LU 8.2. Pinhole camera

Overview

School textbooks usually have a nice introduction about the pinhole effect and pinhole camera. In this Learning Unit, students will first make a pinhole camera using some easily available stationery material. They will explore how the pinhole camera can be used as a measurement device, and also understand why one can observe an image in it without using any additional devices like lenses.

Start the class with some discussions on students' prior experience with pinhole camera. You could ask them questions like the following to start the discussion.

- Have you ever made or seen a pinhole camera or read about it in textbooks?
- Have you seen an image of a tree or a building in a pinhole camera? Can you describe the image?
- Other than pinhole camera, what instruments you have used to capture image of objects in your science laboratory and outside? What are the components of those instruments?
- Do you think that this camera can be used as an instrument to measure size of these observed objects (trees or buildings)?
- Can you use pinhole camera to measure size of any large objects?

Motivation for the Learning Unit

The pinhole camera is an optical instrument that is simple to make and demonstrates some very important properties of light and concepts about image formation. In this Learning Unit, students will construct a pinhole camera that measures distances or size of objects in addition to capturing an image, without using any additional devices like lenses.

This unit consists of three tasks: 1) Making a cylindrical-shaped pinhole camera and carefully observing a clear image of a bright, large object. Here, the students are expected to discover that the image is vertically and laterally inverted; 2) Constructing a theoretical explanation for the inverted image based on evidences gathered in task 1, and 3) Using the pinhole camera to measure the size of a building or any large object.

Minimum time required: Four sessions of 40 minutes each

Type of Learning Unit: Classroom and field

Unit-specific objectives

- To design and understand the working and use of a pinhole camera
- To learn about scientific processes like model building, construction of explanation, and checking their validity
- To understand the optics of image formation in a pinhole camera, and (possibly arrive at) its implications on our theoretical understanding of the nature of light
- To learn a technique of measuring the size of a distant object

Links to curriculum

Class 6 Science	Class 8 Science
Chapter 11: Light, Shadows and Reflections	**Chapter 16:** Light

Introduction

The pinhole camera is a simple device which allows light to pass only through a very small hole of the size of a pin tip. By putting a screen (flat surface) at a distance from this hole, you can see the image of an object (present in front of the pinhole on other side) on the screen. If the screen is a thin translucent sheet, then the image can be observed on both sides of screen. See figure 1 below.

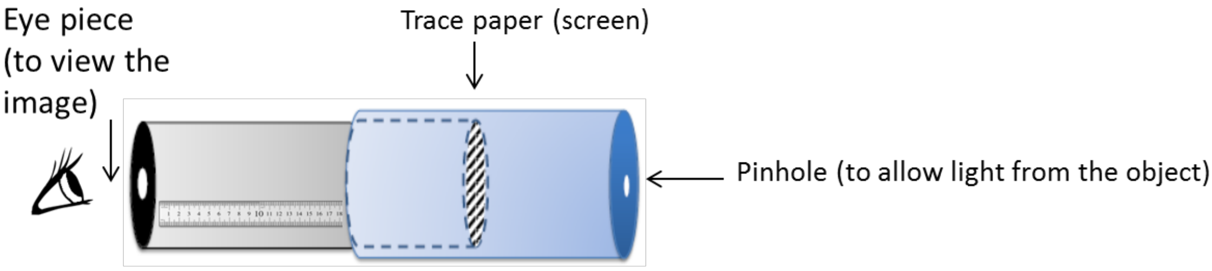

Figure 1 *Schematic of pinhole camera that also acts as a measuring device*

In this unit, you will make a pinhole camera and use it as a measurement device. You will also understand how image is formed by a pinhole.

Materials

Black chart paper, tracing paper/translucent polythene sheet, printed ruler on paper or graph paper, measuring tape, scissors, adhesive, cutter, sticky tape, aluminium foil used in kitchen.

Task 1: Making a pinhole camera

This stage is one of making and the task is to come up with a working pinhole camera. Instructions for making are given below.

i. Cut a rectangular piece from the black chart paper and roll into a hollow tube. Secure with sticky tape or with rubber bands so that the tube is firm. The diameter should be approximately 3 cm and height 25 cm.

Figure 2(a): *Rolling chart paper*

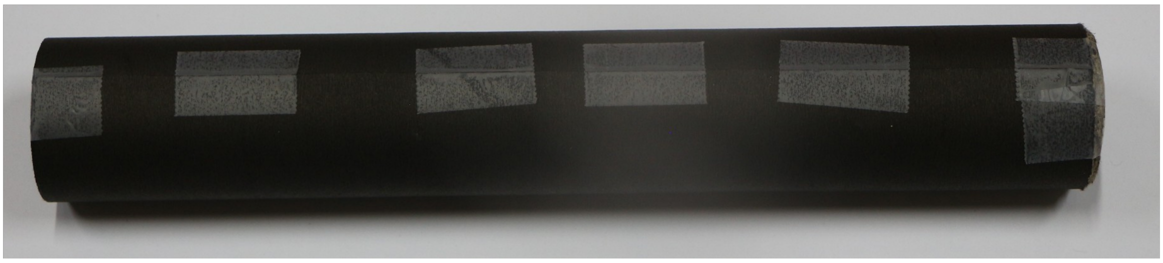

Figure 2(b): *Chart paper as pipe*

You can also vary the diameter and length of the tube. Smaller diameter will increase the clarity of the image. (One can also use the cardboard tubes on which aluminium foil or kitchen paper tissue are rolled.)

ii. Cover the other end of the tube with a translucent sheet of tracing paper or a similar material. This sheet will work as the screen. Let us call this tube as the image tube (IT). Put the markings on the screen as shown in figure 3 at every 5 mm. The markings will help in measuring the size of the image formed on the screen in task 3.

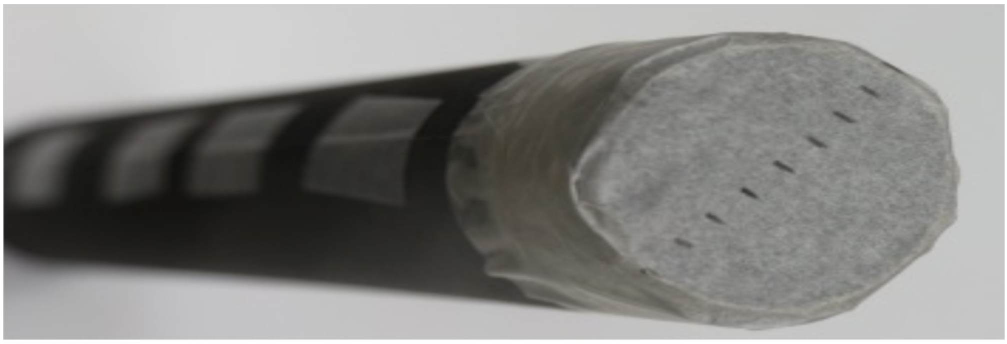

Figure 3: *Markings on screen for measuring image size*

iii. Fold another rectangular chart paper into a cylindrical tube such that it is smaller in length and slightly larger in diameter than the IT, so that the IT can slide inside smoothly. Cover one end of this tube with a circular black chart paper or aluminium foil and make a hole in the centre using a pin (aluminium foil is slightly easier to work with). We will call this tube the pinhole tube (PT).

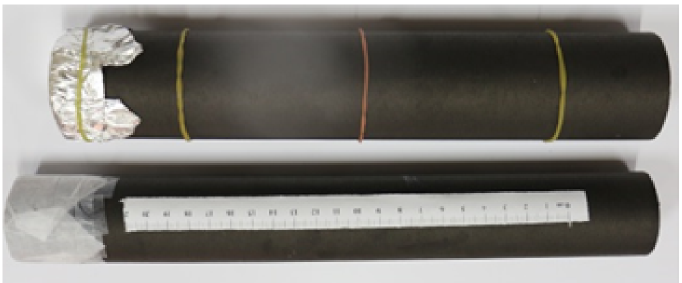

Figure 4: *IT and PT*

iv. Insert IT inside PT (as shown in figure 5) till the screen just touches the pinhole (refer figure 1). Mark a point 'O' on the IT where PT ends. Now take the IT out and stick a strip of white paper on it along its length (which is already done in figures 4 and 5). Taking point 'O' as zero, mark 5 mm intervals on the paper so that it can be used as a scale [You may also use a printed scale, if available]. This scale will be used to measure *l*, i.e., the distance between the screen and pinhole.

Now the pinhole camera is ready to use!

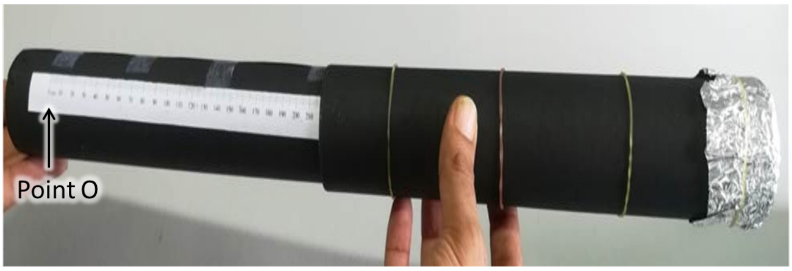

Figure 5: *Assembling the camera*

v. To view an image, point the pinhole towards the object (the object should be brightly lit) and adjust the distance between the screen and the pinhole to view a clear image of the object on the screen. A picture of Homi Bhabha Centre for Science Education building, Figure 6(a), when viewed through the pinhole is shown in Figure 6(b).

Figure 6(a): *Object*

Figure 6(b): *Image in pinhole camera*

Q1. What has changed from the object to the image? Can you describe the changes and think of reasons?

Q2. What happens to the image:

(I) if without changing the pinhole camera setting, if you move the pinhole further away from the object? Compare your image in terms of what view is covered now and before, size of image etc.

> This would be an exploratory activity for students. As they move away from the object, keeping the screen to pinhole distance same, the image size should decrease, and the **field of view** increases. You may prompt students to notice the image in terms of field of view, and image size if they don't discuss these changes.

(ii) if you increase the distance between the pinhole and the screen?

> This distance can be increased by moving IT. As this distance increases, the image size increases. This observation by students would be helpful to them later in understanding task 3.

(iii) if the illumination (brightness) of the object changes, or you look towards another object with lesser illumination?

> This observation is very important for students to understand that illumination of the object is one of the crucial factors to be able to see an image. For a poorly illuminated object, they may not be able to see the image.

Q3. Now explore what happens if pinhole size is smaller and larger respectively. First, make some guess of how variation in the pinhole size will affect the image. [You may compare the same object with pinhole cameras of different groups, which may vary in pinhole size.]

Task 2: Constructing a model to explain the image formation in task 1

Here our aim is to construct a geometrical model that would explain the image formation observed in task 1.

> A possible starting discussion: If time permits, teacher can start the discussion about image formation with the following two questions. These questions can help bring out some deeper alternate conceptions among students regarding nature of light and help them better understand the optics of pinhole camera.
>
> QT1. What do you think happens when we see an object with our eye? Can you explain?
>
> i) Light goes from our eyes and hits the object?
>
> OR
>
> ii) Light from the object reaches our eyes?
>
> QT2. Which of the above possibilities is consistent with what you observe in the pinhole camera? Historically, over the centuries, many philosophers and scientists tried to interpret light by looking for the answer to the above question. Option A was known as extramission theory of light and was considered by many scientists. Recent education research in many countries

> shows that a large number of students still have this conception in their mind. Such an explanation coincides with the colloquial perception that we see because we have light in our eyes and this idea is intuitively appealing.
> Option B is known as intromission theory of light and became acceptable because of the evidence that without a primary light source, our eyes cannot see.
> Note that the same ray optics diagrams can be drawn for both theories, with the difference that the direction of rays would be opposite in two cases. Hence, the fact that ray diagrams can explain image formation cannot be a basis for rejecting one of the theories completely.
>
> The pinhole camera provides significant evidence against extramission theory. When we look inside the pinhole camera tube, the screen is brightly lit but the sides are very dark. If the light were to emanate from our eyes as per extramission theory, then we should see the inside of the tube equally bright as the outside of the tube. Secondly, if we block the pinhole, then no image is observed on the screen. This observation also goes against the extramission theory.

One of the understandings that evolved over the years is that when light travels in a medium of constant refractive index, it travels in a straight line. Therefore, the path of light is represented using a ray. You must have seen ray diagrams in your science book.

> Although discussed in higher classes, it is important to remember in background (in case a discussion arises) that light travels in a straight line only when the medium is uniform throughout. The bending of light path can be observed in two conditions. The first case is when the medium has variations in refractive index (shift in medium density when light moves from cool to hotter air, e.g., observation of mirages on hot days). The second is when light encounters an obstacle or a thin slit (causing diffraction, e.g. seen as diffracted sunlight appearing behind trees).

Q1. Let us try to draw a ray diagram to represent the image formation obtained in task 1. One ray TP starting from an object which goes in a straight line towards the pinhole P will meet the screen at point T’, as already drawn in figure 7 below. Can you draw three rays similar to TPT’ originating from different points from the object in the figure?

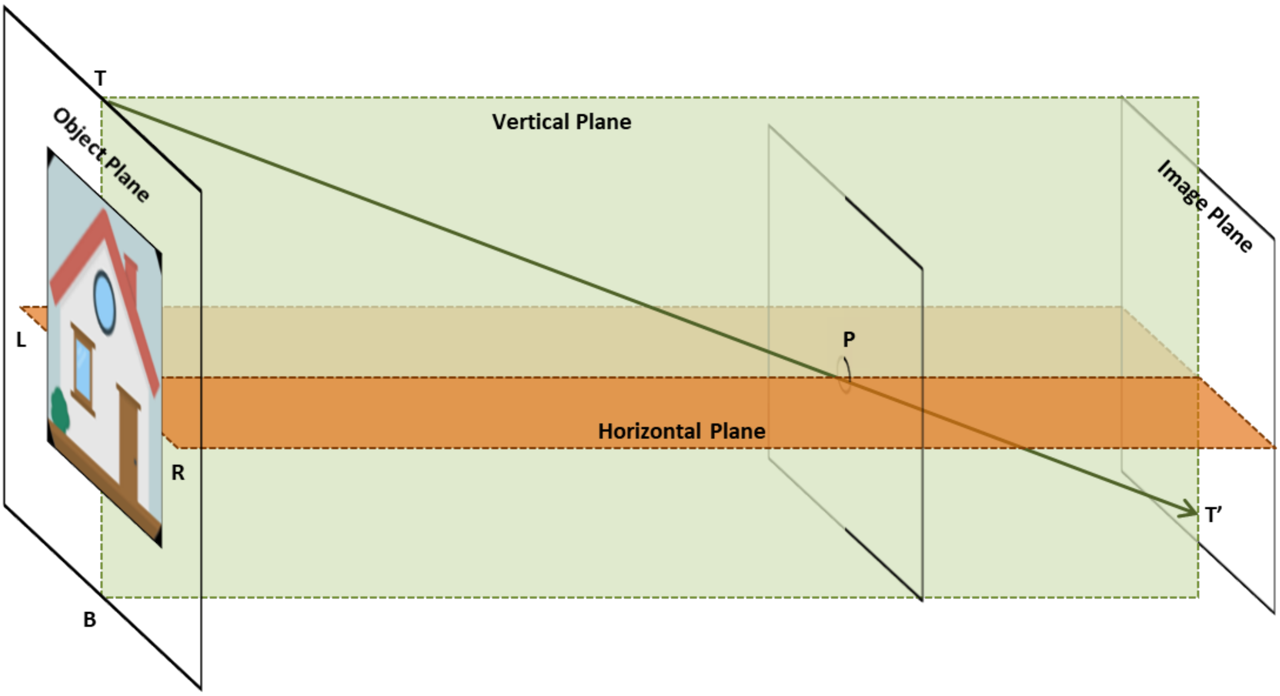

Figure 7: *Draw rays originating from the object and falling on screen*

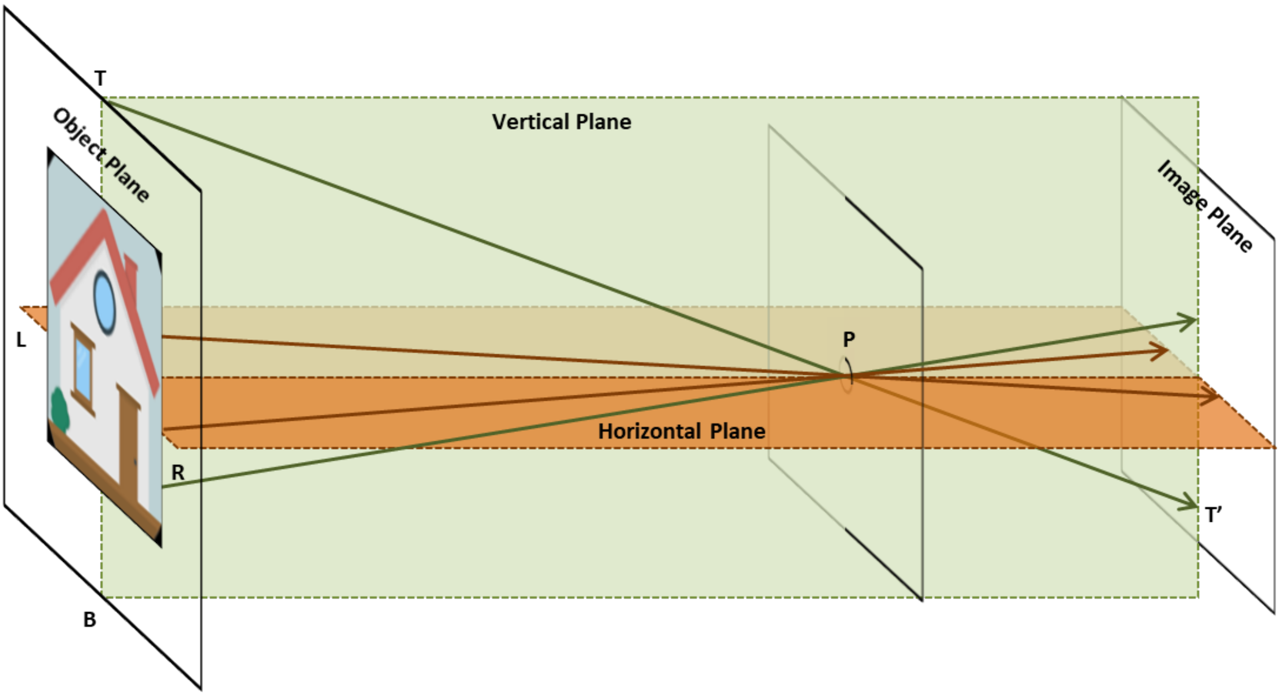

Figure 7T: *By drawing the rays in figure 7, students may be able to predict that the image will be vertically and laterally inverted*

Q2a. Refer to figure 8. Consider the ray ZPZ'. The ray starts from a green coloured point Z in the object. There is a brown coloured point at Q. What do you think will be seen at Z' in the image plane? A green dot or a brown dot? Similarly, suppose there is another ray QPQ'. What will you see at Q' in the image plane?

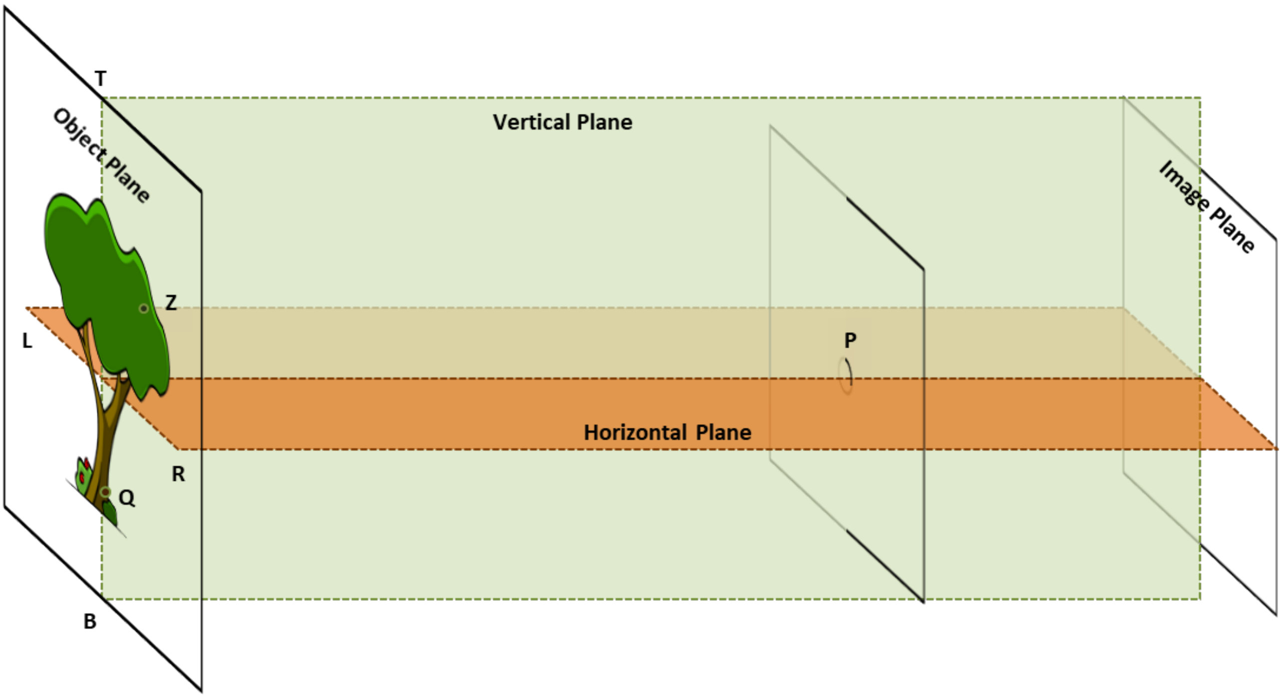

Figure 8: By drawing rays originating from the object, predict where green and brown points would be observed on the screen (image plane).

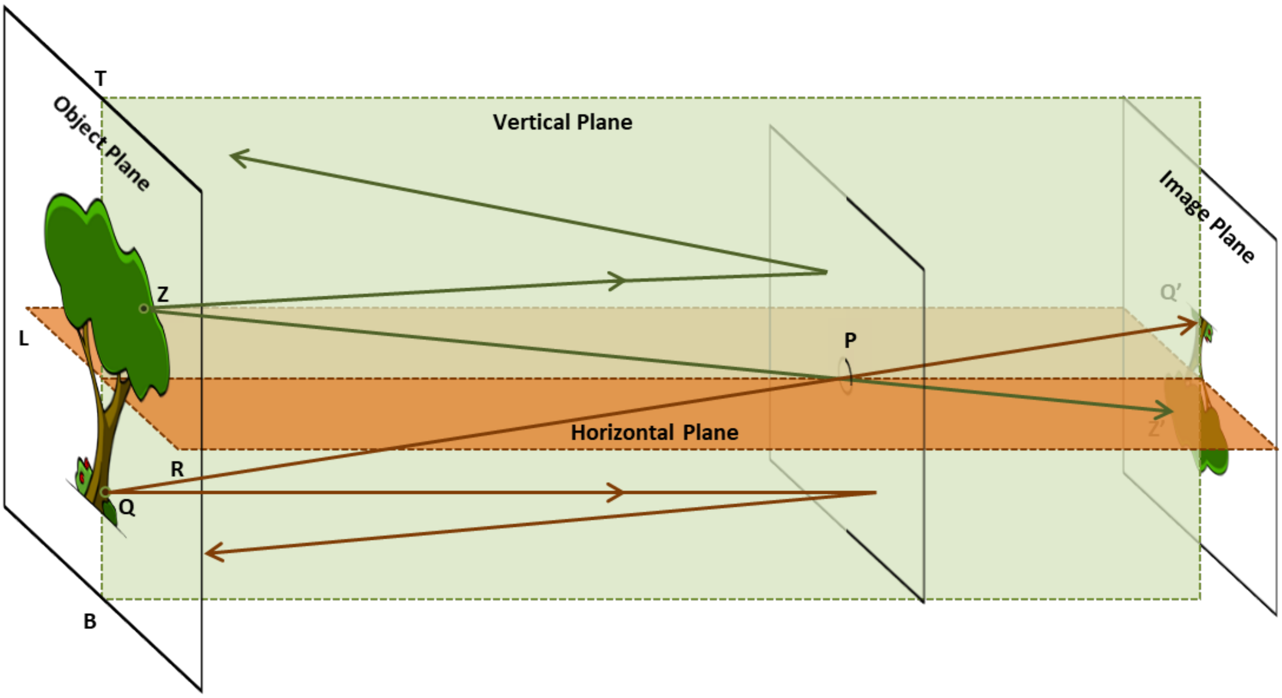

Figure 8T: Ray diagram that can help predict location of various colour points on the screen.

Q2b. Do you think there is a relation between the points on the object and the image plane? Discuss.

> There is a one to one correspondence between the points in object plane and image plane. For example, Z in object plane corresponds to Z' in image plane. Similarly, Q in object plane corresponds to Q' in image plane. Note that this idea may not be easy for students to understand, they may need some time to reflect on their observations and discuss with each

other.

Q2c. Referring to figure 8, can you explain the orientation of the image observed?

Q2d. What should be the light path if the image was to be of same orientation as the object? Check if this is observed in any of the pinhole cameras made by you or your friends.

Probe students about the orientation of image. The light must bend/travel in curved path for the image to be of same orientation as the object. This is never observed. Thus, pinhole camera is one optical device which can provide simple "evidence" for "light travelling in straight path".

Q3. Now, with the knowledge of light path discussed in the previous question, draw two rays in figure 8 which originate from the same point on the object, fall on the surface surrounding the pinhole (which acts as a blocking surface), and don't enter the hole. Where will these rays go?

Q4. If this blocking surface is removed, then where would these rays go? What would be the effects of these light rays on the image on the screen?

Some rays from the brown part will coincide with rays coming from green points. Hence multiple images will overlap, effectively producing no image at all.

Q5. What do you think will happen to the image if the size of the pinhole is too big? Is your answer consistent with your observations in task 1?

If the pinhole size is big, a larger number of rays originating from the same point on the object will enter the hole at different angles, forming images at different places on the screen reducing the clarity of image. In other words, we won't get a clear image.

Further questions to discuss: Based on the above model/representation of image formation, answer the following questions:

Q6. To get a clear image, why do you think object should be well-illuminated?

Because with less intensity of light coming from the object, a very faint image would form on the screen which may be difficult to see.

Q7. What do you think will happen to the image, if the size of the pinhole is too small? Is your answer consistent with your observations in task 1?

If the size of the pinhole is too small, very little light will enter, forming a very faint image which may be difficult to see. For a brightly illuminated object (or in bright sunlight), this may not be a limitation, and will result in sharper image. At this point, instructor can also mention about diffraction of light (bending of light) at the edges of pinhole. If the hole is extremely small, the image will be less clear due to significant diffraction effects. Although students need not have to be familiar with diffraction at this stage, it is a good place to spark students' curiosity about other optical phenomena.

Here, it might also be useful to reflect that the operational principle of the pinhole camera is different from (and simpler than) lens-based cameras. In this case, unlike lenses, the hole is not focusing any light on the screen. Here, it is the opaque material surrounding the hole (paper/foil) that blocks the light falling at numerous points on the material from transmitting and hence prevents formation of numerous other images (that would have been spatially displaced from the image) on the screen. Hence, you are able to see only one image with clarity. Increasing the size of the pinhole blurs the visible image because actually more images start overlapping around the central image (also the brightness on screen increases with hole size indicating more light is coming). Before 19th century, it was also known as *Camera Obscura*, as it worked by blocking most of the light (producing a dark chamber), while most other optical devices (such as *Camera Lucida*, microscope, or telescope) had lenses to collect maximum light and focus numerous images to overlap each other with minimal lateral displacement.

Task 3: Measuring the height of a very tall object

Pilot (Ideal scenario)

Figure 9 below shows the diagram for image formation in a pinhole camera.

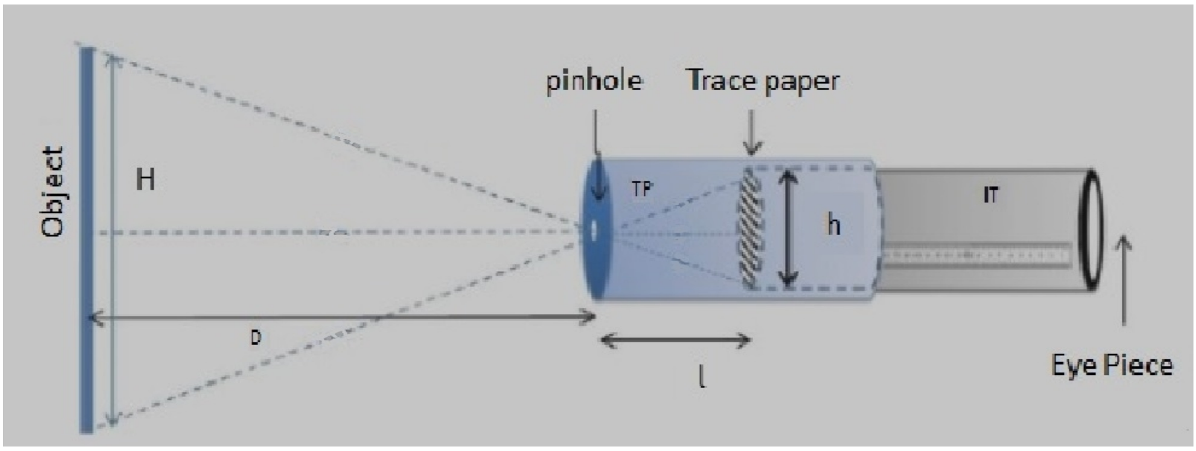

Figure 9: *Schematic diagram of pinhole camera*

You have to measure three quantities, distance (*D*) between pinhole and the object, screen-pinhole distance (*l*), and size (*h*) of the image on the screen.

Once you know *D*, *l,* and *h* you can find the height of the object H based on the following considerations.

Consider the two triangles in figure 9 with shared vertex at the pinhole. Since they are similar triangles, $h/l = H/D$. Rearranging we get $H = hD/l$

You may use the formula directly at this point without deriving it but you might want to check the properties of similar triangles to learn how the formula is derived.

The above scenario is an ideal one which may not be exactly the same in a practical situation. In the above derivation, the horizontal axis through the pinhole is assumed to be located at half the height of object. Also, the screen is assumed to be parallel to the object plane. In many situations, for example when you are looking at a building standing at the ground, the pinhole is located almost close to the base of the object. In such a case, the derivation would be slightly different. Even then, by using properties of similar triangles and approximating the screen to be parallel to the object plane, the above relation can be derived. Since students of Class 8 have not studied properties of similar triangles, this derivation may be skipped, but may be taken up with students of higher grades who are familiar with this concept.

Working (real) example

Now, we will make use of this equation in a real-life example. Take your pinhole camera, and capture an image of a distant (well-illuminated) object such as a building or a tree. Measure D using a tape, measure l using the scale on the inner tube, and h using the scale marked on the screen.

Obtain clear inverted image for multiple values of D. Tabulate your reading of D, l and h below:

D (cm)	l (cm)	h (cm)	$H = hD/l$ (cm)

Average height of the object, (Mean) H = _______________

Q1. Can you estimate the height of the object by any other methods? Compare it with the answer you obtained using pinhole camera?

Teachers should also try to get estimate of the height of the object with other methods (such as by knowing the height of each floor and multiplying by the number of floors) or from official records, to match the answer obtained from pinhole camera.

Discuss

Q2. If you want to see a bigger image on the screen (without changing the pinhole screen distance l), should you move the pinhole closer to the object or farther away?

Q3. What will happen to the image if you make the screen using a transparent plastic sheet instead of translucent sheet?

Suggested Readings

1. A brief history and principle of pinhole camera: http://www.alternativephotography.com/pinhole-history/
2. A website dedicated to pinhole camera's (History, principles, technical detail, etc): http://www.pinhole.cz/
3. A detailed history of pinhole cameras and its construction is available at:

https://jongrepstad.com/pinhole-photography/pinhole-photography-history-images-cameras-formulas/

4. Pinhole cameras have been used for taking actual photographic pictures. In 2017, pinhole lens (an attachment with a hole, and no glass) has been launched for DSLR cameras. (https://www.digitaltrends.com/photography/pinhole-pro-kickstarter/ and https://thingyfy.com/story-lens/)

Credits

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