Vigyan Pratibha Learning Unit (Teacher version)

Shadows

Take a look around and you will notice that all things form shadows. You must have played in the ground on a bright sunny day and seen that shadow formed by your body runs around with you. Have you ever noticed that the shadows change in size as the day progresses? Have you tried to check direction in which these shadows are formed with respect to you (object creating the shadow) and the Sun? Do you think that these shadows can be used to find the time of the day of your town?

In this unit we will try to get answers to the above questions using a simple model and a fairly easy experiment.

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Materials:

• 2 A3 size cardboard sheets	• Pins (3-4)
• A4 size blank papers	• Glue
• Mobile phone torch / LED light	• Cello tape
• Protractor	• Thread
• 30 cm ruler + 1 mt wooden ruler	• Scissors
• Pen/pencil	• Stone

Are you familiar with these ideas?

1. Latitudes and Longitudes
2. Tilt of the Earth’s axis of rotation
3. Equinox and Solstices
4. Horizon

Learning objectives:

- Understand how the length of a shadow changes with change in the altitude of Sun in the sky.
- Understand the variation in length of shortest shadow with the inclination of Sun's apparent path in the sky.
- Understand the concept of local noon and that it isn't necessarily at 12 noon according to your watch.

Task 1:

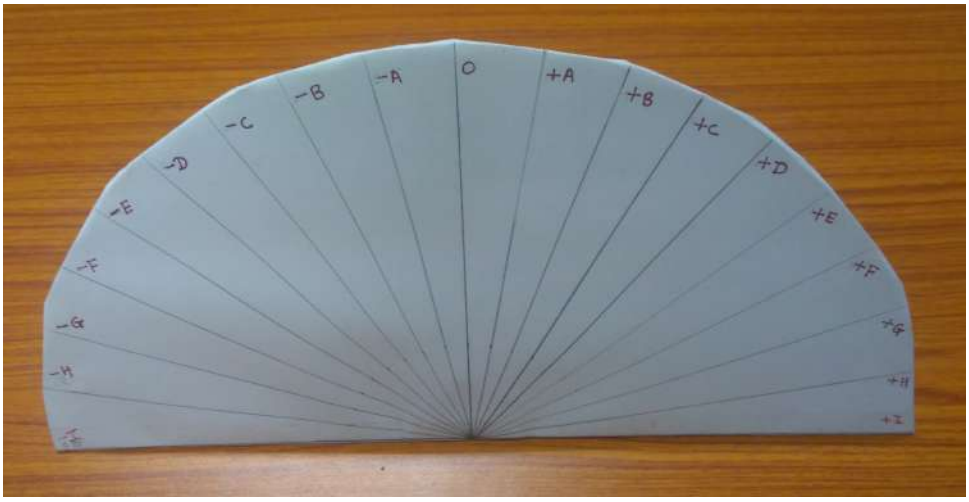
Model of Sun's apparent path in the sky

In this task, students are expected to make a cardboard model depicting the apparent path of the Sun at a particular latitude. This will be used to calculate the variation in length of the shadow with altitude of the light source (representing the Sun). Carry out the following task in groups of 4-5 students.

- Why is it called the apparent path of the Sun?

  Ans: The daily motion of Sun in the sky is observed due to the rotation of Earth about its axis. It is the Earth that goes around itself and since we are standing on the Earth we feel that the Sun is in motion (Earth rotates around itself from West to East once in ~24 hours).

1) Take an A3 size cardboard sheet and cover it completely with white paper (call it the "base").
2) Take another cardboard sheet and cut a semicircular arc (let's call it "arc") of diameter equal to the smaller edge of the cardboard (30 cm). This arc will represent the apparent path of Sun in the sky. Calibrate the arc using a protractor by marking angles at intervals of 5/10°. Mark the 90° point as letter 'O' and angles to the right as (A, B, C, D, E, F, G, H and I) and angles to the left as (-A, -B, -C, -D, -E, -F, -G, -H and -I). You need to make sure that the straight edge of the protractor coincides exactly with the straight edge of the arc while marking the angles.



3) Now, stick this arc to the base using cello tape at an angle in the range of 63°-70° from the base, such that the diameter of the arc is parallel to the larger edge of the base. This can be done using cardboard triangles cut at appropriate angles to support the arc.

   Note for the teachers: The axis of rotation of Earth is inclined with respect to the perpendicular to the Sun-Earth plane at an angle of 23.5°. Hence from the Sun-Earth plane the angle of inclination of a Sun's orbit will be 66.5° (we give a margin here of +/- 2.5° since this is just a demonstration). See the figure to the right.

4) Draw a line perpendicular to straight edge of the arc on the base such that it touches the line named "O" on the arc at the base.

5) Name point -I and I on the arc as "R" and "S" i.e. the rising point and setting point of the Sun respectively.

6) Fix a small pin (~ 2 cm) at the centre of the base (lets call it the central pin), such that it remains perpendicular to the base. Call this point as P.

   Note for the teachers: Height of the pin should be small (~ 2 cm) so that the minor tilts in the mobile phone torch's position will not cause significant changes in the length of the shadow.

7) Switch on the torch in a mobile phone and ensure the LED is close to the circumference of the arc. A shadow of the central pin will fall on the horizontal cardboard and it will move as the torch is moved along the circumference of the arc. Observe the motion of the shadow on the horizontal plane. Here, torch represents the Sun and the pin represents an object whose shadow is cast. The motion of the torch represents the movement of the Sun during the course of the day.

Note for the teachers: Make sure the torch/LED is a point source like mobile phone torch and not a directed source like the general torch. We need to make sure that the LED gently touches the arc. It should not change the inclination of the arc. Also, while making measurements, the lower tip of the LED should touch the arc.

8) Note the position of the LED light on the arc at which the shadow is shortest. Mark the position of the tip of the shadow as (P_1) and measure the length PP_1.

Note for the teachers: The length of the shadow is shortest when the Sun is at the highest point in its path. You should point out that Sun is not necessarily overhead. If the Sun is exactly overhead then the there is no shadow formed.

9) Now, move the mobile phone torch to point +A on the arc such that the bulb remains on the circumference of the arc. Measure the length of the shadow and mark the position of its endpoint as (P_2). Move the mobile phone torch to -A on the arc and repeat the exercise. Call this point as (P_3). Compare the lengths PP_2 and PP_3.

10) Measure angle P_1PP_2 and P_1PP_3 and compare it with the arc -AO and +AO.

11) Repeat step 9 and 10 for +B & -B and +C & -C and measure the length of shadow in each case.

12) What can you conclude after comparing the lengths in each case?

Note for the teachers: The length of the shadow in case of +A and -A will be approximately the same. Similarly, the lengths when the light is at

+B and -B will be same. Also angle P_1PP_2 and P_1PP_3 are equal to each other but they are not equal to arc -AO and +AO.

13) What will happen if you place another pin toward one of the sides?

a) When another pin is attached parallel to the straight edge of the arc besides the central pin, i.e. either towards the rising or setting point.

Ans: The angle on the arc at which the shortest shadow occurs changes for this model. This is not what actually happens. In real life, the object will always be at the centre of the horizon circle, by definition, hence this kind of situation will never occur.

b) When a third pin is attached perpendicular to the straight edge of the arc either between the arc and the central pin or beyond the central pin?

Ans: The length of the shortest shadow which is formed when the torch is at point O on the arc, changes. It reduces when you move closer to the arc and increases as we move away from the arc. This is similar to Sun's annular motion but we will explore this in detail in the follow-up units.

14) What do you think will happen to the length of the shortest shadow if the tilt of the arc is changed? Try to check it using the model and answer the question below.

- If the arc is at an angle lesser than 50^{o} to the base then,

a) There will be no shadow when the torch is at O mark on the arc.

b) The length of the shadow will be smaller when the light is at O mark on the arc.

c) The length of the shadow will be larger when the light is at O mark on the arc.

Note for the teachers: If the tilt of the arc is decreased, the length of the shadows will increase, while if the tilt of the arc is increased, the length of the shadows will decrease. Students might wonder if this really happens in the case of Sun? The answer is **YES**. This is exactly what happens when you go to different latitudes.

Task 2:

Students will use the knowledge of task 1 to understand the variation in the length of shadows and the concept of local noon. They will also understand how to find directions using shadows. Carry out the following task in groups of 4-5 students.

1) Find a flat portion of the ground where Sun is clearly visible and insert a 1m ruler in it making sure it is exactly perpendicular to the ground using a protractor or a string and mass.

   Note for teachers: One can also use flag-pole on the school ground.

2) Keep this setup ready before 10:30 a.m.

3) At around 10:30 a.m., mark the end point of the shadow of ruler on the ground using a chalk. You can mark the end point of the shadow by keeping a piece of chalk. Measure its length and note the time.

4) If you are in or around Mumbai, repeat this around 2:30 p.m. and then at an interval of 10 minutes till 3:30 p.m. Note the time and length for each measurement. If you are in Kolkata repeat this from 12:30 p.m. to 1:30 p.m. at intervals of 10 minute and note the time and the length of the shadow.

5) Find the time when the length of the shadow equal to that its length at 10:30 a.m.

6) What do you do if you do not find the exact same length of the shadow as it was at 10:30 a.m.?

   Note for the teachers: Measure the length of the shadow at a particular time (t_1) in the morning. Notice the change in the length and note the time (t_2) when the length of the shadow is exactly the same measured in the morning. If there is no exact match to the length as it was at 10:30 a.m. find the nearest value and try to interpolate the time when the lengths would match.

7) How will you now calculate the time of the shortest shadow?

   Note for the teachers: Students should use the concept learned in task 1. They have calculated the lengths of the shadows at same angles on either side of the highest point (which gave the shortest shadow) to be equal. The time of the shortest shadow is the mean of t_1 and t_2.

8) Can we find the four directions (N,E,S,W) using the shortest shadow?

Note for the teachers: Yes. The shortest shadow points in the North direction. And hence the perpendicular to the shortest shadow of the scale will show us the East and West direction. If you are facing North direction then to your right is East and to the left is West.

If you conducting the task close to Summer solstice, the shadow will point towards South for southern parts of India.

9) The moment at which the Shadow is shortest is called "*local noon*". See if the time you get for the shortest shadow is same as 12 noon in your watch. We will learn more about this in the next task.

Questions:

1) What would be the length of the shadow if the Sun was exactly above the stick?

   a) The length of the shortest shadow will be the same as you measured.

   b) The length of the shortest shadow will be zero i.e. you will see no shadow.

   Ans: If the Sun was overhead there will not be any shadow. You may ask the students to think if the Sun really comes overhead at local noon everyday. We will learn more about this in the later unit. The sun does come overhead twice a year for people living at latitudes less than 23.5° to the north and south of equator.

2) Do you think local noon is dependent on the place where your school is? Give reason?

   Ans: The answer is yes. We will learn more about this in detail in task 3. The reason is that Indian Standard Time (IST) is defined as per the local noon at 82.5° E longitudes (approximately close to Allahabad or Jabalpur) which is to the East of Mumbai and to the West of Kolkata. Hence in Mumbai, the local noon occurs after 12 noon in our watch while in Kolkata it occurs before 12 noon in the watch.

3) Will the time of the shortest shadow change, if the stick is tilted towards East or West?

   Ans: No. The time of the shortest shadow remains the same for a given tilt. For a different tilt angle, the length of the shortest shadow will be different.

4) Will the time of the shortest shadow change, if the stick is tilted towards North or South?

Ans: No. The time of the shortest shadow remains the same for a given tilt. For a different tilt angle, the length of the shortest shadow will be different.

Task 3: (Extd.)

1) Repeat task 2 after one month. Check if you get local noon exactly at the same time. What has changed?
2) Observe the point of rising and setting of the for next one month every 5 days. Try to see if there is any change in the position of the rising and setting point.
3) Go to Vigyan Pratibha portal and check the readings of the shortest shadow for school from some other states (call it school B and call your school A). Check the local noon times for their place and compare it with your local noon time.
    1) Was your local noon earlier than their local noon?
    2) Suppose school A, i.e. your school, observed that the local noon at your place was at 12:45 pm and on same day school B observed that their local noon was at 11:50 am then,
        a) School A is to the East of school B.
        b) School B is to the East of school A.
        c) School A is to the North of school B.
        d) School B is to the North of school A.