topic IV

What Are the Motions of the Earth?

Time Emphasis: 10 days

TOPIC OUTLINE

INVESTIGATION	A-1a	A-1b	A-1c	D-1a	D-1b	D-1c	D-2a	LTI - #6	LTI - #7	LTI - #8	LTI - #9	LTI - #10					
Estimated Time (Periods)	2	1+	1	1+	1	2	1										

A. Celestial observations

A-1 Motion of objects in the sky

What Observations Can Be Made of Celestial Objects?

		A-1a	A-1b	A-1c	D-1a	D-1b	D-1c	D-2a	LTI - #6	LTI - #7	LTI - #8	LTI - #9	LTI - #10					
A-1.1 Star paths	A-1.11	■							■									
	A-1.12	■							■									
A-1.2 Planetary Motions	A-1.21									■								
	A-1.22				■													
	A-1.23																	
A-1.3 Satellite motion	A-1.31		■								■							
	A-1.32		■															
A-1.4 Sun motion	A-1.41			■														
	A-1.42			■														
	A-1.43			■									■					
	A-1.44			■								■						
	A-1.45			■								■						
	A-1.46						■											

B. Terrestrial observations

B-1 Motion at the earth's surface

What Terrestrial Evidence Suggests Earth Motions?

		A-1a	A-1b	A-1c	D-1a	D-1b	D-1c	D-2a	LTI - #6	LTI - #7	LTI - #8	LTI - #9	LTI - #10					
B-1.1 Foucault Pendulum	B-1.11																	
B-1.2 Coriolis Effect	B-1.21																	

C. Time

C-1 Frames of reference for time

How Are Frames of Reference Determined for Time?

		A-1a	A-1b	A-1c	D-1a	D-1b	D-1c	D-2a	LTI - #6	LTI - #7	LTI - #8	LTI - #9	LTI - #10					
C-1.1 Earth motions	C-1.11			■														
	C-1.12			■									■					

D. Solar system models

D-1 Geocentric and heliocentric models

What Models Explain the Observations of Celestial and Terrestrial Motions?

		A-1a	A-1b	A-1c	D-1a	D-1b	D-1c	D-2a	LTI - #6	LTI - #7	LTI - #8	LTI - #9	LTI - #10					
D-1.1 Geocentric model	D-1.11	■		■	■	■	■				■							
	D-1.12																	
D-1.2 Heliocentric model	D-1.21	■		■	■	■	■				■							
	D-1.22																	
	D-1.23				■	■												

Continued on next page

	INVESTIGATION		A-1a	A-1b	A-1c	D-1a	D-1b	D-1c	D-2a	LTI - #6	LTI - #7	LTI = #8	LTI - #9	LTI -#10
	Estimated Time (Periods)		2	1+	1	1+	1	2	1					
TOPIC OUTLINE	D. Solar system models (continued)													
	D-2 Simple celestial model *What Simple Celestial Model Can be Synthesized from Observations?*													
	D-2.1 Geometry of orbits	D-2.11						■	■					
		D-2.12							■					
		D-2.13							■					
		D-2.14												
	D-2.2 Force and energy transformations	D-2.21												
		D-2.22												
		D-2.23												
		D-2.24												
PROCESS OF INQUIRY OBJECTIVES	Mathematical Skill	PIO-1	■	■	■			■	■					
	Measurement Skill	PIO-2	■		■		■	■	■			■		
	Creating Models	PIO-3	■	■	■	■	■	■	■			■		
	Analysis of Error	PIO-4												
	Data Analysis	PIO-5	■	■	■		■		■			■		
TITLES			Celestial Observations	Moon's Path	Sun's Path Analysis	Planet Phases	Heliocentric & Geocentric Models	Solar Diameter	Orbits	Big Dipper	Planet	Moonrise-Moonset	Sunrise-Sunset	High Noon

Multimedia: Check Multimedia Section of Supplement for reference to this topic.

Difficult (2)

IV-A-1a: CELESTIAL OBSERVATIONS

QUESTION:

What observations can be made of celestial objects?

MATERIALS:

compass, star maps (optional), transparent hemisphere, water-color felt-tip pens, external protractor, astrolabe (or alternate procedure)

SUGGESTED APPROACH:

1. This investigation should be done individually during a 2-hour period on a clear evening during which three readings can be taken.
2. Briefly discuss the use of the star charts, if available, to help the student orient himself when he is observing the sky.
3. To check the student's plottings on the plastic hemisphere, place the position of the North star above the North Pole of a globe. The paths of all stars should be parallel to the lines of latitude.

PRECAUTIONS:

1. The student must observe the <u>same</u> stars at each of the different times.
2. All vertical angles must be measured from a true horizon rather than the local horizon.
3. Remind the students that the orientation of the plastic hemisphere must be the same each time that the stars are plotted.

TYPICAL RESULTS:

Some shift of position should be detectable for all stars. As the angular distance between the chosen star and the North star increases toward 90°, the linear displacement should increase.

MODIFICATIONS:

1. The entire exercise can be conducted with excellent results in a planetarium if one is available.
2. "Hand span method." Let each student devise his own, by holding his hand at a constant distance from his eye and sighting across it (e.g., from index to little finger), and scanning from horizon to zenith or around the complete horizon, he can calibrate his hand span. This method can be utilized in the absence of astrolabes.
3. Teachers should make the measurements in advance, anticipating the possibility of bad weather. Providing the student with the data is not as desirable as having him measure it, but in some cases this may be necessary.

4. Other alternative methods:

   a. Inv. 4-1, Investigating the Earth: Investigating motions in the sky watch.

   b. Have a star party preceding this exercise simply to get familiar with some of the more obvious constellations and bright stars.

   c. Photographic records: students with cameras may wish to take time photos of various portions of the sky. Students using high-speed film may take a succession of photos of the same portion of the sky and compare positions of stars on each.

<u>REFERENCES</u>:

Investigating the Earth, Teacher's Guide, pp. 123-126

IV-A-1a: CELESTIAL OBSERVATIONS

QUESTION:

What observations can be made of celestial objects?

INTRODUCTION:

In this investigation you will have an opportunity to observe and measure the positions of some stars in the nighttime sky. After having repeated your observations at different times during the night, you should look for patterns of change and attempt to explain them by devising a model.

OBJECTIVES:

When you finish this investigation you should be able to:

1. determine the location of north, south, east, and west in the nighttime sky.

2. measure the horizontal and vertical angles for objects in the sky.

3. describe the apparent movement of stars in various parts of the sky.

METHOD:

1. Determine the locations of north, south, east, and west at your observation point by using the North Star as the key reference point. Mark these directions in some way so that they can be referred to as the investigation progresses. If you cannot identify the North Star or the compass directions, select some landmark (e.g., tree, pole) on the horizon from which you can make measurements. Divide the sky into four sections based on your landmark reference.

2. Choose four stars that you can easily find again - one in each section of the sky. Mark these stars on the star map, if one is available.

3. Using the astrolabe or any alternate method, determine and record the horizontal and vertical angles for each of the four reference stars.

4. Repeat these readings for the same four stars 1 hour later, and a third time an hour after that. Make sure that you record the exact time for each set of the readings. Record each observation in the chart below.

5. Plot the values on the transparent hemisphere for each of the four sets of star readings. Use the water-color felt-tip pens and external protractor. Make sure that your orientation is the same as that used during the original readings.

	Time	Time	Time
Northern Star	VA	VA	VA
	HA	HA	HA
Southern Star	VA	VA	VA
	HA	HA	HA
Eastern Star	VA	VA	VA
	HA	HA	HA
Western Star	VA	VA	VA
	HA	HA	HA

VA = Vertical Angle (measured from the horizon)

HA = Horizontal Angle (measured from the North point or some suitable landmark on the horizon)

QUESTIONS:

1. What motions of the stars did you observe during the 2 hours of observation?

(A-1.11) 2. If you were to extend these motions over a 24-hour period, what shape path would be formed?

(A-1.12) 3. What was the rate of star motion during your period of observation?

4. Did any of the stars you observed shift position relative to each other? Explain.

(D-1.11) (D-1.21) 5. Based on your observations of the night sky, what are some possible causes for the motions you observed?

Easy (1+)

IV-A-1b: MOON'S PATH

QUESTION:

What observations can be made of celestial objects?

MATERIALS:

polar-coordinate (circular) graph paper, drawing compass

SUGGESTED APPROACH:

1. Students should work individually on the investigation.

2. The students should become familiar with angular measurement by use of the following exercise:

   Place a globe or some comparably shaped object in the front of the room. Have students hold a coin perpendicular to their line of sight and adjust its distance from their eye so that it just blocks out the shape of the globe. Have the students maintain their position and walk toward them carrying the globe in front of you. Ask the students to describe the apparent change observed in the globe's size (angular diameter).

   Illustrate to the students that the angular diameter of an object could change as a result of an actual change in the size of the object, with or without a distance change.

3. A brief discussion should follow emphasizing the relationship of the apparent change in angular diameter to the moon's distance from the earth. This discussion may be directed at the relationship evident in Columns 3 and 4 in the table found on the student sheet. (The values in Column 4 were derived by multiplying the reciprocal value of angular diameter (in seconds of arc) by a constant 1.25×10^{6}.)

4. Special emphasis should be applied to the discussion following the completion of this investigation. The answers to the student questions and the ensuing discussion should aid in gaining a better understanding of the relationship between the earth, moon, and sun.

PRECAUTIONS:

1. The student may need assistance in using the circular coordinate graph paper. Remind the student that the two coordinates on this type graph paper are distance from the center and angle.

2. Use a scale such that each circle on the graph represents 100 units of the distance between the earth and moon.

MODIFICATIONS:

If available, use the actual data for the sun and moon for the month in which the unit is taught. If this is done students can be instructed to make observations of the phases to coordinate with the predictions from the activity.

REFERENCES:

Investigating the Earth, p. 482, Teacher's Guide, pp. 611-614

IV-A-1b: MOON'S PATH

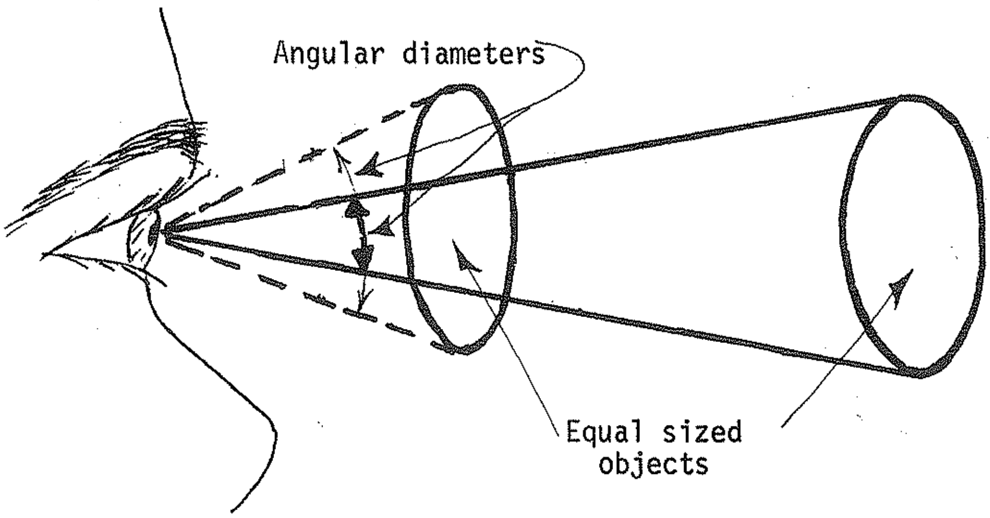
QUESTION:

What observations can be made of celestial objects?

INTRODUCTION:

The moon is very often the brightest object in the night sky, yet it appears to change in appearance with regularity. Using the data concerning the moon's position, distance and appearance, you will investigate this change.

The angular diameter of an object is determined by measuring its apparent width in degrees (see diagram).



The angular diameter of an object can be measured without reference to distance. However, a change in angular diameter of an object means either the distance between you and the object is changing or the actual size of the object is changing.

OBJECTIVES:

When you finish this investigation you should be able to:

1. plot lunar positions relative to the earth, given appropriate data on polar graph paper.

2. indicate the lunar phase given the relative positions of the sun, earth, and moon

METHOD:

1. Plot the data from the chart below on the polar graph paper.

2. Plot the earth at the center of the graph. Plot the location of the moon, in relation to the earth, for each day shown in the data chart.

3. Because the sun's distance is much greater than the moon's distance, show its position with an arrow indicating the direction the sun's rays are traveling toward the earth for that date.

Date	Celestial* Longitude of Moon	Angular Diameter of Moon	Distance from Earth	Celestial* Longitude of Sun
May 1	185°	33.1'	629	40°
3	215	33.2	628	42
5	244	32.6	638	44
7	273	31.7	657	46
9	299	30.7	678	48
11	324	30.0	695	50
13	348	29.5	705	52
15	12	29.5	707	54
17	36	29.7	702	56
19	60	30.0	693	57
21	85	30.5	682	59
23	111	31.1	670	61
25	138	31.7	657	63
27	166	32.3	645	65
29	195	32.7	637	67
31	224	32.8	636	69

*Celestial longitude is the angle measured clockwise from some reference point to the object.

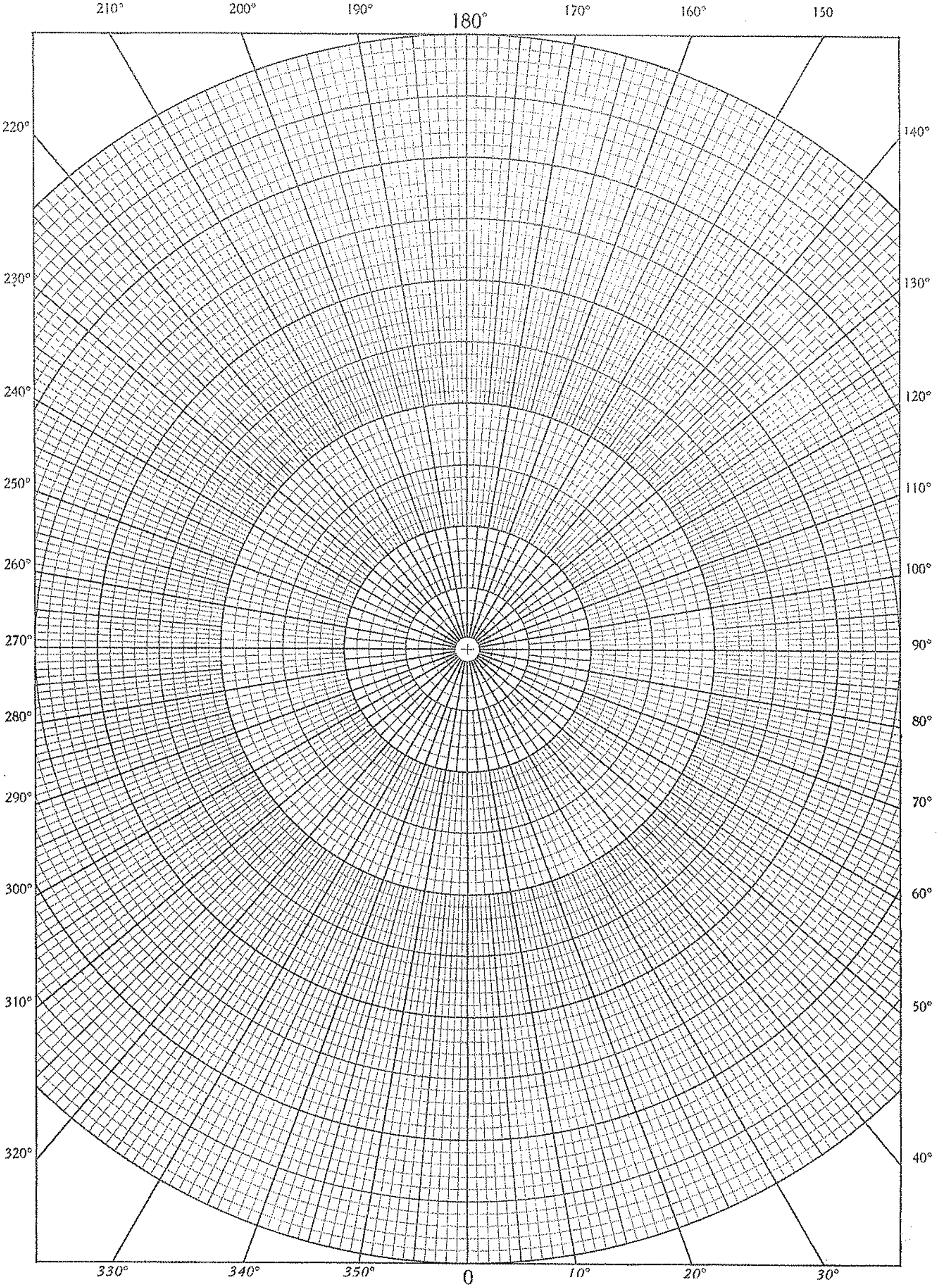
QUESTIONS:

(A-1.32) 1. How could you best describe the pattern of change of the moon's angular diameter over a long period of time?

2. If, as in the Figure, the observer remains stationary:

   a. How would the angular diameter of the sphere change if it were one-half the distance shown in the diagram?

   b. What do you think is the relationship between the earth-moon distance and the moon's angular diameter as measured from the earth?


210°
200°
190°
180°
170°
160°
150
220°
140°
230°
130°
240°
120°
250°
110°
260°
100°
270°
90°
280°
80°
290°
70°
300°
60°
310°
50°
320°
40°
330°
340°
350°
0
10°
20°
30°

(A-1.31) 3. Indicate on the graph where the moon will be when it is in:

a. Full phase

b. Quarter phase

c. New phase

4. At what locations might lunar eclipses occur?

5. Since the sun appears to shift approximately 30 degrees each month, where will the next full moon be? Locate it on the graph.

6. The moon's period of revolution is 27.3 days. What is the time from one full moon to the next?

7. How does the moon's orbit compare to a circular path?

Challenging (1)

IV-A-1c: SUN'S PATH ANALYSIS
(Continuation of LTI #3 - Sun's Path)

QUESTION:

What observations can be made of celestial objects?

MATERIALS:

metric ruler, string, protractor (external or internal protractor if available), graph paper

SUGGESTED APPROACH:

1. Have the students analyze the data collected during "The Sun's Path - Long Term Investigation" as indicated on the student sheet.

2. Have the students do the supplementary sheet exercise as a homework exercise.

3. Conduct a discussion after completion of the student investigation. Consider topics such as, "What model or models explain the observations made in this investigation."

BACKGROUND INFORMATION:

1. To determine the number of hours of daylight: Measure the distance (d) along the base of the hemisphere between the sunrise and sunset points. This is the projection of the sun's path in the horizontal plane.

   Compare distance (d) with the circumference of the hemisphere (c) which is the projection of the entire 24-hour path of the sun.

   Use the equation: $\frac{d}{c}$ X 24 hrs. = L (length of day expressed in hours). Solve for L.

2. To measure the sun's motion expressed as angular distance per hour: Use the equation: $\frac{d}{c}$ X 360° = Φ (degrees covered during daylight hours). Solve for Φ.

   Use the Relationship $\frac{\Phi}{L}$ = A (angular distance per hour). Solve for A.

3. To measure direction of sunrise and sunset, use a protractor and measure the angle between the north line and the sunrise and sunset points along a horizontal plane. This can then be translated into a directional bearing (i.e., 5° north of east).

Do not print

IV-A-1c: SUN'S PATH ANALYSIS

(Continuation of LTI #3 - Sun's Path)

QUESTION:

What observations can be made of celestial objects?

INTRODUCTION:

The sun has always been of prime importance to men. Long before it was clearly understood that the sun was indeed the primary energy source for the earth, men knew of some of the effects of sunlight on their lives. The rising and setting of the sun provided a natural rhythm for man's daily activities. The seasonal changes in the intensity and duration of sunshine regulated growing seasons. Because his life was so organized around the behavior of the sun, man came to realize the regularity and predictability of the sun's actions.

OBJECTIVES:

When you finish this investigation you should be able to:

1. determine the number of hours of daylight, given a hemisphere containing a plot of the sun's path for a day.
2. determine the number of degrees the sun moves per hour, given a hemisphere containing a plot of the sun's path for a day.
3. determine the direction of sunrise and sunset, given a hemisphere containing a plot of the sun's path for a day.
4. identify the appropriate season, given a plot of the sun's path for a day in either summer or winter.

METHOD:

1. Analyze the data collected during the "Sun's Path Long-Term Investigation" for the following information:
   a) length of day (expressed in hours) for each path;
   b) angular distance per hour that the sun moved for each path;
   c) comparison of heights of noontime sun on different dates;
   d) compass direction of sunrise and sunset for each path.
2. Compare each of the above observations with the season during which it occurred and list inferences that you can draw from the evidence.

QUESTIONS:

(A-1.41) 1. What is the shape of the apparent path of the sun through the sky?

(A-1.42) 2. How does the apparent path change with the seasons?

3. What is the approximate angular distance the sun moves in one hour? How does this vary with the seasons?

4. What was the angular distance of the sun above the southern horizon at midday? What do you think will happen to this angular distance during the course of the school year?

(A-1.45) 5. How does the length of the sun's path vary with the seasons? How will this affect the length of day?

(A-1.43) 6. What evidence do you have to prove or disprove the following statement: "The sun is directly overhead at noon"?

(A-1.44) 7. What evidence do you have to prove or disprove the following statement: "The sun always rises in the east and sets in the west"?

(D-1.11) (D-1.21) 8. What are some models of motions in the earth-sun system that can explain the observations made in the investigation?

SUPPLEMENTARY SHEET #1

ANALYSIS OF HIGH NOON OBSERVATIONS

Observations of the sun were made each week for one year. Measurements of the maximum altitude of the sun were taken. The time of day at which the maximum altitude occurred was also noted.

The table contains the observations as recorded on the days listed.

Draw a graph of the data in the table using coordinates of altitude on the vertical axis and time the horizontal axis. Each point represents where the sun was at "high noon" on the particular day.

Date	Maximum Altitude of the sun		Time of Maximum Altitude
	degrees	minutes	
Jan. 1	24	54	12:03
8	25	37	12:06
15	26	40	12:09
22	28	04	12:11
29	31	46	12:13
Feb. 5	32	44	12:14
12	33	56	12:14
19	36	19	12:14
26	38	52	12:13
Mar. 4	41	30	12:12
11	44	14	12:10
18	47	00	12:08
25	49	45	12:06
Apr. 1	52	29	12:04
8	55	09	12:02
15	57	43	12:00
22	60	09	11:58
29	62	25	11:57
May 6	64	30	11:56
13	66	21	11:56
20	67	56	11:56
27	69	16	11:57
June 3	70	18	11:58
10	71	00	11:59
17	71	23	12:01
24	71	25	12:02

Date	Maximum Altitude of the sun		Time of Maximum Altitude
	degrees	minutes	
July 1	71	07	12:04
8	70	30	12:05
15	69	33	12:06
22	68	19	12:06
29	66	48	12:06
Aug. 5	65	01	12:06
12	63	02	12:05
19	60	50	12:03
26	58	28	12:02
Sept. 2	55	58	12:00
9	53	23	11:57
16	50	42	11:55
23	48	00	11:52
30	45	26	11:50
Oct. 7	42	34	11:48
14	39	55	11:46
21	37	22	11:45
28	35	56	11:44
Nov. 4	32	40	11:44
11	30	37	11:44
18	28	49	11:45
25	27	17	11:47
Dec. 2	26	04	11:50
9	25	12	11:52
16	24	42	11:56
23	24	34	11:59
30	24	40	12:03

Supplementary Sheet #2

QUESTIONS:

(A-1.43) 1.
a. What was the maximum altitude observed?
b. When did the maximum occur?
c. What was the minimum altitude observed?
d. When did the minimum occur?

(C-1.11) (C-1.12) 2.
a. How does clock time (noon) compare with solar time (solar noon) for the year?
b. Describe the variations between the times.

(D-1.11) (D-1.21) 3. What model can you devise to explain this evidence?

Easy (1+)

IV-D-1a: PLANET PHASES

QUESTION:

What models explain the observations of celestial and terrestrial motions?

MATERIALS:

Small incandescent light source, small ball such as a ping-pong ball or styrofoam sphere to represent planet X, photos of phases of Venus. (Optional)

SUGGESTED APPROACH:

1. A student grouping of two is recommended for this investigation.
2. A brief discussion may be required in order that the ball, light, and observer be identified as planet, sun, and earth respectively. From that point on, the students are to investigate possible ways to create the phases of planet X, as described in the introduction on the student sheet.
3. The photos of Venus may be used after the students have had a good deal of time to work with the problem.

PRECAUTIONS:

1. You must have a sharp, bright light source or the phases will not be evident to the students.
2. The darker the room, the easier it is to see the phases.
3. Do not label models of the solar system such as heliocentric or geocentric to begin with. After the investigation is complete you might label several of the models proposed.
4. Remember planet X is not conclusive proof of the heliocentric model. It would serve to cause serious doubt on the Ptolemaic version, but would not necessarily discredit Tycho Brahe's scheme. Perhaps one of your students will want to show the rest of the group why not.

MODIFICATIONS:

1. Use photos of a superior planet, and have the students relate any differences that they see in the two planets.
2. For more complete analysis, use questions from the reference below.

REFERENCES:

Investigating the Earth, pp. 497-498, Teacher's Guide, pp. 629-631.

Do Not Print

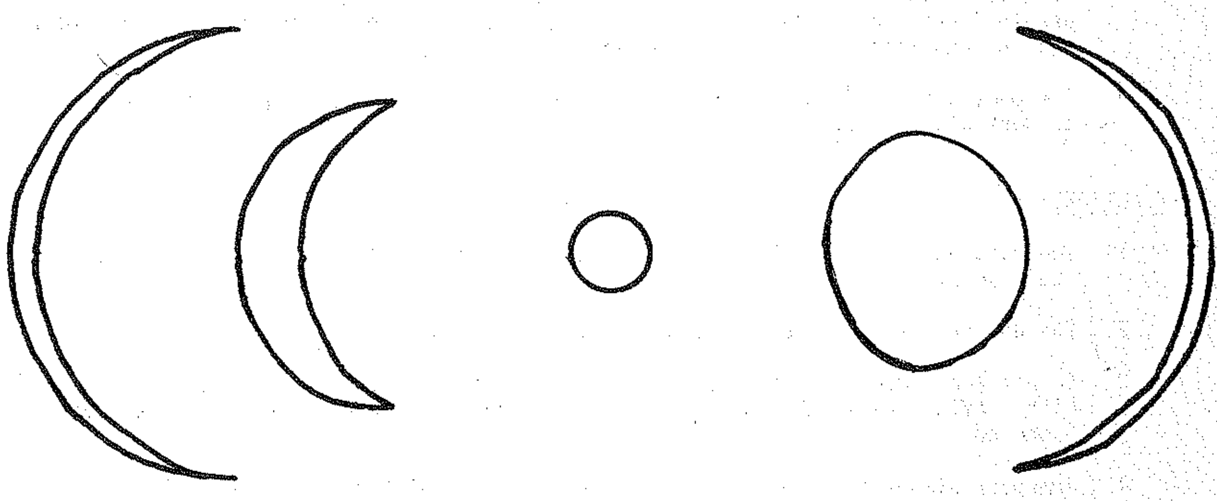
IV-D-1a: PLANET PHASES

QUESTION:

What models explain the observations of celestial and terrestrial motions?

INTRODUCTION:

There is a certain planet which is always observed just before sunrise or just after sunset. It never wanders far from the sun. Sometimes it is observed on successive evenings to have moved eastward among the stars. It reaches a maximum distance from the sun (greatest eastern elongation) and begins to move westward among the stars. One of the first discoveries made with a telescope was that this planet exhibits phases similar to those of our moon. However, the apparent size of the planet is least during full phase and greatest at crescent phase as shown in the diagram below.



OBJECTIVES:

When you finish this investigation you should be able to:

1. describe a model for an earth-sun-planet X system that will satisfactorily explain the observation of a planet.

METHOD:

1. Use the light (sun) and small ball (planet X) to simulate the actual observations of planet X.

2. Devise a diagram or description which will explain the results of your simulation.

QUESTIONS:

(D-1.11) (D-1.21) 1. What models of the earth-sun-planet X system can you devise to explain the observations made during this investigation?

(D-1.23) 2. Which model for the earth-sun-planet X system best explains the observations?

(A-1.22) 3. What is the pattern of changes observed in planet X over a long period of time?

4. What is the relationship between the orbit of planet X and that of the earth?

5. Which planet is planet X?

6. What could be a possible cause for the difference in appearance between the phases of the moon and planet X?

7. How would a planet, orbiting between the earth and sun, differ in appearance from a planet at a greater distance from the sun than the earth?

Challenging (1)

IV-D-1b: HELIOCENTRIC, GEOCENTRIC MODELS

QUESTION:

What models explain the observations of celestial and terrestrial motions?

MATERIALS:

Data table containing observations of planet X and planet Y, diagrams for heliocentric and geocentric models, protractor, straightedge.

SUGGESTED APPROACH:

1. Initiate a discussion with the students about the motions of the planets, sun, and earth.
2. Most students contend that the earth and planets are moving around the sun. Challenge their belief by asking what evidence they can offer to prove their contentions.
3. Discuss the types of evidence that can be observed, namely positions of the celestial objects and apparent size.
4. Discuss possible means of measuring the angle between a planet and the sun. Review the data in previous investigations about measuring changing diameters.
5. Have the students select either planet and then plot its apparent motion in both systems, heliocentric and geocentric. It is suggested that this step be completed as a homework assignment.
6. In the follow-up discussion, the two resulting paths for each planet should be compared. Ths students should evaluate each model for its simplicity in representing the paths.

PRECAUTIONS:

1. The students will probably experience some difficulty in plotting the first few points. Be sure they understand that heliocentric plots are made from the various points on the circle, the geocentric ones from the center.
2. Both paths of planet Y will extend beyond the paper. Students can add extra sheets of blank paper to continue the path. The geocentric path of planet X will also extend beyond the paper.

TYPICAL RESULTS:

If the students connect the points with a smooth curved line, a complex figure will result with both geocentric models. The heliocentric models will result in reasonably smooth circular paths. The average distance from the planets to the sun can be calculated and should result in an identification of planet X as Venus and planet Y as Mars. The students can make a tentative identification of the planets based on this evidence.

MODIFICATIONS:

1. Have the students make observations of planets and devise a system for measuring the angle between the planet and the sun.
2. Have the students consider the problem of plotting the moon's position in a manner similar to that used for the planets.

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IV-D-1b: HELIOCENTRIC, GEOCENTRIC MODEL

QUESTION:

What models explain the observations of celestial and terrestrial motions?

INTRODUCTION:

Does the earth move with the planets around the sun, or do the planets and sun move around the earth? You most likely contend that the former scheme is the true one, but what is the basis for your contentions? Some observational evidences that we can gather easily to prove one scheme or the other are: 1) relative positions of the planets and the sun; 2) apparent sizes of the celestial objects from which a relative distance may be inferred.

Two planets were carefully observed for a 2-year period. Measurements of their positions and apparent distances were made for each month.

OBJECTIVES:

When you finish this investigation you should be able to:

1. measure angles and distances in plotting experimental data to an accuracy of one half of the smallest scale divisions of the protractor and distance scale.

2. devise a heliocentric or geocentric model for the observations of a planet.

3. evaluate heliocentric and geocentric models for planetary motion to determine which provides the simpler explanation of the observations.

METHOD:

1. Use the data in the table below to create a model for the motions of one of the planets. You may use either planet, but plot both a sun-centered (heliocentric) and an earth-centered (geocentric) model for the planet chosen. Which one will best explain the observations?

   A. Heliocentric model: Use the diagram for the heliocentric model that shows the sun at the center of the earth's path over the 2-year period. Plot the position of the planet for each date, making your measurements <u>from the earth's position in each case</u>. Connect the points with a smooth line.

B. Geocentric model: Use the diagram for the geocentric model that shows the earth at the center of the sun's path over a 2-year period. Plot the position of the planet for each date, making your measurements each time from the center, <u>the earth's position</u>. Note carefully that each time the sun is in a different location. Connect the points with a smooth line.

When you are locating the points, draw construction lines <u>lightly</u> so that they may be erased after the point is plotted.

2. The first date for planet X has been plotted as an example.

3. Analyze the two models and determine the average distance of the planet <u>from the sun</u>.

4. Determine the minimum amount of time (in months) for the planet to make one revolution.

<u>QUESTIONS</u>:

1. What is the average distance from the sun for the planet you plotted?

2. What is the minimum amount of time (period) for the planet to make one complete revolution?

(D-1.11) (D-1.21) 3. Which model satisfactorily explains the observations of the planets?

(D-1.23) 4. Which model seems to be a simpler explanation of the observations?

5. On the basis of the evidence and your analysis, what planet of the solar system did you plot?

SUPPLEMENTARY SHEET 1

CELESTIAL OBSERVATIONS OF PLANET X AND PLANET Y DURING 1966 AND 1967

(Taken on the 15th day of each month.)

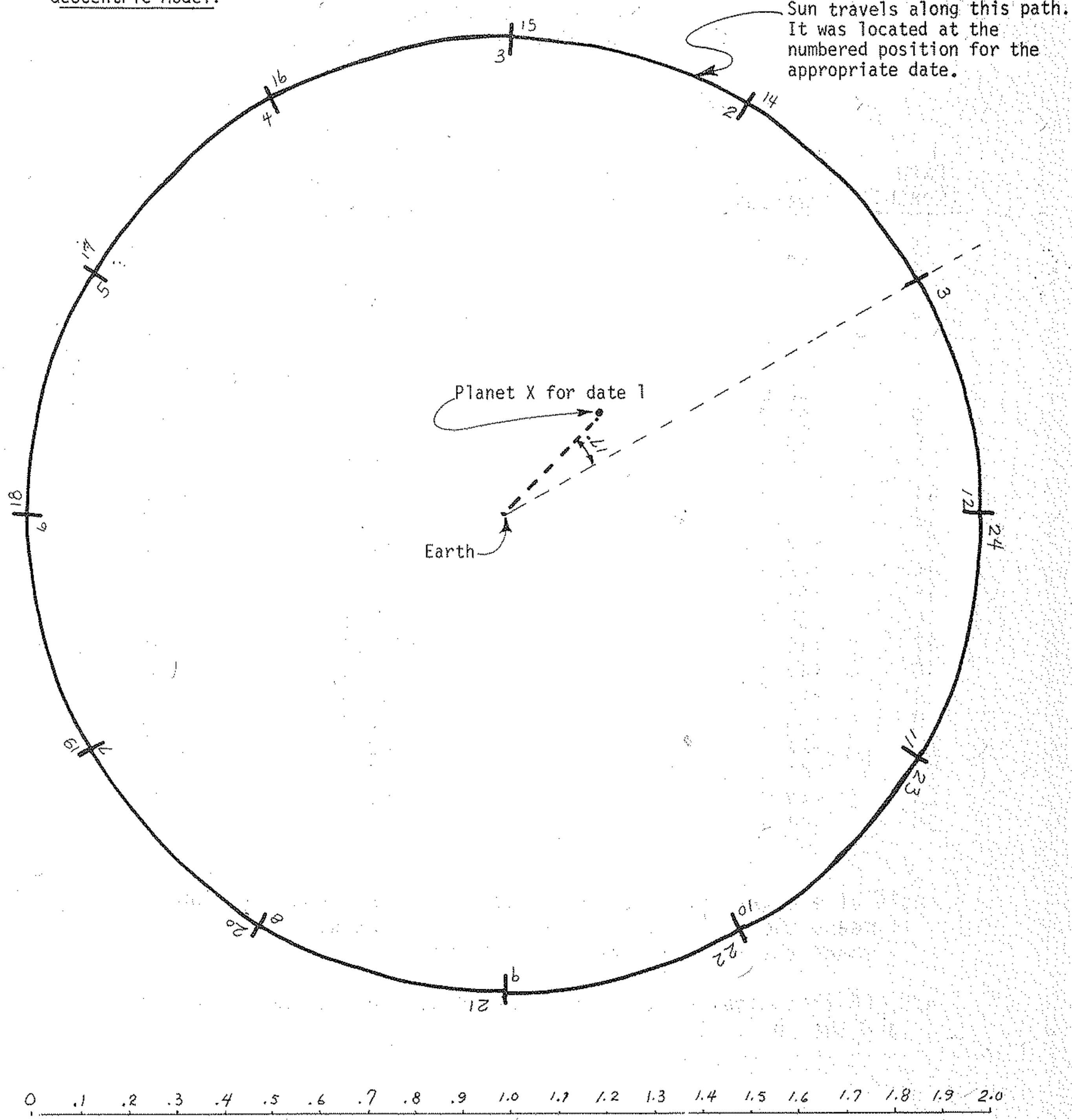
	Planet X		Planet Y	
Date (Month)	Angle of Elongation (degrees)	True Distance from Earth (A.U.)	Angle of Elongation (degrees)	True Distance from Earth (A.U.)
1	+17.0	.28	+ 24.5	2.23
2	-29.3	.33	+ 16.0	2.31
3	-43.1	.51	+ 9.7	2.37
4	-42.8	.75	+ 3.3	2.43
5	-40.6	.98	- 3.8	2.48
6	-38.0	1.21	- 12.3	2.49
7	-32.6	1.39	- 21.0	2.47
8	-22.6	1.54	- 21.1	2.40
9	-13.0	1.65	- 36.8	2.27
10	- 5.2	1.70	- 45.5	2.10
11	+ 1.8	1.71	- 57.7	1.86
12	+ .9	1.68	- 76.0	1.62
13	+17.3	1.62	- 96.5	1.28
14	+22.5	1.52	-118.5	.97
15	+27.2	1.39	-142.5	.74
16	+35.8	1.21	-178.5	.61
17	+45.0	1.00	+144.0	.65
18	+49.0	.75	+113.3	.81
19	+42.5	.51	+ 91.8	1.00
20	+18.3	.32	+ 77.3	1.19
21	-24.5	.32	+ 68.8	1.37
22	-41.0	.50	+ 64.3	1.53
23	-44.0	.73	+ 59.2	1.69
24	-44.5	.95	+ 51.3	1.83

Angle of elongation: The angle between the sun and the planet.
+ means the angle is measured counterclockwise
- means the angle is measured clockwise

A.U. (Astronomical Unit): The average distance between the earth and the sun is 1 A.U.

SUPPLEMENTARY SHEET #2

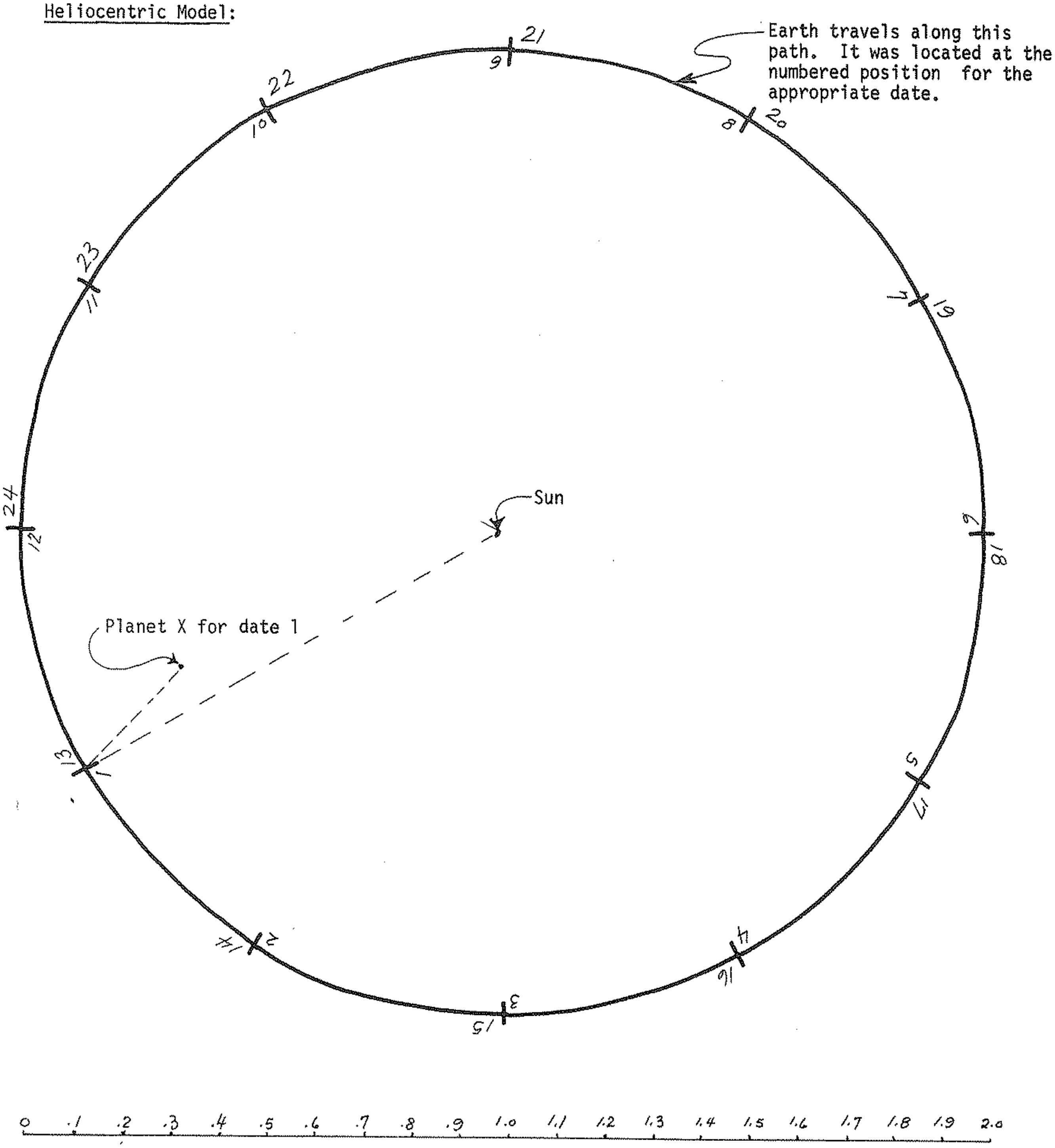
Geocentric Model:



SCALE IN ASTRONOMICAL UNITS
(to be used in plotting position of planets)

SUPPLEMENTARY SHEET #3

Heliocentric Model:



SCALE IN ASTRONOMICAL UNITS
(to be used in plotting position of planets)

Challenging (2)

IV-D-1c: SOLAR DIAMETER

QUESTION:

What models explain the observations of celestial and terrestrial motions?

MATERIALS:

1 meter stick, 2 opaque lined cards (one 8 X 10" and the other 4 X 6"), 1 pair of scissors, drawing compass, graph paper, solar diameter data (student sheet).

SUGGESTED APPROACH:

This investigation consists of two parts. Part I involves actual measurement of the sun's angular diameter. Part II consists of plotting a graph from the data table which is provided for the students. Part II may be done in class, or more preferably, as a homework assignment.

Part 1

1. This investigation is best accomplished with a student grouping of two or three.
2. Have the students assemble the apparatus as indicated on the student sheet.
3. Have the students make the necessary measurements and calculate the angular diameter of the sun.

Part II

4. This investigation can be accomplished individually within a 40-minute period or as a homework assignment.
5. Have the students plot a graph of the data from the supplementary sheet.
6. In order to allow better comparisons during the post-laboratory discussion it will be necessary to establish some uniform scale for the students' graphs.
7. The discussion concerning interpretation of the graphs should be centered around the nature of the orbit. A lively discussion usually ensues if the teacher takes the position that the sun revolves around the earth and supports it with observations made during the investigation.

PRECAUTIONS:

Part I

1. Do not allow the students to look directly at the sun which can damage their eyes.
2. Make sure that the students keep the cards perpendicular while making all observations and measurements.
3. A small circle (.5-.8 cm. dia.) can be drawn on the small card which is then moved until the image fills it. However, construction of such a circle is difficult and it may be desirable to use parallel lines instead as suggested in the approach.

Do not print

Part II

4. The main objective of the investigation is to demonstrate the use of angular measurement as indirect evidence of the nature of the earth-sun orbit. Students should not be allowed to dwell on the mechanics of the lab to the point where they lose sight of its main objective.

TYPICAL RESULTS:

The students' graphs in Part II should illustrate the cyclic change in angular diameter of the sun. The students should be able to relate the change in diameter to the distance of the sun and defend possible earth-sun models which would support their observations. Some students may interpret the change in diameter as an actual change in size. From the data provided this cannot be disproved.

MODIFICATIONS:

1. Old mailing tubes can be used in place of the apparatus suggested above. Aluminum foil with a pinhole and a translucent screen for viewing can be fastened to opposite ends of the tube.

2. Use the same basic apparatus as in Part I to measure the angular diameter of the full moon.

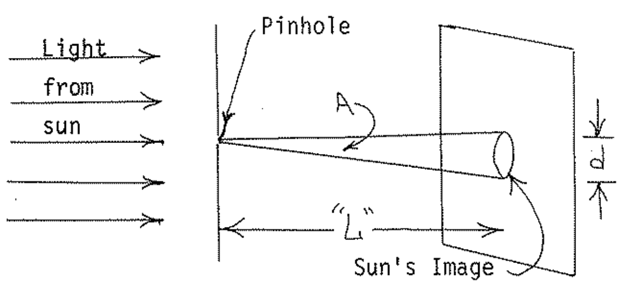
3. Given the diameter of the sun, find the distance to it.

4. As a subsequent activity to Part II, the students might take data collected for other years, graph them, and compare the results to 1967.

BACKGROUND INFORMATION:

Students should express the measurement of the sun's diameter as an angle. The size of the angle can best be described by use of radian measure. The following diagram may help to describe the use of radian measure in determining the angular diameter of the sun.

Figure 1

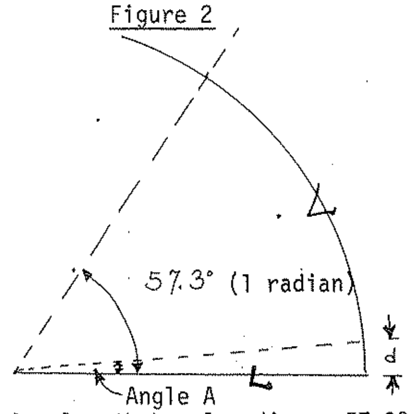


A = angular size of image

d = diameter of the image

L = distance from pinhole to screen

Figure 2



Arc length L = 1 radian = 57.3°

Angle A $= \frac{d}{L}$ radians

Angle A $= \frac{d}{L} \times 57.3$

REFERENCES:

Investigating the Earth, p. 530

IV-D-1c: SOLAR DIAMETER

QUESTION:

What models explain the observations of celestial and terrestrial motions?

INTRODUCTION:

Measurement of the distance to the sun or its diameter are difficult to determine since many variables are involved. However, the angular diameter of the sun can be determined with considerable accuracy. In this investigation, you will have an opportunity to measure the angular diameter of the sun and analyze similar data to look for patterns of change.

OBJECTIVES:

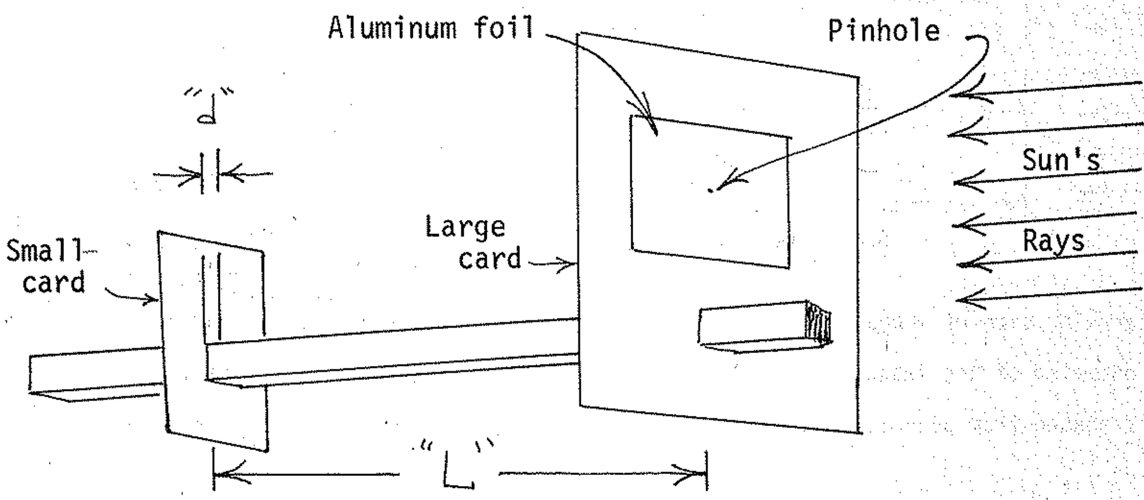
When you finish this investigation you should be able to:

1. calculate the angular diameter of the sun from measurements you have made, when provided with the necessary equipment.
2. draw a graph which represents angular measurements of an object.
3. propose and defend possible models of the earth-sun motions based on the observed change in angular measurements.

METHOD:

Part I

A. Assemble the apparatus as shown below.



a. Cut slots in each of the cards, in the position shown, so that the meter stick can fit through them. Each slot should be slightly smaller than the width and breadth of the stick to ensure a tight fit.

b. If the small card is unlined, draw two parallel lines .8 cm. apart as shown.

c. Make a large hole in the largest card, cover it with aluminum foil, and then punch a very small hole through this with a compass point or pin.

B. Place the large card near the end of the meter stick and move the small card until the image of the sun just fills the space between the two lines.

C. Measure (to the nearest 1/10 cm.) the distance between the cards and the distance between the lines filled by the sun's image.

D. Calculate the angular diameter of the sun.

Part II

A. Plot a graph of the sun's angular diameter versus time from the data table below.

OBSERVATIONS OF SOLAR DIAMETER
(Adapted from 1967 Amer. Ephemeris & Nautical Almanac)

Date	Angular Diameter	Date	Angular Diameter
Jan 1	32' 35.0"	July 10	31' 30.9"
Jan 10	32' 34.8"	July 20	31' 31.8"
Jan 20	32' 33.5"	July 30	31' 33.6"
Jan 30	32' 31.4"	Aug 10	31' 36.4"
Feb 10	32' 28.1"	Aug 20	31' 39.8"
Feb 20	32' 24.1"	Aug 30	31' 44.0"
Mar 1	32' 20.1"	Sept 10	31' 49.0"
Mar 10	32' 15.7"	Sept 20	31' 54.1"
Mar 20	32' 10.3"	Sept 30	31' 59.5"
Mar 30	32' 04.9"	Oct 10	32' 05.0"
Apr 10	31' 58.8"	Oct 20	32' 10.5"
Apr 20	31' 53.4"	Oct 30	32' 15.9"
Apr 30	31' 48.4"	Nov 10	32' 21.1"
May 10	31' 43.8"	Nov 20	32' 25.5"
May 20	31' 39.7"	Nov 30	32' 29.2"
May 30	31' 36.4"	Dec 10	32' 32.0"
June 10	31' 33.5"	Dec 20	32' 34.0"
June 20	31' 31.7"	Dec 30	32' 35.0"
June 30	31' 31.0"		

B. Analyze the graph and describe some possible explanations for its pattern.

QUESTIONS:

Part I

1. When the card with the image is moved away from the pinhole card, what happens to the size of the image? Why?

2. How can this size be expressed in terms of an angular measurement?

3. How could we calculate the sun's actual size by the method used in this investigation? What other information would be needed?

4. How would you measure the angular diameter of the moon?

5. What is the maximum difference in solar diameter on your graph? What is the percentage change? Use the formula: $\text{percentage change} = \frac{\text{difference}}{\text{average}}$

(A-1.46) 6. What is the pattern of the changes in diameter of the sun?

(D-1.11) (D-1.21) 7. What are some possible models of earth-sun motions which could support your interpretation of the data?

(D-2.11) 8. What shape of orbit for the earth or sun would best satisfy the data in this investigation?

Easy (1)

IV-D-2a: ORBITS

QUESTION:

What models explain the observations of celestial and terrestrial motions?

MATERIALS:

Two thumbtacks, about 25 cm. of carpet thread, notebook size piece of corrugated cardboard, copy of an ellipse (see supplementary sheet).

SUGGESTED APPROACH:

1 Ask students to make a sketch of what they think the earth's orbit looks like. Ask them to describe the shape of the orbit, then introduce the investigation as a study of orbits and of the elliptical orbit of the earth.

2. Have students follow the steps under Method on the student version.

3. Lead the students in a discussion in which you compare the shape of the students' drawings with the shape of the earth's orbit. Ask them what observations could be made from earth that might suggest the shape of the earth's orbit.

MODIFICATIONS:

Make a scale model of the earth's orbit. How big does the model have to be before it begins to look elliptical?

REFERENCES:

Our Planet in Space, pp. 89-91.
Investigating the Earth, pp. 499-501.

Do Not Print

IV-D-2a: ORBITS

QUESTION:

What models explain the observations of celestial and terrestrial motions?

INTRODUCTION:

Make a sketch of what you think the earth's orbit looks like. Save your sketch until the end of this investigation, then look at it again. In this investigation, you will make a study of orbital paths, in particular, the orbital path of the earth around the sun.

OBJECTIVES:

When you have finished this investigation you should be able to:

1. choose from among several given models the one that best represents the true shape of the earth's orbit.

METHOD:

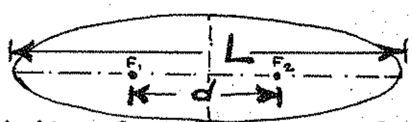
1. Put the blank paper on top of the cardboard and stick in two thumbtacks near the center of the paper. They should be about 3 centimeters apart. Tie a circle of string, with a circumference of about 20 cm., and loop it around the thumbtacks. With someone holding the tacks so that they don't pull out, place your pencil inside the loop, pull it taut, and move it around the tacks until you have completed a smooth closed curve.

2. Repeat step one several more times, varying first the distance between the tacks and then the length of the string.

3. On the predrawn orbit, compare the area inside the triangle drawn from focus A to the left-hand portion of the curve with the area of the triangle drawn from focus A to the right-hand portion of the curve. You can do it easily by counting squares. Measure and record the length of the arcs cutoff by the legs of each triangle.

4. Orbits are usually described in terms of their eccentricity (e) which is defined as the distance between the foci (d) divided by the length of the major axis (1):

$$e = \frac{d}{L}$$



Calculate and record the eccentricity of at least two of the orbits you constructed and of the predrawn orbit.

QUESTIONS:

1. What effect does changing the length of the string have on the shape of the orbit?

2. What effect does changing the distance between the foci (thumbtacks) have on the shape of the orbit?

(D-2.11) 3. What is the shape of the earth's orbit around the sun? Where is the sun located within the orbit?

(D-2.12) 4. What are the shapes of the orbits of the other planets? Where is the sun located within each of these orbits?

5. From the table below, which planets have the most eccentric orbits? Which have the most nearly circular orbits?

Name	Distance from Sun	Eccentricity of Orbit
Mercury	36 million miles	0.206
Venus	67	0.007
Earth	93	0.017
Mars	142	0.093
Jupiter	483	0.048
Saturn	886	0.056
Uranus	1780	0.047
Neptune	2790	0.008
Pluto	3670	0.247

6. How does the eccentricity of the predrawn orbit compare with the eccentricity of the earth's orbit? With your first sketch of the earth's orbit?

(D-2.13) 7. A planet traveling along the predrawn orbit reached position 1 on December 14, 2 on December 29, 3 on June 14, and 4 on June 29. How many days does it take to travel from 1 to 2? From 3 to 4? What is the relationship between areas swept out by an imaginary line connecting the sun and a planet and the time necessary to accomplish this?

8. What effect could these changes in earth motion have on the length of day on the earth?

SUPPLEMENTARY SHEET

Predrawn Orbit

A and B are foci.

C - D is the major axis