7 - Pinhole Tube and Telescope

Instructions: Follow Parts I–IV to explore simple optics. Complete the questions (Q1–Q35) on a separate piece of paper and the provided Observing Log Sheets. Work with your group but submit your work separately.
Due: in one week, at class time

Part I: Pinhole

Purpose: To build a pinhole tube and use it to make a terrestrial measurement.

Materials:

- 2 nesting cardboard tubes
- straight pin
- aluminum foil
- ruler (may be on protractor)
- tracing paper
- measuring tape
- rubber bands
- 200-watt, unfrosted light-bulb lamp
- 2 stands
- clamps
- calculator

Pre-lab Question—What do you think?:

On your separate piece of paper, write your best estimate, based on your personal experience.

Q1) How many Sun-diameters fit between Earth and the Sun?

Procedure:

1. Filament Size: Measure the length of the filament (tightly coiled piece of wire) in the bulb (line XY in Figure 2). To make the measurement, place the ruler in front of the bulb. Close one eye and record the length. The filament is slightly curved; therefore, measure the straight-line distance between the two ends of the filament. Measure and record the length with the ruler behind the glass. Average these two values.

Q2) Record and label the length of the filament (XY) in centimeters (cm)

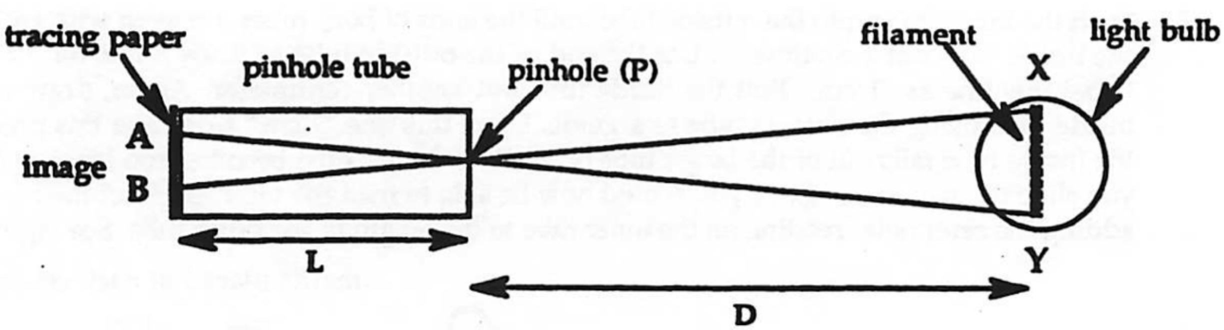

Figure 1: Diagram of the relationship between the filament length (XY), pinhole-to-filament distance (D), length of pinhole tube (L), and length of image of the filament on the tracing paper (AB).

2. Check that the two paper tubes fit together easily. Slide the inside tube into the outside tube. Check to see whether or not the inside tube slips out on its own. If the inner tube slips out without pulling, you can experiment with adding a layer of tape to the inside tube or wrapping a rubber band around the end of the outside tube to prevent the inside tube from slipping out.

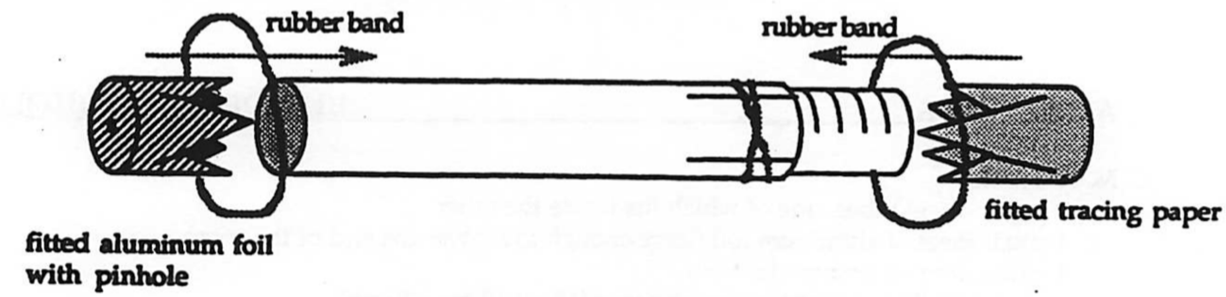

Figure 2: Pinhole tube

3. As in Figure 2, 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 a straight pin, slowly and carefully punch a small hole in the center of the aluminum foil. Check that the pinhole is round and not a linear rip.

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

6. Have the instructor or TA turn on the lamp for your station. DO NOT TOUCH THE BULB WHEN IT IS ON OR FOR A FEW MINUTES AFTER IT'S OFF. YOU MAY BE BURNED!

7. Acquire Filament Image: Set up the pinhole tube on a stand about one meter from the bulb. Aim the pinhole at the filament, keeping the pinhole tube horizontal and perpendicular to the filament of the bulb. Slowly move the tube and stand until you see a clear image of the bulb's filament on the tracing paper; it will appear as a small, curved bright line.

8. Investigate: Change the size of the tube by sliding the smaller tube in and out.

   Q3) Describe what happens to the image as you change the length of the tube.

9. Measure: Once you have found a nice, clear image of the filament, trace it on the paper. As accurately as possible, measure the distance between the filament and the pinhole, the length of the tube, and the length of the filament's image on the tracing paper.

   Q4) Record and label the length of the tube (L in Figure 1) in centimeters (cm).

   Q5) Record and label the distance between the bulb filament and the pinhole (D) in centimeters (cm).

Q6) Record and label the length of the filament's image on the paper screen (AB), in centimeters (cm).

Q7) Examine Figure 1. Draw a similar diagram on your separate sheet of paper. Label the filament, the tube, and the two triangles. Include your measurements from Q4–Q6.

Q8) Describe how triangles APB and XPY are related. For example, what property (or properties) is common to them both?

Q9) Calculate the ratio of the bulb-pinhole distance (D) to the filament length (XY). Show what happens to the units.

Q10) Calculate the ratio of the pinhole-tube length (L) to the filament image length (AB). Show what happens to the units.

Q11) Discuss the usefulness of the relationship of the ratio in question Q9 and the ratio in Q10. Compute the percent error: $\%\ \text{Error} = \dfrac{\left|\text{Q9} - \text{Q10}\right|}{\frac{1}{2}\left(\text{Q9} + \text{Q10}\right)} \times 100\%$

The Lab 7 Field Work: Estimating the Diameter of the Sun is a take-home portion of this lab. Before you leave, use the provided tube (not the sliding cardboard one used in class) and equipment to make a pinhole telescope. Plan with your group to observe the Sun (not looking directly at it) to measure its image size and estimate the number of Sun-diameters that fit between Earth and the Sun.

Part II: Simple Telescope or Camera

Purpose: To build a simple telescope or camera and use it to make terrestrial observations. Continue answering questions on your separate piece of paper, with your group.

Materials:

- 1 cardboard-tube set
- meter stick and measuring tape
- 1 large lens and red end-cap
- 2 stands
- tracing paper
- ruler (may be on protractor)
- 1 200-watt, unfrosted light bulb
- clamps
- Observing Log Sheet

Pre-lab Question—What do you think?:

On your paper, write your best estimate based on your personal experience.

Q12) 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 at all)? Describe what you expect. For example, would the image from a lens be brighter or dimmer? Bigger or smaller? Right-side-up or upside-down? Clearer or blurrier?

Procedure:

Refer to Figure 3 for the following instructions on how to build the telescope/camera.

Figure 3: Replace the pinhole with the large lens using the red cap (not tape).

10. Build the telescope: Remove the pinhole from the tube (if it's still on). Fit the large lens snugly against the front of the outer tube, making sure it's positioned perpendicular to the tube and well centered in the tube. Leave the tracing paper on or add a new piece of tracing paper to the end of the inner tube and secure it with a rubber band.

11. Investigate: Change the size of the tube by sliding the smaller tube in and out.

Q13) Describe what happens to the image of the bulb filament as the length of the tube is changed from as long as possible to as short as possible.

12. Measure: Stand about 2.5 meters from the 200-watt bulb. With the room lights off, aim the lens end of the tube at the bulb. Acquire a clearly focused image of the filament on the tracing paper.

    Q14) Measure the exact distance between the lens and the bulb filament. Record and label the value in meters (m).

    Q15) Measure the length of the tube at this distance, when the image is in focus. Record and label the value in centimeters (cm).

13. Move Away and Measure: Aim the telescope/camera at a distant bulb or move far from your bulb. Acquire a clearly focused image of the filament on the tracing paper.

    Q16) Describe the image you see on the tracing paper, including comparing it to how it looked in the previous step.

    Q17) Measure the exact distance between the lens and the bulb filament in meters (m) and the length of the tube in centimeters (cm). Record and label these values.

    Q18) Is the length of the telesscope tube longer or shorter than it was when you were closer to the bulb? Both times you were looking at clearly focused images.

    Q19) Thinking critically, if you want to project a clear image of a very distant object, would the telescope length have to be longer or short? How would the image change? Explain why you think so.

14. Observe a Distant Object: Step out of the laboratory and aim the telescope at a very distant object; try to go outside (take the manual, Observing Log Sheets, meter stick, and other lens). Adjust the sliding tube until the image is focused clearly on the paper. Be patient and let your eyes adjust; consider shading the paper end.

    Q20) Describe and accurately draw the image of the distant object you're observing on an Observing Log Sheet provided in lab. This will be a common form when we observe with the 6-in Celestron telescopes; become familiar with it and be descriptive and precise in recording your observations

    Q21) Measure, record, and label the length of the tube (cm) when the image of the distant object is as in focus as possible.

    Q22) Relative to the telescope-tube length measured in Q17, did you have to lengthen or shorten the telescope to bring the image into focus?

For a very distant object, the length of the tube or the distance between the tracing paper and 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.

Q23) Thinking about the images you created when standing close and far from the bulb in lab and then the distant object, describe what ways are the images similar and different.

You have now built a camera 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 such as spectrographs. The lens or mirror collects the light coming from a distant object. When taking astronomical pictures, the image can be focused on a CCD detector, like a digital camera. The tracing paper on your tube takes the place of a CCD.

CCDs were not invented until the late 1960's. Photographic film was not invented until the 1800's. Before then, astronomers looked through their telescopes and made drawings of what they saw. You will now convert your telescope so you can look through it.

Part III: Basic Use of Telescope

Purpose: To build a telescope and use it to make terrestrial observations.

Materials:

1 cardboard tube set
1 large lens with red end-cap
stand
1 small lens in foam and end-cap
tracing paper
Observing Log Sheet

Procedure:

Refer to Figure 4 for the following instructions on how to build the simple telescope.

15. Convert the Camera to a Telescope: Remove the tracing paper from your pinhole tube. Gently squeeze the foam holder and press the lens/holder assembly into the end of the smaller tube. Use the white cardboard ring to help push the foam holder into 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.)

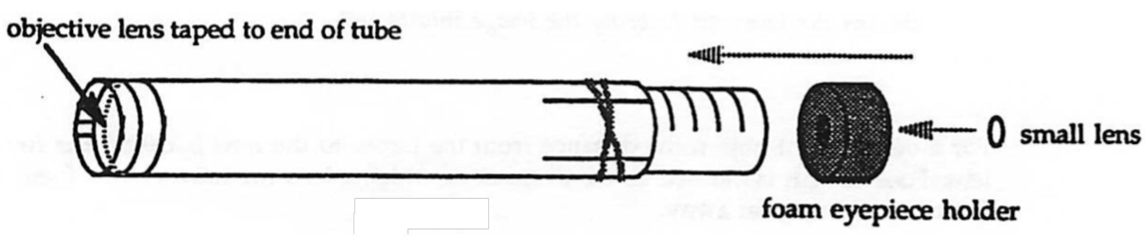

Figure 4: Replace the tracing paper end of the tube with the small lens inserted in the foam lens holder. Make sure the lens is positioned perpendicular to the tube.

NEVER LOOK AT THE SUN THROUGH THE TELESCOPE!

The large lens is called the objective lens. The small lens is called the eyepiece.

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

16. Measure: Take the telescope with the stand and go outside to observe an object at a great distance. Looking through the eyepiece, aim the objective lens of the telescope at the object. Adjust the telescope length until you see a focused image of the distant object.

Q24) Record and label the length of the tube in centimeters (cm).

Q25) Record your observation on an Observing Log Sheet.

Part IV: Calibrating Your Telescope

Purpose: To calibrate your telescope so that what you measure through the telescope can be used to measure the physical size of or the distance of the object.

Materials:

- 1 simple telescope (Part III)
- meter stick
- stand
- ruler (may be on protractor)
- calculator
- Observing Log Sheet

Procedure:

17. Measure: Find a meter stick, affixed vertically or horizontally against a wall, a few meters away. Position your telescope on the table and focus it on the meter stick. For this procedure, be careful to use the correct units. Recall: 1 m = 100 cm = 1000 mm.

    Q26) Carefully measure how many millimeters of the meter stick are visible in the whole field-of-view of your telescope. Record and label this value. Sketch it.

    Q27) Accurately measure the distance from the objective lens of your telescope to the region of the meter stick you viewed. Record and label this value.

18. Find the telescope scale:

    Q28) Divide your answer to question Q26 by your answer to question Q27:
    Q26/Q27 = (size)/(distance) and has units of mm/m.

The number in question Q28 is the telescope calibration scale. This scale is a size-to-distance ratio. The scale tells you the size of the object in millimeters that fills the whole field-of-view at a distance of one meter. This scale can be used to determine an object's size when the distance is known or to determine the distance to the object when the size is known.

19. Application: Set up your telescope to focus on a large object on the opposite side of the lab. Carefully observe the portion of the object that fills the entire field-of-view of the telescope.

    Q29) Describe and draw the object you've chosen on an Observing Log Sheet.

    Q30) Accurately measure the distance from the objective lens to the object in meters (m). Record and label this value.

    Q31) Using the telescope calibration scale (Q28), calculate the width of the portion of the object you observed to fill the field of view. Show your work, including units (should be millimeters).

    Q32) Measure and record the actual width of the portion of the object you observed.

Q33) Compute the percent error: $\% \text{ Error} = \dfrac{|Q31 - Q32|}{Q32} \times 100\%$

Given the equipment we are using, if percent error is less 10%, your calculated width (Q31) is accurate.

Q34) Now that you have calibrated your telescope, go back to your Observing Log Sheet (Q25). Make an estimate of either the size of the object you observed or its distance, using your telescope calibration scale (Q28). Describe your thought process (at least 100 words).

Q35) If you know the calibration scale 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? Describe in detail (about 100 words).