate star chart; astrolabe or hand sextant, compass.

Planetarium: planetarium sextant; star atlas or nautical almanac (for class reference); world map with coordinate lines at 15° intervals or less (one per student); pencils, paper, pen lights, drawing compasses.

PROCEDURES <u>In the Classroom</u>

1. The assumptions and principles underlying celestial navigation are the same as those Eratosthenes used in determining the circumference of the earth. Review his method with the class, pointing out that he assumed (a) the earth is round; (b) celestial objects are so distant that the direction to any of them from all places on earth must be the same--the apparent differences in the direction of the objects as viewed from Earth are caused by the earth's spherical shape; (c) light rays are essentially parallel.

   Emphasize that Eratosthenes knew from geometry that the difference in the angle at which the sun's rays struck the earth at Syene and Alexandria equaled the size of the angle at the earth's center between the two cities. He therefore used a stick to measure the angle of the sun to the vertical in Alexandria at the moment the sun was directly overhead at Syene and found the arc of the angle measured to be 1/50th of a circle. This told him that the distance between Alexandria and Syene was 1/50th of the earth's circumference. The rest was a matter of pacing off stadia between the two towns and multiplying by 50.

2. Ask the class for ideas on what the sky can tell a person about his location on Earth. Ideas about the nighttime sky to highlight are that the stars overhead vary with latitude, longitude, and the time of night--and that each of these variables offers a clue to location if other facts are known.

3. Provide for review as needed of the following understandings and skills which will be used in the planetarium: (a) understanding of the horizon as a primary great circle of

the celestial sphere where the sky and Earth's surface appear to meet; (b) measurement of longitude and latitude, right ascension and declination; (c) the relationship of hours of right ascension to longitude and to Greenwich sidereal time; (d) measurement of altitude, azimuth, and angles. Through the review use a celestial globe, world map, coordinate star map, astrolabe or sextant, compass, and protractor as needed.

In the Planetarium

Preset the planetarium for any given date at a latitude and longitude of a location at sea, but neither the latitude nor longitude of home location. Some well known stars should be no more than 25° to 35° above the horizon. (The latter is important--the stars to be plotted should be at fairly low altitude to allow for a large zenith angle for purposes of better accuracy.) No cardinal points should be visible.

1. Turn on the night sky and ask students to assume they are at sea and need to use the stars to find their way. They may locate the North Star and some familiar constellations. But where exactly are they? In what part of what ocean?

2. Distribute the world maps and ask the class to take part in the following procedures, which are much like those actually used in navigation.

3. The class locates and identifies three familiar bright stars 25° to 35° above the horizon and about 120° apart in azimuth. One student uses the planetarium sextant projector so that others may measure and record the altitude of each star.

4. Using a star atlas or nautical almanac, another student looks up the right ascension and declination of the three stars and reports to the class.

5. The declination of a star gives the latitude of its substellar point--because the celestial equator, from which declination is measured, is simply an extension of the earth's equator from which latitude is measured. The students will need the latitude of the three substellar points for plotting, but you may wish to take time out to discuss that they can determine their own latitude from the declination of one star if it is located on the meridian.

6. Students next determine the longitude of the substellar points of the three stars, using Greenwich sidereal time (give the class Greenwich sidereal time for the setting). Students know (a) that the right ascension

of a star coincides with Greenwich sidereal time when the star's substellar point is on the longitude of Greenwich; and (b) that the earth revolves from west to east at 15° per hour. Therefore, the longitude of a star's substellar point may be found by subtracting Greenwich sidereal time from the right ascension of the star, and multiplying by 15. For example, if the right ascension of a star is 14 hours and it is 0800 Greenwich sidereal time,

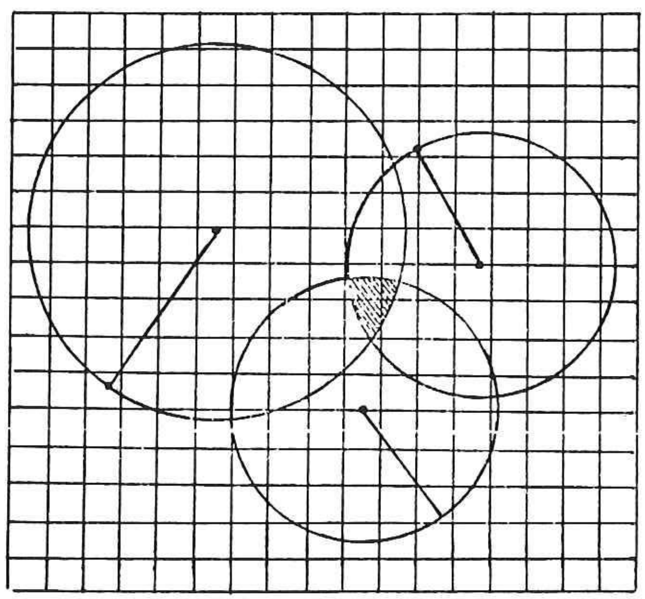
14 - 8 = 6 hours west of Greenwich (a negative number indicates east of Greenwich)

6 x 15= 90° west longitude (a negative number indicates east longitude)

7. After students have found the latitude and longitude of the substellar points of the three stars, they should plot them on their world maps.

8. The next step is for students to determine a zenith angle--the angular distance from the zenith--for each of the three stars. They do this by subtracting the altitude of the star from 90°. They then use the zenith angle of each star as the radius of a "circle of position" which they draw around the star's substellar point as plotted on the map. The latitude scale of the map should be used to measure degrees in constructing each radius.

9. The three circles of position should meet to form a small triangle representing the student's "tour position" at sea, as shown in the figure below. Students should examine what it tells them about their location and consider what else they need to know.



10. The small triangle (shaded area) should tell students where they are on earth within a few degrees. But they must remember that they are at sea and have not yet determined the direction they should head the craft to get to their destination. Now they plot a heading to their destination, drawing a line to that point on the map. To do so, they:

    a. Determine a north-south line. (In the planetarium this can be done with the meridian; aboard ship, it would be done with a compass.)

    b. Measure the azimuth angle between north and the desired heading. This is done by measuring on the map with a protractor and then measuring the same number of degrees around the horizon from the position determined as north. (It may need to be pointed out that both azimuth and bearing are measured clockwise around the horizon from 0° north to 360°.)

    At this point, the student mariners should mentally head the ship in the determined direction.

11. The above steps complete the procedure for celestial navigation. But explain to students that in practice, once isn't enough. The procedure is repeated over and over again by navigators to keep a ship or an aircraft on course. You might also point out that the planetarium sky hasn't moved--a convenience you have arranged. The stars in the real sky would "move" all the while--a substellar point would be a substellar point only for an instant. Therefore navigators need to take their measurements and make their calculations with speed. How can they do so? They travel (usually) a known course; they know what ocean they are on or over; they have their favorite stars to steer by and know these stars' right ascension and declination. They also have handy instruments to get altitude, a clock set for Greenwich sidereal time, and mathematical tables. Through the night, they get a "fix" from the stars many times, quickly going through procedures comparable to the ones above; during the day, they use the sun and depend on other, but often less satisfactory, methods to steer by.

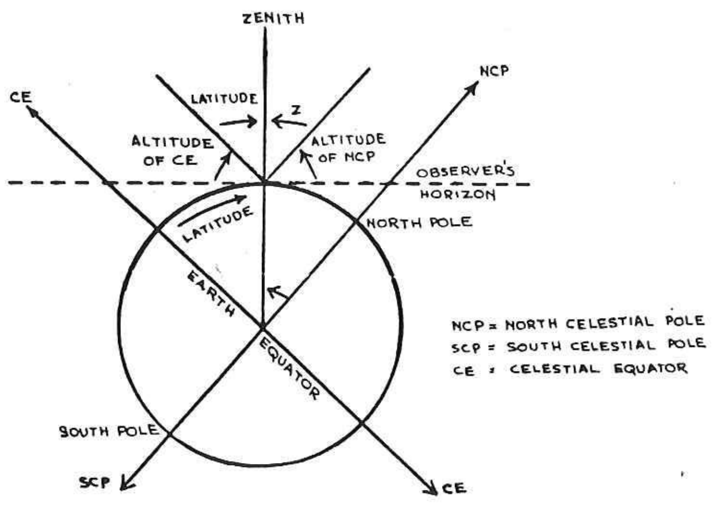
12. If time, move the planetarium sky and let students redetermine their position at sea.

Follow-Up Activities

1. Unless the topic has been well-covered previously, pursue the idea that an observer can determine his own latitude if he finds the declination and altitude of <u>one</u> star located on the meridian. Students know (a)

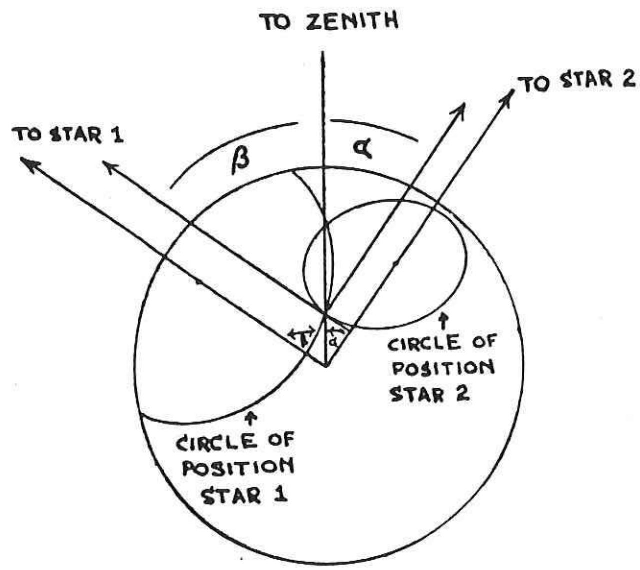
that the celestial equator is directly above the earth's equator at 0° declination; (b) that the celestial poles are an extension of the earth's poles and are 90° from the celestial equator; and (c) that the zenith is 90° above the horizon. Therefore, if a star with a declination of -10° has an altitude of 35°, the celestial equator at the latitude of the observer's location has an altitude of 25°. To obtain his own latitude, the observer subtracts the altitude of the celestial equator from the altitude of the zenith: 90° - 25° = 65°. For class emphasis: 65° is the angular distance of the celestial equator from the zenith point (or the zenith angle). Since the celestial equator's substellar point is the earth's equator, and since the zenith's substellar point is the position of the observer north or south of the equator, the latitude of the observer is the zenith's substellar point of 65°.

2. Discuss the zenith angles used in plotting the navigational triangle in greater detail. From the diagram below, it should be recognized by students that the zenith angle, Z, is 90° minus the observer's latitude, and that it is also 90° minus the altitude of the north celestial pole. Thus the altitude of the north or south celestial pole is equal to the observer's north or south latitude.



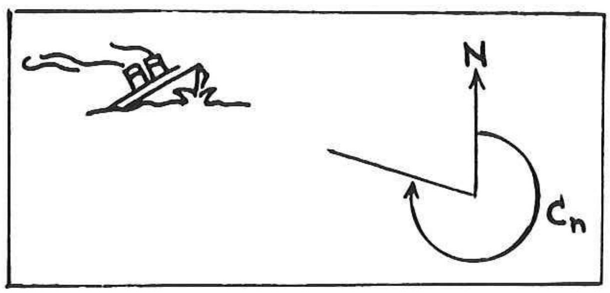
3. Discuss in some depth the principles involved in using three stars to get a "fix." The angle in the sky between the navigator's zenith and a star (the zenith angle) is the same as the angle at the center of the earth between the observer and the star's substellar point. (Mathematically, this is the same principle Eratosthenes used and underlies all determination of location by means of celestial objects.) Having found the zenith angle for <u>one</u> star, the navigator knows his distance in degrees of an arc from the star's substellar

point--he is somewhere along the rim of a circle whose center is the substellar point of the star and whose radius is his zenith angle from the star. But the one circle offers possibilities of position that may vary as much as 130° in all directions. By finding his zenith angle for a second star and constructing a second circle of position, the navigator limits the possibilities: the intersections of the two circles define the two places on earth where he may be located. (Two circles often will be enough for a ship's navigator--for instance, one of the possible positions may be on land.) The third circle of position defines a "tour" position in a spherical triangle which contains one of the intersections of the first two circles and which is within all three circles. A drawing such as below may clarify these ideas for students.

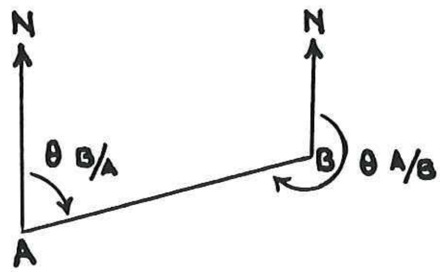


4. Students who are interested in sailing may wish to examine in more detail procedures for plotting course and bearing:

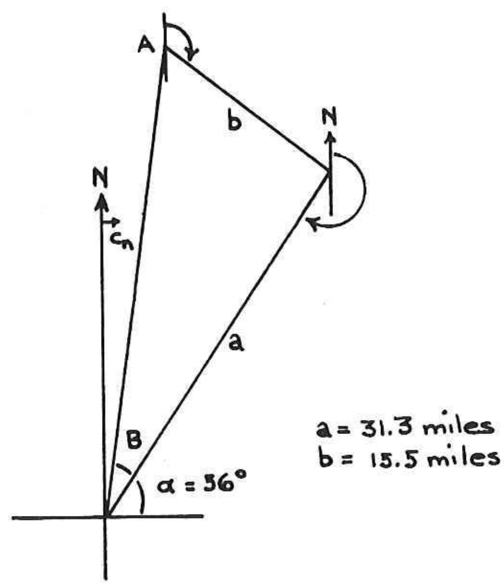
   a. After a north-south line is constructed through the ship's position (that is, the intersection of the circles), the course, C, is measured from the north clockwise to the direction the ship is sailing:



b. Bearing is also measured clockwise from north. Below the bearing of a ship at A headed toward B is the angle measured clockwise from the north line and is the angle B/A (B/A means B relative to A). Likewise the bearing of a ship at A headed toward B is the angle A/B.



c. To provide an example of the computations involved in navigation, present the following problem: A ship sails 15.5 miles on course 124.0°. It then sails 31.3 miles on course 214.0. What course must it then sail to return to its starting point? The sketch below represents the given conditions. We have a right triangle with two legs known.



To find B use:

$$\tan B = \frac{b}{a}$$

$$\tan B = \frac{15.5}{31.3}$$

$$\tan B = 0.4951$$

$$B = 26°20'.$$

To find C_n, note that $\alpha = 30°$

Hence $\alpha + B = 30° + 26°20'$

and $C_n = 90° - (\alpha + B)$

or $C_n = 33°40'$.

5. To conclude the activity, invite someone familiar and experienced in navigation to talk with the class on celestial and other navigation techniques--and/or conduct an evening session and see if the students are able to obtain their position from observations of the real sky.

EVALUATION SUGGESTIONS

Give students data and let them repeat the procedures used in the planetarium.

The maps prepared by students can serve in part for evaluative purposes.

VOCABULARY

horizon
zenith angle
celestial navigation
right ascension   declination
altitude   navigational triangle   azimuth
longitude   great circle   latitude
Greenwich sidereal time
circle of position
heading bearing
"fix"

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 98-99.
Bernhard, et al., New Handbook of the Heavens, pp. 187-198.
Investigating the Earth, ESCP, pp. 60-68.

"Mean Places of Stars," American Ephemeris and Nautical Almanac.
MacRae, Donald A., "The Brightest Stars," The Observer's Handbook.

METEOR OBSERVATION: GETTING THE FACTS

Meteors and meteorites are of value in science for the information they offer about characteristics of the upper atmosphere and the composition of bodies in space. However, meteor observation is of use to students primarily for the opportunities it provides for training and growth in the skills required to make and report observations.

In the following activity, students will be challenged to figure out ways to observe and describe a meteor after seeing one unexpectedly in the planetarium. When other meteors fortuitously cross the planetarium sky, they will be ready to practice specific techniques through which observations may be quantified and reported. (If this activity can be timed for a period of meteor showers in the real sky, so much the better.)

STUDENT PREPARATION

Grade level: secondary
Content background: working knowledge of measurement of angles; some familiarity with constellations; ability to use a coordinate star chart.

FACTS AND CONCEPTS

Science advances through careful observations and the collection of quantitative data. This means that ways must be found to record and describe sensory impressions quantitatively.

The observation of meteors requires measuring techniques in order to determine azimuth, altitude, direction of motion, brightness, duration, color, accompanying sounds, and time of observation.

Meteorites provide information on the composition of bodies in space.

OBJECTIVES

- Given appropriate instruments, the student will be able to determine and communicate to others the altitude and azimuth of the beginning and end points of a meteor observed in the planetarium and its angle to the horizon.

- The student will be able to chart the course of a planetarium meteor on a coordinate star chart and to determine, with a protractor, the angle of the meteor trail to the celestial equator.

- The student will be able to provide such other data on a fireball meteor observed in the planetarium as is sought on real fireballs by members of the Network for Analysis of Fireball Trajectories.

MATERIALS

Classroom: astrolabes or materials for making them (see Appendix); constellation charts, coordinate star chart; protractor.

Planetarium: degree markings around planetarium dome; meteor projector (or use other projection device or flashlight to simulate meteor trail on planetarium dome); note pads, pencils, pen lights; Fireball Observation Chart--two copies per student; planetarium sextant projector.

PROCEDURES

In the Classroom

1. If the students have not had previous experience in making an astrolabe, they should make one. In any event, they should practice using one to determine the altitude of objects outdoors.

2. Familiarize students with the constellations that will be visible in the night sky on the date of the planetarium visit. After showing the shape of the constellation on a constellation chart, ask students to locate the same constellation on a coordinate star chart, giving them the coordinates.

In the Planetarium

1. Turn on the stars for 9 p.m. date of planetarium visit. Let students use the night sky to determine cardinal points, then proceed with the identification of stars

and constellations. (Be sure to review those that will be in the paths of the meteors to be projected.)

2. As star identification goes on, project the first meteor.

3. Turn up the lights and ask students to record what they saw. Discuss and compare descriptions so that students will note what no doubt will be the result: conflicting reports, inconsistency in the use of terms, scattering of data.

4. Ask the group to consider the types of data that could be collected on a meteor and to jot down a list of observable characteristics as each is agreed upon. Press for mention of the following characteristics and discuss how each might be described and, if possible, measured--

   a. Brightness and color: Students who have seen meteor showers or who have read about them may offer suggestions. Otherwise, ideas may have to await further planetarium experiences.

   b. Location: Where were the beginning and end points of the meteor? Could these be determined in relation to the star background? How might the altitude and azimuth of the beginning and end points be determined?

   c. Angle of meteor trail: Might this be determined in relation to the horizon from the altitude and azimuth of the beginning and end points?

   d. Direction of motion? Might this be determined from the azimuth of the beginning and end points?

   e. Time of night, duration: The observer, of course, would check his watch; he might count to estimate duration--if he had seen many meteors he could make a comparative estimate. Announce the time of the planetarium setting--students will need the information later.

5. Turn on the stars again. Letting students offer suggestions, point out the beginning and end points of the first meteor in reference to constellation background, and show how the planetarium sextant, meridian, and degree markings around the dome can be used to determine azimuth and altitude. As you conclude, offer a few minutes of "waiting time," then--

6. Suddenly project a fireball meteor--it comes as a sudden flash, a trail, a "sonic boom." Ask students to collect their thoughts and try to remember all they can

about the meteor, particularly the beginning and end points in reference to the stars.

7. Distribute one copy of the Fireball Observation Chart to each student. Let the class as a whole assemble the requested data, with each student filling in data agreed upon (or his own observations if there are sharp differences of opinion). Explain the chart as one based on a chart in actual use by members of the Network for Analysis of Fireball Trajectories, a group sponsored by the planetarium at Michigan State University, Lansing. Except in this context, some of the questions may strike students as odd; in the context, the questions make sense. Insist that the class answer all. (Students will get a laugh out of the item "Reliability of Observer." Let each evaluate his own reliability.)

8. Use the planetarium sextant and meridian as required for determining "Position in the Sky" and "Angle to Horizontal." Then ask students to note their own latitude and longitude and to consider whether other data might be recorded as to the two above items by an observer at another location.

9. Distribute to students another copy of the Fireball Observation Chart. Inform them that they will be expected to collect data independently for the next fireball seen in the planetarium sky. After turning on the stars and providing a few moments of anticipatory time, project another fireball meteor. Give students opportunity to fill in the charts, project the planetarium sextant and meridian as needed--then collect the charts for evaluation purposes.

Follow-Up Activities

1. Return the evaluated Observation Charts, discuss, and distribute coordinate star charts. Ask students to plot the trail of the meteor on the chart and to use a protractor to determine its angle to the celestial equator.

2. Let students investigate the dates of the next meteor showers, using The Observer's Handbook. If possible, meteor watches should be planned for those nights, with students again collecting the data called for on the Fireball Observation Chart.

3. Ask students to observe and describe aircraft moving through the sky--an investigation that will require similar observational and communications skills.

4. Assign reading through which students will investigate the relationship of the asteroid belt and comets to

meteor showers--and the distinctive terms used to differentiate between objects from space (meteoroid, meteor, meteorite, fireball meteor, bolide).

5. Let students investigate the values of meteors to science.

6. Encourage students to collect and analyze meteor dust. For example, they might collect water from an eavespout, straining it through muslin. Then they should let the cloth dry and collect particles from it with a magnet. You can explain that what they collect will be micrometeorites, and rust from the gutter. Using a hand glass, they can distinguish between the two--the rust will appear as flakes; the micrometeorites will resemble small grains with ragged edges. (More capable students may also be able to subject the micrometeorites to tests for unknown elements.)

EVALUATION SUGGESTION — Student performance may be determined by evaluation of the completed Fireball Observation Chart and by the student's ability to plot the trajectory on a coordinate star chart.

VOCABULARY

meteor
trajectory
end point/beginning point
meteoroid fireball bolide meteorite
altitude angle to horizontal azimuth
micrometeorite
asteroid
comet

SUGGESTED RESOURCES

Chamberlain, Von Del, Functioning as a Member of the Network for Analysis of Fireball Trajectories, pp. 1-18, East Lansing, Mich., Michigan State University, 1969.
Degani, Astronomy Made Simple, pp. 172-174.
Millman, Peter M., "Meteors, Fireballs, and Meteorites," The Observer's Handbook.
Zim, Baker, Stars, pp. 129-133.

NOTE — For Fireball Observation Chart, see following page. For details on student-constructed astrolabes, see Appendix.

FIREBALL OBSERVATION CHART*

TIME ____ ____ ____ ____ ____ ____ ____

year month date hour minute second time zone

WEATHER ____________________

LOCATION OF OBSERVER
WHEN FIREBALL WAS SEEN ____________________

Latitude________ Longitude______

POSITION OF FIREBALL IN SKY

First seen ________ ________ ________

azimuth altitude star background

End point ________ ________ ________

azimuth altitude star background

Angle to horizontal ____________

Direction of motion ____________

DURATION ____________________

BRIGHTNESS ____________________

COLOR ____________________

SOUNDS ____________________

Interval between first seeing
fireball and hearing sounds ____________

RELIABILITY OF OBSERVER ____________

DATE OF INTERVIEW ____________

*Based on Fireball Observation Chart of Network for Analysis of Fireball Trajectories, Lansing, Michigan.

PARALLAX: FINDING STELLAR DISTANCES

Most astronomical distances are so vast that obtaining direct measurements are impossible. In this activity, students will examine parallax through laboratory exercises and investigations in the planetarium. They will explore not only its use in determining the distance to stars, but also how we depend on it every day for depth perception.

In a final laboratory activity (optional, but recommended), the students will make a three-dimensional model of a constellation. Examination of the model will show them that the three-dimensional configuration is based on the actual distance in light years from each star to the earth, as determined by parallactic shift.

STUDENT PREPARATION

Grade level: secondary

Content background: ability to measure angles with an astrolabe or sextant; (preferably) prior experience with technique of triangulation.

FACTS AND CONCEPTS

Parallax is the apparent displacement of an object due to a change in the observer's position or point of observation.

Parallax is directly proportional to the change in the observer's position in relation to the object.

Depth perception depends on parallax.

Stellar parallax is an angular shift in the position of a star as viewed from the earth due to changes in the earth's position in its orbit.

Stellar parallax provides us with a means for indirectly measuring the distance to many stars.

OBJECTIVES

- Using direct observations of the apparent shift of a planetarium star, due to parallax, the student will be able to use indirect measurements to determine the distance of the star from a known base line.

- The student will be able to use triangulation to determine the height of, or distance to, an object.

- The student will be able to explain verbally or in writing the base line used for determining stellar parallax, and will relate this base line to earth motions.

MATERIALS

Classroom: astrolabes or sextants, protractor; additionally, the various materials listed with the two laboratory investigations and copies of the investigations for distribution to students (see end of activity for the two investigations).

Planetarium: grain of wheat lamp or other light source suspended with black thread from planetarium dome; astrolabe or sextant; tape for measuring base line; pen lights, paper, ruler, protractor, pencils.

PROCEDURES

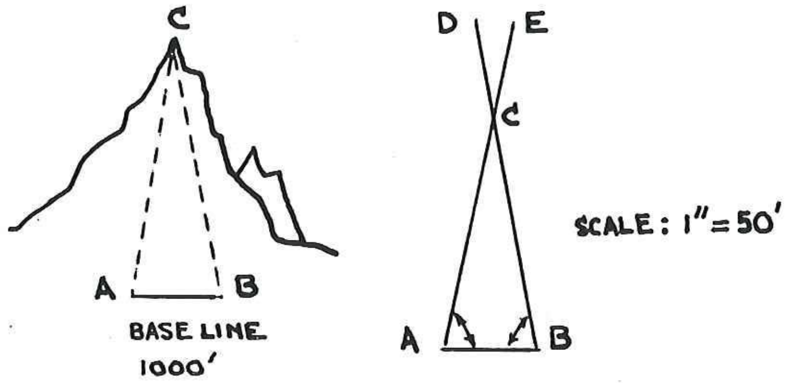
<u>In the Classroom</u>

1. Let students investigate a simple example of parallactic shift. Ask them to hold up a finger directly in front of them and to look at it alternately with one eye and then the other, keeping the other eye close. They should note the position of the finger against the background. Then stretching their arm more and less, they should notice whether distance makes the parallactic shift increase or decrease.

2. Use Laboratory Investigation I (Parallax and Depth Perception).

3. Review how the distance to an inaccessible point may be determined by triangulation. Suppose the distance is sought to a mountain peak. This can be determined by setting up two observation stations at A and B, separated by a known distance, the base line, and assuming triangle ABC, with point C representing the top of the mountain. At station A the angle A is observed and measured between the directions

to B and C; at station B, the angle B is observed and measured between the directions to A and C.



Enough information is now available to construct a scale drawing of the triangle ABC. The base line AB is laid out at some convenient scale and lines AE and BD are constructed at angles A and B, using a protractor to measure the angles. The points where lines AE and BD intersect is the object C. The distance to point C from any point on the base line may now be determined by measuring in the drawing and converting to scale. The result is as accurate as the scale of the drawing, with the margin of error increasing as the scale decreases. (Solutions of triangular distance may be much more accurately accomplished through trigometric function of right angles; this method should be used by students who have the required mathematical background.)

4. Give students opportunity to try out the above method (perhaps determining the distance to the top of a tower) so that they will get practice in setting up a base line, sighting and taking angle measurements, using a protractor to construct angles, and converting to scale (or using trigometric functions).

<u>In the Planetarium</u>

Presetting: Suspend the grain of wheat lamp or other light source with black thread one or two feet from the center of the planetarium dome. The stars may be set for evening, date of visit.

1. Darken room, turn on stars and the suspended light. Ask students how they might determine the distance to the light.

2. When indirect measurements and triangulation are suggested, students should measure a base line between opposite sides of the planetarium dome and measure the

base angle to the suspended object from both ends of the base line. This measurement may be made with an astrolabe or sextant. Then the distance should be found to the suspended light through the method previously used in the classroom.

3. Ask students how they might measure the distance to a star on the dome. (The students should repeat the procedures of Step 2 for one or several stars.)

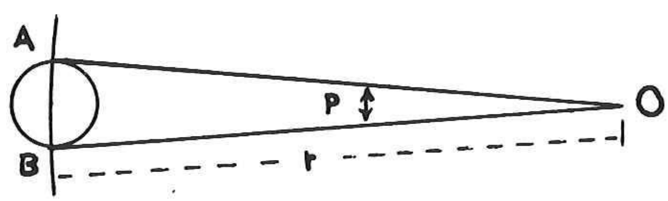
4. The class should now compare the parallax angle for the suspended light with the parallax angle for the star or stars. Discuss what happens to the parallax angle for more distant objects.

5. Discuss the base line used in astronomy for determining the distance to stars--and ask someone to use an atlas of the heavens or <u>The Observer's Handbook</u> to look up the parallax angle for the particular star or stars considered above.

<u>Follow-Up Activities</u>

1. Provide for study and discussion of historical methods for determining the distance to celestial objects. The students might note that the distance to the moon was determined surprisingly accurately by the ancient Greeks through triangulation procedures (two distant points were used as the base line).

2. Present the solution of the astronomical "skinny triangle" as a means for finding the distance to nearby celestial objects (sun, moon, planets). Suppose it is found that the displacement in direction of an object--that is, parallactic shift--as viewed from opposite sides of the earth, is the angle <u>p</u> in the diagram below. Then <u>p</u> is the angle at O subtended by the diameter of the earth.



Imagine a circle centered on O that passes through points A and B on opposite ends of a diameter of the earth. If the distance to O is very large compared with the size of the earth, then the length of the chord AB is very nearly the same as the distance along the arc of the circle from A to B. This arc is in the same ratio to the circumference of the entire circle as the angle p is to 360°. Since the circumference of a circle of radius r is $2\pi R$, we have

$$\frac{AB}{2\pi r} = \frac{p}{360°}$$

By solving the above equation for r (the distance to O), we find

$$r = \frac{360°}{2\pi} \quad \frac{AB}{p}$$

If p is measured in seconds of arc rather than in degrees, it must be divided by 3600 (the number of seconds in 1°) before its value is inserted in the above equation. After the arithmetic, the formula for r becomes

$$r = 206,265 \frac{AB}{p \text{ (in seconds)}} .$$

As an example, suppose p is 18 seconds of an arc (about what would be observed for the sun). Since AB, the earth's diameter is 7929 miles,

$$4 = 206,265 \frac{7927}{18} = 9.1 \times 10^7 \text{ miles.}$$

3. Continue with problems for solution in which the parallax angle is measured from two opposite sides of the earth's orbit. Discuss limitations of parallactic shift and the "skinny triangle" for determining astronomical distance and ask for reports on other methods.

4. Use Laboratory Investigation II (Parallax and the Constellations). Note: This investigation provides instructions for making three-dimensional models of the Big Dipper and Orion. You can prepare instructions for making models of additional constellations--or students can develop the details themselves--by: (1) determining the distance of each star in light years, (2) devising a scale for light years, such as ¼" = 1 light year, and (3) by plotting the constellation in right ascension and declination to fit the cardboard from which the constellations will be suspended.

EVALUATION SUGGESTIONS

Ask students to measure the distance and/or height of various objects, such as to the top of the flagpole, and check on their techniques and mathematical procedures.

Ask students to describe verbally, or in writing, procedures for determining the distance to a star on the planetarium dome.

Ask students to describe verbally, or in writing, the base line used for determining stellar parallax, and the procedures used.

Students' results in Laboratory Investigation II may be used for evaluation purposes.

VOCABULARY

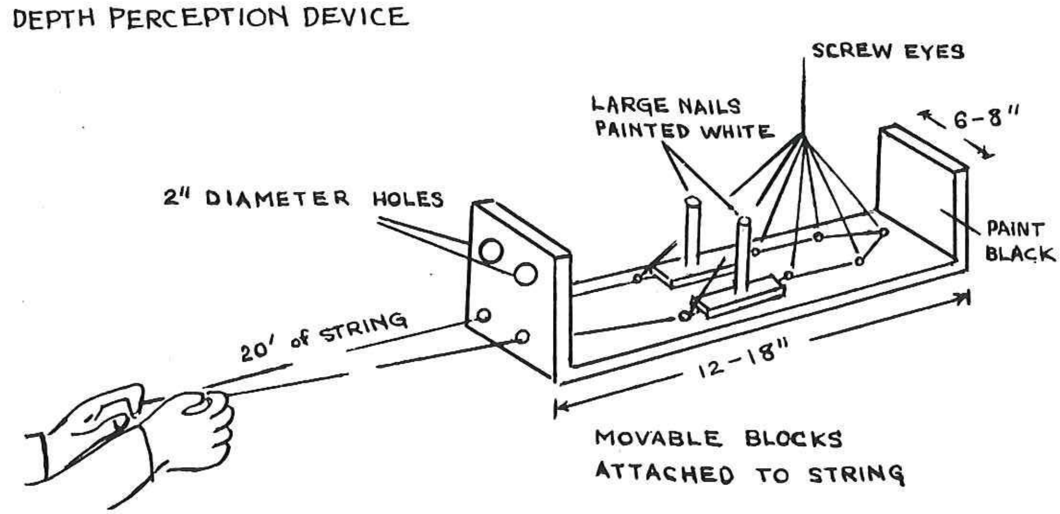
parallax
parallax angle
base line   base angle
triangulation

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 325-327, 337-340.
Dietz, All About the Universe, pp. 70-75.
Freeman, Mae and Ira, Fun with Astronomy, pp. 18-19.
Investigating the Earth, ESCP, pp. 522-523.
Neely, Triangles, pp. 13-19.

NOTE

See following pages for Laboratory Exercises I and II.



Materials:

The frame may be of wood or cardboard.

If wood, use
- 1 piece 18" x 8" x 3/4"
- 2 pieces 8" x 8" x 3/4"
- 6 wood screws, 1¼" long (to assemble frame)
- 3 screw eyes (string will be threaded through these)

If cardboard, use a shoebox 12" to 18" long, 6" to 8" wide, and 6" to 8" deep. Make loops of string in the positions shown for screw eyes, threading them through the bottom of the cardboard and taping in place on the bottom.

2 wood blocks, each 2" x 1" x ½"
2 large nails painted white
45-foot length of string
watch with second hand or stop-watch

Construction and Assembly

Construct apparatus as shown in diagram. Tape or clamp it to the end of a table and thread the string through the screw eyes as shown in the picture. The two ends of the string should extend 20 feet from the apparatus.

Add a scale along both sides of the apparatus. The scale should not interfere with the movable blocks.

Procedures

Pairs of students are to work together, with one manipulating the strings and the other keeping the record. After one student completes all of Step 1 below, he should keep the record while his partner carries out the same step.

1. Sit on a chair 20 feet back from the apparatus. Use a tallback chair or sit where you can support your head against the wall, because you need to keep your head in the same position throughout this step. Hold one string in each hand.

   a. Hold your head in a position so that you can look through the two-inch diameter holes and see the nails.

   b. Using both eyes, line up the nails on the wood blocks, as quickly as possible, in the center of the apparatus.

   Your partner is to time you and read from the scale how far each nail is off from being in the center of the apparatus and how far the two nails are off from being aligned. He is to record this information for three trials on the chart below.

   c. Repeat the above procedure, using only your left eye. Try it three times, with your partner recording information.

   d. Repeat the above procedure, using only your right eye, three times. Again your partner is to record results.

Performance Record Chart

	Time	Units off from Center	Units each peg is off from each other
Trial I			
Trial II			

2. Did the results differ for each eye? ________________

3. Did the parallax (angle of shift) move uniformly for each eye? ___________

4. Change the color of the backboard (tape colored paper over it) and run the investigation again. Does depth perception improve with color? ____________________

LABORATORY INVESTIGATION II: PARALLAX AND THE CONSTELLATIONS
(Three-Dimensional Constellation Models)

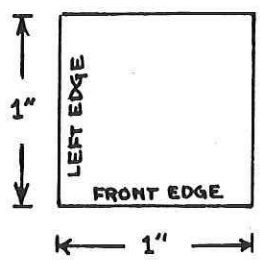
A constellation is a chance arrangement of stars as viewed from earth. If we were to leave the earth in a spaceship and travel to a distant star, the constellations as we know them would no longer be observable. Perhaps the two most famous constellations are Orion, the Hunter, and Ursa Major, the Great Bear (better known as the Big Dipper). How would these constellations appear from other places in space? A three-dimensional model will provide the answer. Choose either of the two constellations and make your model according to the instructions below.

Materials:

1 piece of corrugated cardboard 8" square
1 spool of heavy-duty thread
scissors
aluminum foil
ruler
pin or heavy needle

Construction Procedures

1. Label the cardboard as follows:



2. Using a ruler and pencil, measure and mark on the cardboard the position of each star in the constellation according to instructions provided in the construction table below. Notice that each star's position has two measurements--one for the left edge of the cardboard and one for the front edge.

3. When you are certain that the star positions are plotted correctly, punch a small hole at each star position on the cardboard, using a needle or scissors point.

4. Cut pieces of thread for each star of the lengths designated in the construction table.

5. Push the thread for each star through its correct hole position in the cardboard, leaving 1 inch of its length to be taped to the top of the cardboard.

6. Roll up small balls of foil to represent the stars. The foil ball for Alpha will be the largest (about ½" in diameter), the one for Beta will be the next largest, and so forth. Here is the Greek alphabet to assist you:

alpha	- α	eta	- η	nu	- ν	tau	- τ
beta	- β	theta	- θ	xi	- ξ	upsilon	- υ
gamma	- γ	iota	- ι	omicron	- ο	phi	- φ
delta	- δ	kappa	- κ	pi	- π	chi	- χ
epsilon	- ε	lambda	- λ	rho	- ρ	psi	- ψ
zeta	- ζ	mu	- μ	sigma	- σ	omega	- ω

7. With a pin, needle or scissors tip, punch a hole through the center of each foil ball.

8. Pass the free end of the thread through the foil ball, making sure to put the correct size ball on its corresponding thread (again, see construction table) and tape in place.

Investigative Procedures

1. Hold the cardboard horizontal with the floor, view the constellation at eye level, and record its appearance.

2. Hold the cardboard horizontal with the floor but over the head, view the constellation from underneath, and record its appearance.

3. Hold the cardboard so that the front edge is vertical with the floor, view the constellation, and record its appearance.

4. Hold the cardboard so that the left edge is vertical with the floor, view the constellation, and record its appearance.

5. Try to relate your observations to your view of the constellation from earth, to a view of it from other points in the universe, and to parallactic shift.

6. Try to relate your observations to the movement of the earth in space and to the parallactic shift that results

from Earth's motion in space. The parallax angle for each star is given in the last column of the construction table. You can convert parallax angle to distance in light years as shown below:

Distance (in parsecs) = $\frac{1}{\pi}$ (parallax sec of arc)

Example

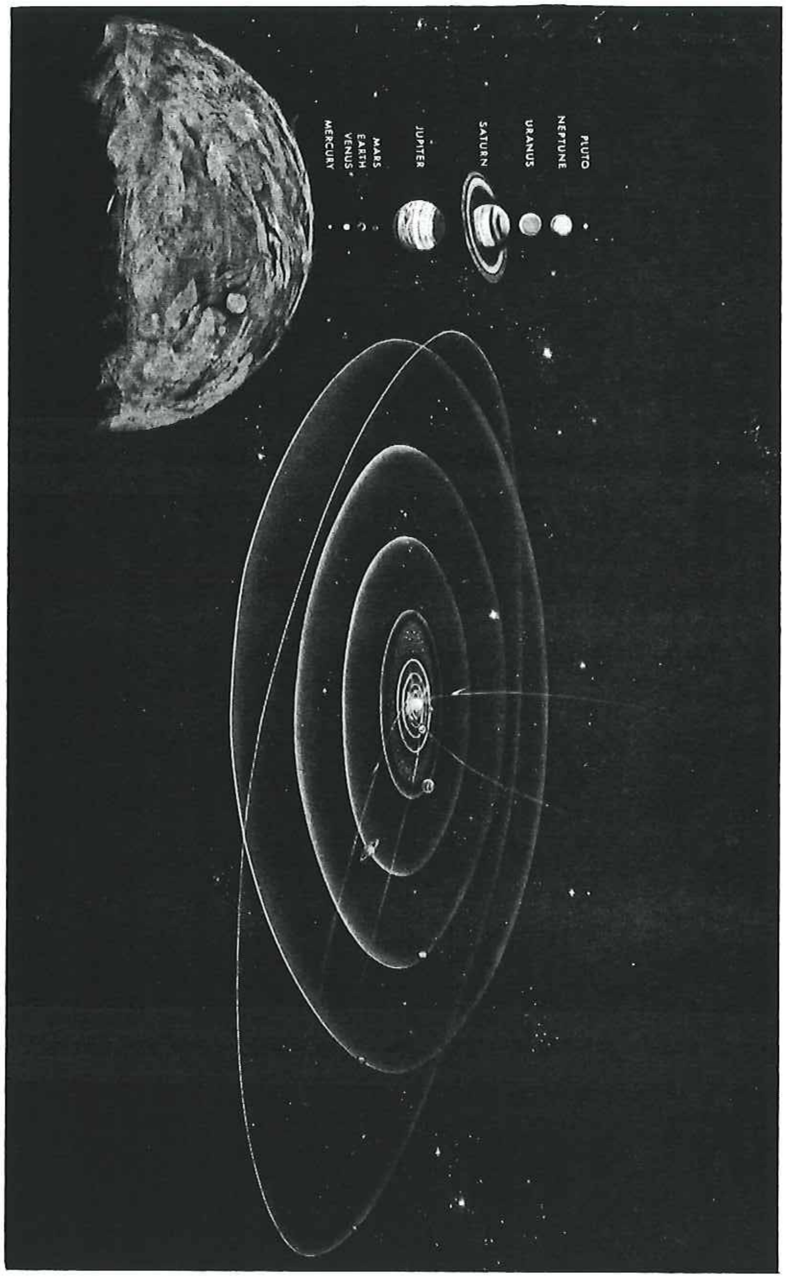
Star's parallax = 0".007

Distance (parsecs) = $\frac{1}{.007}$ = 142.9

1 parsec = 3.263 light years

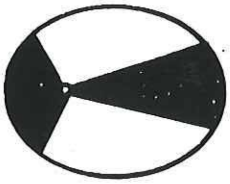
D (light years) = light yr/parsec x distance (parsecs)

D = 3.265 x 142.9
D = 466.4 light years



THE SUN THE SEASONS OF THE YEAR SUPPLIES
AND BIDS THE EVENING AND THE MORNING RISE,
COMMANDS THE PLANETS WITH SUPERIOR FORCE,
AND KEEPS EACH WANDERING LIGHT TO HIS APPOINTED COURSE.

- *Lucan's Pharsalia*
(*Rowe's trans.*)



Motion of the Planets

To early man, the planets were wandering stars because over a period of time they appeared to shift their positions against the background of stars. Later, many theories were proposed to account for the peculiar motions these celestial objects systematically displayed. All of the theories were based on the idea that Earth ruled the solar system.

Even though now it has been more realistically established where and how our planet fits into the solar system, the planets have not been forgotten by astronomers. One of the most important branches of modern astronomy is concerned with planetary motion.

The way planets appear to move as seen from Earth, and their actual motion in orbit, can be dramatically demonstrated in the planetarium. In these activities, the student will view these motions and will learn for himself what Kepler discovered.

DISCOVERING NEPTUNE

It's difficult for students to comprehend the method through which a scientist can predict discoveries. Yet if they use a similar procedure themselves in making a prediction, the method becomes quite clear.

The method students will use to predict the existence of Neptune in the following activity has much in common with that which John C. Adams and U. J. Leverrier actually used to predict the planet and its location. In the planetarium, the students will plot the orbit of Uranus from a position in space, and then will be led to analyze the data, look for irregularities, and seek their causes.

STUDENT PREPARATION

Grade level: secondary
Content background: basic knowledge of planetary motions; fundamental knowledge of forces that hold a planet in orbit.
Note: This activity fits in well with Chapter 23, "The Solar System," in Investigating the Earth, Earth Science Curriculum Project.

FACTS AND CONCEPTS

Discoveries may be predicted in science through analyzing and interpreting irregularities in data.

Through interpretation of irregularities plotted in the orbit of Uranus, a prediction can be made as to the existence of another planet.

The perturbation in the orbit of a planet is caused by a change in gravitational forces acting on the planet.

OBJECTIVES

- Given an orbital drawing, the student will be able to identify a perturbation and predict the location of the body causing it.
- Given a planetarium experience through which he plots the orbit of Uranus, the student will be able to identify the perturbation in its orbit.
- The student will be able to explain the perturbation in the orbit of a planet in terms of gravitational forces.

MATERIALS

Classroom: steel ball, inclined plane, carbon paper, strong horseshoe magnet; for follow-up--Orbit Analysis Sheet.

Planetarium: polar coordinate system, with rays 30° apart and concentric circles 20° apart (project with either overhead or overlay projector); planetarium orrery with all bulbs removed except Venus, which will be used as Uranus; three fixed projectors--as zenith, pole, and home latitude--set for indicating perturbation in orbit of Uranus; Orbit of Uranus Worksheet, pencils, pen lights.

PROCEDURES

<u>In the Classroom</u>

In preparation for the planetarium visit, set up a laboratory exercise in which students--

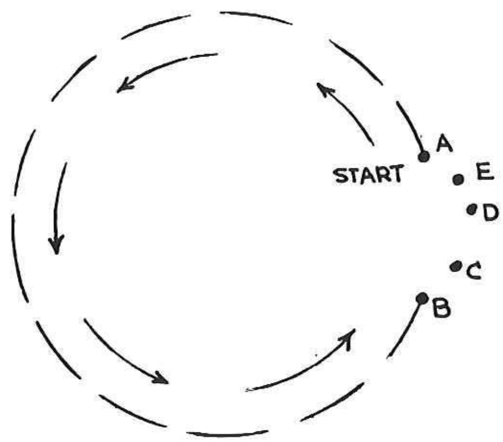
1. roll a steel ball down an inclined plane which is covered with white paper overlaid with carbon paper;
2. repeat the above procedure (using new carbon and white paper), this time introducing a strong horseshoe magnet at a point along the path of the steel ball;
3. compare the paths traced out on both sheets of white paper, discussing the cause of the deflection observed;
4. discuss observations as analogous to those that might be made of a planet in orbit were the planet to enter a new gravitational field.

<u>In the Planetarium</u>

1. Project the polar coordinate system on the dome; then turn on Uranus (Venus) at point A in its orbit as shown in the figure with Step 3.

2. Pass out the Orbit of Uranus Worksheets, explaining that students will soon see the planet in orbit and that they are to plot its path at 15° intervals.

3. Start motion and let the plotting proceed. When point B in the orbit (see figure) is reached, turn off orrery and use the three fixed projectors in succession so that points C, D, and E (demonstrating the perturbation in the orbit) may be plotted. Then turn on Uranus again at point A to indicate completion of the planet's 84-year orbit.



4. Turn up the lights and ask students to examine the data. Suggest that each write a brief description of the orbit of Uranus and a short statement providing an interpretation of anything unusual observed and plotted. Collect worksheets.

5. Continue with a discussion of the nature of orbits and gravitational attraction.

6. Discuss the orbit of Uranus as plotted and ask students to offer hypotheses as to why the bulge in the orbit exists. Tell the Adams-Leverrier story about the prediction of Neptune or ask a student who knows it to do so.

7. Conclude with the suggestion that students investigate the prediction and discovery of Pluto and Planet X (Brady's planet).

Follow-Up Activities

1. Distribute Orbit Analysis Sheets and ask students to analyze the orbits shown. Using a protractor to draw circular orbits for the planets will help. Let the class discuss and identify any new gravitational fields entered by the planets as depicted by the orbital

drawing--and predict the location of any body that may be causing a perturbation.

2. Ask for reports on the discovery of Pluto and Planet X, referring students to recent science periodicals for information on the latter (there have been recent reports on Planet X in both scientific journals and popular science magazines).

3. Ask for (and present) other examples of scientific discoveries that have been made as a result of interpreting irregularities in scientific data.

EVALUATION SUGGESTIONS

The worksheets completed by students in the planetarium can serve as one basis for evaluation.

A student's contribution to discussion of the Orbit Analysis Sheet can serve as another basis. Or you may distribute a similar analysis sheet for independent analysis and explanation.

VOCABULARY

orbit
perturbation
gravitational forces
(names of planets)
Planet X

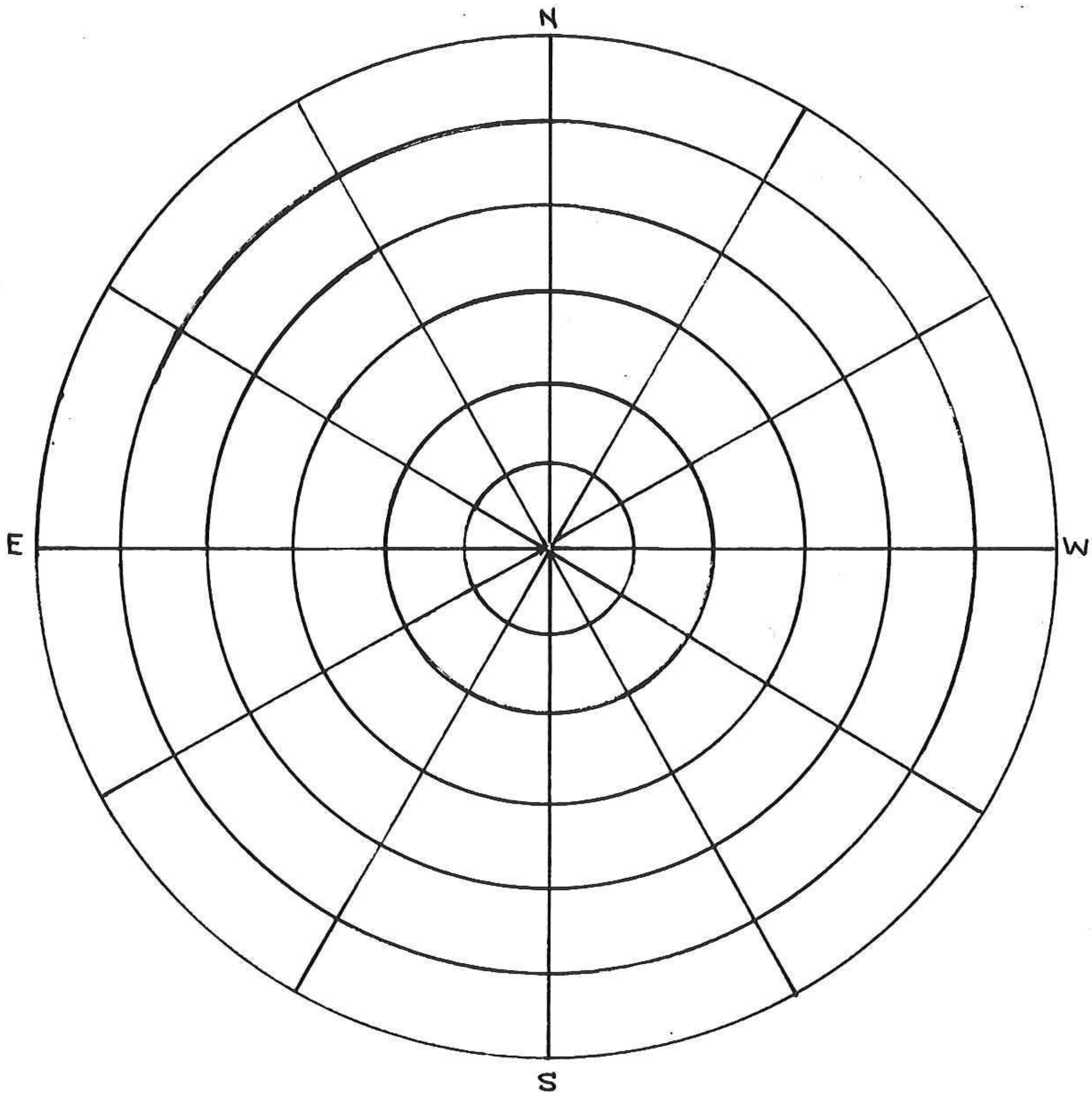
SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 272-274.
Baker, When the Stars Come Out, pp. 116-117.
Bonestell, The Solar System, p. 57.
Investigating the Earth, ESCP, 496-505.

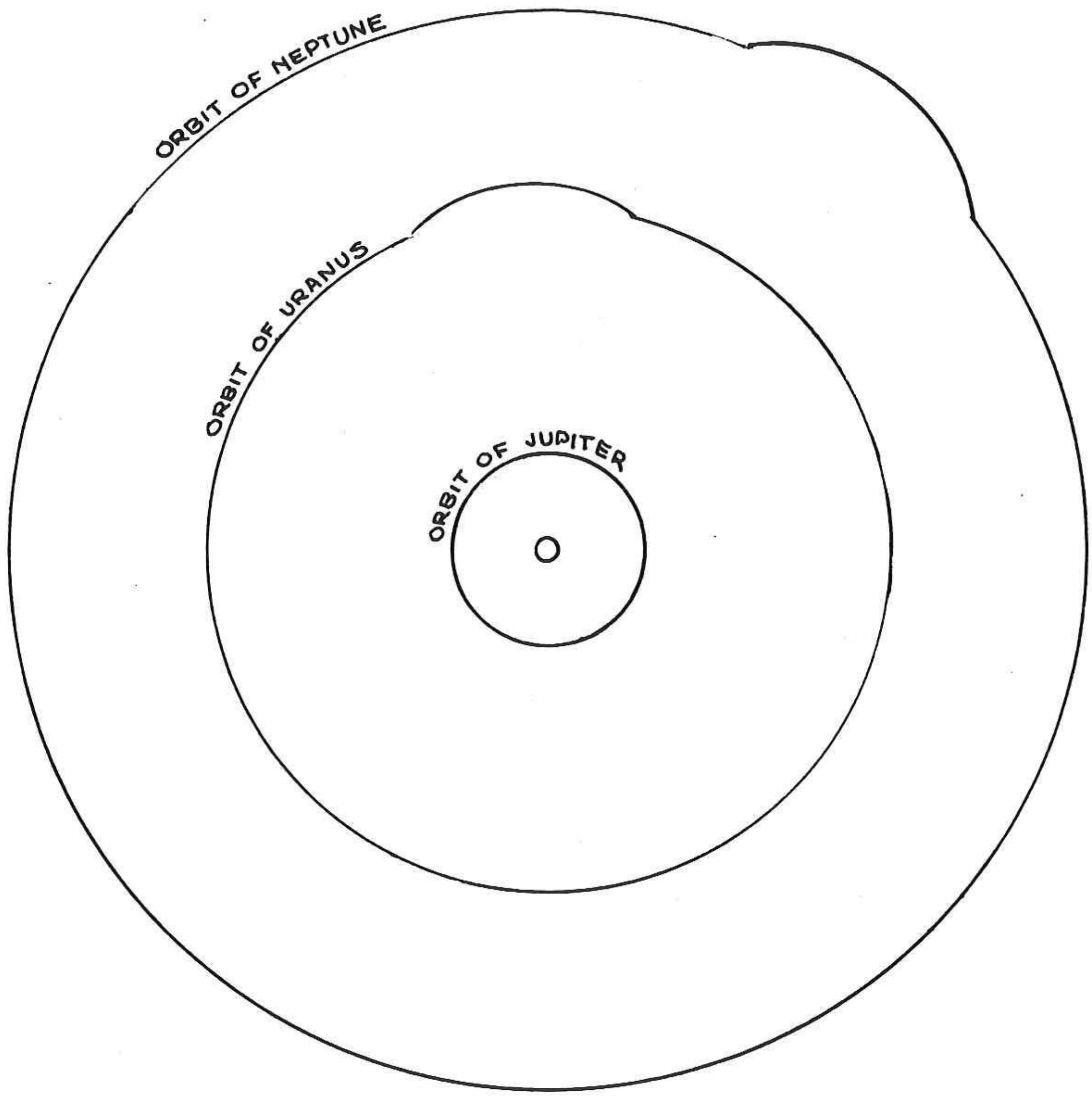
NOTE

See following pages for worksheets used in the activity.

WORKSHEET: ORBIT OF URANUS



ORBIT ANALYSIS SHEET

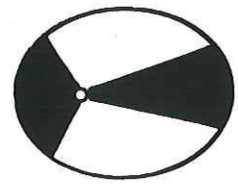


Mean Distance from Sun

Jupiter - 5.2 a.u.

Uranus - 19.2 a.u.

Neptune - 30.1 a.u.



ORBIT OF AN INFERIOR PLANET

Throughout recorded history, man has been able to distinguish planets from the stars, but today's generation has little time for stargazing. Students may be better acquainted with the motions of planets as depicted in textbooks than they are with their motions as observed in the sky.

In this activity, the planetarium is used to make up for students' lack of direct experience. After making observations, students will use data collected on the apparent positions of the inferior planets in relation to the sun to plot models of orbits. The investigation is limited to the orbits of the inferior planets; another activity on the orbits of the superior planets follows.

STUDENT PREPARATION

Grade level: secondary
Content background: prior introduction to Kepler's laws; working knowledge of angles and use of protractor.

FACTS AND CONCEPTS

As seen from the earth, the inferior planets always appear to follow the ecliptic and to be relatively close to the sun.

The apparent motion of an inferior planet results from the motion of the planet as well as from the motion of the earth.

Because the orbits of the inferior planets are located between the earth and the sun, the inferior planets show phases to earth-based observers.

A reasonably accurate drawing of the orbit of an inferior planet can be made from observations of its apparent motions over a period of time.

OBJECTIVES

- The student will be able to construct an orbital model of an inferior planet from data collected in the planetarium and use it to support Kepler's laws of planetary motion.
- Given instructions and data on greatest eastern and western elongation, the student will be able to construct the orbit of an inferior planet.
- The student will be able to correlate the positions of greatest eastern and western elongation, and of inferior and superior conjunction, with the phases of an inferior planet.
- The student will be able to describe and account for the motions of an inferior planet through one complete cycle, both as seen from the earth and from the ecliptic north pole.

MATERIALS

Classroom: various materials for use as three-dimensional models of the solar system; protractor, drawing compass, ruler; instructions and data sheets for orbital drawings of inferior planets (see last part of activity). One styrofoam ball (4"-6" diameter) painted yellow to represent sun; two styrofoam balls (2" diameter) painted ½ yellow, ½ black to represent earth and planet; white styrofoam ball (6"-8" diameter); 60-100 watt light bulb in a photographic bell reflector; one jar lid; two bottle caps; large table covered with white paper or posterboard.

Planetarium: orrery, planetarium sextant; slides showing phases of Venus and supplementary projector; Inferior Planet Observation Sheet (see end of activity); pencils, pen lights.

PROCEDURES

<u>In the Classroom</u>

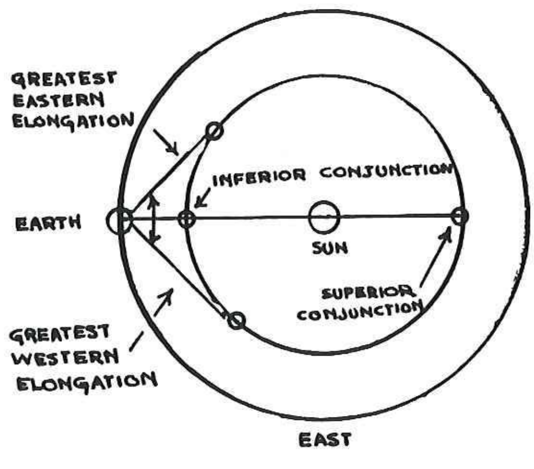
1. Discuss with students the ancient concept of the universe as described by Ptolemy and Copernicus. This may be introduced by viewing in the planetarium the lesson on planetary motions, both real and apparent; then asking the students to construct a model and/or diagram that illustrates and explains the motions.

2. The planetarium lessons on Kepler's laws and retrograde motion are good preparations for this lesson.

3. Review the use of a compass and protractor in constructing, measuring, and bisecting angles by having the students construct the perpendicular bisectors of lines 2½, 3½, 13/4 and 7/8 inches long. Also have the students draw and construct with a protractor angles 56°, 110°, 31°, and 78°; then bisect each angle by construction and measurement.

4. In a darkened room, use a light source (preferably a 60 to 100 watt light bulb in a photographic bell reflector) and a white styrofoam ball to demonstrate that the inferior planets have phases like the moon as seen from the earth. Have one student hold the light so that it always shines on the ball while the teacher or another student holds the ball as he walks around the sun (student with light source). This should be done in front of the classroom so that the remainder of the class represents the earth viewing the planet (ball) as it is being moved in its orbit around the sun (student with light source).

5. The following orbital positions may also be demonstrated in the above activity:



a. An <u>inferior planet</u> whose orbit lies between the sun and the orbit of the earth (Mercury and Venus).

b. <u>Inferior conjunction</u> of an inferior planet occurs when the planet passes between the earth and the sun.

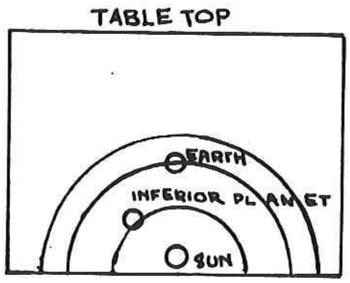
c. <u>Superior conjunction</u> of an inferior planet occurs when the planet passes on the far side of the sun from the earth.

d. <u>Greatest eastern elongation</u> of an inferior planet occurs when the planet is at its greatest angular distance east of the sun as viewed from the earth.

e. <u>Greatest western elongation</u> of an inferior planet occurs when the planet is at its greatest angular distance west of sun as viewed from the earth.

6. After performing the above demonstration, have the students use three styrofoam balls, table top and chalk to construct a model of the orbital positions. At one

side of the table, place the sun ball on a jar lid around which three semi-circles are drawn with chalk to represent orbits. Place one of the small styrofoam balls (inferior planet) in a bottle cap on the first semi-circle from the sun and the second small styrofoam ball (earth) on the second semi-circle making sure the yellow halves of the balls face the sun. Move the inferior planet to various positions in its orbit (elongations and conjunctions) and view the inferior planet from the dark side of the earth ball. Always keep the yellow sides of the balls facing the sun. Record the phase of the inferior planet at each of its positions and explain the phase in terms of the planets' orbital positions.



SEMI-CIRCLES (ORBITS) DRAWN IN CHALK

In the Planetarium

1. Using the sun and inferior planets of the planetarium instrument, demonstrate their motions as viewed from the earth. After allowing time for brief observation, turn on the ecliptic and go through one complete revolution for both Mercury and Venus.

2. In contrast, use the orrery--with only the bulbs for Mercury, Venus, and Earth in place--to show the motion of the inferior planets around the sun as viewed from the ecliptic north pole. Stop motion, as appropriate, to permit observation of eastern elongation, western elongation, inferior conjunction and superior conjunction.

3. Discuss the relative orbital speeds of the two planets and the relationship between them.

4. Distribute the Inferior Planet Observation Data Sheets and project the planetarium sun and inferior planets. Use the hand sextant projector to measure the angles of position east and west of the sun during one revolution of each planet. These positions are recorded by each student on his data sheet.

5. Pose the following questions for explanation: Does Mercury or Venus move more rapidly? What governs rate of movement? When an inferior planet is at greatest eastern elongation, does it rise and set before the sun or after the sun? Is it a morning or evening star?

6. Show phases of Venus, using a slide projector. Ask students to explain the reason for the phases. Let a

student use a light source and styrofoam ball at one end of the darkened chamber to demonstrate the phases. Continue with a discussion of phases that would be observed from the earth when a planet is at greatest eastern and western elongation and at inferior and superior conjunction.

7. Discuss Kepler's laws and instances in which they have been observed in action during the planetarium session.

Follow-Up Activities

1. Provide each student with the Instructions/ Data Sheet for making an orbital drawing of an inferior planet. Let the class work together until procedures are clarified. (Note the sample orbital drawing and teaching explanation on the page following the sheet provided for reproduction and distribution to students.)

2. Review the components of an ellipse and a circle. Also define the major axis of an ellipse as the maximum diameter of the ellipse and the semi-major axis as half the major axis.

3. Have students examine and measure (in terms of fractional astronomical units) their constructed orbits to determine the shape, major axis, semi-major axis, perihelion point and aphelion point. (They might compare their measurements with the figure offered in planetary data tables and compute their percent of error.)

4. Given a statement of Kepler's laws of planetary motion, have the students use their data to support or refute the laws.

EVALUATION SUGGESTIONS

Give students a list of the terms used in the activity and ask them to illustrate their meaning through diagram.

Ask students to draw the phase of an inferior planet at each position mentioned above.

Ask students to describe (orally, through diagrams, or demonstration) the motion of an inferior planet (a) as seen from the earth, (b) as seen from the ecliptic north pole. The description should cover a complete cycle, from inferior conjunction to inferior conjunction.

You can use the orbital drawings students constructed for evaluation purposes.

VOCABULARY

inferior planet
superior planet
greatest eastern elongation
greatest western elongation
inferior conjunction superior conjunction
semi-major axis perihelion
aphelion

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 23 ff.
Hynek, Apfel, Astronomy One, pp. 301-317.

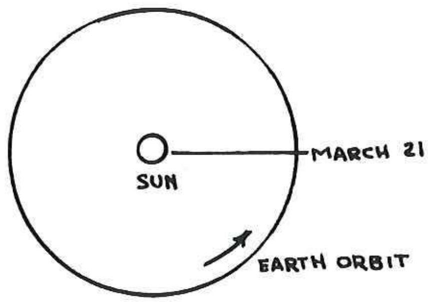
NOTE

See following pages for Inferior Planet Observation Sheet, Instructions/Data Sheet for Orbital Drawing of Inferior Planet, and sample orbital drawing of Mercury and Venus.

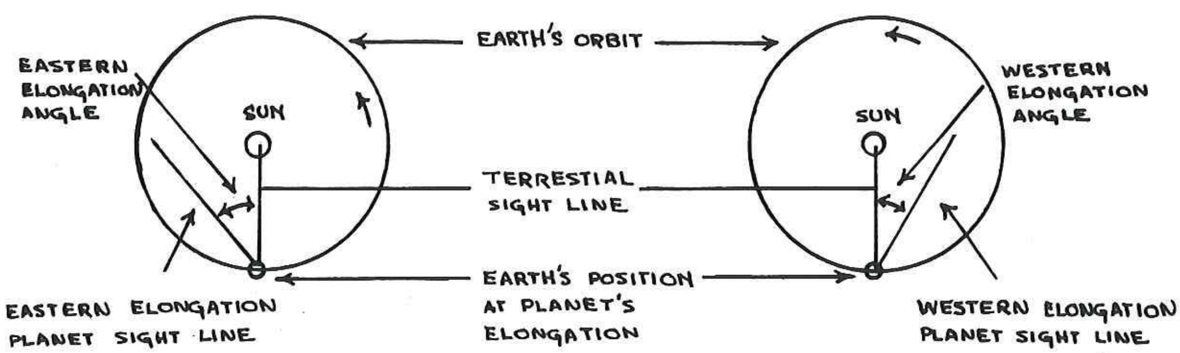
It is suggested that the teacher prepare a worksheet for each planet by constructing the orbit of the earth and plotting each earth position given in the table. Then plot the first seven planet positions for the selected planet. It is essential this be done particularly if this activity is to be used with students who have not had geometry. When all the plots are constructed on the same sheet of paper, there are so many lines very close together that students are apt to become confused. If the students are to plot and construct the entire activity, they should plot half of the points of the planet positions on two separate sheets retaining exactly the same earth orbit measurements on each sheet. Then overlay and transfer the planet plots from the second sheet to the original by tracing.

INSTRUCTIONS/DATA SHEET FOR ORBITAL DRAWING OF INFERIOR PLANETS

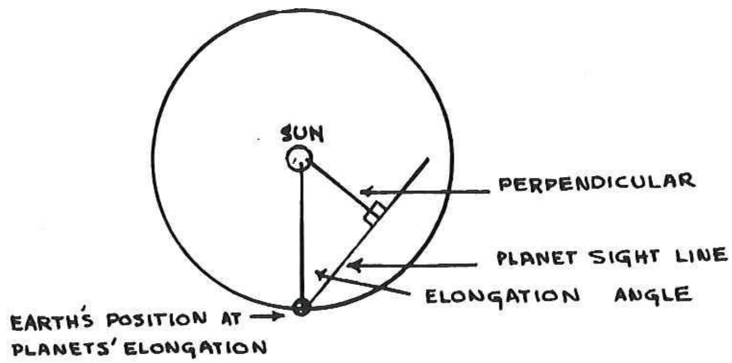
1. Construct a circle of radius 1½ to represent the orbit of the earth as seen from the north ecliptic pole and place a dot in the center of the circle to represent the sun. Also draw an arrow to indicate the direction of the earth's revolution counter clockwise about the sun. Next draw a line from the sun to the earth's orbit to position the earth at the vernal equinox (March 21).



2. Construct a terrestrial sight line from the sun through the earth's orbit for each elongation date advancing around the earth's orbit from the vernal equinox 1°/day counter clockwise. (Plot each date from its closest vernal equinox to reduce error.) Using the terrestrial sight line and the earth's orbit position as the origin of the angle, construct an elongation angle for the planets' elongation positions as seen from the earth. If the greatest elongation value is east, the side of the elongation angle opposite the terrestrial sight line should be constructed to the left side of the terrestrial sight line whereas west greatest elongation vaules should be constructed to the right side of the terrestrial sight line.



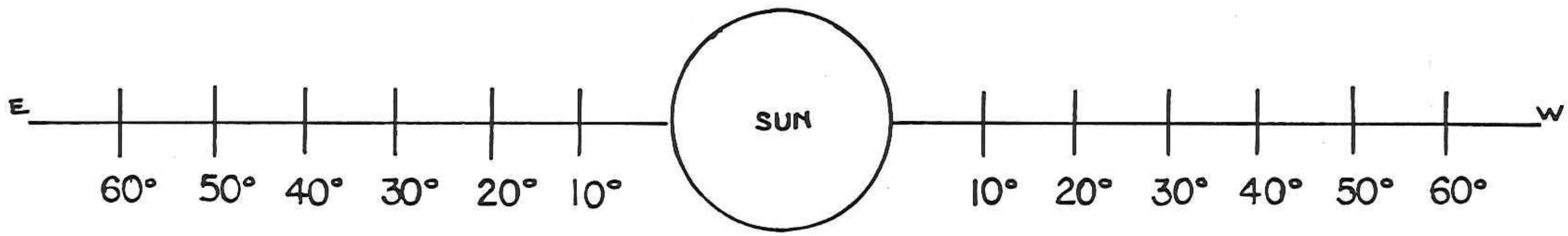
3. Extend the planet sight line (the line opposite the terrestrial sight line) beyond the sun. Construct a perpendicular from the sun to the planet sight line. The planet is located at the intersection of the perpendicular with the planet sight line.



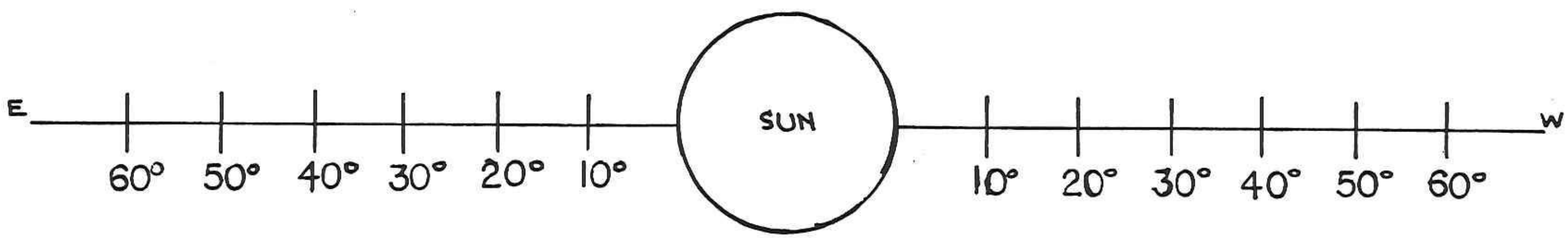
INFERIOR PLANET OBSERVATION SHEET

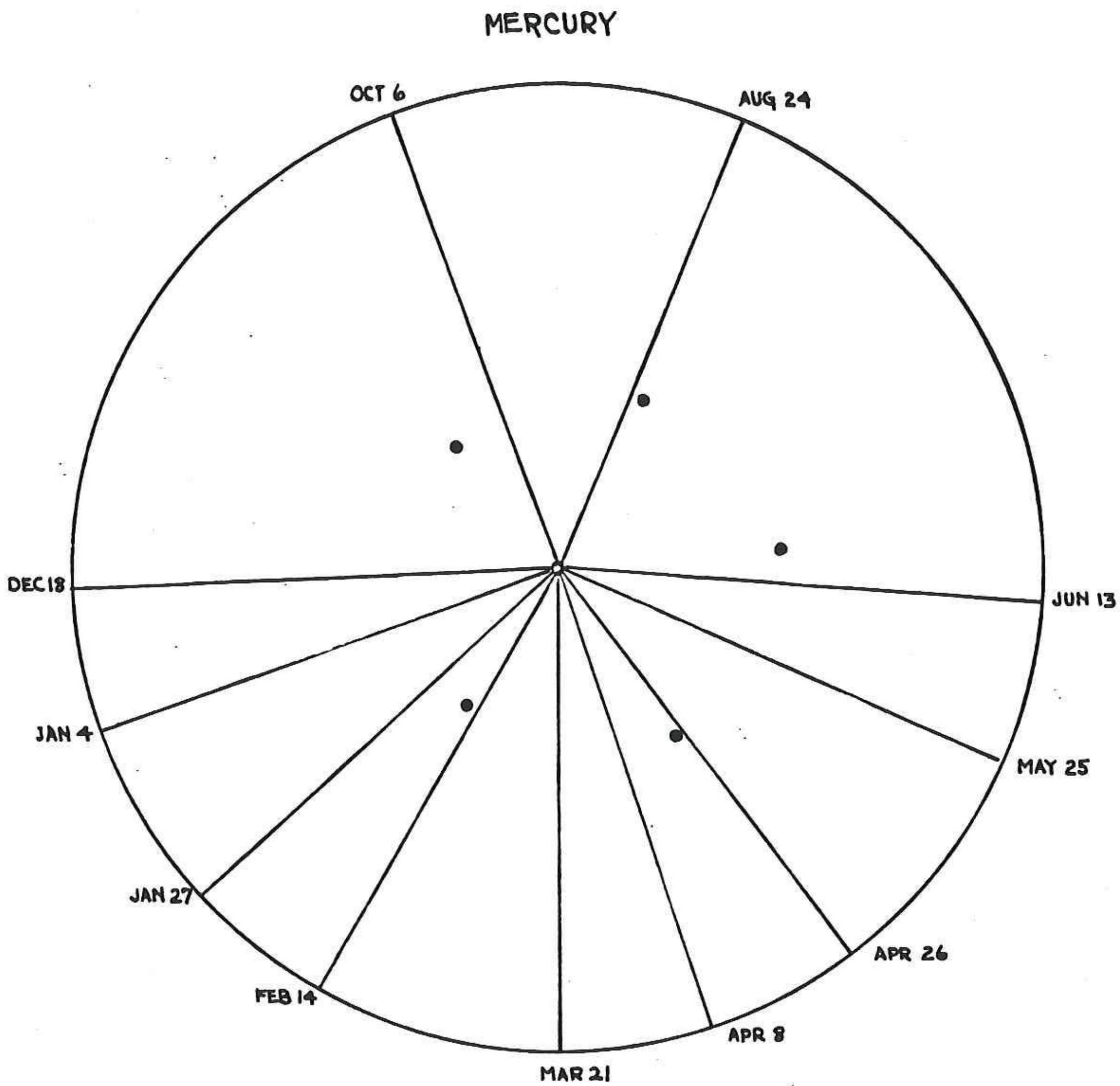
Directions: Plot the positions of Mercury and Venus in degrees east or west of the sun on each date announced by the planetarium director. Write down the date beside each plotting.

MERCURY



VENUS

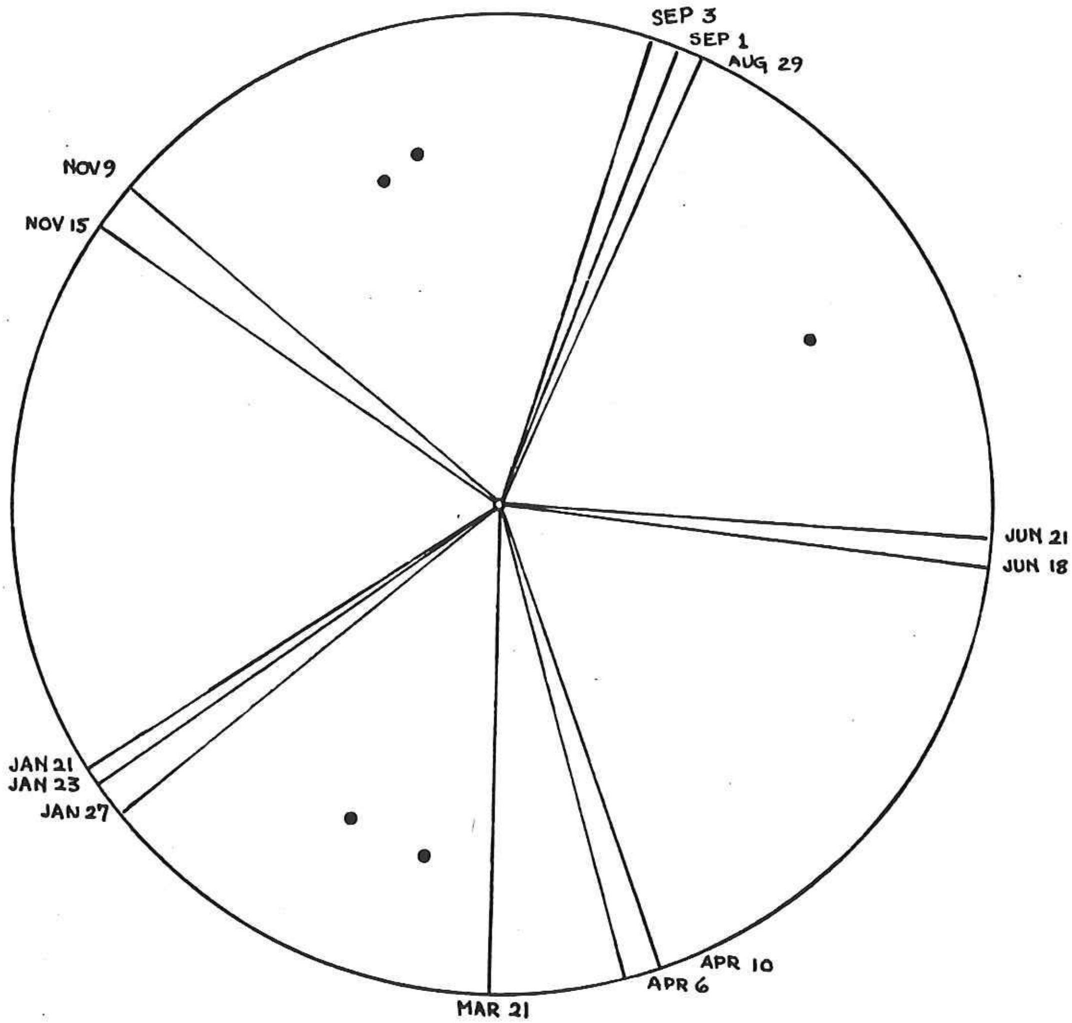




ELONGATION DATA TABLE

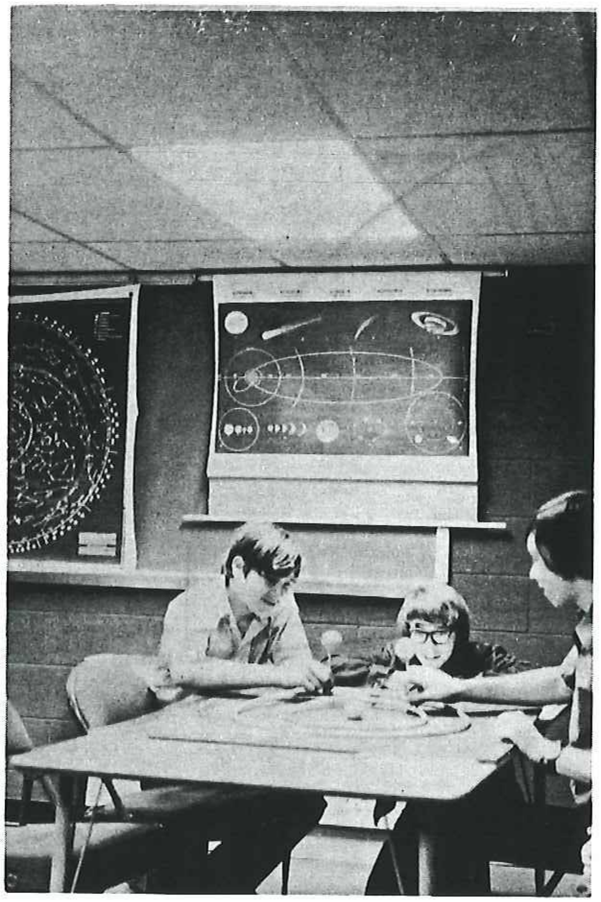
Date	Angle
January 4, 1963	19°E
February 14, 1963	26°W
April 26, 1963	20°E
June 13, 1963	23°W
August 24, 1963	27°E
October 6, 1963	18°W
December 18, 1963	20°E
January 27, 1964	25°W
April 8, 1964	19°E
May 25, 1964	25°W

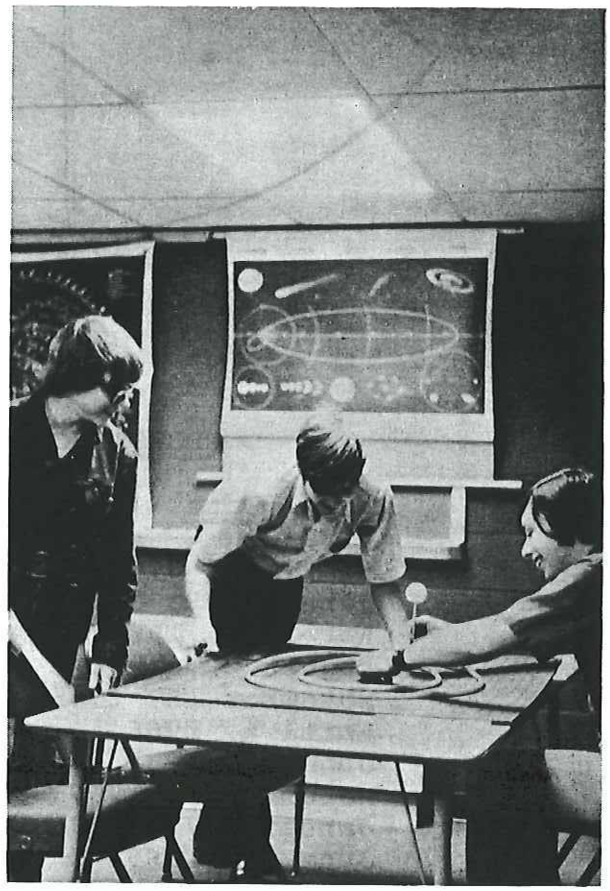
VENUS



ELONGATION DATA TABLE

Date	Angle
September 3, 1962	46°E
January 23, 1963	47°W
April 10, 1964	46°E
August 29, 1964	46°W
November 15, 1965	47°E
April 6, 1966	46°W
June 21, 1967	45°E
November 9, 1967	47°W
January 27, 1969	45°E
June 18, 1969	47°W
September 1, 1970	46°E
January 21, 1971	48°W





ORBIT OF A SUPERIOR PLANET

This classroom-planetarium investigation is a companion activity to the lesson on the orbit of an inferior planet. Together or singly, these activities should do much to help students gain a better understanding of the scientific processes that have gone into developing the contemporary model of the solar system.

After preliminary discussion in the classroom, the students will go to the planetarium to observe an orbital model of the superior planets and to collect data on their apparent motion as provided by the planetarium instrument. Students will return to the classroom to make orbital drawings and calculations and to extract from them data supporting Kepler's laws.

STUDENT PREPARATION

Grade level: secondary
Content background: prior introduction to Kepler's laws; working knowledge of angles and use of protractor. (Previous study of the orbits of inferior planets is desirable.)

FACTS AND CONCEPTS

As seen from the earth, the superior planets always appear to follow the ecliptic and to move all the way around the sky.

The apparent motion of a superior planet results from the motion of the planet as well as from the motion of the earth.

A reasonably accurate drawing of the orbit of a superior planet can be made from observations of its apparent motions over a period of time.

OBJECTIVES

- The student will be able to construct an orbital model of a superior planet from data collected in the planetarium and use it to support Kepler's laws of planetary motion.
- Given opposition and quadrature data, the student will be able to construct a reasonably accurate drawing of the orbit of a superior planet.
- The student will be able to correlate retrograde motion with the positions of conjunction, quadrature and opposition.
- The student will be able to describe and account for the motions of a superior planet through one complete cycle, both as seen from the earth and from the ecliptic north pole.

MATERIALS

Classroom: various materials for use as three-dimensional models of the solar system; protractor, drawing compass, ruler; instructions and data sheets for orbital drawings (see end of activity).

One styrofoam ball (4"-6" diameter) painted yellow to represent the sun; two styrofoam balls (2" diameter) painted ½ yellow and ½ black to represent the earth and planet; white styrofoam ball (6"-8" diameter); 60-100 watt light bulb in a photographic bell reflector; one jar lid; two bottle caps; large table covered with white paper or posterboard.

Planetarium: orrery, planetarium sextant; pencils, pen lights.

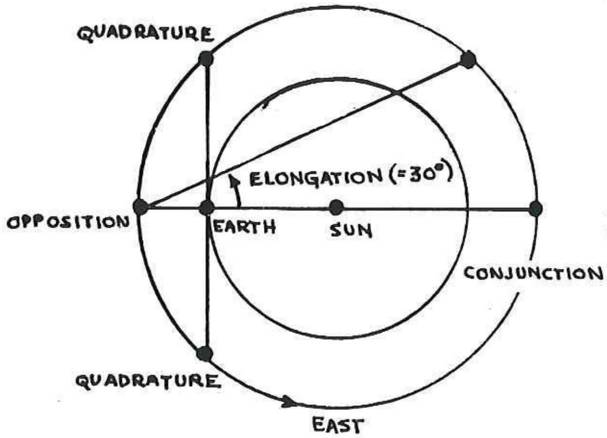
PROCEDURES

In the Classroom

1. Discuss medieval and modern ideas of planetary motion (if this has not been done before in relation to inferior planets). The students should use diagrams and three-dimensional models to illustrate pre- and post-Copernican ideas.

2. Review, as needed, the measurement and construction of angles and the use of a protractor.

3. Discuss Kepler's laws, review retrograde motion and define the terms that describe the position of a superior planet in its orbit.



a. A superior planet is any planet whose orbit lies outside the orbit of the earth (Mars, Jupiter, Saturn, Uranus, Neptune, Pluto).

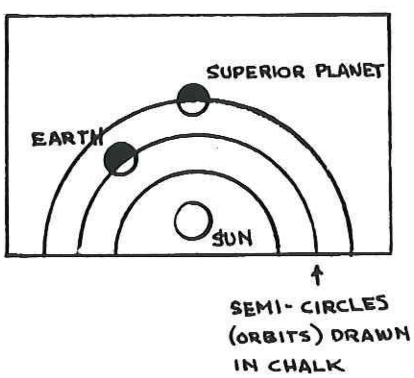
b. Opposition of a superior planet occurs when the earth is directly between the sun and the planet. At opposition, the sun and the planet appear in opposite directions in the sky.

c. Conjunction of a superior planet occurs when the planet is in the same direction as the sun as seen from the earth. The sun is directly between the earth and the superior planet.

d. Quadrature of a superior planet occurs when the planet appears 90° away from the sun in the sky. A line from the earth to the sun makes a right angle with the line from the earth to the planet.

e. Elongation of a planet is its angular distance from the sun as seen from the earth. Thus, at conjunction, a superior planet has an elongation of 0°, at opposition 180° and at quadrature 90°.

4. In a darkened room, demonstrate that the superior planets do not have phases like the inferior planets and the earth's moon. Use a light source (60-100 watt bulb in a photographic bell reflector) as the sun and a white styrofoam ball (6-8 inches in diameter) mounted on the end of a pencil as the planet. The light is held so it always shines on the rotating planet which is carried simultaneously around the sun and seated students who perceive the earth's view of the planet (ball).



5. After performing the above demonstration have the students use three styrofoam balls, the table top and chalk to construct a model of the orbital positions. At one side of the table place sun ball on jar lid around which three semicircles are drawn with chalk to represent orbits. Place one of the small styrofoam balls (earth) in a bottle cap

on the second semi-circle from the sun making sure the yellow half faces the sun. The second small styrofoam ball (superior planet) is placed in a bottle cap on the third semi-circle from the sun. Move the earth at various positions in its orbit (always keeping yellow side towards sun) and view the superior planet positions of quadrature and opposition as seen from the earth's dark side.

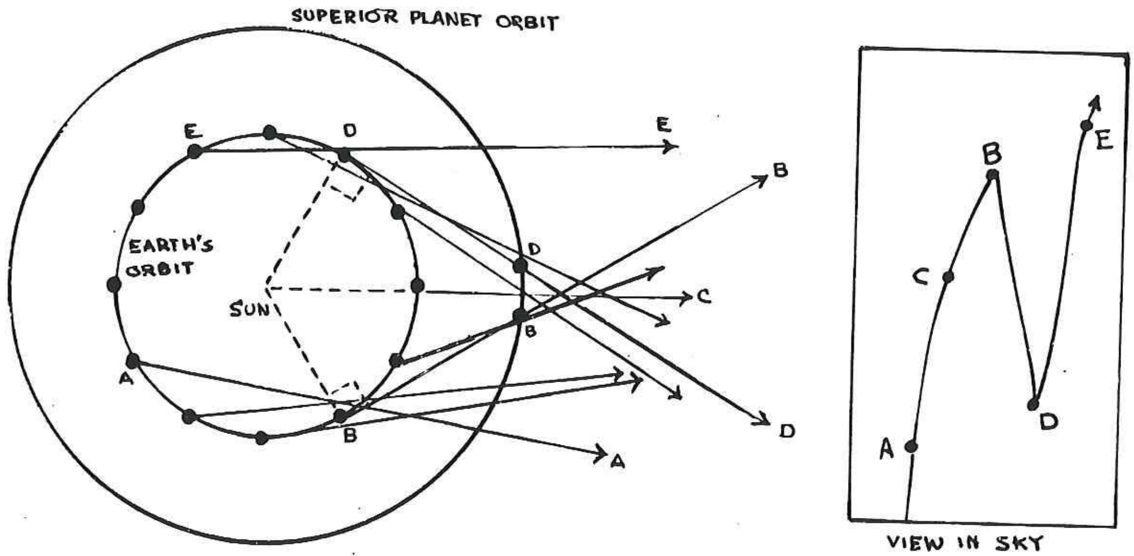
In the Planetarium

1. Using the orrery projector sun, earth and superior planets, have students observe the relative motions, speeds, distances and positions as viewed from the ecliptic north pole.

2. Projecting the planetarium ecliptic, sun and superior planets, demonstrate the planets' apparent motions as viewed from the earth over the period of one year. Keep the planets constantly in view by using daily and annual motion. Stop motions, as appropriate, to permit observation of conjunction, quadrature, and opposition.

3. Discuss and determine from observations the orbital position of conjunction, quadrature or opposition at which a superior planet must be viewed from the earth to be seen in the sky all evening from sunset to sunrise. Since Mars is nearest to the earth and is most favorably disposed, it is readily observed above the horizon all night at opposition. However, its distance from the earth can range anywhere from 35 to 63 million miles depending on where it is in the orbit when passed by the earth. Thus, the most favorable oppositions are those that occur when Mars is near perihelion in its orbit.

4. Observe and discuss retrograde motion relative to the planets' positions of conjunction, quadrature and opposition. The diagram below clearly shows that the superior planets appear to retrograde as the earth swings between them and the sun. From positions B to D as the earth passes the planet, it appears to drift backwards to the west even though it is actually moving to the east.



C - Opposition position by definition
B - Quadrature position by definition
D - Quadrature position by definition

Follow-Up Activities

1. Provide each student with the Instructions/ Data Sheet for making an orbital drawing of a superior planet - Mars. Let the class work together until procedures are clarified.

2. Review the components of an ellipse and a circle. Also define the major axis of an ellipse as the maximum diameter of the ellipse and the semi-major axis as half the major axis.

3. Have the students determine from library research the actual figures for major and semi-major axis, perihelion and aphelion of the planets and compute the percent of error their constructed orbital data is off from the actual data.

4. Given a statement of Kepler's laws of planetary motion, have the students use data gathered from measurements of their constructed orbital model to support or refute the laws.

EVALUATION SUGGESTIONS

Use the orbital drawings for evaluation purposes.

Give students a list of terms used in the activity and ask them to illustrate their meaning through diagrams.

Ask students to describe orally the motion of a superior planet as seen from the earth and ecliptic north pole.

VOCABULARY

conjunction
retrograde motion
opposition   quadrature
superior planet   inferior planet

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 23-26, 30.
Wyatt, Principles of Astronomy, pp. 147-149, 158-161.
"Heliocentric Ephemerides of Major Planets," The American Ephemeris and Nautical Almanac.
"Sun-Ephemeris for O.E.T. Precession and Nutation in Longitude; Obliquity," The American Ephemeris and Nautical Almanac.

NOTE

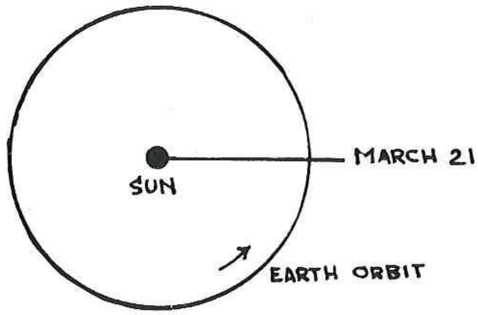
It is suggested that the teacher prepare a worksheet for each planet by constructing the orbit of the earth and plotting each earth position given in the table. Then plot the first seven planet positions for the selected planet. It is essential this be done particularly if this activity is to be used with students who have not had geometry. When all the plots are constructed on the same sheet of paper, there are so many lines very close together that students are apt to become confused.

If the students are to plot and construct the entire activity, they should plot half of the points of the planet positions on two separate sheets retaining exactly the same earth orbit measurements on each sheet. Then overlay and transfer the planet plots from the second sheet to the original by tracing.

See following pages for Instructions/Data Sheet for Orbital Drawing of Superior Planet, Mars Orbital Drawing Worksheet, and Sample Mars Orbital Drawing.

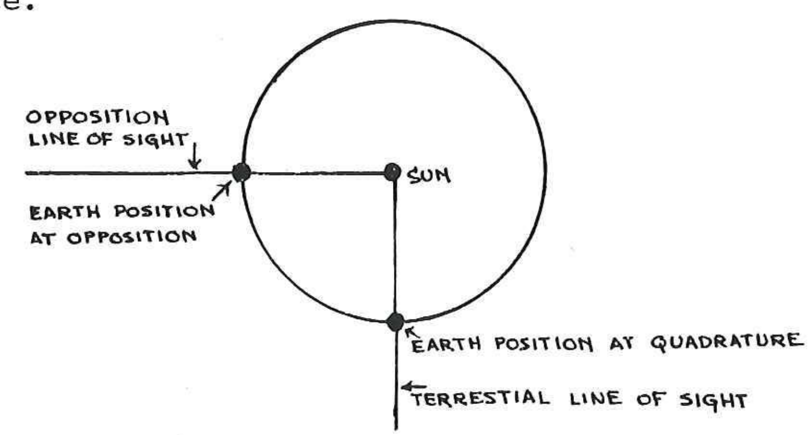
INSTRUCTIONS/DATA SHEET FOR ORBITAL DRAWING OF SUPERIOR PLANETS

1. Construct a circle of radius $1\frac{1}{2}$" to represent the orbit of the earth as seen from the north ecliptic pole and place a dot in the center of the circle to represent the sun. Also draw an arrow to indicate the direction of the earth's revolution counterclockwise about the sun. Next draw a line from the sun to the earth's orbit to position the earth at the vernal equinox.



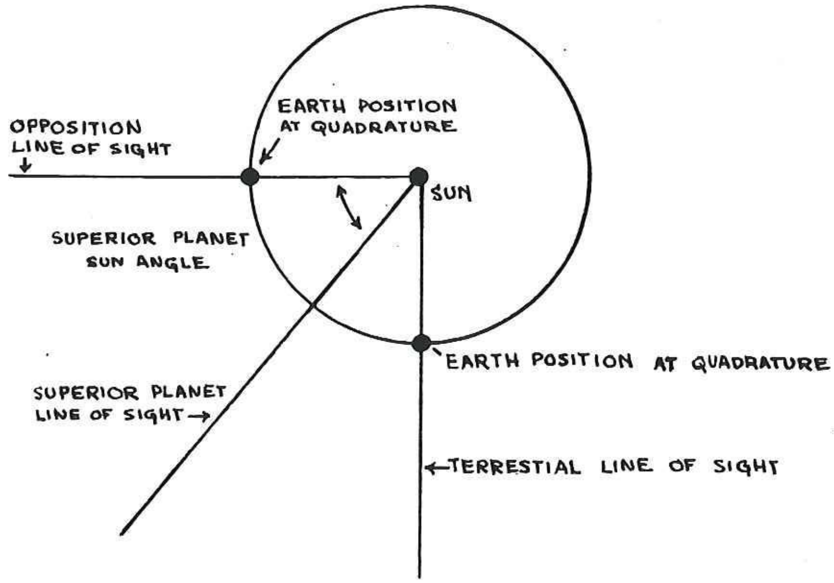
2. Construct an opposition line of sight from the sun through the earth's orbit for each opposition date advancing around the earth's orbit from the vernal equinox 1°/day counterclockwise.

   Advance the earth to the quadrature date of the planet and construct a terrestrial line of sight from the sun through the earth's orbit position for the planet's quadrature. Extend the terrestrial line of sight beyond the earth's orbit and label the line with the date.

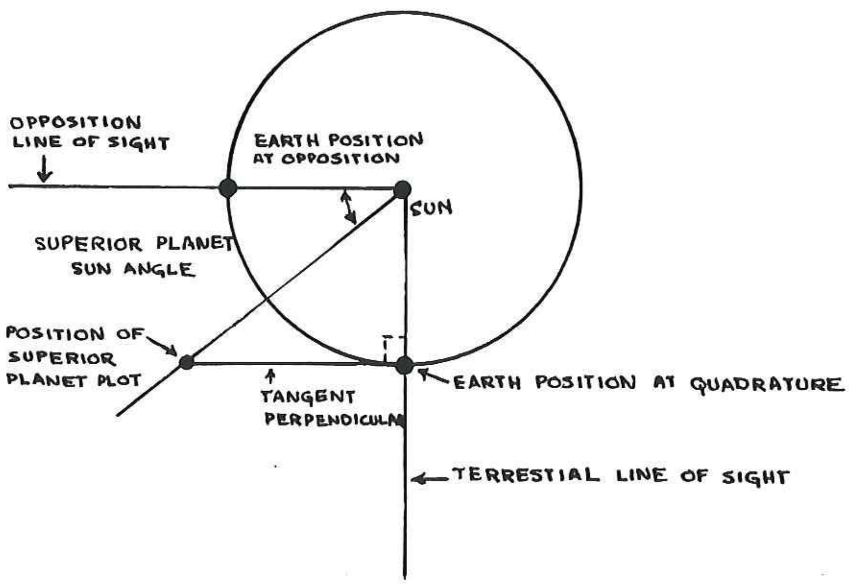


3. Knowing the period of revolution of the planet (Mars to be .524°/day), determine the amount the planet has moved in its orbit which constitutes the superior planet--sun angle and superior planet line of sight by multiplying the number of days from opposition to quadrature times the number of degrees the superior

planet moves per day. (For example, from Mars opposition date of March 23, 1950 to Mars quadrature date of June 27, 1950 is 97 days. Mars moves 97 days x .524°/day = 50.828 degrees in the orbit from opposition to quadrature.) Next use the total number of degrees the planet has moved in its orbit from opposition to quadrature to construct the superior planet--sun angle and superior planet line of sight.



4. To determine the exact location of the superior planet on the superior planet line of sight, construct a tangent perpendicular to the terrestrial line of sight at the earth position at quadrature. Extend the perpendicular until it intersects the superior planet line of sight. This point of intersection is the position of the superior planet.



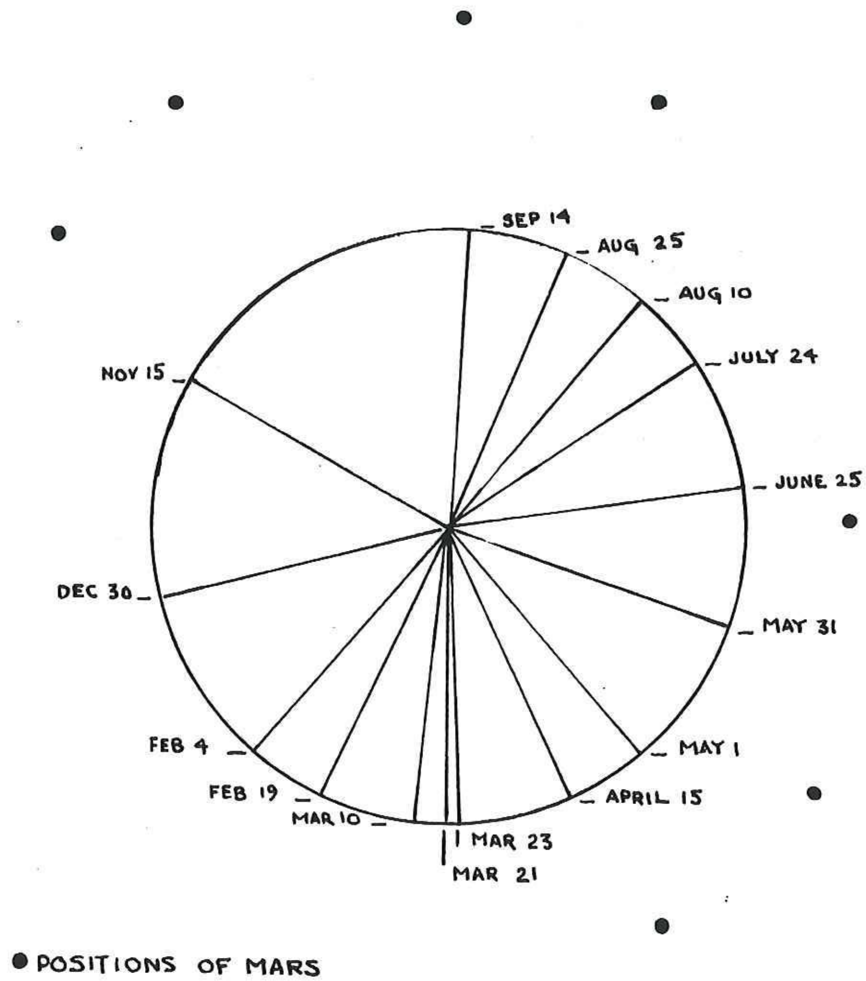
5. Continue the above procedure for each position of the superior planet until all points are plotted. Then connect the plotted superior planet points with a continuous curve which completes the orbit of the planet.

General observations that should be determined by the students from the plotted orbit:

1. When a superior planet appears as a morning star or an evening star, explain and/or determine whether the planet will be seen east or west of the sun, as observed from the earth.

2. Using the radius of the earth's orbit as 1 A.U. (astronomical unit), compute the planet's perihelion and aphelion distances in A.U.'s and derive the planet's mean distance (semi-major axis) from the sun.

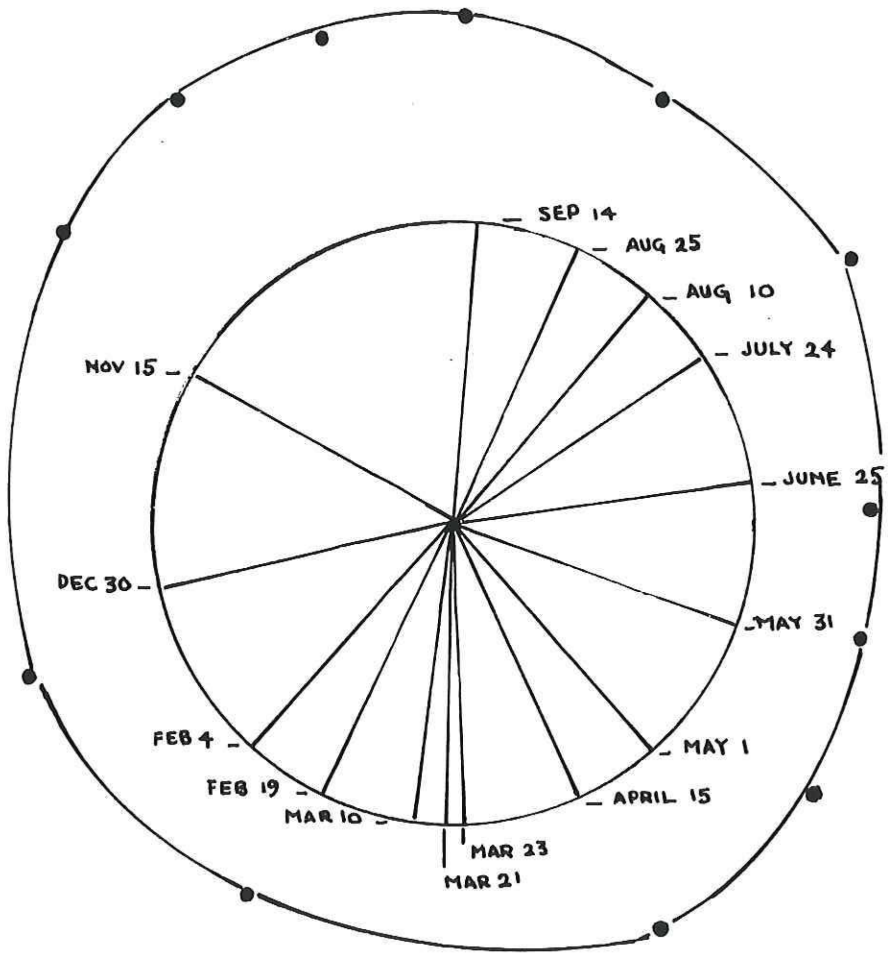
MARS



	OPPOSITION	QUADRATURE	EARTH OPPOSITION QUADRATURE ANGLE VALUES	MARS PLANET-SUN ANGLE VALUES
1.	August 25, 1924	December 25, 1924	110°	57.640
2.	July 24, 1939	December 9, 1939	108°*	56.592
3.	February 19, 1948	May 31, 1948	102°	53.448
4.	March 23, 1950	June 27, 1950	97°	50.828
5.	May 1, 1952	August 3, 1952	95°	49.780
6.	June 25, 1954	November 7, 1954	108°	56.592
7.	September 14, 1956	January 2, 1957	111°	58.164
8.	November 15, 1958	February 21, 1959	99°	51.876
9.	December 30, 1960	April 5, 1961	97°	50.828
10.	February 4, 1963	May 12, 1963	98°	51.352
11.	March 10, 1965	June 17, 1965	100°	52.400
12.	April 15, 1967	July 17, 1967	94°	49.256
13.	May 31, 1969	September 26, 1969	103°*	53.972
14.	August 10, 1971	December 15, 1971	109°*	57.116

*Data given has been adjusted from the lapse number of days to compensate for the long stationary period of the planet in years of close oppositions. In the case of Mars, the adjustment also eliminates the error included by the assumption of a uniform rate of motion for the planet. The orbital drawing produced has an accurate semi-major axis and is slightly more eccentric than the actual Mars orbit.

COMPLETED ORBIT OF MARS



INVESTIGATING RETROGRADE MOTION

The movements of the planets as viewed from the earth provide an interesting study in the distinction between the actual motions of a celestial object and its motions as seen by an earth-based observer.

In this activity, students will observe in the planetarium that a superior planet appears to stand still in space briefly at certain times and then to back up for a while before continuing a forward motion. The students then will be provided with a view of the planets and the earth in orbit. From the two views, they should be able to arrive at the reasons why a superior planet must necessarily exhibit a period of retrograde motion to an observer on earth.

STUDENT PREPARATION

Grade level: secondary
Content background: familiarity with celestial coordinate system and basic graphing techniques; understanding of the relative rates of revolution of the planets; (preferably) classroom study of planetary motion under way. (Note: The activities "Examining the Orbit of an Inferior Planet" and "Examining the Orbit of a Superior Planet" might be scheduled before this one.)

FACTS AND CONCEPTS

When viewed from the earth, all superior planets appear, at certain points along their orbits, to move in a backward direction--that is, westward.

This apparent retrograde motion is caused by the earth's overtaking and passing the superior planet; to the earth-based observer, the planet for a period of time appears to move backwards in relation to the star background.

The inferior planets exhibit retrograde motion also; because they are located between the earth and sun they just appear to swing back and forth on either side of the sun.

Earth-bound observers cannot see a complete retrograde cycle of inferior planets because much of the time they are lost in the sun's glare.

OBJECTIVES

- After making visual observations of a superior planet in retrograde motion, the student will be able to compare and contrast orally, in writing, or through demonstration the actual and apparent motion of a planet during a period of retrograde motion.

- Given the apparent right ascension and apparent declination of an inferior and superior planet for one year, the student will be able to make a graph showing the motion of the planets and use it to explain retrograde motion.

- The student will be able to plot the apparent path of a superior planet through the star field from observations made in the planetarium.

- The student will be able to complete or construct an orbital diagram explaining retrograde motion.

MATERIALS

Classroom: celestial globe, coordinate star chart, orrery; for follow-up activities--metric graph paper, table of right ascension/declination of visible planets for one year. One of two alternative follow-up activities are recommended. Both require a ruler and sharp pencils; the first requires a diagram form for constructing a diagram of the retrograde motion of Jupiter; the second requires a drawing compass and good protractor. Note: see end of activity for metric graph paper, right ascension/declination table for planets, and form for diagraming retrograde motion of Jupiter.

Planetarium: coordinate star charts (one per student); planetarium orrery; pen lights, pencils; styrofoam ball, flashlight.

PROCEDURES In the Classroom

1. Use a celestial globe to review with the class basic fundamentals of the celestial coordinate system. Offer some practice in locating celestial objects by coordinates.

2. Discuss the orbits of the planets generally, reviewing students' acquaintance with (a) the positions of the planets in relation to the sun, (b) the meaning of the terms "inferior planet" and "superior planet," and (c) the relative rates of revolution of the planets about the sun.

In the Planetarium

1. Preset planetarium to show a retrograde motion sequence of a superior planet. (Consult the Ephemeris for a planet currently or soon to be undergoing retrograde motion.)

2. Turn on the stars and planet and acquaint students with the date of the setting. Let some constellations be identified and call the planet to the group's attention.

3. Distribute coordinate star charts and turn on the coordinate system. Ask students to plot the position of the planet, using the stars and coordinate lines as reference. The students should mark the point plotted for the planet with the date of the setting.

4. Run annual motion for 15 days and stop. Ask students to observe the position of the planet. They should plot the new position and label the point by date.

5. Repeat the step above every 15 days until the end of the retrograde cycle.

6. Ask students to join the points they have plotted in calendar order.

7. Discuss observations of the apparent path taken by the planet and the data collected. See if the students can explain how the backward motion came about. Let them support one another's ideas or offer better explanations.

8. Turn on the planetarium orrery, asking students to observe and comment on the rates

of revolution of the superior planets and the earth. Ask for further explanations of the backward motion observed. If no one offers a vehicle analogy in explanation, be sure to provide it.

9. Provide a simple demonstration of an analogous retrograde motion: set a styrofoam ball on a support to represent a superior planet; use a projector (or some other object) to represent the sun; you (or a student) can act out the role of the earth. In doing so, move in an "orbit" around the projector (sun), keeping a flashlight directed on the styrofoam ball (superior planet). The shadow produced by the ball will demonstrate retrograde motion, seeming to reverse its direction as the "earth" passes it; then the shadow starts moving forward again.

10. Turn on the planetarium orrery again and this time ask students to observe and comment on the rates of revolution of the inferior planets and the earth. Discuss why we cannot observe a complete loop motion of these planets.

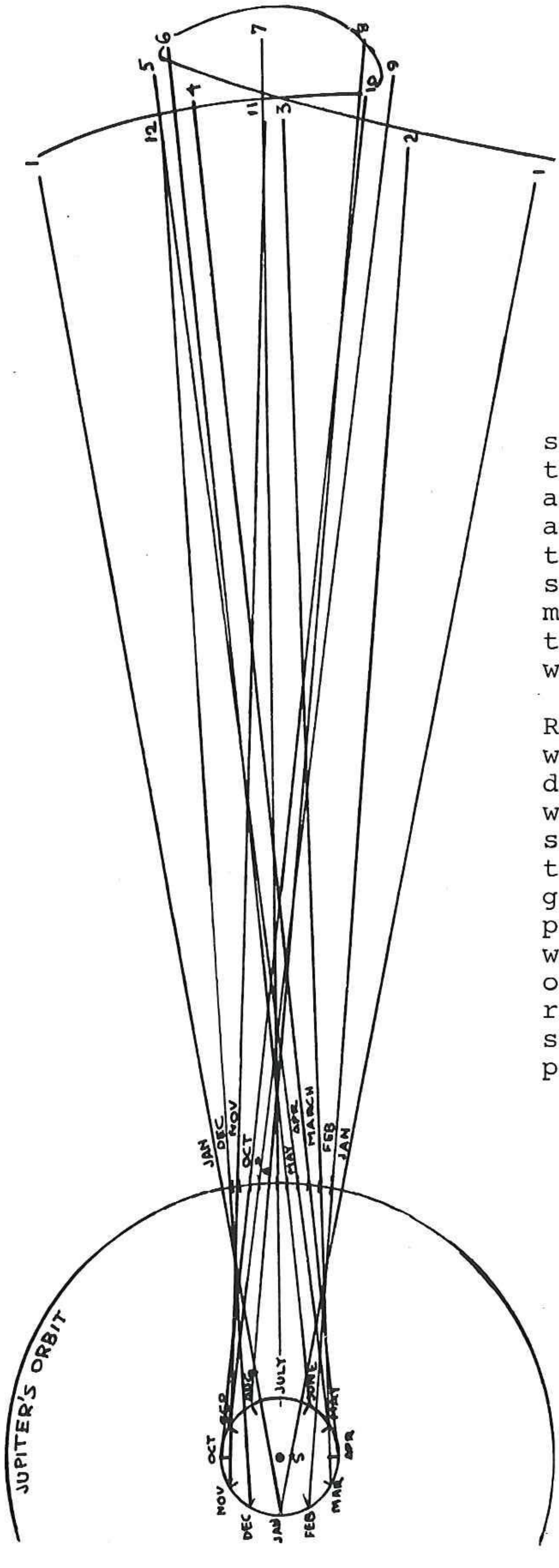
Follow-Up Activities

1. Distribute to each student two sheets of metric graph paper and a table giving the right ascension/declination of the visible planets for one year. Ask students to select one superior planet and one inferior planet and to plot their apparent motions. (Instruct students to put right ascension on the horizontal axis, declination on the vertical axis, and to label the lines on the graph paper.) Each position given in the listing should be plotted and labeled by date. When finished the students should connect the points for each planet by calendar dates.

2. Ask the class to examine the apparent path of the planets from the plotted data and to compare the retrograde motion of the superior and inferior planet.

3. (Alternative with step 4 below) Distribute the pattern for constructing an orbital diagram showing Jupiter's retrograde motion. Let students examine the pattern and discuss what it tells them. Emphasize that the orbits, but not the distance to the star field, are drawn to scale; point out the opposition line of sight; and note that Jupiter, as determined by its sidereal period, completes about 30° of its orbit (or 1/12th) during the time that the earth makes one revolution.

   The students should follow instructions on the sheet to complete the diagram. This will require accuracy in connecting points. If the student tapes another



sheet of 11 x 8½ paper to the edge marked "Stars" and extends the star field and lines of sight farther to the right, the representation of retrograde motion will be better and the labeling of the lines will be easier.

Results should look somewhat like those in the diagram below. After the work is completed, the students should compare the diagram with any graphs that have been plotted for Jupiter and with their original observations of the retrograde motion of a superior planet in the planetarium.

4. (Alternative with step 3 above) If students have had previous experience constructing planetary orbits--as in the activities on the orbits of inferior and superior planets in this publication--there would be no need to give them the diagram form; they should be able to do the entire construction themselves, given general instructions and helpful hunts (such as size of paper and appropriate scale). The retrograde motion of Jupiter will be the easiest to diagram, although the students might try Mars and Saturn for the sake of noting and trying to conquer the practical problems that crop up.

5. Suggest observations in the night sky of any planet undergoing or soon to undergo retrograde motion. The student should record observations of the planet every 10 or 15 days on a star chart, using the stars as reference.

EVALUATION SUGGESTIONS

The graphs made in the planetarium and classroom will serve in part for evaluation purposes.

Ask students to compare and contrast the apparent and actual motion of a superior planet.

Ask students to compare and contrast the retrograde cycle of a superior and inferior planet.

VOCABULARY

retrograde motion
inferior planet   superior planet
right ascension   declination
conjunction   opposition
line of sight
actual motion   apparent motion
direct motion

SUGGESTED RESOURCES

Abell, <u>Exploration of the Universe</u>, pp. 23-26, 30.
<u>Investigating the Earth</u>, ESCP, pp. 496-500.

"Heliocentric Ephemerides of Major Planets," <u>American Ephemeris and Nautical Almanac.</u>
"Sun-Ephemeris for O^{h}E..T. Precession and Nutation in Longitude; Obliquity," <u>American Ephemeris and Nautical Almanac.</u>

NOTE

See following pages for right ascension/declination table of planet, metric graph paper, and diagram form referred to in activity.

APPARENT RIGHT ASCENSION/DECLINATION OF SUPERIOR PLANETS

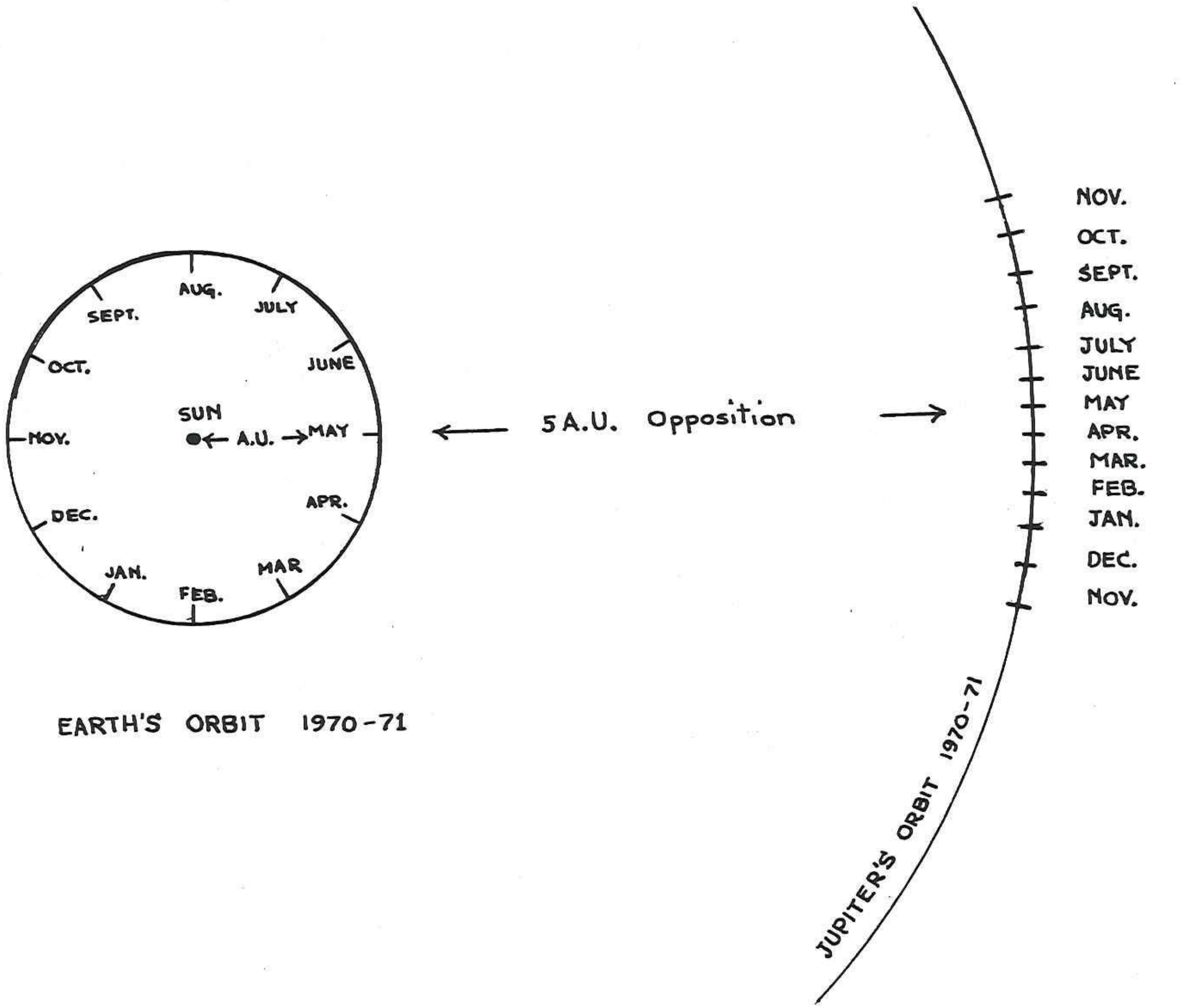
	DATE	R.A.	DEC.
JUPITER	January 1, 1972	17 hrs. 26 mins.	-22' 49"
	February 1, 1972	17 hrs. 55 mins.	-23' 0"
	March 1	18 hrs. 17 mins.	-23' 02"
	April 1	18 hrs. 32 mins.	-22' 55"
	May 1	18 hrs. 35 mins.	-22' 53"
	June 1	18 hrs. 27 mins.	-23' 03"
	July 1	18 hrs. 11 mins.	-23' 14"
	August 1	17 hrs. 57 mins.	-23' 20"
	September 1	17 hrs. 53 mins.	-23' 24"
	October 1	18 hrs. 02 mins.	-23' 28"
	November 1	18 hrs. 21 mins.	-23' 25"
	December 1	18 hrs. 47 mins.	-23' 07"
SATURN	January 1, 1972	3 hrs. 55 mins.	+18' 14"
	February 1	3 hrs. 51 mins.	+18' 11"
	March 1	3 hrs. 54 mins.	+18' 28"
	April 1	4 hrs. 04 mins.	+19' 04"
	May 1	4 hrs. 13 mins.	+19' 45"
	June 1	4 hrs. 34 mins.	+20' 26"
	July 1	4 hrs. 50 mins.	+20' 57"
	August 1	5 hrs. 05 mins.	+21' 18"
	September 1	5 hrs. 15 mins	+21' 28"
	October 1	5 hrs. 19 mins.	+21' 29"
	November 1	5 hrs. 16 mins.	+21' 23"
	December 1	5 hrs. 07 mins.	+21' 13"
	January 1	4 hrs. 56 mins.	+21' 02"
MARS	January 1, 1972	0 hrs. 10 mins.	+ 0' 55"
	February 1	1 hr. 27 mins.	+ 9' 35"
	March 1	2 hrs. 40 mins.	+16' 25"
	April 1	4 hrs. 03 mins.	+21' 47"
	May 1	5 hrs. 27 mins.	+24' 22"
	June 1	6 hrs. 54 mins.	+24' 03"
	July 1	8 hrs. 15 mins.	+21' 00"
	August 1	9 hrs. 35 mins.	+25' 33"
	September	10 hrs. 50 mins.	+ 8' 30"
	October 1	12 hrs. 01 min.	+ 0' 51"
	November 1	13 hrs. 15 mins.	-10' 37"
	December 1	14 hrs. 31 mins.	-14' 17"

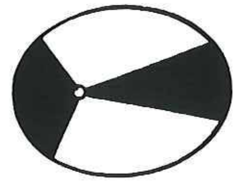
APPARENT RIGHT ASCENSION/DECLINATION OF INFERIOR PLANETS

VENUS	January 1, 1972	20 hrs. 55 mins.	-19' 35"
	January 15, 1972	22 hrs. 03 mins.	-13' 42"
	February 1	23 hrs. 20 mins.	- 5' 58"
	February 15	0 hrs. 20 mins.	+ 1' 50"
	March 1	1 hr. 24 mins.	+ 9' 31"
	March 15	2 hrs. 23 mins.	+16' 0"
	April 1	3 hrs. 35 mins.	+22' 18"
	April 15	4 hrs. 34 mins.	+25' 43"
	May 1	5 hrs. 32 mins.	+27' 32"
	May 15	6 hrs. 09 mins.	+27' 21"
	June 1	6 hrs. 18 mins.	+25' 26"
	June 15	5 hrs. 51 mins.	+22' 33"
	July 1	5 hrs. 15 mins.	+18' 59"
	July 15	5 hrs. 13 mins.	+17' 52"
	August 1	5 hrs. 45 mins.	+18' 35"
	August 15	6 hrs. 30 mins.	+19' 19"
	September 1	7 hrs. 37 mins.	+18' 59"
	September 15	8 hrs. 37 mins.	+17' 06"
	October 1	9 hrs. 49 mins.	+13' 04"
	October 15	10 hrs. 51 mins.	+ 8' 07"
	November 1	12 hrs. 07 mins.	+ 0' 52"
	November 15	13 hrs. 10 mins.	- 5' 56"
	December 1	14 hrs. 24 mins.	-12' 27"
	December 15	15 hrs. 33 mins.	-17' 38"
MERCURY	January 1	17 hrs. 04 mins.	-20' 50"
	January 15	18 hrs. 19 mins.	-23' 21"
	February 1	20 hrs. 10 mins.	-21' 49"
	February 15	21 hrs. 46 mins.	-15' 35"
	March 1	23 hrs. 29 mins.	- 3' 59"
	March 15	0 hrs. 43 mins.	+ 7' 05"
	April 1	0 hrs. 34 mins.	+ 6' 41"
	April 15	0 hrs. 14 mins.	+ 0' 48"
	May 1	0 hrs. 55 mins.	+ 2' 49"
	May 15	2 hrs. 07 mins.	+10' 52"
	June 1	4 hrs. 15 mins.	+21' 20"
	June 15	6 hrs. 26 mins.	+25' 10"
	July 1	8 hrs. 23 mins.	+20' 37"
	July 15	9 hrs. 22 mins.	+14' 06"
	August 1	9 hrs. 24 mins.	+10' 16"
	August 15	8 hrs. 49 mins.	+14' 05"
	September 1	9 hrs. 40 mins.	+14' 55"
	September 15	11 hrs. 18 mins.	+ 6' 23"
	October 1	13 hrs. 01 mins.	- 6' 02"
	October 15	14 hrs. 22 mins.	-15' 24"
	November 1	15 hrs. 54 mins.	-23' 03"
	November 15	16 hrs. 42 mins.	-24' 28"
	December 1	15 hrs. 46 mins.	-17' 38"
	December 15	16 hrs. 01 min.	-18' 26"

10 SQUARES TO CENTIMETER

WORKSHEET: RETROGRADE MOTION FOR JUPITER'S ORBIT





VERIFYING KEPLER'S LAWS

In the classroom, Kepler's laws do not easily lend themselves to student-inquiry approaches. However, the planetarium orrery can be adapted to display the elliptical shape of a planetary orbit, and additional projections may be used to enable students to collect orbital data.

In the activity below, students visit the planetarium for a double-session period so that they first may view the motions of the planets as observed from the earth and then an orbital model of Venus and Mercury. A special setting of the planetarium orrery permits them to collect data through which they can verify Kepler's second and third laws.

STUDENT PREPARATION

Grade level: secondary
Content background: prior introduction to Kepler's laws and celestial mechanics.

FACTS AND CONCEPTS

Kepler's three laws:

Each planet moves about the sun in an elliptical orbit with the sun at one focus of the ellipse.

A straight line (the radius vector) joining a planet and the sun sweeps out equal areas in space in equal intervals of time.

The square of the sidereal period of a planet is in direct proportion to the cube of the semimajor axis of its orbit.

OBJECTIVES

The student will be able to relate Kepler's laws to Newton's law of gravitation and laws of motion.

- Using data collected in the planetarium, the student will be able to verify Kepler's second law.

- Using data collected in the planetarium the student will be able to verify Kepler's third law.

- Using data derived from an orbital model, the student will be able to use Kepler's second law to show that the inverse square force law follows from an elliptical orbit.

MATERIALS

Classroom: celestial globe, planetary models (three-dimensional and drawings).

Planetarium: planetarium orrery; grid for projection (see note below); four or more stop watches; one four-page set of data sheets per student and sheet of grid paper (see end of activity); pencils, pen lights, drawing compass or preferably, french curve; ruler.

Note: To make the proper grid for projection, photograph the grid paper provided with the data sheets accompanying this activity. Use the Kodalith process (film available from any graphic arts store). Project the grid over the orrery projection. Duplicate the same grid paper for student use--this will assure that their grids match the one on the dome.

PROCEDURES

In the Classroom

Although the planetarium visit might be timed to support class study of Kepler's laws and celestial mechanics, specific preparation should include review of terms used in connection with orbits (ellipse, eccentricity, focus, major axis, semimajor axis, radius vector), review of the unit for measuring distance in the solar system (A.U.), and of vocabulary used in relation to the celestial sphere. Let students use drawings, planetary models, and a celestial globe to illustrate the terms.

In the Planetarium

Since planetarium procedures will take two periods, plan for a period break between steps 8 and 9, when students turn from observing the heavens as viewed from earth to observing the motions of the planets as seen from space. A break at this point will also give you time to see that the presetting required for step 9 is in order.

First presetting: Put the sun on the meridian and set the stars and moon for date of visit, with the tie-in engaged.

1. Turn on the sun and meridian and discuss the time and date. For orientation purposes, proceed to the night and let students identify constellations and visible planets. Continue diurnal motion until the sun is repositioned at noon. The stars should remain visible.

2. Distribute a set of data sheets to each student. Ask the class to plot the position of the sun in the appropriate section of Part I and to sketch in the star background.

3. At this first stop, the students should also note and identify a particular star on the meridian. Explain that this star will be used as a reference star for counting sidereal days--one sidereal day will equal the time it takes the star to return to the meridian. Let one student assume responsibility for counting each meridian passage of the reference star and for calling the end of sidereal days to class attention as procedures continue.

4. Continue diurnal motion. Stop on the first sidereal day as the moon and planets cross the meridian so that students may also plot their positions on appropriate sections of Part I of the data sheet and sketch in their star backgrounds. (There are spaces for two planets. Let students select those that they wish--or provide additional sheets for planets.)

5. Continue daily motion for 10 days with the tie-in engaged. During this time, students should be noting gradual changes in the star background of the objects in the solar system; the student assigned the job should be counting meridian passages of the reference star; and you can insert commentary on the historical background leading up to the work of Kepler.

6. As the reference star returns to the meridian for the last time, stop motion and ask for observations. Then students should replot the position of the sun on their data sheets and again sketch in the star background.

7. Continue with motion through the 10th day, stopping for students to replot the positions of the moon and planets and sketch the stars in which they appear.

8. Turn up the lights and allow time for discussion of observations and the data.

(period break)

Second presetting: Subsequent procedures require exact positioning of the orrery for good results, for all depends upon demonstrating planetary orbits as ellipses, with the sun at one focus. To do this, place the orrery flat on a table so that the beam of light from the sun projector points vertically up to position the sun's image with its lower edge on the 40° meridian line at azimuth 180°. However, remove the sun lamp from the orrery and instead place the planetarium sun on the meridian at 180° azimuth, 53° altitude. This will place a circular sun image at the correct focus of the elliptical planetary orbits. Use only Mercury and Venus, with all other planets off. This is because the scaling of the periods for Mercury and Venus on the planetarium orrery is more accurate than the scaling of the periods of the other planets.

The meridian will serve as a distance scaling device. Let 10° on the meridian equal 0.2 A.U. Since Mercury is 0.39 A.U. from the sun at mean distance, position it on the meridian at 25° for aphelion and 64° for perihelion. Since Venus is 0.72 A.U. from the sun at mean distance, position it on the meridian at 11° for aphelion and 83° for perihelion.

9. Turn on the orrery and meridian, letting students observe Mercury and Venus in orbit. Discuss the shape of the orbital paths.

10. Distribute several stop watches (be sure students know how to use and read them). Ask two or three students to determine the period of Mercury while two or three others determine the period of Venus, beginning as the planet transits the lower meridian. Concurrently, others in the class should be determining the distance across the orbit (major axis) of each planet. The students can do this by reading the degrees on the meridian scale as each planet makes its lower and upper transit of the meridian.

11. Discuss data collected and ask students to fill in Part II of the data sheet.

12. Now project the grid over the orrery projection and distribute matching grid paper to students. Stop orrery motion to permit them to plot the position of the sun and one planet. Encourage half the class to plot Mercury, the other half to plot Venus.

13. Turn on motion and then stop every five seconds (or at other equal intervals) so that students may plot the new position of the planet they have chosen. Continue until both Mercury and Venus have completed one revolution.

14. Ask students to exaggerate the size of each point plotted and to connect the points with a continuous curve. Then students should draw a straight line from each plotted point to the sun.

15. Discuss the lines connecting the orbital points to the sun as radius vectors of the orbit. From their plotting of these points, the students should recognize that the radius vector of the orbit swept each segment in equal time (five seconds). According to Kepler's second law, the segments should therefore be equal in area. Do they appear to be equal in area? After discussion of the question, preserve the graphs and data sheets for later use and completion in the classroom.

Follow-Up Activities

1. First students should make the orbital analysis called for on Part III of the data sheet. This requires that they count the blocks in various segments of the grid for the planet they plotted. The students who plotted Mercury will need to provide information to those who plotted Venus and vice versa. Discuss results, particularly for the aphelion and perihelion segments.

2. Ask students to do the calculations called for on Part III of the data sheet and to answer the remaining questions.

3. Discuss results, emphasizing the following:

   What is the significance of the constant R^3/T^2 discovered by Kepler? (An explanation in terms of forces involved.)

   What force phenomenon did Newton employ in his explanation of why the planets remain in orbit around the sun?

   What are the mathematical links between Kepler's third law, contripetal acceleration, and Newton's expression of gravitational force?

   For the last question, seek the explanation that--

   centripetal acceleration, or $\underline{a} = \frac{4\pi^2 R}{t^2}$

   centripetal force, or $F = \frac{m4\pi^2 R}{t^2}$, where $\underline{m}$ is mass of planet (derived from F = ma).

   To express F as functions of radius, and R and $\underline{m}$ alone:

If $R^3/T^2 = K$ (constant), then $T^2 = R^3/K$
Substituting for T^2 in force equations above,

$$F = 4\pi^2 K \frac{m}{R^2}$$

4. Ask also, what conclusion can be drawn concerning the relation of the attraction force of the sun-planet system to the mass of the planet and its distance from the sun? ($F \propto m$; $F \propto 1/R^2$)

EVALUATION SUGGESTIONS

The data sheets will serve for evaluation purposes.

Give practical problems in which students use mathematics to apply the concepts developed in the activity.

VOCABULARY

focus
ellipse
major axis   semimajor axis
astronomical unit (A.U.)
radius vector
eccentricity

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 33-41.
Physics, PSSC, 347-353.

NOTE

Lab Worksheets and Planetarium Settings credited to Rolfe Chandler, Herndon Planetarium, Herndon, Va.

See following pages for set of data sheets and grid paper used in activity.

KEPLER'S LAWS: DATA SHEET, PART 1

Directions: Show the positions of the sun, moon, and planets and sketch in their star backgrounds on two dates 10 days apart.

SUN:

Date ________

80°

50°

10°

E S W

Date ________

80°

50°

10°

E S W

MOON:

Date ________

80°

50°

10°

E S W

Date ________

80°

50°

10°

E S W

(Part I continued)

KEPLER'S LAWS: DATA SHEET, PART I (continued)

PLANET ________:

Date ________

80°

50°

10°

E S W

Date ________

80°

50°

10°

E S W

PLANET ________:

Date ________

80°

50°

10°

E S W

80°

50°

10°

E S W

KEPLER'S LAWS: DATA SHEET, PART II

Comparative Periods of Planets

1. Mercury ____________ seconds

2. Venus ____________ seconds

Comparative Distance from Sun

A. Determine the vertical distance across the model orbits of Mercury and Venus in astronomical units, A.U. (One A.U. is the mean distance of the earth from the sun.) The scale for the model is 10° = 0.2 A.U.

Answer for Mercury ____________

Answer for Venus ____________

B. The value obtained in (A) above is called the major axis of the orbit. Now divide that value by 2 to obtain the value of the semimajor axis.

Answer for Mercury ____________

Answer for Venus ____________

KEPLER'S LAWS: DATA SHEET, PART III

ORBITAL ANALYSIS.................	FOR MERCURY	FOR VENUS
Period	________	________
Time interval for each segment	________	________
No. of squares in perihelion segment	________	________
No. of squares in aphelion segment	________	________
Is the area the same in the above two segments?	________________	
By what percent does the area differ?	________________	

<u>Calculations</u> (R = semimajor axis and T = period):

Mercury

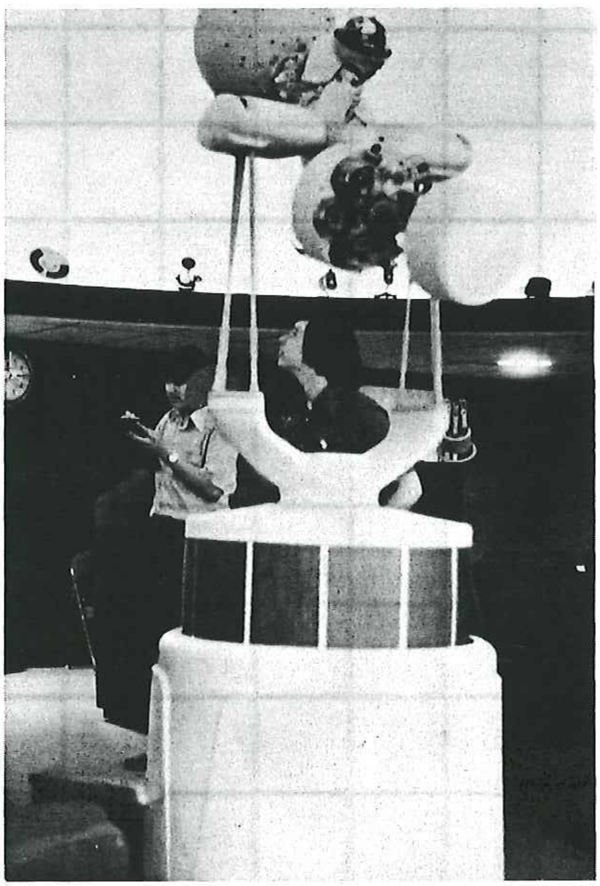
$$\frac{R^3}{T^2} = \underline{\hspace{3cm}} = \frac{\text{A.U.}^3}{T^2}$$

Venus

$$\frac{R^3}{T^2} = \underline{\hspace{3cm}} = \frac{\text{A.U.}^3}{T^2}$$

Do the resulting values for Mercury and Venus equal a constant? ________

Within what percent difference are they equal to a constant? ________



MOTIONS OF EARTH SATELLITES

Most physics teachers employ many techniques to develop concepts related to circular motion--and are continually searching for better ones. What would be more useful and appropriate than providing means for students to observe and analyze the motions of artificial or natural earth satellites?

This lesson introduces students to the concept of centripetal acceleration through idealized satellite orbits projected on the dome of the planetarium.

STUDENT PREPARATION

Grade level: secondary
Content background: prior unit on linear motion through which students have gained understanding of the concepts of velocity and acceleration.

FACTS AND CONCEPTS

A force acting upon all objects moving in a circular path results in an acceleration toward the center of the circle. This acceleration is called "center-seeking" or centripetal."

The magnitude of the centripetal acceleration of an object moving in a circle depends on the radius of the circle and the object's velocity.

OBJECTIVES

The student will be able to establish from observations in the planetarium and the data he collects that the ratio of the centripetal accelerations of bodies moving in a circle is inversely proportional to the ratio of their radii if velocity is constant.

- By employing vector analysis, the student will be able to interpret the motion of an object moving in a circle.

- The student will be able to apply the mathematical relationship of radius, velocity, and acceleration as it pertains to circular motion in solving problems.

MATERIALS Classroom: film loop on centripetal acceleration (see Suggested Resources).

Planetarium: orrery; four slides (see planetarium procedures) and three slide projectors; planetarium sextant, Centripetal Acceleration Data Sheets (see end of activity), several stop watches, pencils, pen lights.

PROCEDURES <u>In the Classroom</u>

1. Discuss with the class familiar examples of circular motion--an automobile making a turn, an object whirling at the end of a string, etc.

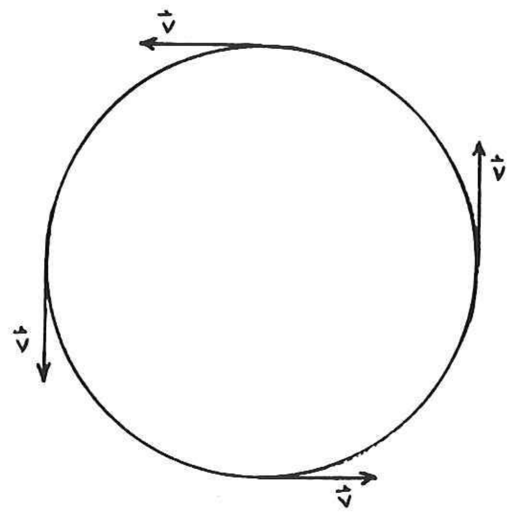
2. Review terminology and ideas related to linear motion, providing for review and discussion of linear motion formulas.

3. Show a film or filmstrip (such as the film loop recommended in the Suggested Resources) to introduce ideas and vocabulary related to centripetal motion.

<u>In the Planetarium</u>

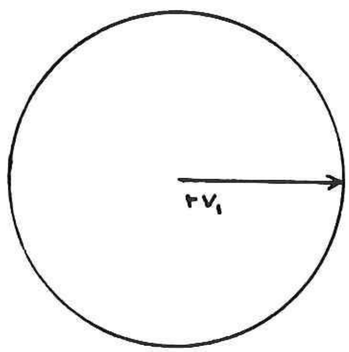
Presetting and slides: Use Venus or Mercury, with other planets off, to represent a satellite. Set the orrery projector so as to obtain as nearly perfect a circular orbit as possible (center close to the zenith and on the meridian). Of the four slides used in the activity (see below), three will be superimposed on each other and <u>on the orbit of the satellite</u>. You will therefore need to set the slide projectors for proper alignment.

1. Start motion of the satellite, permitting students to observe its circular orbit. Then stop motion and discuss the shape of the orbit and the direction of the instantaneous velocity vector. Superimpose slide 1 on the orbit of the satellite:

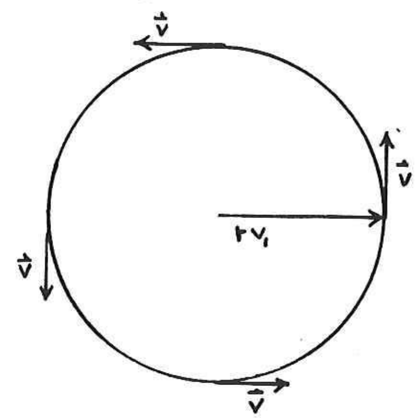


Discussion of the figure on the dome should lead students to discover that the instantaneous velocity vector is changing in direction but not in magnitude from point to point.

2. Project slide 2 to show the radius vector and then superimpose it on slide 1:



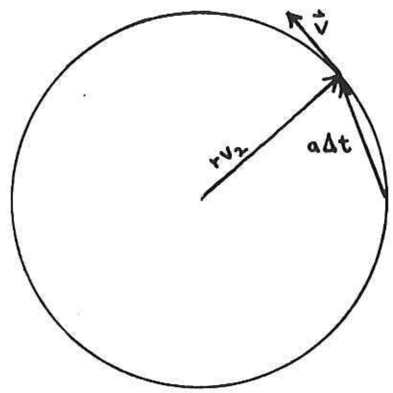
SLIDE 1



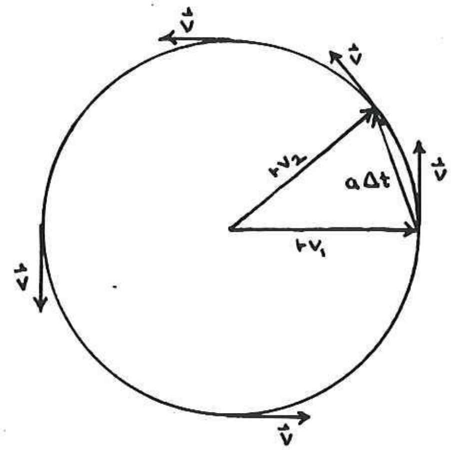
SLIDES 1 & 2 superimposed

Discuss the radius vector as found necessary and appropriate. When the radius and velocity vectors are projected simultaneously, ask students to determine the angular relationship between them (90°).

3. Project slide 3. This adds a new velocity vector, along with a new radius vector to establish the relation of the two velocity vectors. It also shows a new vector that represents the motion of the head of the velocity vector.



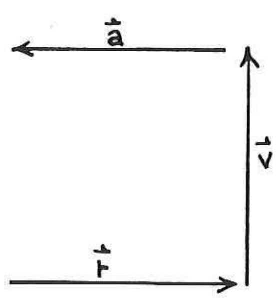
SLIDE 3



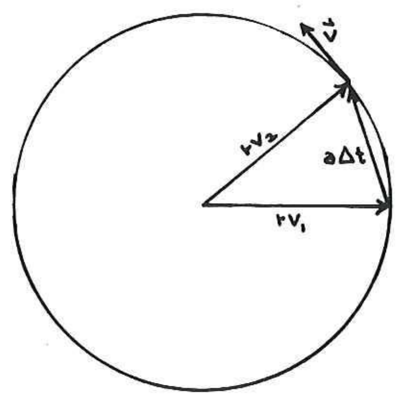
SLIDES 1, 2, 3 superimposed

Discuss the motion of the head of the velocity vector, leading students to discover that this is an acceleration vector ($a\Delta t$). Then discuss the angular relation between the radius vector and the acceleration vector. You can use your planetarium pointer to show that the radius vector is directed outward, the acceleration vector directed inward.

4. Eliminating slide 1, project slide 4 elsewhere on the dome, so that students may view slide 4 alongside a superimposition of slides 2 and 3:



SLIDE 4



SLIDES 2 & 3 superimposed

Slide 4 should clarify the angular relation between the radius vector and the acceleration vector (180°). Use your planetarium pointer to show that the acceleration vector could be moved down to be superimposed on the radius vector:

Students should now realize that the acceleration vector is center-seeking, or centripetal.

5. Distribute data sheets to students, add a second planet to the orrery, turn on the meridian, and start motion. Ask a student to use the planetarium sextant so that others in the class may measure and record the radius of each orbit as each satellite crosses the meridian. The students should convert degrees to a linear unit (a convenient scale is 1° = 1 kilometer). Then given stop watches, several students should time the periods of the satellites and announce results to the class for recording. The data sheets should be preserved for completion in the classroom.

Follow-Up Activities

1. Ask students to complete the data table, doing the calculations called for and providing the formulas for finding velocity, acceleration (centripetal in this case), and the ratio of the accelerations.

2. You may wish to provide advance discussion or, if not, later discussion on the formulas:

$$V = \frac{2\pi R}{T} \qquad \text{(velocity)}$$

$$a = \frac{V^2}{R} \qquad \text{(acceleration)}$$

$$\frac{a_1}{a_2} = \frac{V_1^2/R_1}{V_1^2/R_2} \qquad \text{(ratio of accelerations)}$$

3. Discuss results of the calculations, analyzing what has been discovered.

4. A logical continuation for this activity is a study of escape and binding energy, such as provided in the PSSC physics textbook or other modern physics texts.

EVALUATION SUGGESTIONS

Students work on the data sheets may be used for purposes of evaluation.

Give problems in which students are asked to find orbital radius, velocity, or centripetal acceleration of earth satellites, given necessary data.

VOCABULARY

velocity
acceleration
instantaneous velocity
angular velocity
centripetal
vector

SUGGESTED RESOURCES

Abell, Exploration of the Universe, pp. 53-55, 59.
Physics, PSSC, pp. 330-334.
Strahler, The Earth Sciences, p. 89. (A table provides data on early and famous satellites which may be used in preparing problems.)

"Centripetal Acceleration," Encyclopaedia Britannica Films. (This film loop introducing the activity.)

NOTE

See following page for data sheet used in the activity.

CENTRIPETAL ACCELERATION DATA SHEET

Symbols: Subscript$_1$ = inner satellite

Subscript$_2$ = outer satellite

R = radius or orbit

T = period of satellite

V = velocity

a = (centripetal) acceleration

<u>Measurements taken in planetarium:</u>

R_1 ________

R_2 ________

T_1 ________

T_2 ________

<u>Calculations made in classroom:</u>

Determine the following:

1. V_1 ________
2. V_2 ________

   Formula used for above two calculations ________

3. a_1 ________
4. a_2 ________

   Formula used for above two calculations ________

5. Ratio of radii of orbits ________
6. Ratio of periods of satellites ________
7. Ratio of velocities of satellites ________
8. Ratio of centripetal accelerations ________

   Formula used for finding above ratio ________

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"Heliocentric Ephemerides of Major Planets." A chart of the information described by the title.

"Mean Places of 1,078 Stars." A chart containing the name, magnitude, spectral class, and position of 1,078 stars.

"Moon: Right Ascension, Declination and Horizontal Parallax for Each Hour." A chart containing the information described by the title.

"Sun-Ephemeris for 0^hE.T. Precession and Nutation in Longitude; Obliquity." A chart of the information described by the title.

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"Eclipses During...[the current year]." A chart and map of the year's eclipses.

"The Brightest Stars," MacRae, Donald A. A chart containing nine items of information about 286 stars plus their location.

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APPENDIX

STAR FINDER

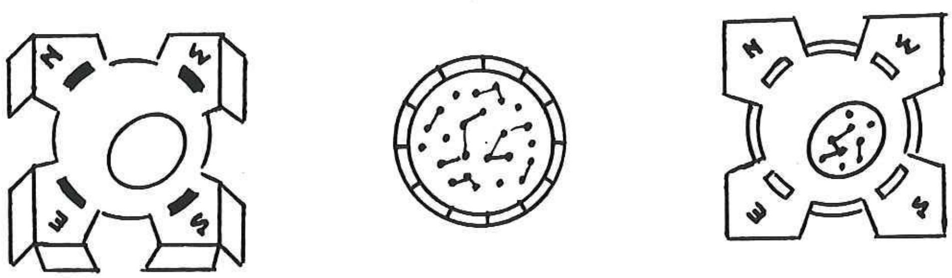
FOR USE IN PLANETARIUM OR OUTDOORS

The following two pages present patterns for a star finder that may be constructed and used, according to instructions below, to locate stars in the planetarium or night sky during any month of the year.

Directions for Assembling

1. Pattern A -- Time Frame. Duplicate on white paper. Cut off (or out) all shaded areas. Fold back at fold lines. Insert a piece of heavy cardboard between the time frame and the fold flaps. The cardboard should be the size of the time frame after folding. Tape the flaps down securely on the back of cardboard. You now have a frame which will hold the star wheel.

2. Pattern B -- Star Wheel. Duplicate on white paper and cut out. Paste down on manilla paper and trim. Insert star wheel in the time disk frame constructed above. Secure time wheel with a brad in the center. The star wheel should be free to move in a circular fashion.



Directions for Using

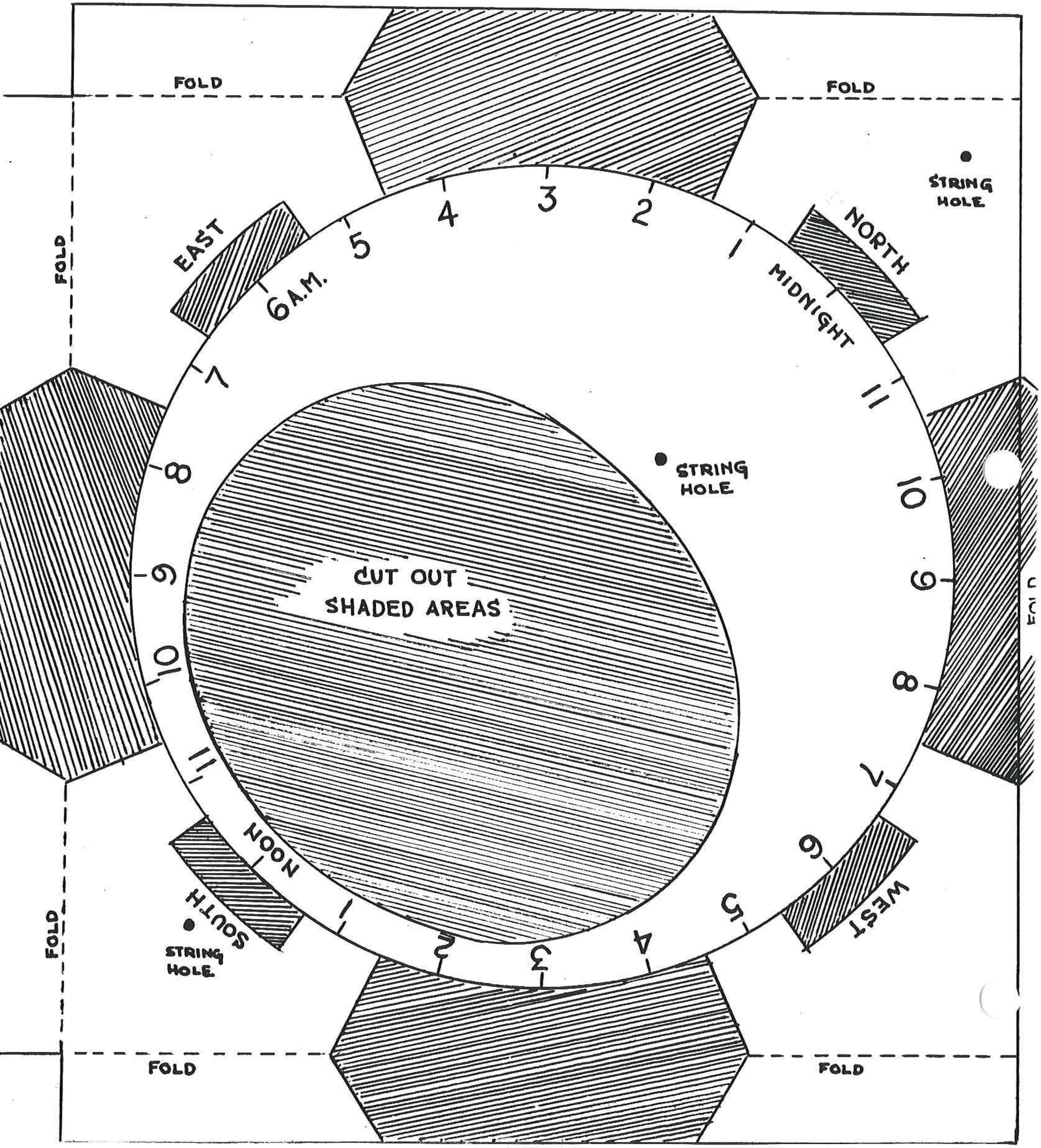
1. Use a flashlight.

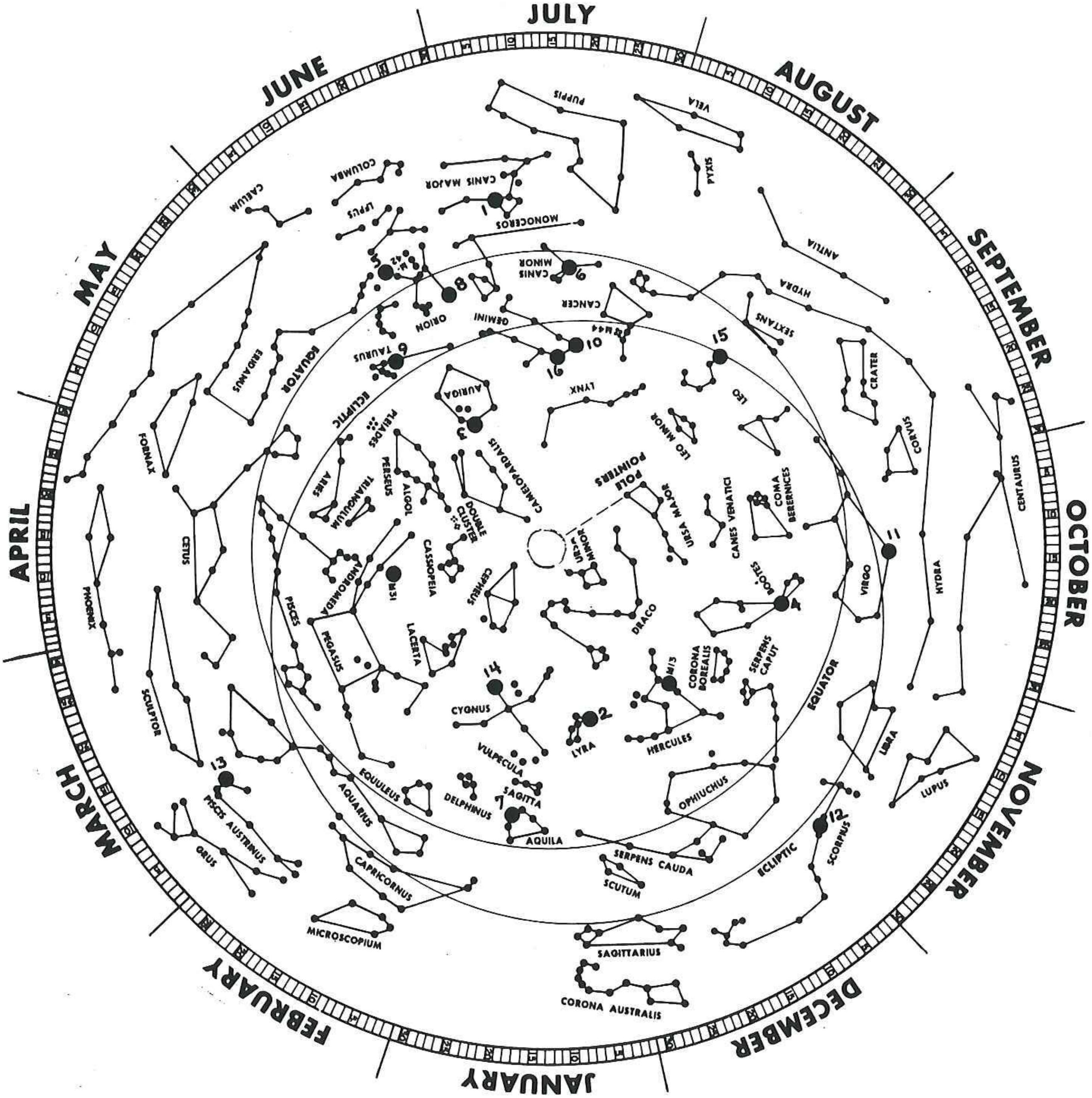
2. Turn star wheel until the date on the star wheel is set to correspond with the time of day you are making your observation.

3. Hold the star finder overhead, with its face down, so that you can see it and so that the north of the star finder points toward the north pole. Thus east and west on the star finder, and on all star charts, are in reverse positions compared with an earth map.

4. Use your flashlight to locate star positions on the star finder--then look in the same position overhead to locate the same stars and constellations in the sky.

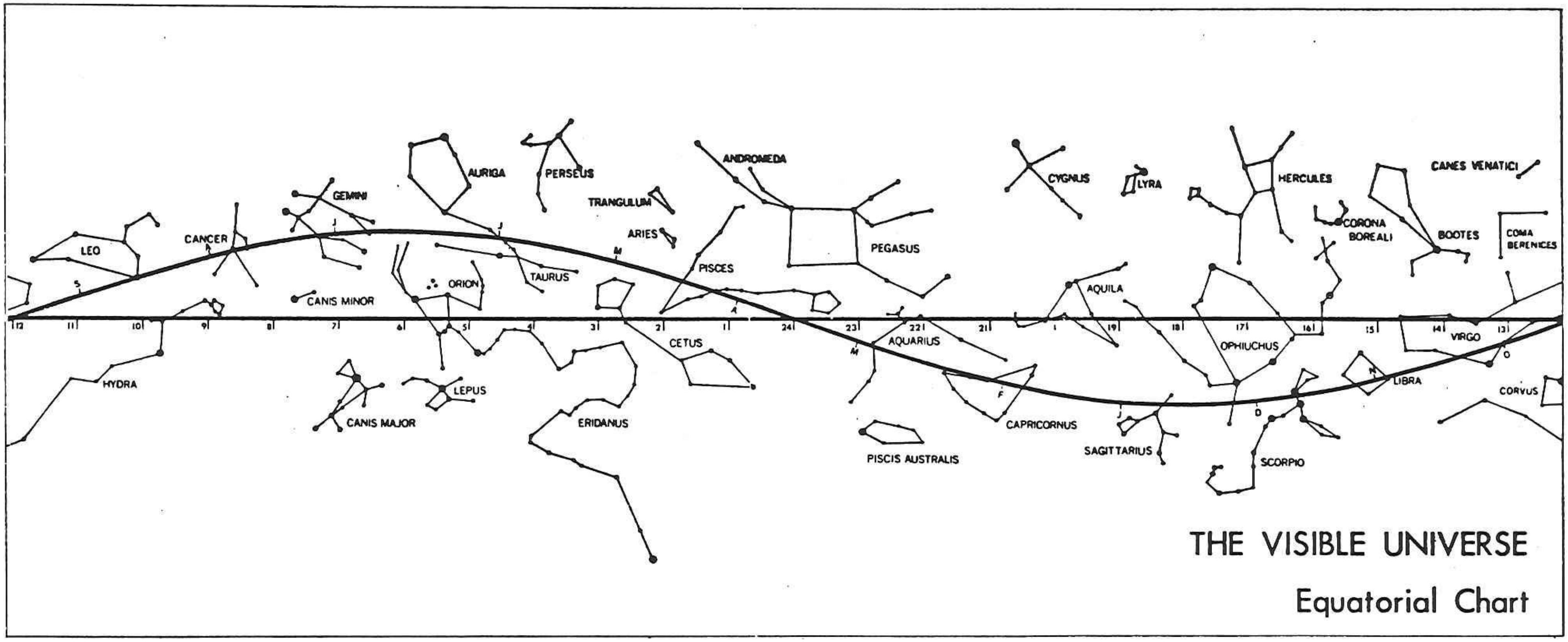
NOTE: The star finder is designed for latitude 35° north, but will be useful at any northern mid-latitude.



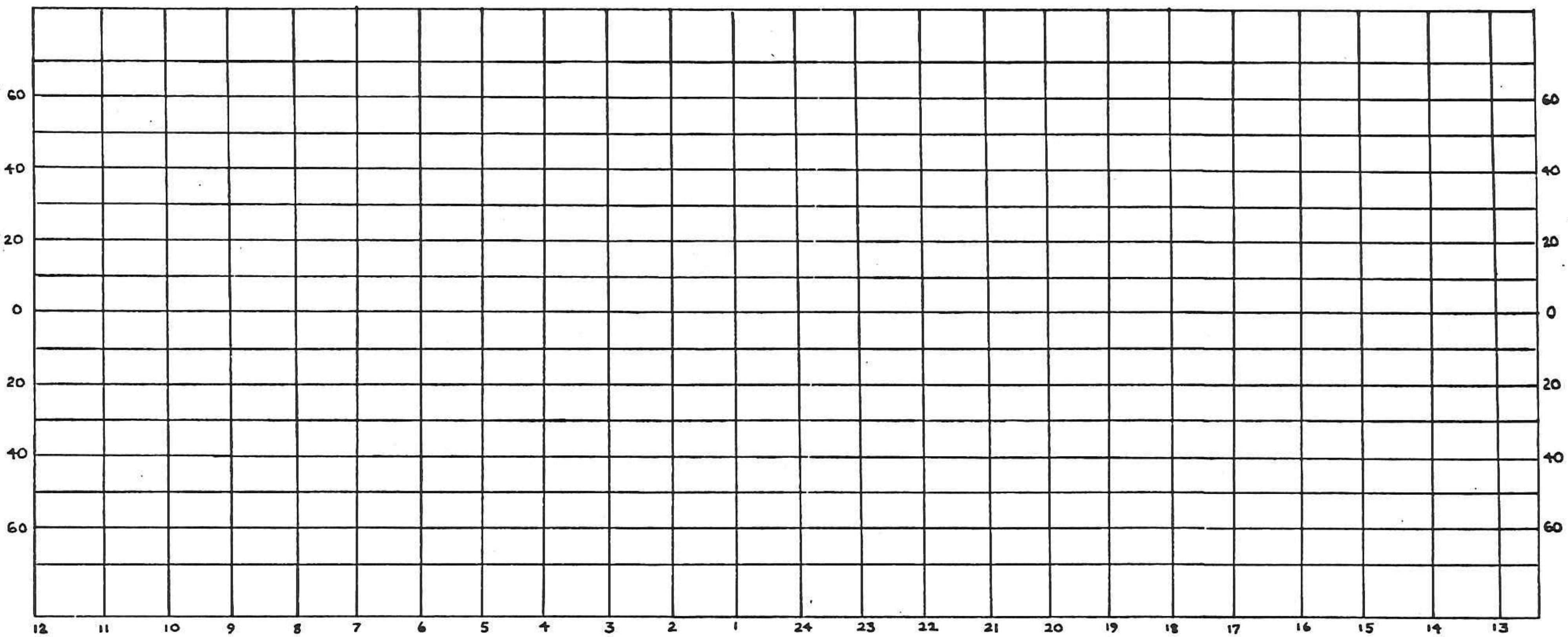


The numbers of the stars on the circular disk match the below names.

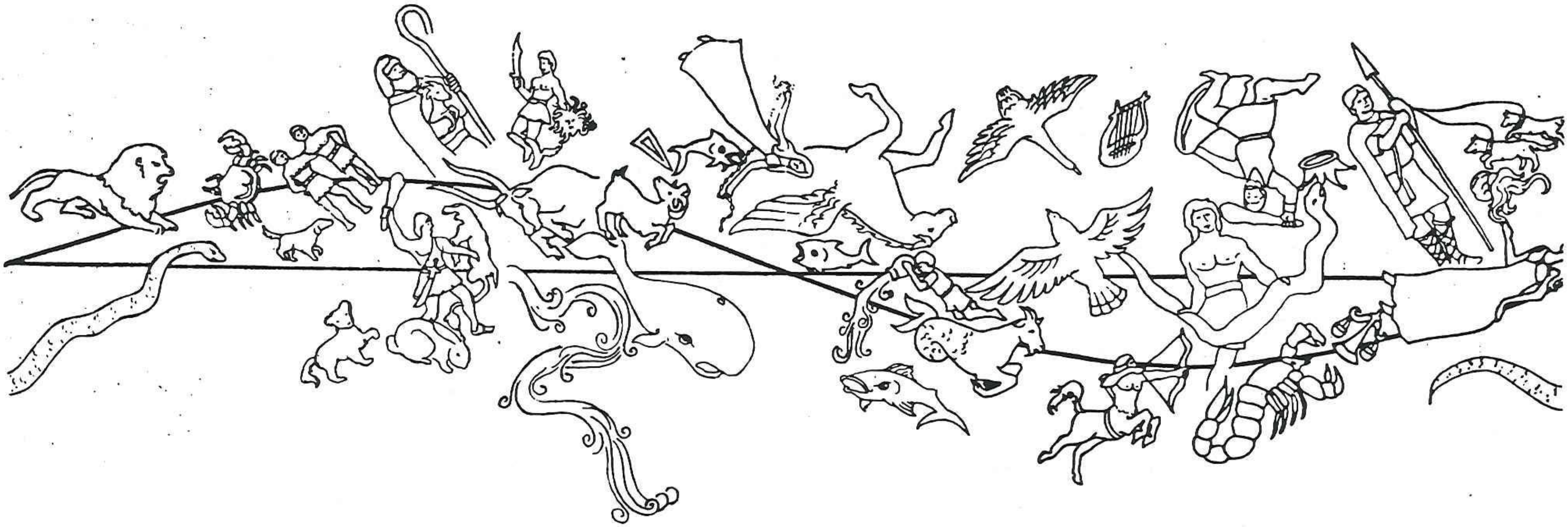
1. Sirius
2. Vega
3. Capella
4. Arcturus
5. Rigel
6. Procyon
7. Altair
8. Betelgeuse
9. Aldebaran
10. Pollux
11. Spica
12. Antares
13. Fomalhaut
14. Deneb
15. Regulus
16. Castor


THE VISIBLE UNIVERSE
Equatorial Chart
LEO
CANCER
GEMINI
AURIGA
PERSEUS
TRANGULUM
ARIES
ANDROMEDA
PEGASUS
PISCES
TAURUS
ORION
CANIS MINOR
CYGNUS
LYRA
HERCULES
CORONA BOREALI
CANES VENATICI
BOOTES
COMA BERENICES
AQUILA
HYDRA
CANIS MAJOR
LEPUS
ERIDANUS
CETUS
AQUARIUS
PISCIS AUSTRALIS
CAPRICORNUS
SAGITTARIUS
OPHIUCHUS
SCORPIO
LIBRA
VIRGO
CORVUS

A4



COORDINATE OVERLAY



CONSTELLATION OF THE ZODIAC OVERLAY

20 BRIGHTEST STARS

STARS	TEMPERATURE IN K°	DISTANCE IN PARSEC*	SPECTRA CLASS**	NO. OF TIMES SUN'S LUMINOSITY	ABSOLUTE MAGNITUDE	VISUAL MAGNITUDE
Sirius	10,400	2.7	A1	2×10^{1}	+1.4	-1.42
Canopus	7,400	30.0	F0	1.2×10^{3}	-3.1	-0.72
Alpha Centauri	5,800	1.3	G2	1	+4.4	-0.01
Arcturus	4,500	11.0	K2	9×10^{1}	-0.3	-0.06
Vega	10,700	8.0	A0	4×10^{1}	+0.5	+0.04
Capella	5,900	14.0	G	1.3×10^{2}	-0.7	+0.05
Rigel	11,800	250.0	B8	4×10^{4}	-6.8	+0.14
Procyon	6,500	3.5	F5	.6	+2.7	+0.38
Betelgeuse	3,200	150.0	M2	1.1×10^{4}	-5.5	+0.41
Achernar	14,000	20.0	B5	1.7×10^{2}	-1.0	+0.51
Beta Centauri	21,000	90.0	B1	3.3×10	-4.1	+0.63
Altair	8,000	5.1	A7	10.0	+2.2	+0.77
Alpha Crucis	21,000	120.0	B1	2.7×10^{3}	-4.0	+1.39
Aldebaran	4,200	16.0	K5	8×10^{1}	-0.2	+0.86
Spica	21,000	80.0	B1	1.9×10^{3}	-3.6	+0.91
Antares	3,400	120.0	M1	4.4×10^{3}	-4.5	+0.92
Pollux	4,900	12.0	K0	3.3×10^{3}	+0.8	+1.16
Fomalhaut	9,500	7.0	A3	1.1×10^{1}	+2.0	+1.19
Deneb	9,900	430.0	A2	4×10^{4}	-6.9	+1.26
Beta Crucis	22,000	150.0	B0	4.8×10^{3}	-4.6	+1.28

*Parsec = 3.26 light years or 19,200,000,000,000 miles.

**The number after the spectral class indicates a subclass.

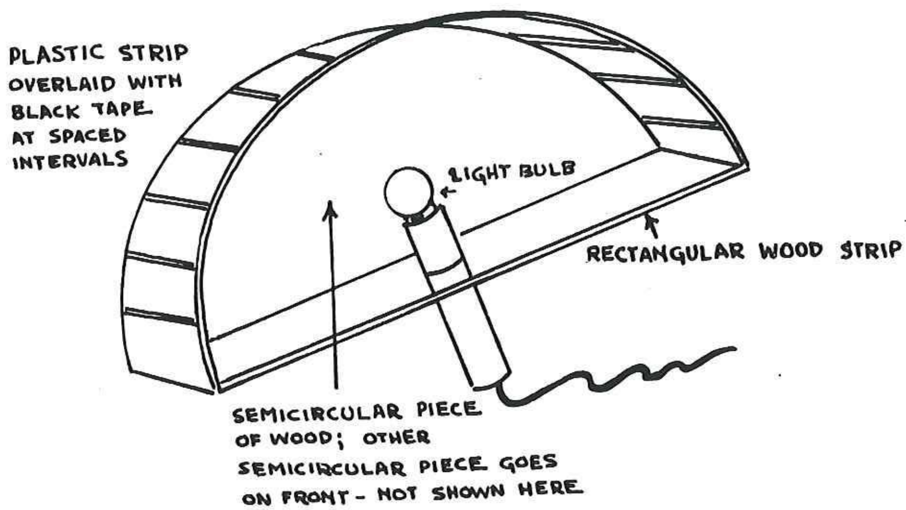
20 NEAREST STARS

STARS	TEMPERATURE IN K°	DISTANCE IN PARSEC*	SPECTRA CLASS**	NO. OF TIMES SUN'S LUMINOSITY	ABSOLUTE MAGNITUDE	VISUAL MAGNITUDE
Alpha Centauri A	5,800	1.31	G2	1	+4.4	-0.1
Alpha Centauri B	4,200	1.31	K5	3.3×10^{1}	+5.8	+1.4
Alpha Centauri C	2,800	1.31	M5	1×10^{4}	+15	+10.7
Barnard's Star	2,800	1.83	M5	4×10^{4}	+13.2	+9.54
Wolf 359	2,700	2.35	M6	1.3×10^{4}	+16.8	+13.66
Lalande 21185	3,200	2.49	M2	4×10^{2}	+7.47	+10.5
Sirius A	10,400	2.67	A1	2.5×10^{1}	+1.4	-1.42
Sirius B	10,700	2.67	WD	1.7×10^{3}	+11.5	+8.7
Luyten 726-8A	2,700	2.67	M5	5×10^{3}	+15.4	+12.5
Luyten 726-8B	2,700	2.67	M6	3.3×10^{5}	+15.8	+12.9
Ross 154	2,800	2.94	M4	4×10^{4}	+10.6	+13.3
Ross 248	2,700	3.16	M5	1×10^{4}	+12.24	+14.7
Epsilon Eridani	4,500	3.30	K2	2.5×10^{4}	+6.1	+3.73
Ross 128	2,800	3.37	M5	2.5×10^{5}	+13.5	+11.13
Luyten 789-6	2,700	3.37	M5	7.7×10^{5}	+12.58	+14.9
61 Cygni A	4,200	3.40	K5	6.7×10^{2}	+7.5	+5.19
61 Cygni B	3,900	3.40	K7	3.3×10^{2}	+8.3	+6.02
Procyon A	6,500	3.47	F5	1.7×10^{2}	+2.7	+0.38
Procyon B	7,400	3.47	WD	4×10^{4}	+13.0	+10.7
Epsilon Indi	4,200	3.51	K5	1×10^{1}	+7.0	+4.73

PLANETARIUM HAND SEXTANT

Materials: 2 pieces of thin wood cut in semicircles; 1 strip of thin wood the length of diameter of semicircles; #1 strip of clear plastic the length of circumference of semi-circles and width of the wood strip; black tape; good glue and/or small screws; tube for white light and plug; light source.

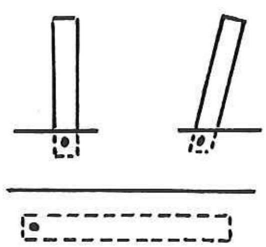
Directions: Put together as pictured below, adhering small strips of black tape at spaced intervals across the plastic strip for the light to shine through and project degree lines on the dome. The width of the tape should be chosen to represent 5° or 10° increments.



Instructions for use: In measuring altitude, use the planetarium sextant as near to the center of the planetarium as possible. It may also be used to measure azimuth, but the means suggested below are easier and no one needs to hold the sextant.

MEASURING AZIMUTH IN PLANETARIUM

Simply thumb tack degree markings at intervals between the planetarium dome and rim. Use white strips of cardboard; tuck them between projection dome and rim when you don't want them showing. See pictures.

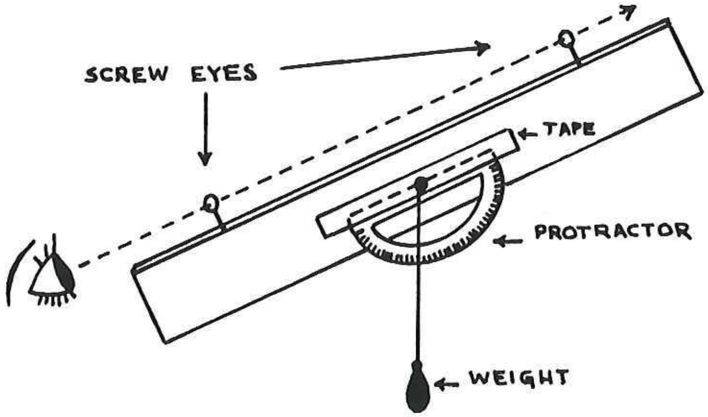


VARIETIES OF STUDENT-MADE ASTROLABES

Two types of student-made astrolabes are pictured below (although there are many other varieties).

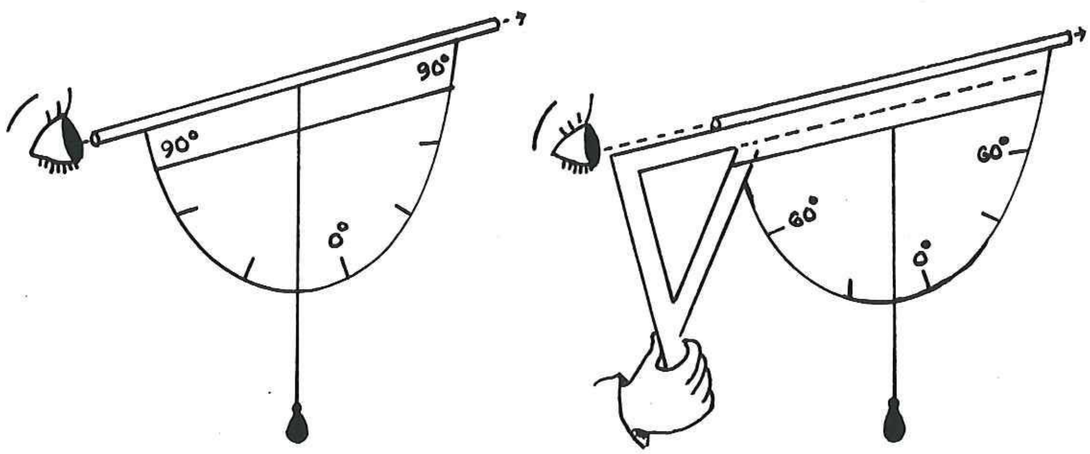
Type A:

Materials: straight piece of plywood, 2 screw eyes, protractor, string, weight, adhesive tape (for affixing protractor), thumbtack. Construct and use as pictured.



Type B:

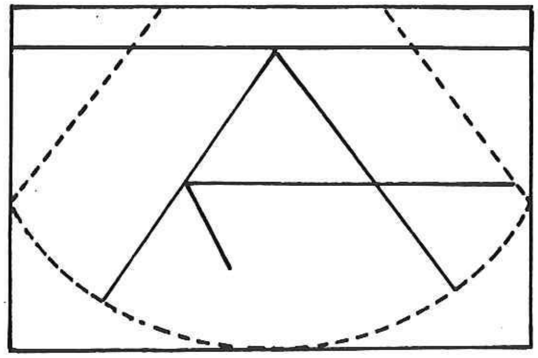
Materials: heavy cardboard marked off in degrees as shown; string suspended as pictured, drawn through hole and knotted on the back of the astrolabe; weight; straw for sighting device; (refinement) lorgnette-type holder of wood or cardboard. Construct and use as pictured.



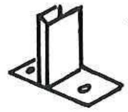
STUDENT MADE SEXTANT

MATERIALS

1. Plywood marked so and cut on dashed lines



2. Four mirror holders



3. Two mirrors

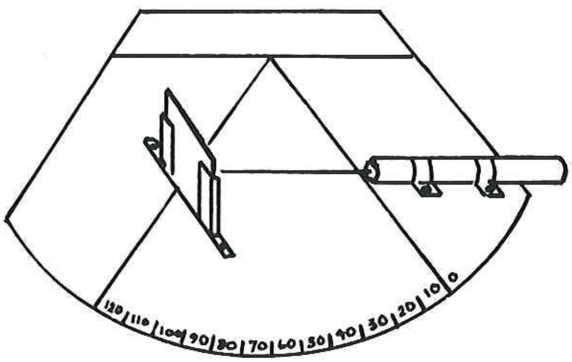
4. Two holders for sighting tube

5. Sighting tube

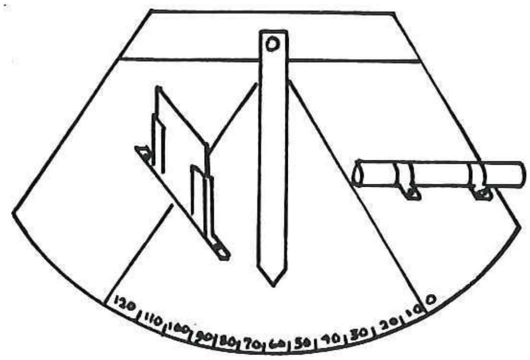
6. Plywood arrow

CONSTRUCTION

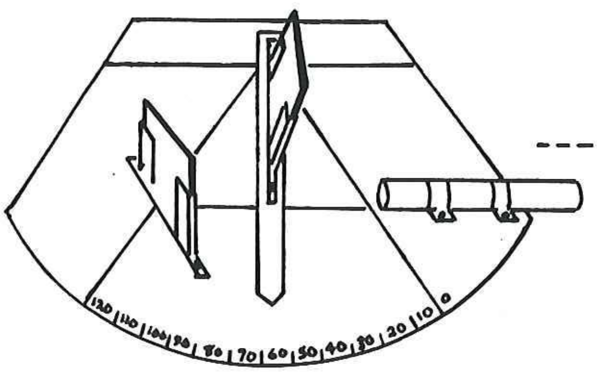
1. First view



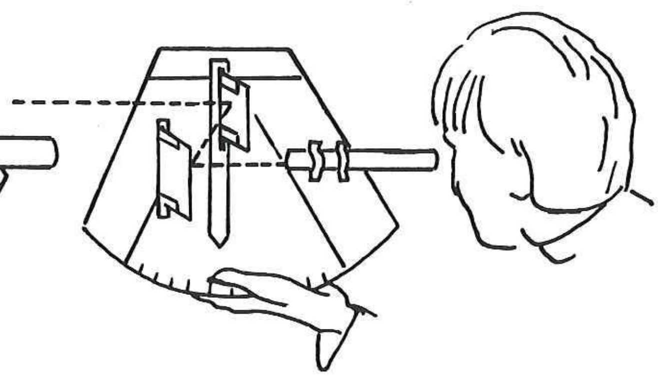
2. Second view



3. Third view



USE

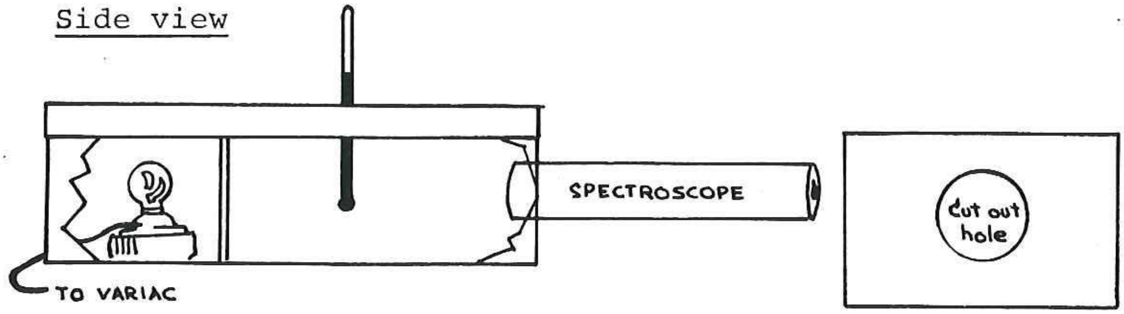


APPARATUS FOR OBSERVING TEMPERATURE-COLOR RELATIONSHIPS

Materials: incandescent bulb, calibrated rheostat or variac, partitioned box with slit in partition, thermometer, spectroscope. If only an uncalibrated rheostat or variac is available, put a paper plate around the control knob and mark degrees on the plate, using a protractor.

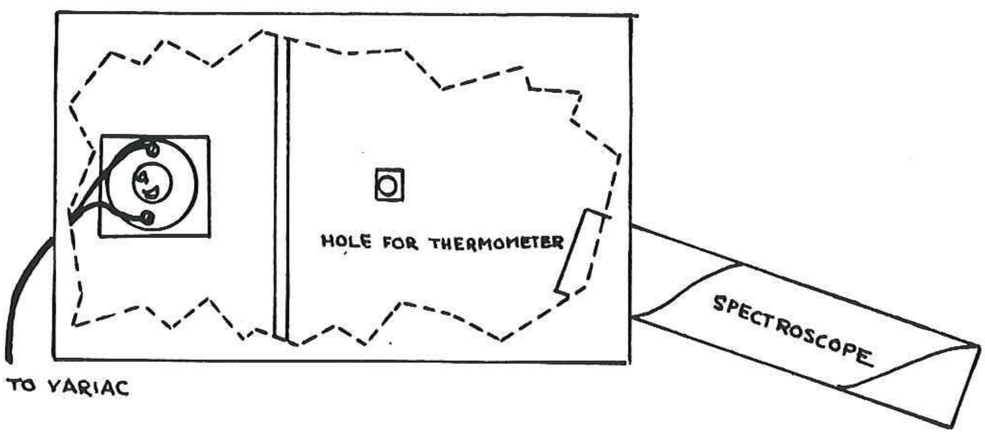
Construct as shown in the following pictures:

Side view



Note: Divider has small opening; end view of divider

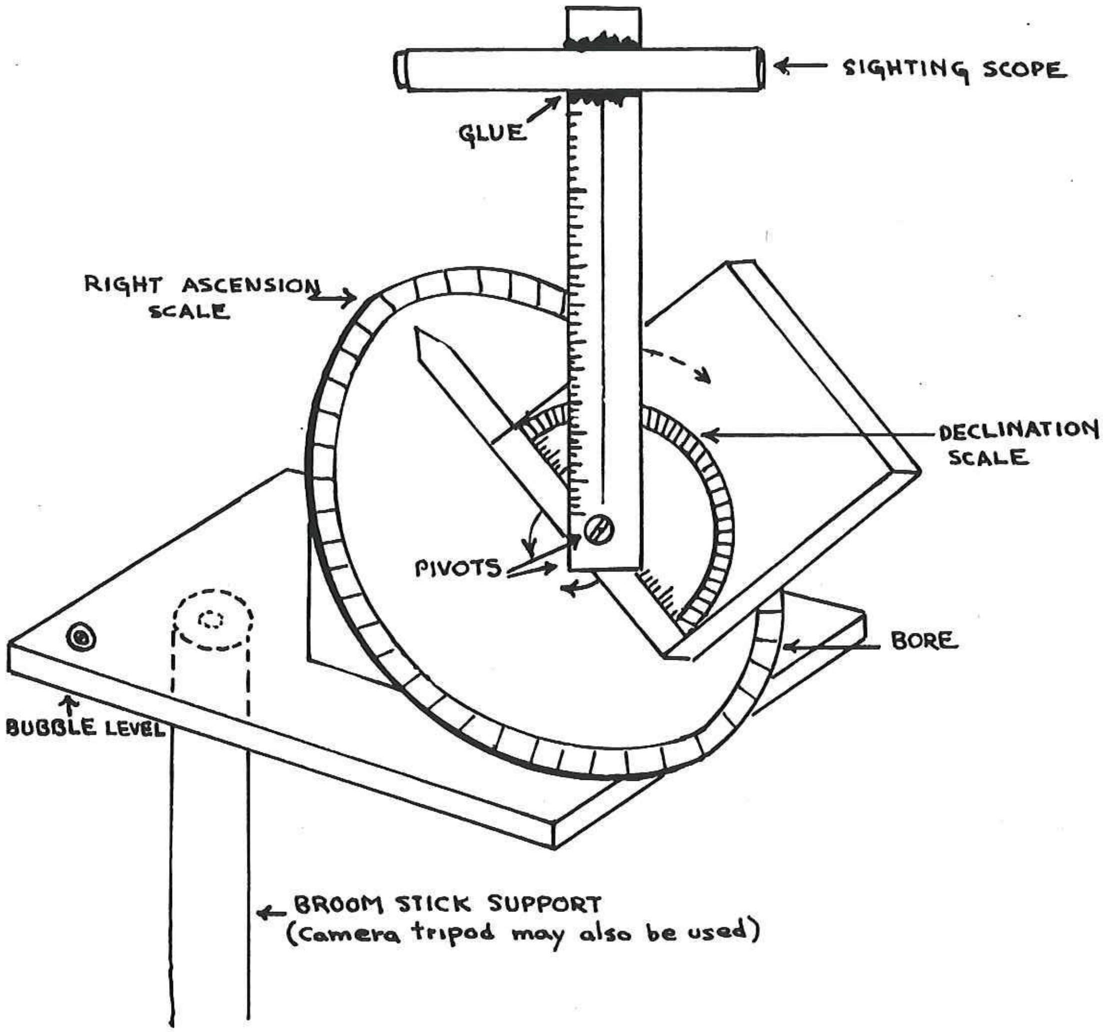
Top view



Directions for use: The thermometer must be in the light beam produced through the opening in the partition. As one student uses the calibrated rheostat to reduce the bulb in brilliance, another student records temperature changes as shown on the thermometer, while a third student looks through the spectroscope and records color bands.

EQUATORIAL COORDINATE STAR FINDER

The drawing below shows materials, construction, and use.



SPECTROSCOPES

Paper Towel - Spool Spectroscope

Materials: One paper towel spool about 12 inches long; knife or single-edged razor blade; tape, hole punch, diffraction grating 1 inch square.

Directions for construction

1. Cut two circles the same diameter as the paper towel spool from cardboard.
2. Cut a slit in the center of one of the circles about 1/8 to 1/10 inch wide and 1/2 to 1 inch long.
3. Cut a hole 1/4 to 1/2 inch in diameter in the center of the other circle. Tape the diffraction grating over this circle.
4. Tape the circle containing the slit over one end of the spool, making sure that it is light tight except for the slit.
5. Tape (temporarily) the circle containing the diffraction grating over the other end of the spool.
6. Test to see a spectrum by pointing the slit end of the spool toward the light. The slit should be vertical. When a spectrum is seen, tape the circle containing the grating solidly in place.

Diffraction Grating

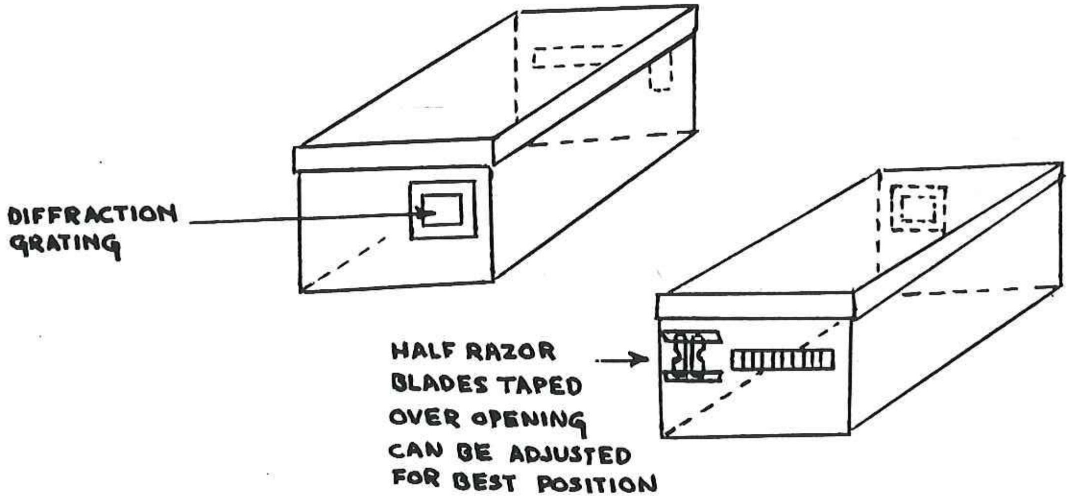
Materials: glass slide, black paint or ink, two single-edged razor blades.

Directions: Coat one side of slide with black paint or ink. Let dry. Tape two razor blades side by side. Scratch very thin lines across the slide, making them parallel and very close together.

Slide for Projecting Slit of Light and/or Continuous Spectrum

Directions: Mount a piece of exposed black 35mm film in a regular 35mm slide frame. Make a very clean slit down the center of the film with a razor blade. Insert slide into projector so that the slit is vertical to the lens.
To project a continuous spectrum, project through a prism or diffraction grating. To get the image where you want it, you will need to experiment and adjust the angle of the prism or the projector.

SHOEBOX SPECTROSCOPE



Materials: shoe box, knife or single-edged razor blade for cutting the box; diffraction grating (see below); masking tape; graph paper; double-edged razor blade cut in half.

Directions for construction

1. Cut a hole 1 inch square at one end of box. Paste or tape the diffraction grating over it, positioning grating so that spectrum will appear horizontal.

2. Cut a slit 1 inch long at other end of box. Tape a half razor blade, edge toward slit, on each side of slit so that you can adjust width and keep the slit straight.

3. Look through the grating with box lid on temporarily. You should see two horizontal spectra, one on each side of the slit. You may need to darken the room and look at an incandescent bulb. Use the spectrum that appears directly in front and not off to one side.

4. Cut an opening on the same end of the box as the "razor-blade" slit at the location of the spectrum just mentioned. This should be 1 inch deep, and wider than the horizontal spectrum. You might start by making a small hole near the center of the area and see where it is in relation to the spectrum.

5. Cut out a strip of graph paper large enough to cover the opening completely. Number the vertical lines on the graph paper starting with zero. Paste the strip of graph paper over the opening, being sure that the scale is visible as you look through the diffraction grating.

SAFETY DEVICES FOR VIEWING SUN

Eye-Safety Device for Viewing Sun:

When students are doing investigations that require viewing the sun, it's best to do more than caution them against looking directly at it. Materials should be made available which they can use for observing the sun without running the risk of eye damage. Ordinary sun glasses are not sufficient protection. However the following methods are considered safe.

Indirect Method

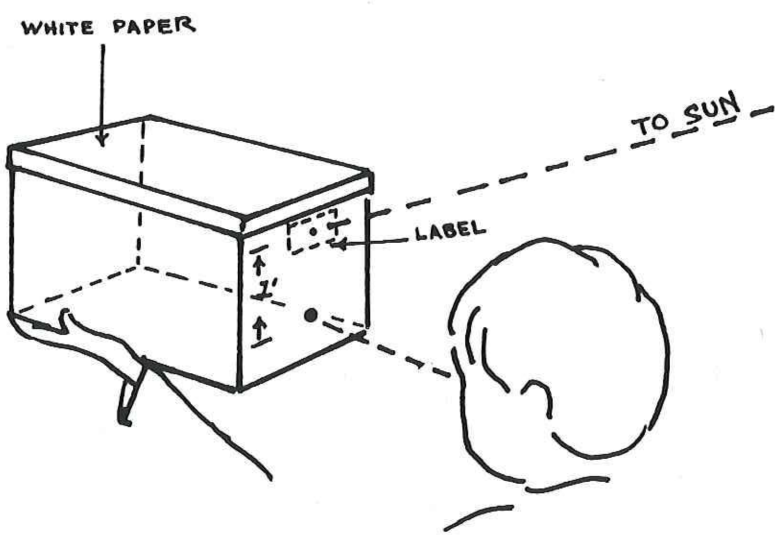
Materials: piece of cardboard, sheet of white paper.

Instructions: Punch a small hole onto the cardboard, and hold it so that the sun is at the viewer's back. The sun's rays can then be focused through the hole onto the white paper, showing safely the sun's disc.

Pinhole Camera Method

Materials: Cardboard carton with a lid (or a box, or a long tube can be modified for use), piece of white paper, gummed label.

Instructions: Paste the paper inside one end of the box. Punch two holes on a vertical line about a foot apart in the opposite end. Place the label over the top hole and pierce it with a pin. Then seal all the box seams so that no extra light enters. The observer stands with his back to the sun, looking through the bottom hole. The box should be moved around slightly until the sun's image comes through the pinhole and appears on the paper.



Telescopic Observations

If you are planning on viewing the Sun with a telescope, be certain that it is equipped with a reliable solar filter. Check the filter before using it, making sure that it has no cracks or scratches. Under no circumstances should you look through the telescope without the proper filter. Similarly, do not look through binoculars or into a mirror to view the Sun.

A projection system can be set up using your telescope or binoculars to view the Sun. By orienting the instrument so that it points in the direction of the Sun, you can project the image of the Sun on a piece of paper or card-board held in front of the eyepiece. DO NOT LOOK THROUGH THE EYEPIECE. Many instruments will be damaged if pointed at the Sun too long, so check with the manufacturer of your instrument before taking a chance.

PLANETARIUM PRECESSION SAFETY DEVICE

Safety-Device for Planetarium Instrument When Showing Precession:

If you have a star projector which uses only one light source for the star field, precess one cycle in one direction and then precess back in the opposite direction. This will extend the life of the wire and prevent it from getting twisted up in the slip rings.

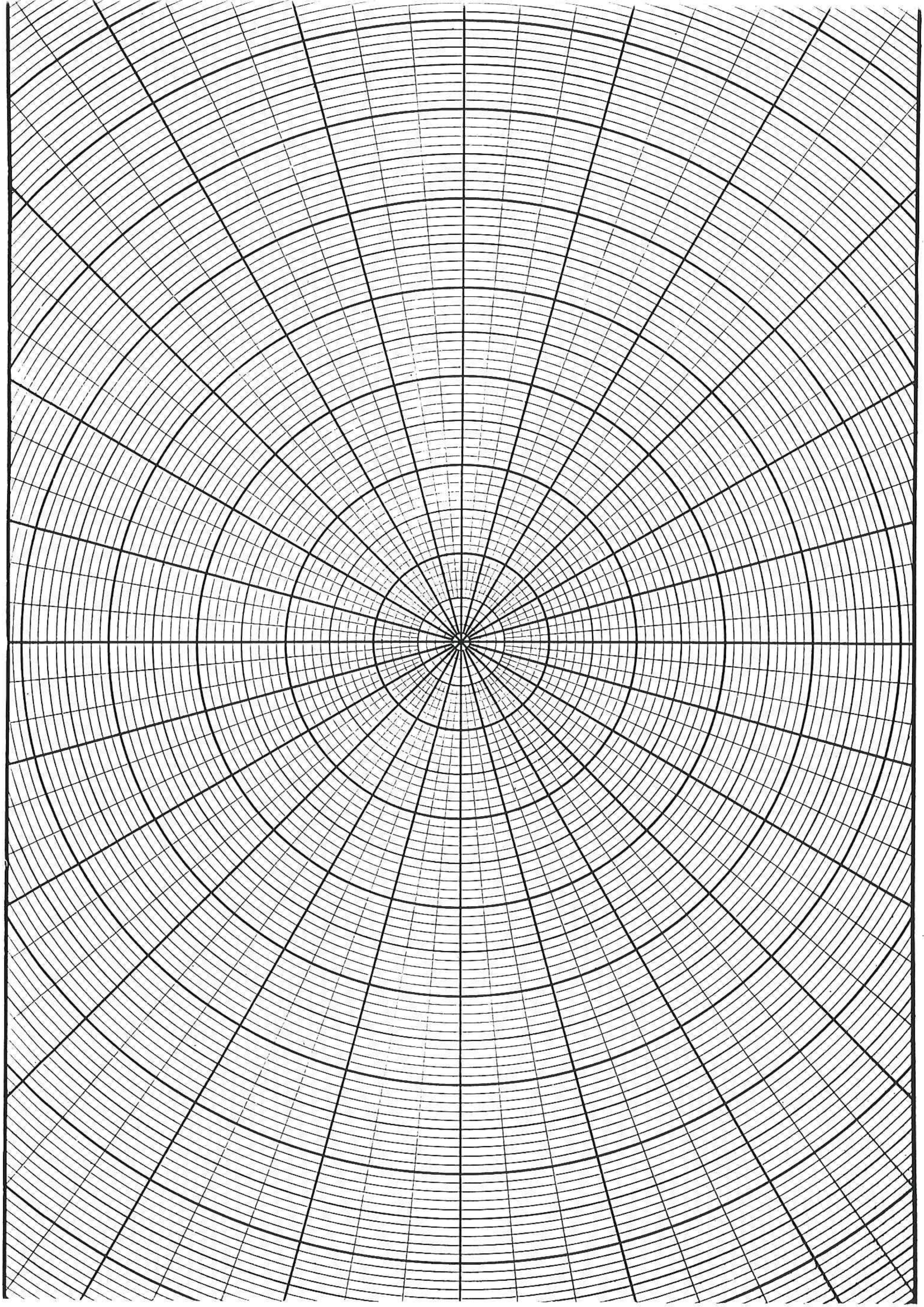


PHOTO CREDITS

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National Aeronautics and Space Administration
page 135, from Apollo 8
page 211, from Apollo 11
page 241, from ESSA 5 Satellite
page 285, Solar System Model

Paul Boston
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Lee Ann Hennig
Fort Hunt Planetarium, Fairfax County, Virginia
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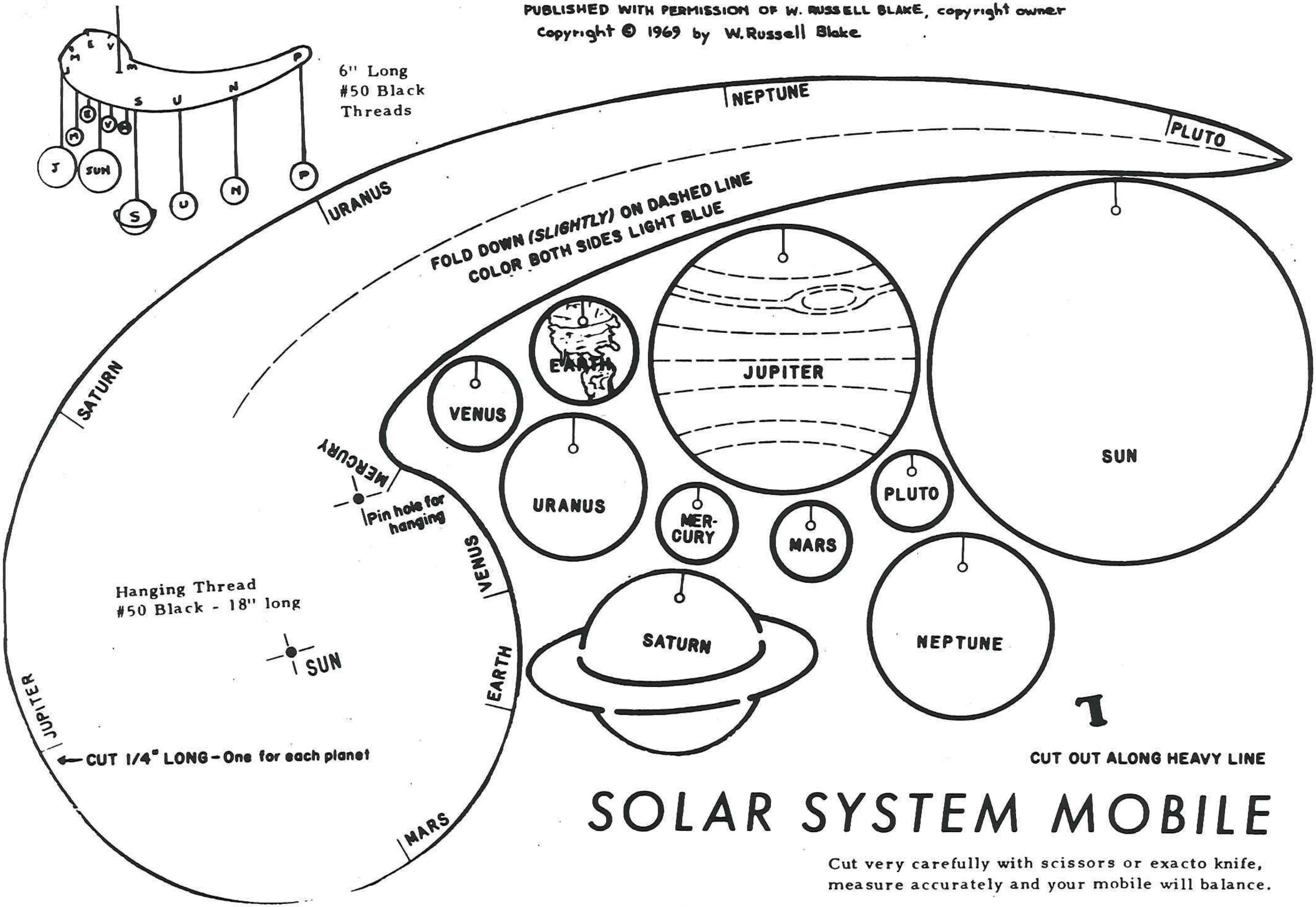

CUT OUT ALONG HEAVY LINE

SOLAR SYSTEM MOBILE

Cut very carefully with scissors or exacto knife, measure accurately and your mobile will balance.