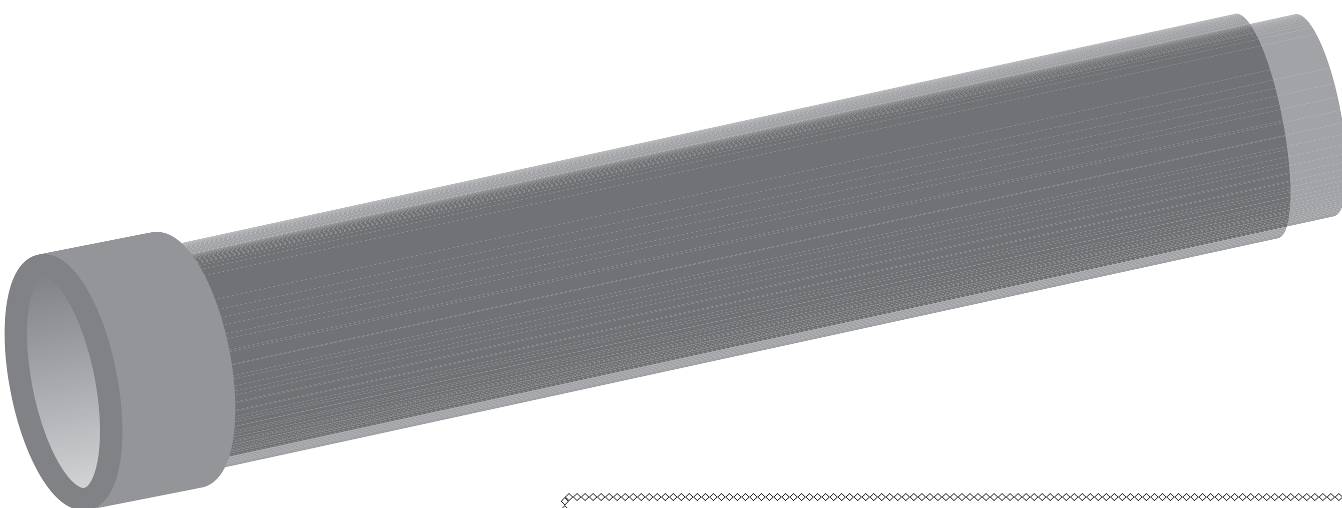
654-0000 654-0010 (PS-04B) Project STAR Telescope

Adapted from the Project STAR Activity Book, *Where We Are in Space and Time*

How to Make and Use a Project STAR Telescope

for Elementary Grades



About Project STAR Hands-on Science Materials

Project STAR Activities were developed by teachers and scientists at the Harvard Smithsonian Center for Astrophysics and have been thoroughly tested by students and teachers worldwide. The activities stress general scientific skills and can be used in a variety of class levels from elementary grades to college.

Project STAR (Science Teaching through its Astronomical Roots) activities are based on the philosophy that students will better learn a concept when they first explore and then test their own theories with hands-on, model-building exercises.

For more information on Project STAR Hands-on Science Materials contact:

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NOTE: These assembly instructions supersede those in the instruction manual

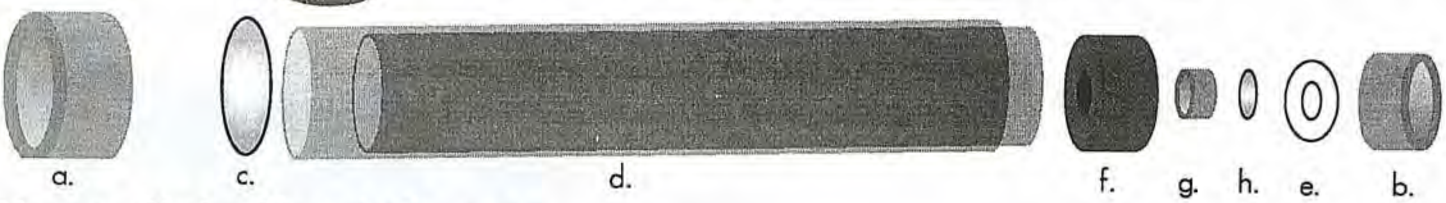
What You Need to Make Your Telescope

You should have the following pieces:

a. Red Cap, large 1.75" Dia 
b. Red Cap, small 1.5" Dia 
c. Big (Objective) Lens 

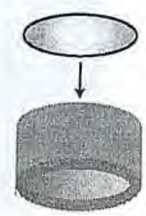
d. Two Sliding Cardboard Tubes 
e. carboard washer 

f. Foam Lens Holder 
g. Cardboard Spacer 
h. Small (Eyepiece) Lens 



How to Make Your Telescope

1. Lay the red cap down on a table with the wide open end up.
2. Holding it carefully by the edges, place the big (objective lens) with the curved side DOWN in the cap. To figure out which is the curved side, carefully place the lens on the table. If it rocks when you touch the edge, the curved side is against the table. If it lays still when you touch the edge, the curved side is facing up.


Step 2

3. Insert the larger end of the 2 sliding cardboard tubes in the cap.

4. Place the foam lens holder on the table.
5. Push the cardboard spacer into the foam lens holder so that it goes all the way to the bottom, touching the table. Using a tissue, push the small (eyepiece) lens into the foam until it stops against the cardboard spacer.
6. Now push the smaller end of the 2 sliding cardboard tubes over the foam eyepiece holder. Place the carboard washer over the end of the tube and secure everything in place with the second red cap.
7. Your telescope is ready to use!


Steps 5-6

What Does This Telescope Do?

Like binoculars, this simple telescope lets you see things that are far away much more easily. You can use it at night to see details on the moon such as craters, to look at the bark on a tree across the street and you can use it in your class to read words on posters that are all the way across the room! But, never, ever use the telescope to look at the sun — you will damage your eyes!

How Does it Work?

When you look at something using the telescope, light enters through the hole in the red cap. The curve of the big lens in the cap (called the objective lens) takes the scatttered light and bends it into one point. When the lens bends the light, it also causes the image (whatever you are looking at) to flip upside down! Then the light goes through the small eyepiece lens at the other end of the telescope. This small lens focuses the image so that you can see it.

Try It!

Activity 1

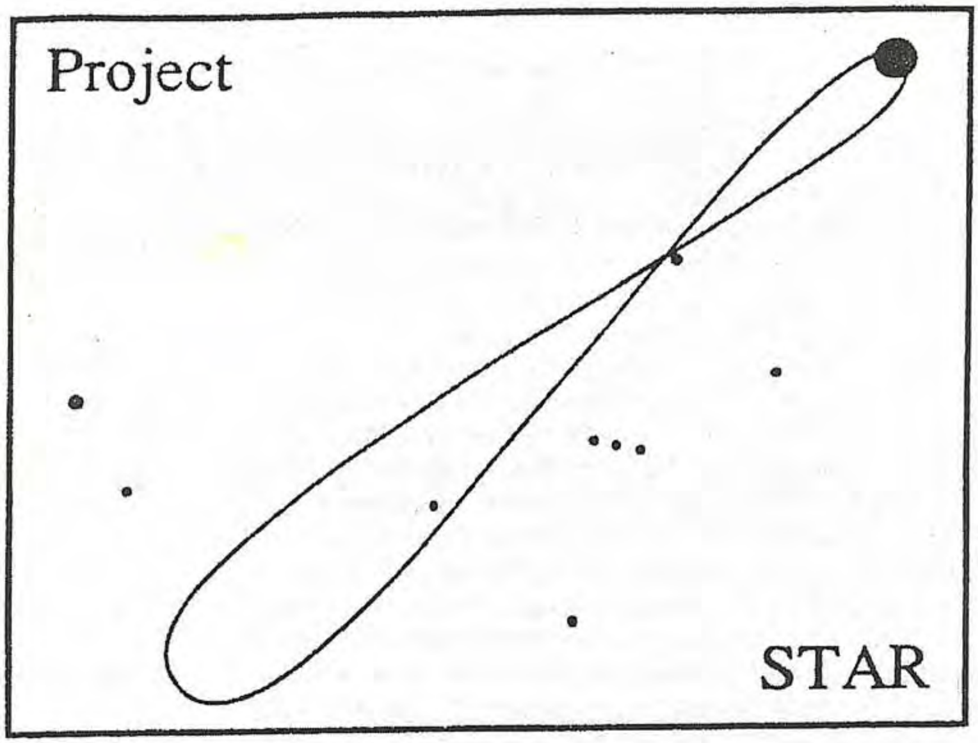
- Anchor your elbows on a stable surface like a desk, table or car if you are outside. Look through the smaller end of the two tubes (the black foam end) then aim the lens end with red cap at a small object far away in the room or outside.
- Slowly slide the tubes in or out to focus the telescope. The closer the object is to you, the further out you will have to slide the telescope tubes to focus on the object. What is the first thing you notice about the image you see? [It's upside down!]

Activity 2

- Now try aiming the telescope at a poster or some words about 20 feet away. Without the telescope you may not be able to read the words, but with the telescope, you can (especially if you are good at reading upside down)!
- The telescope improves your vision, making things look larger and closer! That is because the width (diameter) of the lens in the telescope, and therefore the light-gathering power, is larger than that in your eye.

For Fun

- Decorate your telescope using paints, crayons, markers, stickers and your imagination.
- On a clear night when the moon is visible, use your telescope to take a good look at the moon. Don't forget to anchor your arms to keep the telescope steady. Write down what you see!



Science Teaching through its Astronomical Roots

Telescope Kit
Teacher's Notes and Activities

Abstracted from the Project STAR activity book, Where We Are in Space and Time.

Project STAR Activities

Project STAR (Science Teaching through its Astronomical Roots) began with a grant from the National Science Foundation (NSF) in December 1985. Since July 1986, high school astronomy teachers and scientists at the Harvard Smithsonian Center for Astrophysics have been developing and testing a variety of hands-on activities. These activities are designed to teach basic astronomical and mathematical concepts. STAR activities are unique in that they take into consideration the preconceptions (or misconceptions) that students may possess on entering your course. Students are asked to commit to their preconceptions by filling in the What Do You Think? section at the beginning of each activity. We must stress that the STAR curriculum emphasizes concepts over content; please consider this in planning the use of the STAR activities you have purchased. The activities in this kit, as with most science labs, require some teacher guidance. We strongly recommend doing the activities yourself before using them in class. However, you should allow your students to work with the materials as freely as possible. The key to the success of preconception-based learning is the student's discovery of his or her preconceptions and their abandonment in favor of more powerful concepts through the personal experience offered by the activities.

The activities in this kit are taken from the 1989-90 STAR Activity Manual "Where We Are in Space and Time." The original activity numbering sequence has been retained for the benefit of those teachers who purchase more than one kit or have bought the complete manual. The activities should be done in numerical order to obtain the most effective results. You may have found some "extra" activities in your kit; these were included because we felt that they would provide important experiences in support of the principal activity you ordered. Please read the Teacher's Notes for the kit for specialized instructions, answers to questions, tips, and other information. You have permission to make as many photocopies of the activities in the kit as you need for your classes. Permission for any other use of the materials in this kit must be requested in writing on your school stationery and mailed to:

STAR Activities
Center for Astrophysics
60 Garden Street, MS-71
Cambridge, MA 02138

Questions concerning activities can be sent to the address above. Inquiries about orders must be sent to:

Science First®
86475 Gene Lasserre Blvd.
Yulee, FL 32097
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TEACHER'S NOTES
PROJECT STAR
TELESCOPE KIT

ACTIVITY 7: Estimating Size And Distance

1. Preconceptions

The What Do You Think? section, Questions 7.1 and 7.2, deals with the Moon, but it is designed to get the student to think about how the apparent diameter of any object can be estimated and how its true diameter can be related to its distance from the observer. The Moon is used because it can be investigated with the techniques and equipment that are developed in this activity. For Question 7.1, virtually all students will overestimate the Moon's apparent diameter and give an answer such as "my entire hand, with the fingers spread out." Looking at the Moon is something that the student has experienced, but not quantified. The most memorable views of the Moon may be when it was seen in its full phase near the horizon, conditions that cause it to appear large. In reality, the width of the little finger is MORE than enough to cover the Moon. (The width of a common pencil held at arm's length is about equal to the apparent diameter of the Moon.)

The second question is more abstract, in that it is not based on any direct experience that the student may have had. The student will have to consider how big the Moon is and how far the Moon is from the Earth. (Although unnecessary, many students will consider the relative sizes of the Earth and Moon to "get a feel" for the situation.) Most students believe the Moon is much closer to the Earth than in reality, although they also believe the Moon is smaller than the Earth. This concept tends to be reinforced by improperly scaled drawings of the Earth and Moon that appear in textbooks. Don't expect any student to come up with the real value, which is about 110 Moon diameters.

2. Activity Tips

Activity 7 may seem unrelated to building a telescope. If you look ahead to Activities 9 and 10, however, you will see that similar triangles are used to help the student gain an understanding of the image produced by the pinhole tube and the telescope. Activity 7 is therefore recommended as a lead-in, giving the student some experiences with similar triangles.

The most common problem encountered with Activity 7 is the use of fractions. Relationships such as those shown in the boxed equations for Steps 9 and 10 can cause considerable confusion. The concepts must be developed slowly and carefully. Questions 7.19-7.24 are designed to provide some practice before the homework section. Depending on the math background and proficiency of your students, you may want to offer more practice than is contained in the activity.

3. Answers to Questions

The answers to Questions 7.3 - 7.6 will vary, but the value for 7.5 is usually less than 50/1.

7.7 6.5 cm.

7.9 The ratios for 7.5 and 7.8 should be the same, allowing for reasonable errors in measuring.

7.10 This answer will vary. An upper limit to the ratio is about 60/1; a lower limit is near 35/1.

7.11 The apparent size has increased.

7.12 The distance has decreased; I am closer to the dollar bill.

7.13 This value should be one-half the value reported in Question 7.6.

7.14 The distance recorded in 7.13 should be one-half the distance recorded in 7.6, with allowances for the accuracy of the measurements.

7.15 The apparent size has decreased.

7.16 The distance has increased.

7.17 The distance should be twice the value recorded in 7.6.

7.18 The distance recorded in 7.17 should be twice the distance recorded in 7.6, allowing for normal inaccuracies in measurement.

7.19 This answer should be the same as the answer to 7.8.

7.20 This is an estimate and the result should be considered in this context, as long as it is consistent with information used from Question 7.19 and a reasonable estimate of the size of the object being viewed. You may want to select some objects and measure their sizes and distances before class so you can provide feedback to the students - many students will want to know how accurate their estimates are. Emphasize that the students' answers are estimates, however, based on approximations and should not be judged solely on how close the estimate is to the accepted value. For students with large errors, it may be useful to discuss why such large errors occurred and how they could be reduced.

7.21 This value depends upon the object selected.

7.22 About one-half the width of the upper joint of the little finger.

7.23 This estimate should be between 80 and 120, or twice the value of the student's answer to Question 7.5.

7.24 The results of this comparison will vary, but the majority of students will have overestimated the size of the Moon by a large factor and underestimated the Earth-Moon distance by a very large factor.

7.25 (240 m)(60/1) = <u>14,400 m</u> (47,400 ft)

7.26 (460 m)(60/1) = <u>27,600 m</u> (90,000 ft)

7.27 [(13 km)(1000 m/km)]/[(60/1)(1/4)] = (13,000 m)/(240) = <u>54 m</u>

7.28 (7 LY)(60/1) = <u>420 LY</u>

7.29 [(7 LY)(60/1)]/3 = 420 LY/3 = <u>140 LY</u>

7.30 (30,000 LY)(60/1) = <u>1,800,000 LY</u>

7.31 (a) The relative apparent diameters of the Moon and Venus are established first by direct measurements of the images on the photo. Reasonable values are 8.4 cm for the diameter of the Moon and 0.2 cm for the diameter of Venus. This yields a ratio of apparent diameters of 8.4 cm/0.2

cm, or 42/1 for the Moon compared to Venus. Note that it is not necessary to know the true diameter of Venus compared to the Moon, since you do know the true ratio of the Moon's distance from the Earth compared to its diameter, 110/1, and at this point you are loooking only for the relative distance in Venus diameters. Therefore, the ratio of Venus' diameter compared to Venus' distance from the Earth is:

$$(110/1)[1/(1/42)] = (110/1)(42) = \underline{4{,}620 \text{ Venus diameters}} \text{ for the Venus-Earth distance.}$$

(b) $(12{,}100 \text{ km})(4{,}620/1) = \underline{56{,}000{,}000 \text{ km}}$

7.32 This problem is the same as 7.31, except the apparent size of Mercury compared to the Moon is given (1/150), rather than having to be established from photographic images. The procedure is to combine the steps in parts (a) and (b) from Question 7.31:

$$(4880 \text{ km})\{(110/1)[1/(1/150)]\} = (4880 \text{ km})[(110/1)(150)] = (4880 \text{ km})(16{,}500) = \underline{80{,}500{,}000 \text{ km}}$$

7.33 In this problem you are solving for the real diameter, rather than the real distance as was done in Questions 7.31 and 7.32. The equation is therefore set up to solve for the unknown diameter, X:

$$(X)\{(110/1)[1/(1/40)]\} = 608{,}000{,}000 \text{ km}$$

$$(X)[(110/1)(40)] = (X)(4400) = 608{,}000{,}000 \text{ km}$$

$$X = 608{,}000{,}000 \text{ km}/4400 = \underline{138{,}000 \text{ km}}$$

7.34 (a) The plane is NOT really the same size as the Moon; the plane simply has about the same apparent size as the Moon. The plane was flying between the Moon and the photographer when the picture was made. The plane was much closer to the photographer than the Moon, so a rough, unscaled diagram would look something like the one below:

(b) You need the plane's length and the image sizes of the Moon and plane in the photo. With these values you can proceed as in the previous problems, treating the plane as a planet. Reasonable measurements from the photo are 7.7 cm for the Moon's diameter and 5.4 cm for the length of the 747. NOTE: The plane was photographed at a slight angle and its right tail wing sticks out in the photo as a line appearing to be an extension of the tail. Measure the plane from its nose to the rounded tail cone only.

$$(80 \text{ m})\{(110/1)[1/(5.4/7.7)]\} = (80 \text{ m})[(110/1)(1.4)] = (80 \text{ m})(154) = \underline{12{,}320 \text{ m}} \text{ (about 7 miles)}$$

7.35 (a) 14.4 cm

(b) 12.5 cm

(c) 13.45 cm

(d) The Moon appears smaller as its distance from the Earth increases, e.g., if the Moon were twice as far away it would appear one-half the size. Thus apparent size and distance are inversely related. Therefore, the ratio of the size of the smallest image to the size of the average image is equal to the ratio of the average distance to the maximum distance (comparable to the smallest image):

$$12.5\ cm/13.45\ cm = 400{,}000\ km/\text{maximum distance}$$

$$\text{maximum distance} = (400{,}000\ km)[(13.45/12.50)] = (400{,}000\ km)(1.08)$$

$$\text{maximum distance} = \underline{432{,}000\ km}$$

Activity 8: Seeing Details With The Eye

This activity deals with the ability of the human eye to resolve detail. It is the preparation for Activity 10C, the calibration of the telescope. If you decide not to have your students calibrate their telescopes, you can omit Activity 8. However, since all magnifying devices act to increase the amount of detail visible to the eye, you may want to consider doing Activity 8 to familiarize the students with the concept of resolution so you can refer to it later. Also, if you plan on discussing angular measurement with your students (arc minutes, arc seconds), Activity 8 is a good introduction.

1. Preconceptions

What Do You Think? Questions 8.1 and 8.2 ask the students to consider what their eyes can see. For 8.1, some students will state that you cannot see craters on the Moon with the unaided eye. They have had informal experiences looking at the Moon without a telescope or binoculars and probably have not seen any craters. However, the larger craters, about 150 km in diameter, are within the resolving limit of the eyes of a person with normal vision. These craters can best be seen when the Moon is in a quarter phase and the craters in the Moon's southern hemisphere stand out in the shadows along the day/night line.

The responses to Question 8.2 will vary considerably, but many students will underestimate the distance at which they can resolve details.

2. Activity Tips

For Steps 1-5, the chart should be well-illuminated, either with all the overhead lights on or by placing it on a sunny wall. Shining a bright light on the chart, even with the room lights on, tends to cause eye strain for some students. Results for the distance-to-size ratio will vary. This will be due mostly to estimation procedures used by the students in reading the chart. The example of 1700/1 is on the low side. Try the exercise yourself first to get an idea of the problems associated with judging where the lines first appear to blur together. This will also give you your own resolution value to compare to your students. (Since you are older than your students, they may find it interesting to compare their values to yours. Your value will not necessarily be lower, however.)

Step 6. You should allow a few minutes for the students' eyes to become adapted to the dimmer light before proceeding with the measurements. If everyone is working in the same room, you could darken the room after the class has finished Step 5 and discuss the results for a few minutes to allow time for some dark adaptation.

3. Answers to Questions

The answers to Questions 8.3-8.6 will vary among individuals. The value for 8.4 should be between 3000/1 and 4000/1, allowing for measurement estimations, variation in vision among individuals, and error. (The resolution limit of the normal human eye is about one arc minute, which yields a ratio of 3400/1.) A student who consistently gets a low ratio is either making a uniform, undetected error or needs an eye exam. (CAUTION: This is NOT a definitive eye test. If a student truly seems to have trouble resolving the lines, it is best to do no more than ask when he or she last had an eye exam and leave it to the student to decide whether or not to discuss the matter with his or her parents. This exercise has resulted in a few students either getting their prescription updated or getting glasses for the first time.)

8.7 The answers to 8.4 and 8.6 should be the same; being closer to the chart lets the student see lines that are closer together, but it does not change the eye's resolution limit.

8.8 The value should be the same as in 8.4 and 8.6.

8.9 The value should be the same as in 8.4.

8.10 The eye's ability to see detail diminishes with light intensity. Even when the eye is fully dark-adapted, there will be a decrease in the resolution limit.

8.11 1700 cm/X = 1700/1 <u>X = 1 cm</u>

8.12 3400 km/X = 1700/1 <u>X = 2 km</u>

8.13 - 8.20 The answers will vary according to the student's resolution limit.

8.21 240 km/X = 4,500,000/1.

Convert the 240 km to centimeters: (240 km)(1000 m/km)(100 cm/m) = 24,000,000 cm

24,000,000 cm/X = 4,500,000/1 X = 24,000,000 cm/4,500,000 = <u>5.3 cm</u> (about 2 inches)

This answer is consistent with the known imaging capabilities of U.S. military satellites. Actual resolution limits are undoubtedly higher than the one stated in the problem. (There are similar ground-based imaging systems. One such system was used to examine the underside of the space shuttle Columbia during its maiden flight to check for missing heat tiles. Imagine looking at the shuttle from a distance of 150 miles, trying to detect objects about the size of a brick.)

<u>Activity 9</u>: Building And Using A Pinhole Tube

1. Preconceptions

Question 9.1 probes the student's concept of the distance-to-diameter ratio of the Sun. As in Question 7.2, students will tend to respond based on the impressions they have gained from looking at improperly scaled diagrams showing the Sun and the Earth together. While almost every student knows that the Sun is larger than the Earth, most students think the Sun is only a few times larger than the Earth and relatively close to it. The answer to 9.1 is 109. Expect the majority of your students to state values significantly lower than 109.

2. Activity Tips

Activity 9A:

You can set out collection boxes for paper towel tubes well in advance of this activity and have your students save tubes at home or work. Toilet paper tubes are too short and cannot be stably joined, so do not bother collecting them. Some wrapping paper tubes are wide enough to be useful and you can cut them down to get three or four tubes. Otherwise, you can try rolling and stapling sheets of stiff paper, such as oaktag, to make your own tubes (construction paper is too flimsy).

Step 4. It is very important that the hole poked through the foil is small and round. The best results are obtained using the point of a drawing compass or a clean dissecting pin. If the hole is too large or is not round, it will be impossible to focus a clear image on the tracing paper.

Step 8. This works best if the tube is laid on a table top or other horizontal surface. However, a clear image can be obtained with a hand-held tube. If graph paper is not being used for the screen, then the image should be marked on the paper so its length can be measured. If the tube is being held by hand, a second student can mark the image while the first student holds the tube steady. (If graph paper is used, the student can simply count the number of squares along the length of the image and determine the length by knowing the grid size of the paper. Millimeter graph paper is the most useful type for this method.)

Activity 9B:

Since the distance-to-size ratio for the Sun is about 110, you will get a solar image diameter of less than 5 mm with the tubes extended to their maximum stable length (less than 50 cm). However, the image should be obvious. There is no danger of the sunlight burning a hole through the paper since the pinhole does not focus the light to a point. This is the same method used to safely project and view images of the Sun during a solar eclipse, except that only a sheet of heavy paper with a pinhole in it is used as the projector.

Extension

1. It is important that the mirror is far away from the wall. A flat mirror will act as a pinhole projector only over a large distance. If the mirror is too close to the wall, no clear solar image will be seen.

3. Answers to Questions

9.2-9.6 The answers will vary depending on the set-up.

9.7 Triangles APB and XPY are similar triangles.

9.8 D/XY

9.9 L/AB

9.10 As the triangles involved are similar, the ratios in Questions 9.8 and 9.9 should be equal, allowing for the accuracy of the measurements involved. This means that if any three of the four values found in the two equivalent ratios are known, the fourth value can be calculated. This is indicated by the second comment following Question 9.10: You can now use your pinhole tube to estimate the diameter of the Sun!

9.11 The image is inverted. It is smaller than the image in Step 8 if the tube is farther from the bulb than it was in Step 8. If the tube is closer to the bulb, the image is larger than in Step 8.

9.12 The image is inverted. It is smaller than the image in Step 8 if the tube is farther from the bulb than it was in Step 8. If the tube is closer to the bulb, the image is larger than in Step 8.

9.13 The image is inverted. It is smaller than the image in Step 8 (assuming the object outside the window is farther away than the bulb was in Step 8).

9.14 All of the images were inverted. The image size depends upon the distance between the bulb and the tube: As the distance decreases, the image size increases. (Since the size of the filament does not change, the distance-to-size ratio must change if the distance changes. The distance and image sizes are inversely related: $L/AB = D/XY$.)

9.15 and 9.16 will vary depending on the set-up.

9.17 The value should be about 110.

9.18 About 110 (the answer to 9.17).

9.19 $D/XY = L/AB$. $L/AB = 110$. D equals the distance to the Sun and XY is the Sun's diameter. Solving for XY:

$$XY = 150{,}000{,}000 \text{ km}/110 = \underline{1{,}360{,}000 \text{ km}}$$

Activity 10: Building And Using An Astronomical Telescope

1. Preconceptions

The responses to Question 10.1 will vary depending upon how much experience the students have had with lenses. The only changes caused by replacing the pinhole with the lens is a somewhat clearer, brighter image (especially if the pinhole was not well made).

2. Activity Tips

Activity 10A:

The plastic lens can be scratched. It should be handled by the edges and placed on a clean surface, preferably a piece of paper or cloth. The objective lens has a focal length of 400 mm.

Step 2. The flat side of the lens has to be fitted snugly against the end of the tube. If the width of the tube is very nearly the same as the lens diameter, the tape should be wrapped around the end of the tube first. You may want your students to secure the lens with two pieces of tape. The first piece serves as a collar for holding the lens, with just enough tape protruding beyond the end of the tube to fold up around the edge of the lens. A second piece of tape can be wrapped around the tube a little farther up, so more tape can be folded around the edge of the lens. The effective aperture (width) of the lens will end up being about 40 mm.

Steps 3-5. These procedures work best with the telescope lying on a horizontal surface. In Activity 10B, the student is recommended to secure the telescope for astronomical viewing, or to construct some sort of mount.

Activity 10B:

The same handling precautions used for the objective lens in 10A should be used for the eyepiece lens. The small lens is awkward to hold by the edge, however, so a piece of cloth or lint-free paper should be used to hold it. (Most facial tissues have too much lint for this purpose. You may want to buy a packet of tissues used for cleaning plastic eyeglass lenses and give one piece to each student. It is easier to keep the lens clean than to try to remove smudges.) The eyepiece lens has a focal length of 25 mm.

Step 2. The lens should be wriggled inside the foam holder until the flat side is just inside one end. This will be the viewing end and a little foam projecting beyond the lens surface will help protect it from scratches. The eyepiece assembly can be twisted inside the tube until only a little foam extends beyond the end of the tube. The student can try viewing an object and twisting the eyepiece holder until the clearest image is obtained.

The assembled telescope is similar to those used by Galileo. It is a 16-power instrument that produces an inverted image. The objects suggested for viewing all show significantly more detail than with the eye alone. In fact, low-power observation is ideal for most of these objects. The four large moons of Jupiter are visible through this telescope, so you may want to have your students try tracking them over the course of a single night or several nights if Jupiter is visible. The Great Nebula in Orion appears as a fuzzy mass and does not show color. (Any color seen in the nebula is due to chromatic aberration created by the objective lens. Only a time-exposure photograph would reveal the nebula's colors.) IMPORTANT: Remind your students to view in an area away from bright lights and to wait awhile before starting to observe to let their eyes adjust to the darkness (at least 10 minutes, and up to 30 minutes for some people).

Activity 10C:

This activity involves calibrating the telescope and can be omitted. However, knowing the calibration scale will allow students to estimate the size of craters on the Moon and perform a variety of other measurements that draw upon the distance-to-size ratio work done in Activity 7. It is also a follow-up to Activity 8, demonstrating how a telescope increases the resolving limit of the eye by magnifying objects (effectively bringing them closer to the observer, as neatly demonstrated in a recent TV ad for a camera equipped with a telephoto lens).

3. Answers to Questions

10.2 It will depend upon the set-up, but it should be about the same as the objective's focal length, which is 40 cm.

10.3 An upside-down, smaller than life-size image of the bulb filament.

10.4 The value should be nearer to 40 cm than it was in 10.2. (As the distance to the object increases, the nearer to the focal point the image will appear.)

10.5 The distance should be shorter.

10.6 The telescope length would have to be shorter.

10.7 The value should be 40 cm.

10.8 The telescope had to be shortened.

10.9 The images are similar in that they are all inverted and smaller than life-size. They are different in terms of where they are focused and their size. (The image of an object is larger the nearer you are to the object.) If the object is less than the objective's focal length away, then if the objective lens was used alone, a magnified, upright image of the object would be seen if you looked through the lens at the object - the lens would be a magnifying glass. Note that in the telescope the magnification is provided by the eyepiece. The image projected by the objective lens forms less than 25 mm from the eyepiece, that is, the image can be thought of as an object and the eyepiece as a magnifying glass used to inspect the object in detail. The amount of magnification is equal to the objective's focal length divided by the eyepiece's focal length: 400mm/25 mm = 16X. If an eyepiece with a shorter focal length replaced the 25 mm lens, the magnification would increase. However, the telescope's ability to form a clear, bright image depends upon how much light it can collect, which is determined by the width (aperture) of the objective lens. While a telescope can have interchangeable eyepieces, it is impractical to have interchangeable objective lenses. Therefore, every telescope has a limit to the useful magnification it can provide; beyond a certain point, the image will be too faint to see clearly (unless the object being viewed is very bright). Many inexpensive telescopes come in boxes boasting 500X or more. However, the objective lens (or mirror) is too small to collect enough light from a planet to make the image visible at such a high magnification. Such telescopes can be used at high power for viewing a bright object, such as the Moon, but even then the image may be faint.

10.10-10.14 The results will depend upon viewing conditions, lens alignment, and how stable the telescope is during viewing.

10.15 The value will depend upon the set-up.

10.16 The image is upside-down and smaller than life-size.

10.17 and 10.18 The values will depend upon the set-up.

10.19 The calibration scale for this telescope is approximately <u>2.5 mm/ m</u>.

10.20-10.22 The answers will depend upon the set-up.

10.23 a) X = 525 ft/1000 yds = <u>0.53 ft/yd</u>

b) X/100 yds = 0.53 ft/yd

<u>X = 53 ft</u>

c) 6 ft/X = 0.53 ft/yd

<u>X = 11.3 yds</u>

10.24-10.29 The answers will depend upon the resolution limit of the student's eyes.

ACTIVITY 7 ESTIMATING SIZE AND DISTANCE

PURPOSE

To estimate the distance to an object in terms of its size, or to estimate the size of an object in terms of its distance, using equipment always available: your outstretched arm and little finger.

WHAT DO YOU THINK?

Write answers to questions or problems in the spaces provided.

7.1 *If you hold out your hand at arm's length, what part or parts of your hand or fingers will just cover the Moon?*

7.2 *How many Moon diameters will fit into the distance between the Earth and the Moon?*

MATERIALS

1 one-dollar bill
1 meter stick or tape measure
tape

PROCEDURE

Students should work in pairs for this activity.

1. Tape a one-dollar bill to a wall with the short side of the bill parallel to the floor. See Figure 7.1.

2. Stretch one arm out to full length and make a fist, palm up. Straighten your little finger, keeping the rest of your hand closed in a fist. Position your hand so that your little finger is straight up and down. With your arm stretched in front of you, close one eye.

3. Stand at where the upper joint of your little finger appears to just cover the width of the dollar bill. You may have to chose a certain part of the upper joint of your finger depending on variations in its shape.

4. Have your partner measure the distance from your finger to your eye. KEEP YOUR ARM STRAIGHT AND HORIZONTAL! BE CAREFUL WHEN THE RULER IS NEAR YOUR EYE!

   7.3 *The distance from your finger to your eye is _________cm.*

5. Measure the width of the upper joint of your little finger.

   7.4 *The width of your little finger is _________cm.*

6. Calculate the number of "Finger Widths" that fit into your "Eye-to-Finger Distance".

   7.5 $\dfrac{\textit{Eye-to-Finger Distance}}{\textit{Finger Width}}$ = ____________

   Using the answer from Question 7.5, you may say that _________ finger widths will fit into the distance between your eye and your finger. This number will be called the "ratio of Eye-to-Finger Distance to Finger Width".

7. Have your partner measure the distance from where you are standing (where your finger appears to just cover the dollar bill) to the dollar bill. BE CAREFUL WHEN THE RULER IS NEAR YOUR EYE!

   7.6 Measure and record the distance from your eye to the bill:_________ cm.

   7.7 Measure and record the width of the bill:_________ cm.

   7.8 How many "Dollar Bill Widths" fit between your eye and the dollar bill?

   $$\frac{\textit{Eye-to-Bill Distance}}{\textit{Dollar Bill Width}} = \_\_\_\_\_\_\_\_\_\_$$

   Using the answer from Question 7.8, you can say that _________ dollar bill widths fit into the distance between you and the dollar bill (if you are standing at a position where your outstretched little finger just covers the dollar bill).

   7.9 What are the similarities in your answers for Questions 7.5 and 7.8?

8. Repeat the procedure so that your partner can determine her or his own "Finger-to-Eye" relationship.

   7.10 Compare your finger-to-eye ratio to others in the class.

Figure 7.1 illustrates how your eye, your finger and the dollar bill form similar triangles.

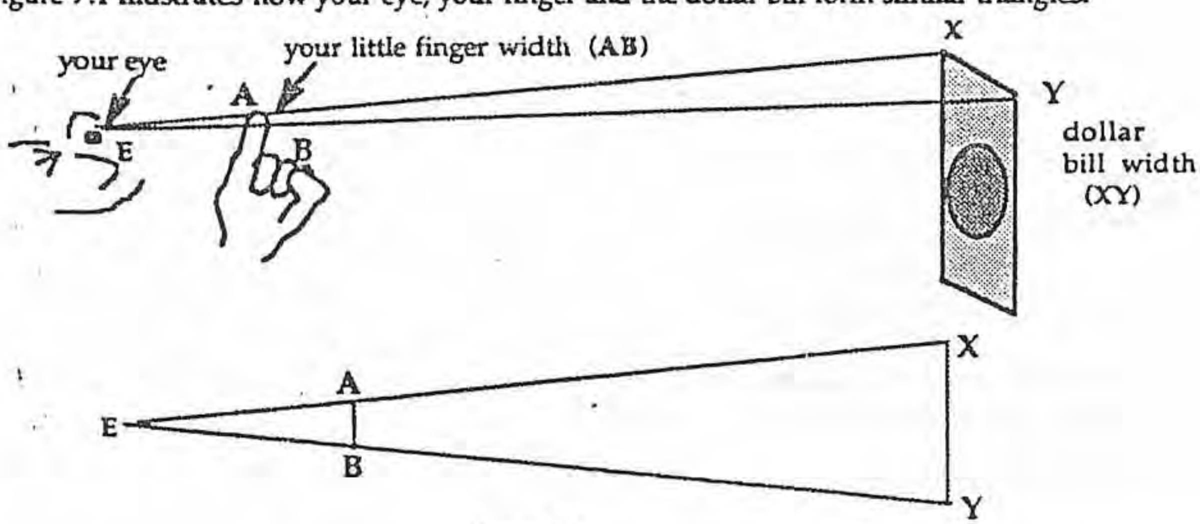


Figure 7.1

Line AB is the width of your little finger (Question 7.4) and line XY is the width of the bill (Question 7.7). The distance from your eye to your finger (Question 7.3) is EA (or EB) and the distance from your eye to the dollar bill (Question 7.6) is EX (or EY).

The triangles AEB and XEY are similar triangles: the angles in AEB are the same as those in XEY. This equality also means that the ratio of the length ("height") to the width ("base") of each triangle is the same. You can measure the triangles in Figure 7.1 to see that they are similar.

The relationships shown in Figure 7.1 can be illustrated by the following ratio:

$$\frac{\text{Distance from eye to finger}}{\text{Finger width}} = \frac{\text{Distance from eye to dollar bill}}{\text{dollar bill width}}$$

9. Now stand at a position where the dollar bill is just covered by two little finger widths.

7.11 Has the apparent size of the dollar bill increased, decreased or stayed the same?

7.12 What has happened to the distance between you and the dollar bill?

7.13 The distance between you and the dollar bill is _________cm.

7.14. How does this distance compare to the distance in Question 7.6?

This is illustrated by the following ratio:

$$\frac{\text{Distance from eye to finger}}{\text{2 finger widths}} = \frac{\text{Distance from eye to dollar bill}}{\text{dollar bill width}}$$

10. Move to a position where the dollar bill is just covered by only half of your finger width.

7.15 Has the apparent size of the dollar bill increased, decreased or stayed the same?

7.16 What has happened to the distance between you and the dollar bill?

7.17 The distance between you and the dollar bill is _________cm.

7.18 How does this distance compare to the distance in Question 7.6?

This comparison is illustrated by the following ratio:

$$\frac{\text{Distance from eye to finger}}{\frac{1}{2}\text{ Finger width}} = \frac{\text{Distance from eye to dollar bill}}{\text{dollar bill width}}$$

11. Find an object outside your classroom window (such as a tree or a building) that you can just cover with the width of your little finger when your arm is fully extended.

7.19 How many of the objects would fit in the distance between you and the object?__________

7.20 Estimate the distance from you to the object_________m.

7.21 What is the actual distance to the object? _________m

12. Go outside on a clear night or day when the Moon is visible in the sky. Use your little finger with arm outstretched to measure the full diameter of the Moon.

7.22 How many finger widths, or what fraction of a finger width, will just cover the Moon?

______

7.23 *Estimate the number of lunar diameters the Moon is away from you. (Even if the Moon is a crescent, you can estimate its full diameter by measuring from one tip of the crescent across to the other tip.)*

7.24 *How do the answers to Questions 7.22 and 7.23 compare with the predictions you made in Questions 7.1 and 7.2?*

You now have a tool to determine the distance from you to some distant object if you can estimate the object's size. You can also determine the size of a distant object if you can estimate its distance. The following problems are meant to help you practice using this tool.

Each individual has different arm lengths and different finger widths, therefore the following **assume a standard "Ratio of Eye-to-Finger Distance to Finger Width" of 60 to 1.**

HOMEWORK - SET A

Write answers to questions or problems in the spaces provided.

FOR THESE QUESTIONS: Use a Ratio of Eye-to-Finger Distance to Finger Width of 60 to 1.

7.25 *You are standing in a park on a hill outside Boston, Massachusetts. At this position, the width of a little finger will just cover the height of the John Hancock building found in downtown Boston. The visitor's guide to the city states that the Hancock building is 240 m (790 feet) tall. Estimate your distance from the building.*

7.26 *You are on a boat entering New York City Harbor. You observe that the towers of the World Trade Center appear about one little finger width tall. The guidebook to New York City states that the towers are 460 m (1500 feet) tall. Estimate your distance from the towers.*

7.27 You attend a launch of the space shuttle from Cape Canaveral, Florida. The observing site is 13 km (8 miles) from the launching pad. The shuttle (with fuel tank) appears about one fourth of a little finger width tall. What is the height of the shuttle in meters?

The distances to stars are so large that astronomers use the time it takes for light to travel a given distance as a unit of measure. The LIGHT YEAR is the distance light travels in ONE YEAR. One light year is about 9.5 million million kilometers or 6 million million miles.

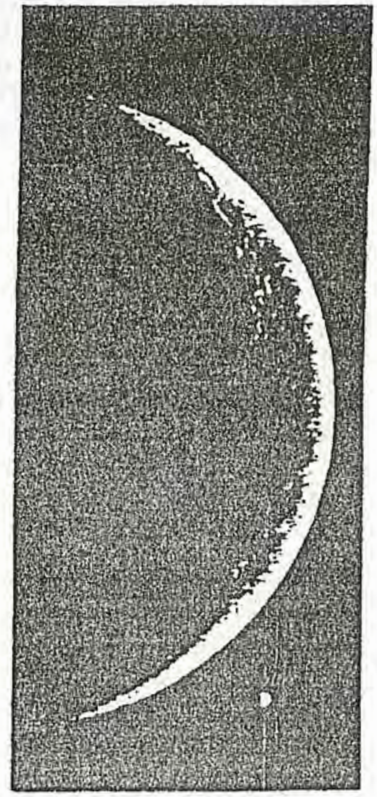
7.28 The Pleiades, a star cluster in the constellation of Taurus the Bull, appears about one finger width big in the sky. If one assumes the cluster to be about 7 Light Years in diameter, how far away is the cluster? Give the answer in Light Years.

7.29 Another cluster in Taurus is the Hyades, which forms the "face" of the Bull. This cluster appears to be about 3 fingers wide. If you assume it to be about 7 Light Years in diameter, how many Light Years are the Hyades from us?

7.30 *The only galaxy easily visible to people in the Northern hemisphere is the Andromeda Galaxy in the constellation of Andromeda. The bright nucleus of the galaxy can be seen with the naked eye on a very clear, moonless night. This nucleus, which astronomers estimate to be about 30,000 Light Years in diameter, appears about one fingerwidth wide. How many Light Years is this galaxy from us?*

HOMEWORK - SET B

Write answers to questions or problems in the spaces provided.
Assume the Moon is 110 of its diameters away from the Earth.



7.31 *(a) The picture at right shows the Moon and Venus as they appeared together in the sky a few years ago. By taking measurements from the photo, determine the number of Venus diameters Venus is from the Earth.*

(b) Given that the diameter of Venus is 12,100 km, what was the distance from the Earth to Venus when this picture was taken?

7.32 *The largest apparent size of Mercury that we ever see in the sky is 1/150 the apparent diameter of the Moon. The diameter of Mercury is 4880 km. What is the closest that the Earth and Mercury approach each other?*

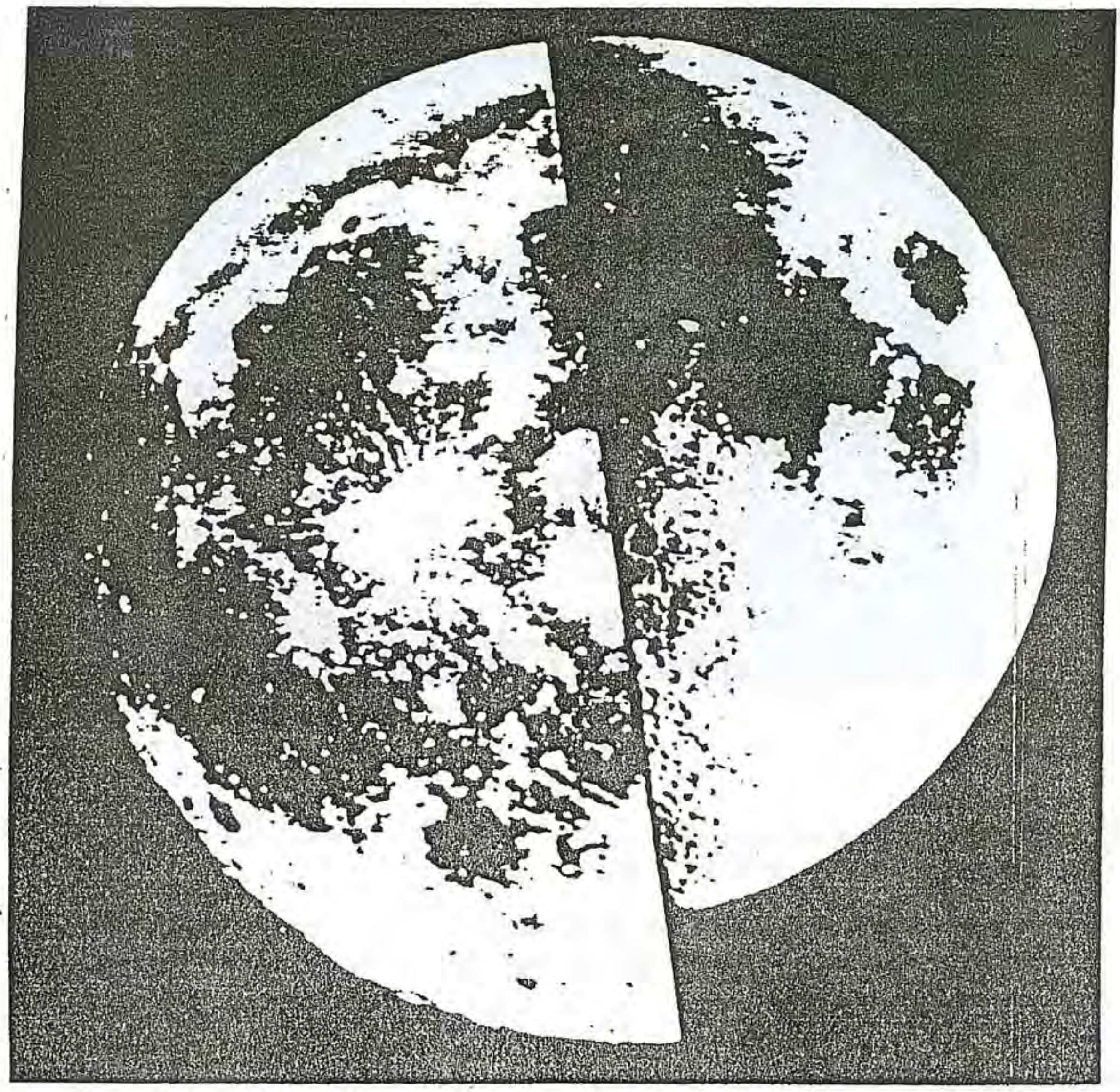
7.33 *On August 4, 1985, the Earth made its closest approach in 12 years to the planet Jupiter. The distance between the two planets was then about 608,000,000 km. Jupiter's image on a photograph taken then measured 1/40 of the apparent diameter of the Moon. Calculate the diameter of Jupiter in kilometers.*

photo by Byron Hogan, Clifton, NJ

7.34 *The above picture of the Moon and an airliner is from a single photograph; it is not a double exposure. Is the airliner really almost as big as the Moon?*

(a) Describe the situation that this photo recorded. Draw a diagram showing where the photographer, the plane, and the Moon were with respect to one another.

(b) What information would you need to determine the distance from the photographer to the plane? Try it! (Hint: a Boeing 747 airliner is about 80 meters long.)



7.35 *The above picture shows two photos of the Moon, one photo taken when the Moon was closest to us and one when it was farthest from us. Measure the apparent diameter of the Moon in each photo.*

(a) The diameter of the larger image is_______________cm.

(b) The diameter of the smaller image is _______________cm.

(c) The average diameter is _______________cm.

(d) The average distance from the Earth to the Moon is about 400,000 km. Calculate the maximum distance of the Moon from the Earth.

ACTIVITY 8 SEEING DETAILS WITH THE EYE

PURPOSE

To determine the smallest separation that your eyes can see at a given distance.

WHAT DO YOU THINK?

8.1 What is the diameter of the smallest crater that you can see on the Moon?

8.2 At what distance would you see a pair of headlights on a car blur together so you would see only one point of light?

MATERIALS

Per team of two students
Figure 8.1
1 blank sheet of paper
1 meter stick

PROCEDURE

Students should work in pairs for this activity.

1. Tape Figure 8.1 to a wall in a well-lighted room.
2. Stand 10 meters from the chart.
3. Your partner will hold a sheet of paper across the top of the chart. Tell your partner to move the paper very slowly down the chart, keeping the paper horizontal. When you start to see the chart lines blur together just above the paper, tell your partner to hold the paper in place.
4. Your partner will read the line spacing printed on the chart nearest to the top of the paper. Record this value.

8.3 The line spacing value is:______________mm.

EXAMPLE

When Ronnie, a typical student in a typical astronomy class, stood 10 meters (10,000 mm) from the chart, she was just able to distinguish the separation of the lines spaced 6.0 mm apart. The distance-to-size relationship for her eyes is 10,000 mm (the distance to the chart) divided by 6.0 mm (the line spacing):

$$\frac{10{,}000 \text{ mm}}{6.0 \text{ mm}} = \frac{1700}{1}$$

This ratio can be written as 1700/1, the distance-to-size ratio for her eyes. This ratio is read as "1700 to 1" and can also be written as 1700:1.
The larger the distance-to-size ratio, the more detail your eyes can see.

8.4 The distance-to-size relationship for your eyes is:_______________.

5. Repeat Steps 2-4, standing at a different distance from the chart.

   8.5 The distance is__________meters.

   8.6 The distance-to-size relationship for your eyes is______________.

   8.7 How do the answers to Questions 8.4 and 8.6 compare?

Now you will determine how much detail your eyes can see when the lighting is dim.

6. Find a dark location where the chart is visible at a distance of 10 m.

7. Repeat Steps 2-4, standing 10 meters from the chart.

   8.8 The distance-to-size relationship for your eyes is:______________.

   8.9 How do the answers to Questions 8.4 and 8.8 compare?

   8.10 Describe how the amount of light affects your eyes' ability to see details.

The distance-to-size ratio for your eyes determines how much detail you can see. Using the similar triangle method from ACTIVITY 7, you can estimate the "sharpness" (ability to see detail) of your eyesight. The EXAMPLE for Question 8.4 gave a distance-to-size ratio of 1700/1 for Ronnie. In Figure 8.2, E is the position of your eyes; X and Y are two side-by-side lights. The distance of the observer from the lights is EX (or EY); the distance between the lights is XY.

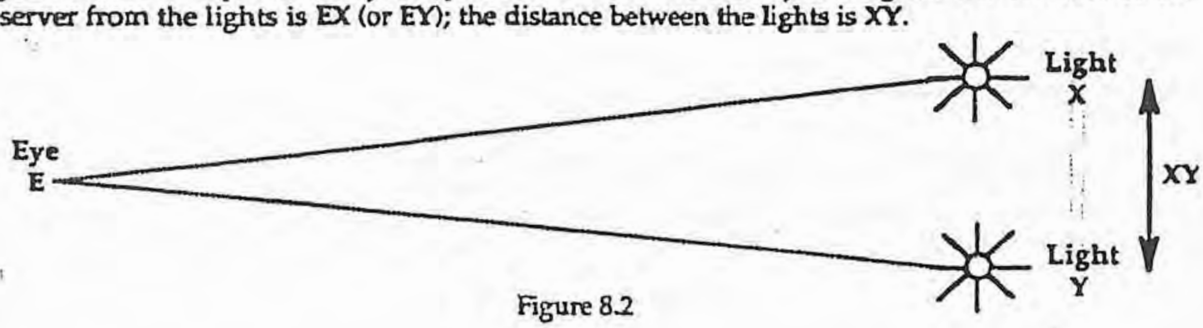


Figure 8.2

Ronnie's ratio means that if she were closer than 1700 meters away from two lights separated by 1 meter, she would see two separate lights. If she were farther away than 1700 meters, she would see one light. (NOTE: If the diameters of the two lights are much smaller than the space separating them, the lights will be more easily seen as separate points.)

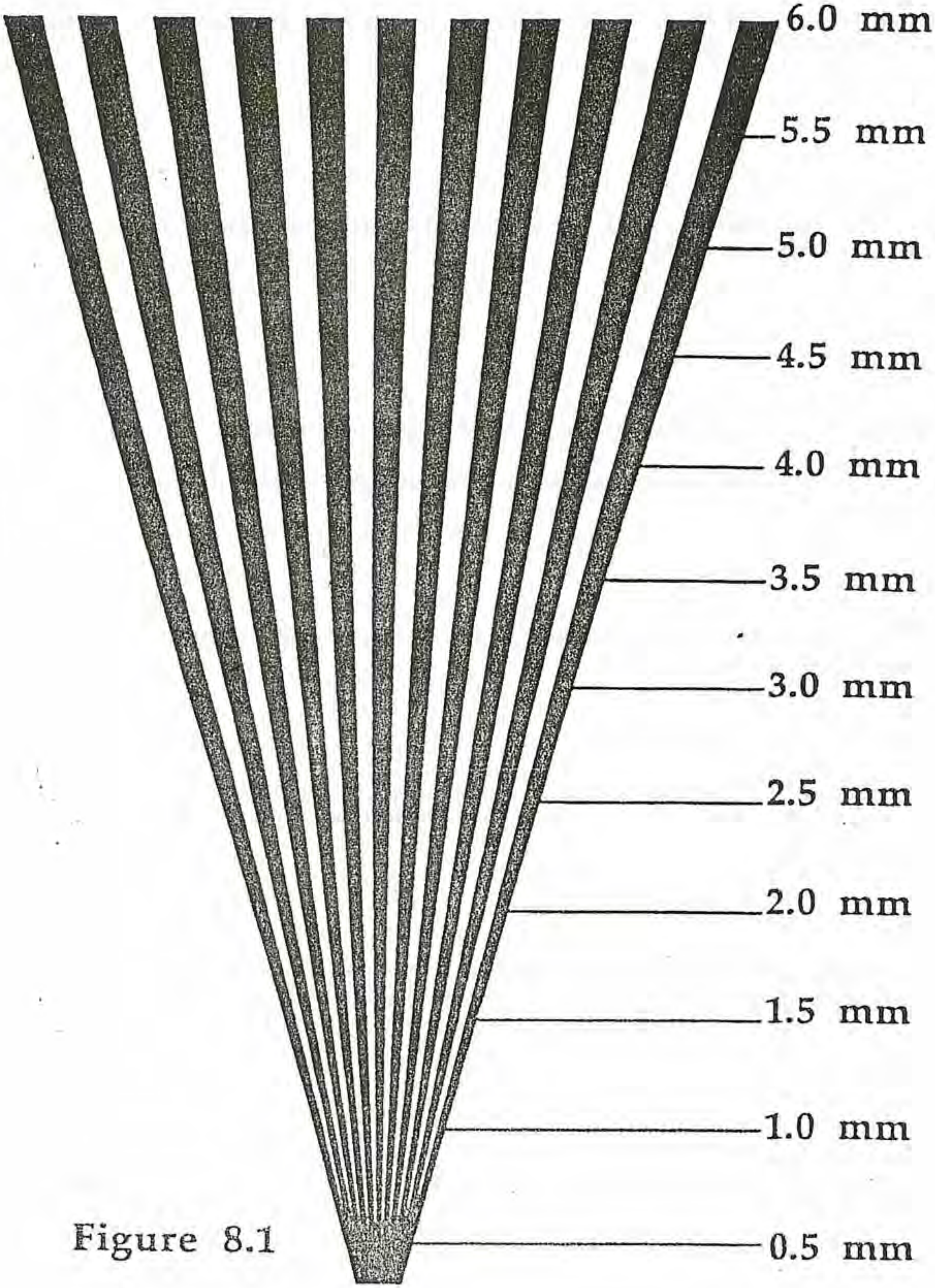


Figure 8.1

21

8.11 *How far apart would lights have to be for Ronnie to see two lights if she were standing 1700 cm away from the lights?*

8.12 *How far apart would the lights have to be for Ronnie to see two lights if she were standing 3400 km away from the lights?*

Use the distance-to-size ratio for your eyes to answer the following questions.

8.13 *What is the farthest distance you could be from two lights, separated by 1 cm, and still see them as two lights?*

8.14 *What is the farthest distance you could be from two lights, separated by 1 km, and still see them as two lights?*

8.15 *Describe how two lights, separated by 50 cm, would appear to you if you were standing 500 m from the lights. Show the work you do to solve this problem.*

8.16 *An automobile has headlights placed 1 m apart. If the car were driving toward you at night, how close to you would it have to be for you to tell it was a car and not a motorcycle?*

8.17 *The Moon is about 400,000 km (240,000 miles) from the Earth. What is the diameter of the smallest crater that you could see on the Moon's surface?*

HOMEWORK

Write answers to questions or problems in the spaces provided.

Confirm that distances and sizes are always in the same units before making any calculations. Use the resolution limit for your own eyes (Question 8.4) to answer Questions 8.18 - 8.20.

8.18 Two marbles are separated by 5 cm. How far could you be from the marbles and still see them as separate objects?

8.19 Venus and the Earth can approach each other as closely as 40,000,000 km (25 million miles). The Moon is about 400,000 km from the Earth. If you were on a spacecraft orbiting Venus at the time of its closest approach to the Earth, would you be able to see the Earth and the Moon as separate objects? (Assume you are viewing the Earth and the Moon at their greatest separation.)

8.20 Neptune is 30 times farther from the Sun than is the Earth (Earth-Sun distance is about 150 million km). Using the distance-to-size ratio for your eyes, would the Sun appear as a disk or a point of light if you were at Neptune? (The Sun's diameter is about 1,400,000 km.) Show the work you do to answer the question.

8.21 The imaging system of a reconnaissance satellite has a resolution limit of about 4,500,000/1. The satellite orbits 240 km (150 miles) above the Earth's surface. If the satellite records the image of a truck convoy, how small could the spaces between the numbers stenciled on the roofs of the trucks be and still be "readable" on the image?

EXTENSIONS

1. Look up the resolution limits for a variety of animal species. Consider how resolution limits fit with the living conditions of the animals.

2. Research the structure of the human eye. What physical factors of the eye affect its resolution limit? Is the "sharpness" of an astronaut's eyes in space different from what it is on the Earth?

3. Study the radar mapping of the surface of Venus done by the Pioneer Venus spacecraft. What was the imaging system's resolution limit? What surface features have been discovered with this system? What important information about the surface cannot be obtained with this system? Compare this resolution to that for the Magellan spacecraft which is now on its way to Venus. (The Pioneer Venus survey began in 1978. Articles have been printed in periodicals such as Astronomy, Science, Scientific American, and Sky & Telescope. Information can also be found in most current astronomy textbooks.)

ACTIVITY 9 BUILDING AND USING A PINHOLE TUBE

PURPOSE

To build a pinhole tube and use it to make terrestrial and astronomical measurements.

WHAT DO YOU THINK?

Write answers to questions or problems in the space provided.

9.1 *How many Sun diameters fit between the Earth and the Sun?*

ACTIVITY 9A BUILDING A PINHOLE TUBE

MATERIALS

2 paper towel tubes, one of which fits inside the other
1 small sheet of aluminum foil (about 10 cm x 10 cm)
1 straight pin or a drawing compass
1 piece of millimeter tracing graph paper (about 10 cm x 10 cm)
3 rubber bands
1 200-watt clear light bulb with clamp socket
1 meter stick
1 pair of scissors

PROCEDURE

Refer to Figure 9.1 for Steps 1 and 2.

1. Be sure your two paper towel tubes fit together easily. Cut four slits equally spaced around the circumference of the outside tube with each slit being about one inch long. Slide the inside tube into the outside tube and wrap a rubber band tightly around the cut end of the outside tube to prevent the inside tube from slipping out.

2. Push the inside tube into the outside tube until the ends of both tubes are even with each other. Pull the inside tube out 1 centimeter. Use the end of the outside tube to draw a line on the inside tube. Label this line as "1 cm". Pull the inside tube out another centimeter. Again, draw a line on the inside tube using the outside tube as a guide. Label this line "2 cm". Continue this procedure until the inside tube falls out of the larger tube or until the inside tube becomes too loose to be stable. As you slide the two tubes apart, you should now be able to read the total length of the pinhole tube by adding the centimeter reading on the inner tube to the length of the outer tube. See Figure 9.1.

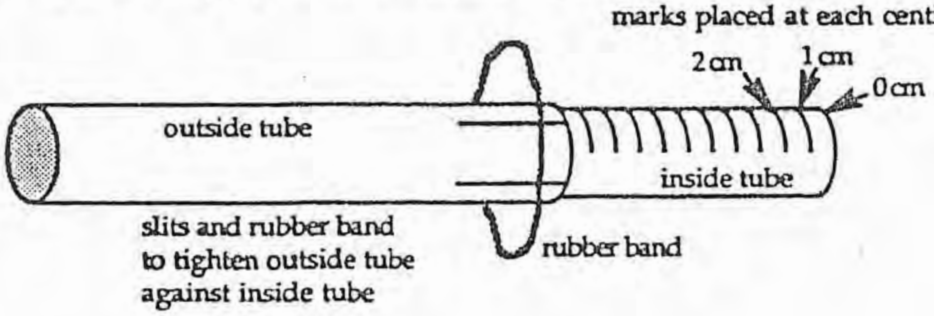


Figure 9.1

Refer to Figure 9.2 for Steps 3 - 5.

3. Place the aluminum foil over the end of the outside tube. Use a rubber band to hold the foil in place. Be careful to keep the foil smooth over the end of the tube.

4. Using either a straight pin or the point of a drawing compass, slowly and carefully punch a small hole in the center of the aluminum foil. Verify the pinhole is round and not a linear rip.

5. Place the graph paper or tracing paper over the end of the smaller tube. Hold the paper in place with a rubber band and be careful to keep the paper smooth over the end of the tube.

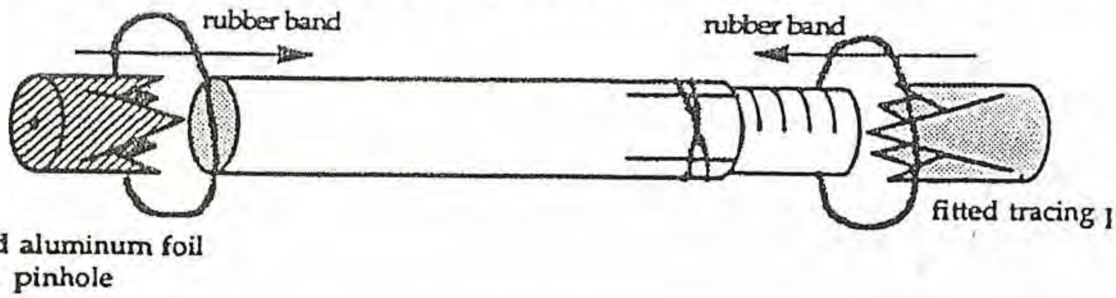


Figure 9.2

Refer to Figure 9.3 for Steps 6 - 8. Figure 9.3 shows the arrangement as seen from above.

6. Place the 200-watt light bulb at one end of the room. Take care to keep the long axis of its filament perpendicular to the length of the tube. (The filament is the tightly coiled piece of wire inside the glass bulb.) This experiment will work best if the walls, floor, and ceiling are as dark as possible. (The dark color will make the filament easier to see.) DO NOT TURN ON THE BULB YET.

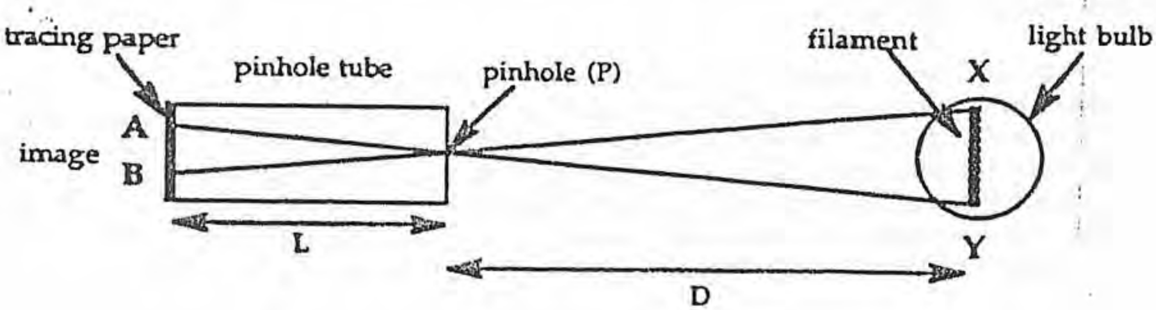


Figure 9.3

7. KEEP BULB OFF. Measure the length of the filament (line XY in Figure 9.3). To make the measurement, look straight down on top of the bulb and hold a ruler against the glass. Close one eye and estimate the length straight across (the filament will probably be slightly curved).

9.2 The length of the filament (XY) is ________ cm.

8. Turn on the bulb. Stand across the room from the bulb and aim the pinhole at the bulb, keeping the pinhole tube horizontal and perpendicular to the filament of the bulb. Slowly move the tube around until you can see an image of the bulb's filament on the tracing paper; it will appear as a small, bright line. Slide the smaller tube in or out until the image of the filament is sharply focused on the paper.

DO NOT TOUCH THE BULB WHEN IT IS ON OR FOR A FEW MINUTES AFTER YOU TURN IT OFF. YOU MAY BE BURNED.

9.3 The length of the tube (L) is _________ cm.

9.4 The distance between the bulb filament and the pinhole (D) is _________ cm.

9.5 The length of the filament's image on the paper screen (AB) is _________ cm.

9.6 Look at Figure 9.3. Draw a diagram like it, showing the filament, the tube and the two triangles, labeling the points as in Figure 9.3. Mark the diagram with the measurements from Questions 9.3 to 9.5.

9.7 How is triangle APB related to triangle XPY?

9.8 Calculate the ratio of the bulb-pinhole distance (D) to the filament length (XY):

9.9 Calculate the ratio of the pinhole tube length (L) to the filament image length (AB):

9.10 Discuss the usefulness of the relationship of the ratio in Question 9.8 to the ratio in Question 9.9.

For Steps 9-11 keep the tube length the same as in Question 9.3.

9. Stand about 3 meters from the 200-watt bulb. With the room lights off, aim the pinhole end of the tube at the bulb.

9.11 Measure and describe the image you see on the tracing paper.

10. Take your telescope to the side of the room farthest from the bulb.With the room lights off, aim the pinhole end of the tube at the bulb.

9.12 Measure and describe the image you see on the tracing paper.

11. Aim the pinhole end of the telescope out a window at a distant object that is silhouetted against the sky.

9.13 Measure and describe the image you see on the tracing paper.

9.14 In what ways are the images projected in Steps 9, 10, and 11 similar? How do they differ?

Discuss the results of ACTIVITY 9A with your classmates before continuing to the next activity.

YOU CAN NOW USE YOUR PINHOLE TUBE TO ESTIMATE THE DIAMETER OF THE SUN!

BE CAREFUL NEVER TO LOOK DIRECTLY AT THE SUN!!!!!!

ACTIVITY 9B ESTIMATING THE DIAMETER OF THE SUN

MATERIALS

Per team of two students
pinhole tube from ACTIVITY 9A
ruler

PROCEDURE

Students should work in pairs for this activity, each pair with one tube.

1. Take the pinhole tube outside on a sunny day. Extend the tubes to their greatest possible length without their coming apart.

2. Aim the pinhole end of the tube towards the Sun. Slowly move the tube around until you see a bright disk on the graph paper. This disk is the image of the Sun. LOOK ONLY AT THE GRAPH PAPER, NOT AT THE SUN!!!

9.15 Record the length of the tube from the pinhole to the tracing paper:________________mm.

9.16 Record the diameter of the Sun's image:_______________mm.

9.17 Calculate the number of solar image diameters that, if placed "end-to-end," would fill the length of the tube. (Divide the answer from Question 9.15 by the answer from Question 9.16.)

9.18 How many solar diameters is the Sun from the Earth? ___________
(Hint: Remember ACTIVITY 7)

9.19 Given that the sun is 150,000,000 km from the Earth, calculate the diameter of the Sun.

EXTENSION

1. You can determine the distance-to-size ratio for the Sun by using a mirror instead of a pinhole tube. You will need:
   - 1 small, flat mirror
   - 1 piece of chalk
   - 1 tape measure
   - an outside wall that you can mark on with chalk
   - a sunny day

   WARNING: NEVER LOOK AT THE SUN IN THE MIRROR!!

   Take the mirror outside. Stand so you are facing, and are at least 15 m (50 feet) away from, the shaded wall of a building. The Sun must also be visible either in front of you or to your side. Position the mirror so it reflects an image of the Sun onto the wall you are facing. Prop up the mirror so the image is steady and walk to the wall. Use the chalk to trace the outline of the reflected image of the Sun on the wall.

   With the mirror propped in place, measure the diameter of the outlined solar image on the wall and the distance from the wall to the mirror.

   (a) The diameter of the solar image is _______ mm.

   (b) The distance from the mirror to the image is _______ mm.

   (c) How many solar diameters is the Sun from us?

   (d) How does the number in (c) compare to the number you obtained using the pinhole tube (Question 9.18) ?

2. (a) Repeat ACTIVITY 9B. This time, though, find the distance-to-size ratio of the full Moon instead of of the Sun. Replace the paper on the tube from ACTIVITY 9B with a new piece. (You may need to cover your head and the end of the tube with a jacket to see the Moon's image clearly.)

   (b) How does the size of the Moon's image compare to the size of the Sun's image?

   (c) How does the distance-to-size ratio for the Moon compare to the distance-to-size ratio for the Sun?

   (d) The Moon is about 400,000 km (240,000 miles) from us. Calculate its diameter.

ACTIVITY 10 BUILDING AND USING AN ASTRONOMICAL TELESCOPE

PURPOSE

To build a simple telescope and use it to make terrestrial and astronomical observations.

WHAT DO YOU THINK?

10.1 If you were to replace the aluminum foil in a pinhole tube with a lens, how would the image on the tracing paper change (if it changes)? (Would the image be brighter or dimmer? bigger or smaller? right-side up or upside down? clearer or fuzzier? as those formed by the pinhole tube?)

ACTIVITY 10A BUILDING A SIMPLE TELESCOPE

MATERIALS

1 pinhole tube from ACTIVITY 9A
1 large lens
1 pair of scissors
1 200-watt clear bulb with clamp holder
masking tape
meter stick
small piece of cloth or tissue

PROCEDURE

Refer to Figure 10.1 for the following instructions.

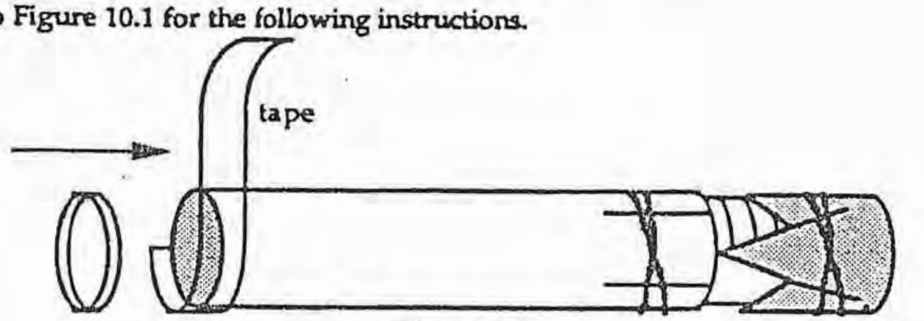


Figure 10.1

1. Remove the aluminum foil from your pinhole tube.

2. Using a small piece of cloth or tissue to prevent smudging, fit the flat side of the large lens snugly against the front of the outer tube, making sure it is positioned perpendicular to and centered on the tube. Wrap a piece of masking tape around the end of the tube to make a collar that firmly holds the lens in place.

3. Stand about 3 meters from the 200-watt bulb. With the room lights off, aim the lens end of the tube at the bulb. Slide the smaller tube in and out until a clearly focused image of the bulb's filament appears on the tracing paper. Record the distance of the tracing paper from the lens.

   10.2 The distance from the lens to the paper is _________ cm.

   10.3 Describe the image you see on the tracing paper.

4. Take your telescope to the side of the room farthest from the bulb. Move the smaller tube inside the larger one, until the image of the filament is focused on the paper.

10.4 The distance of the paper from the lens is________cm.

10.5 Is this distance longer or shorter than it was when you were closer to the bulb?

10.6 If you wanted to project a clear image of a very distant object, would the telescope length have to be longer or shorter?

5. Aim the lens end of the telescope out a window at a distant object that is silhouetted against the sky. Adjust the sliding tube until the image is focused clearly on the paper. Record the length of the telescope.

10.7 The distance from the paper to the lens is __________ cm.

10.8 Relative to the distance measured in Step 4 (Question 10.4), did you have to lengthen or shorten the telescope to bring the image into focus?

For a very distant object, the distance from the paper to the lens is called the focal length of the lens. Focal length is defined as the distance at which a lens (or mirror) will focus to a point light from a source very far away.

10.9 In what ways are the images projected in Steps 3, 4, and 5 similar? How do they differ?

You have now built a telescope that is fundamentally the same as one that an astronomer might use. Astronomers seldom use telescopes to simply view the sky visually. Far more often, they use optical telescopes for taking pictures or gathering light that is analyzed with special equipment. The lens (or in most astronomical telescopes, a mirror) collects the light coming from a distant object. When taking astronomical pictures, the image can be focused on a sheet of photographic film; the tracing paper on your tube takes the place of a piece of film. In this way, the telescope acts as a camera.

Photographic film was not invented until the 1800s. Before then, astronomers looked through their telescopes and made drawings of what they saw. You will now convert your telescope so that you can look through it. Then you will make some astronomical observations similar to those made by Galileo.

ACTIVITY 10B ADDING AN EYEPIECE TO YOUR TELESCOPE

MATERIALS

- telescope from ACTIVITY 10A
- 1 small lens
- 1 foam lens holder
- 1 meter stick
- small piece of cloth or tissue

PROCEDURE

Refer to Figure 10.2 for Steps 1 and 2.

1. Remove the tracing paper from the end of the telescope.

2. Using a small piece of cloth or tissue to prevent smudging, push the small lens into the foam lens holder. Squeeze the foam holder and press the lens/holder assembly into the end of the smaller tube. The flat side of the lens should face out of the tube. Be sure the lens is positioned perpendicular to the end of the tube. (You may have to twist the holder to position the lens properly.)

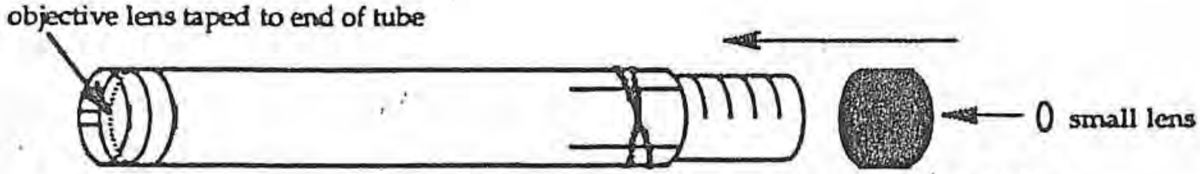


Figure 10.2

The large lens is called the objective lens of the telescope, or more simply the objective. The small lens is called the eyepiece or the ocular.

NEVER LOOK AT THE SUN THROUGH THIS TELESCOPE!

The telescope with the eyepiece is doing two things: 1) the objective lens is forming a very small image of a distant object near its focal point, and 2) the eyepiece is acting like a simple magnifying glass, enlarging that small image.

Magnifying objects also magnifies motion. To prevent vibration, secure your telescope to some object or hold it snugly against a post or a tree. You might even want to try to invent a way to secure the telescope tube to a camera tripod.

The rest of this activity consists of suggested subjects to view with your telescope. Always indicate the date, time, and viewing conditions for any observation. Draw what you see through the telescope in the circle provided. This circle represents the field of view of the telescope.

Good observing!!!

1. View the Moon through your telescope. The best time is near its crescent or quarter phases. During the Full Moon, the lack of shadows makes seeing craters difficult.

   10.10 *Make some sketches in the space below of what you can see. Indicate if you are seeing craters and/or mountains. Record the date, the time, the weather conditions, and the part of the Moon you are observing.*

OBJECT ____________________

DATE ____________________

TIME ____________________

WEATHER
CONDITIONS __________________________

LUNAR REGION___________________________

2. If Jupiter is currently visible in your night sky, try to observe it. (Your teacher will provide information about its visibility and location.)

   10.11 *Make some sketches in the space below of what you can see. Record the date, the time and the weather conditions.*

OBJECT ____________________

DATE ____________________

TIME ____________________

WEATHER
CONDITIONS __________________________

3. The Pleiades is a cluster of stars found in the "shoulder" of the constellation Taurús, the Bull. On a clear night, it is easily visible to the naked eye. When it is visible at a convenient time, locate and observe it with your telescope.

10.12 Make some sketches in the space below of what you can see. Record the date, the time and the weather conditions.

OBJECT ______________________

DATE ______________________

TIME ______________________

WEATHER
CONDITIONS ____________________________

4. The second star from the end of the handle of the Big Dipper (in Ursa Major, the Big Bear) is really two stars that appear close together. The brighter star is Mizar and the other is Alcor.

10.13 Make some sketches in the space below of what you can see. Record the date, the time and the weather conditions.

OBJECT ______________________

DATE ______________________

TIME ______________________

WEATHER
CONDITIONS ____________________________

5. Find the winter constellation of Orion, the Hunter. If you are not familiar with the appearance of this constellation, refer to a star chart. The three stars in the center of the rectangle of stars are called the "belt stars". Below the belt is a bright fuzzy area called the Great Nebula. This appears as the "tip of the sword" hanging from the hunter's "belt". Locate and observe Orion and the "tip of the sword".

10.14 Make some sketches in the space below of what you can see. Record the date, the time and the weather conditions.

OBJECT ____________________

DATE ____________________

TIME ____________________

WEATHER CONDITIONS ____________________

ACTIVITY 10C ______ CALIBRATING YOUR TELESCOPE

PURPOSE

To determine the calibration scale for your telescope and to estimate the distances to some objects using this scale and your telescope.

MATERIALS

telescope from ACTIVITY 10B
2 meter sticks
masking tape

PROCEDURE

1. Tape a meter stick vertically against a wall so that it is five to ten meters from a table or desk. Position your telescope on the table or desk and focus on the meter stick. (Tape the telescope down so it will give a stable image.)

   10.15 How many millimeters of the meterstick are visible in the field of view of the telescope?

   10.16 How far, in meters, is the meter stick from the objective lens of your telescope?

2. Divide your answer to Question 10.15 by your answer to Question 10.16.

   10.17 Record this number: ______________(Remember to label the units.)

   The number in Question 10.17 is the telescope's calibration scale. This scale is a size-to-distance ratio. (The ratios you worked with in the other activities were distance-to-size ratios.) The scale tells you the size of an object in millimeters that fills the field when viewed at a distance of one meter. This scale can be used to determine an object's size when the distance is known or the distance to the object when the size is known (similar triangles!).

3. Secure your telescope as in Step 1 and focus it on a large object on the opposite side of the room. Carefully observe what portion of the object fills the field of view of the telescope.

   10.18 The distance from the objective lens to the object you are viewing is ______________ m.

   10.19 Using the telescope's calibration scale, calculate the width of the portion of the object you observed to fill the field of view:______________ mm.

   10.20 Check your work by measuring the width of the portion of the object you observed. What is the difference between the calculated distance and the measured distance? If the difference (error) is less than 1/10 the measured distance, your calculated distance is quite accurate.

HOMEWORK

Write answers to questions or problems in spaces provided.

BACKGROUND FOR QUESTION 10.21:

Every pair of binoculars is marked with two sets of numbers. (See Figure 10.3.) One set of numbers indicates the magnification and the front lens diameter. For example, the label "7 x 50" (which is read "7 by 50") means that an object seen through the binoculars appears 7 times (7x) larger than it would without the binoculars and that each front lens is 50 millimeters in diameter.

The second set of numbers gives a viewing scale for the binoculars. For example, the label "525 feet at 1000 yards" means that at a distance of 1000 yards, an object 525 feet across will fill the field of view of the binoculars.

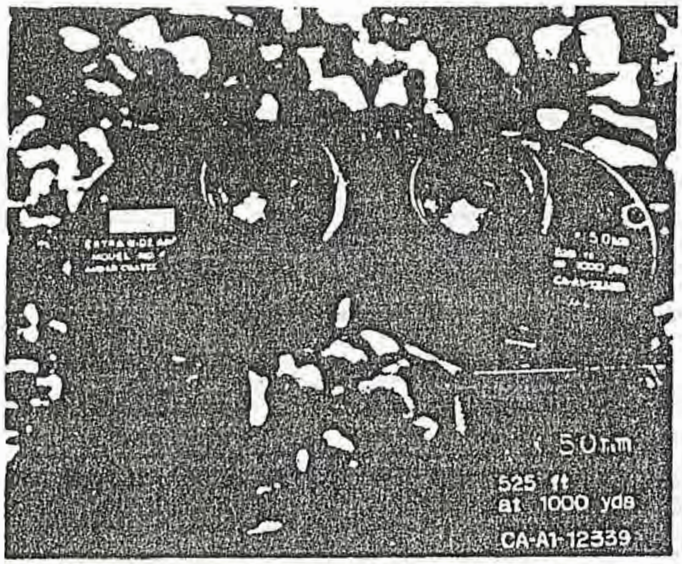


Figure 10.3

Diagraming your answers may help you solve the following problems.

10.21 The following questions refer to the binoculars shown in Figure 10.3.

a) What is the calibration scale for the binoculars?
(See Steps 1 and 2 for help.)

b) How tall would a parade float be if its height filled the field of view when it was a football field length (100 yards or about 30m) away from the binoculars?

c) If a 6-foot-tall (about 2 m) person's image were to just fill the field of view, how far away would the person be standing?

The following problems refer to ACTIVITY 8, determining the resolution limit of your eyes. Since binoculars or telescopes (with eyepieces) increase the apparent diameter of a distant object, the observer can then see more detail. The magnification of a telescope or binoculars tells you how many times your resolution limit has been improved. A 10X (ten power) telescope will increase the resolution limit of your eyes by ten times.

EXAMPLE
In ACTIVITY 8, we learned that our friend Ronnie has a resolution limit of 1700/1. She can see two lights separated by 1 m at a distance closer than 1700 m.
With a 10X telescope, Ronnie could go up to 10 times that distance, or 17,000 m (10 miles), away from the lights and still see two points of light.

This information will be useful to answer some of the following questions:

10.24 Write your eye resolution limit in this space: ____________________

10.25 With your naked eye, what is the smallest diameter crater that you can see on the Moon, which is about 400,000 km (240,000 miles) from you?

10.26 If you were to use the 7X50 binoculars from Question 10.23, what would be the smallest crater you could see on the Moon?

10.27 Would these binoculars allow you to see the Earth and the Moon as separate points of light if you were at Venus during its closest approach to Earth (40 million km)? Show how you get your answer.

10.28 If you were orbiting at a distance of 480 km above the Earth, what would be the diameter of the smallest object that you could see on the Earth's surface?

10.29 What would be the diameter of the smallest object visible to you from this orbit using a pair of 11X80 binoculars?

QUESTIONS TO TEST YOURSELF

1. What are the similarities between the ratios you calculated in ACTIVITY 7 (when distances were measured by fingerwidths) and the ratios you found in ACTIVITY 9 (when distances were measured by a pinhole tube)?

2. How do the distance-to-size ratios calculated in ACTIVITIES 7 and 9 relate to the ratio used for the telescope calibration scale calculated in ACTIVITY 10C?

3. If you know the focal length of your telescope and the width of the image it creates, what else would you need to know to calculate the distance between the telescope and the object on which the telescope is focused?