DAYTIME ASTRONOMY
WITH SELF-CONSTRUCTED EQUIPMENT

PRAJVAL SHASTRI

How do we introduce students to astronomy when regular school hours are nearly always during the day? Can students explore the sky without the expensive equipment that modern astronomers use? What can students learn from daytime astronomy and self-constructed equipment?

Has the sight of the Milky Way on a moonless night left you wondering if the Earth is the only planet that supports life? Have photographs of the distant universe filled you with a deep curiosity about where we come from? Astronomy seeks to investigate questions of this kind. To astronomers, everything we see in the sky with our naked eyes or with powerful telescopes like the Hubble, Spitzer, and Chandra, is an object of observation and study.

How do we introduce our students to the joys of astronomy? Since the sky is accessible to everyone, it is a 'universal laboratory'. Regular school hours are nearly always during the day when the glare of the Sun makes it difficult to see other celestial objects. But this does not rule out all possibilities. The Sun, the star nearest to us, and the Moon, our satellite, are visible during school hours. Daytime astronomy allows us to study these celestial bodies and phenomena related to them.

Observing the daytime Moon

Invite students to locate the daytime Moon (see **Activity Sheet I: Find the Daytime Moon**). You can use a lunar calendar to plan this activity. A lunar calendar is based on the monthly cycles of the Moon's phases. Arrange for your students to make the first of these observations when both the Moon and the Sun are visible in the sky (see **Box 1**). Work with your students to continue recording these observations on each day of an entire lunar cycle so that the days on which the Moon is not visible in the daytime sky are also noted (see **Table I**). You can encourage your students to make and record such observations at night (at home) too. Discuss and connect their

Box 1. What do we see of the Moon?

- The brightness of our Moon is due to the sunlight that is reflected off its surface. At any moment, the half of the Moon that faces the Sun is illuminated. This is called its day side. The other, darker, half of the Moon is called its night side.
- The Moon orbits the Earth (taking about 27 days, 7 hours, 43 minutes, and 11.5 seconds) at the same rate as it rotates on its axis. Consequently, only one of its sides is visible to us. This is called the near side of the Moon. The other side is called its far side (see **Fig. 1**).
- Since the Moon moves 12-13 degrees east on each day of its orbit around the Earth, we do not see the Moon at the same time every day. It only becomes visible to us after the Earth has rotated for a little longer (about 50 minutes more) each day.
- The part of the Moon's near side that is lit by the Sun changes from 0% (at 'new Moon') to nearly 100% (at 'full Moon'). This causes a change in the apparent shape of the Moon. We see eight such shapes, which we call the 'phases' of the Moon (see **Fig. 2**).
- On an average of 25 days of every month in the year, the Moon is close enough to the Earth and bright enough for it to be visible during the day. In contrast, when it is nearly new, too little of the near side of the Moon is lit by the Sun to be seen by us. And when the Moon is nearly full, it 'rises' at about the same time as the Sun 'sets' and 'sets' at about the same time as the Sun 'rises'. Seeing the Moon and the Sun together in the day is easiest in the mornings a week after full Moon ('third quarter' Moon) and in the afternoons a week before full Moon ('first quarter' Moon).

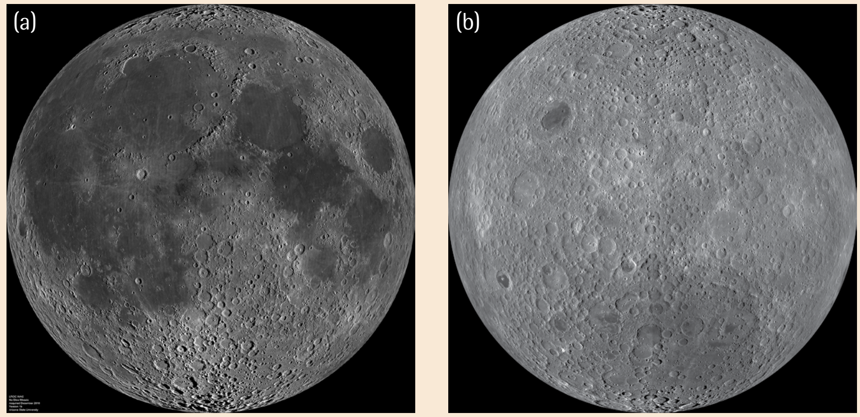

Fig. 1. The sides of the Moon as photographed by NASA's Lunar Reconnaissance Orbiter: (a) Its near side and (b) Its far side.

Credits: (a) NASA/GSFC/Arizona State University, Wikimedia Commons.
URL: https://commons.wikimedia.org/wiki/File:Moon_nearside_LRO.jpg. License: Public Domain.
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URL: https://commons.wikimedia.org/wiki/File:Moon_Farside_LRO.jpg. License: Public Domain.

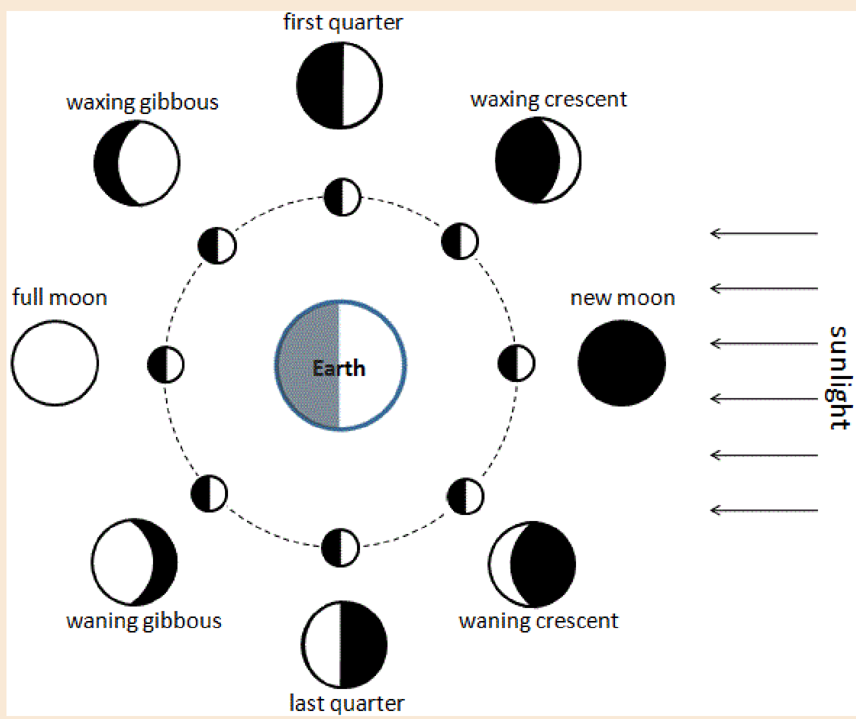

Fig. 2. The eight phases of the lunar orbit.

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URL: https://en.wikipedia.org/wiki/File:Moon_Phase_Diagram_for_Simple_English_Wikipedia.GIF.
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observations to related concepts in their textbooks.

Finding the daytime Moon can be a precursor to more in-depth activities on lunar orbits and eclipses.

Observing the Sun

Observing the Sun directly can cause eye damage. However, we can study the Sun by projecting its image on a flat surface. One way to do this is through a 'magic mirror' (see **Activity Sheet II: Construct a Magic Mirror).** Another is through a mounted solar ball projector (see **Activity Sheet III: Construct a Mounted Solar Ball Projector).** These easy-to-

Table 1. An example of an observation template to track the Moon.

Observing site	Date	Time	Sky condition	Angle between the Sun and the Moon	Shape of the Moon
School playground	Sun 20 Mar 2016	13:00	Clear		
School playground	Mon 21 Mar 2016	15:00	Partially cloudy		
Local park	Sun 20 Mar 2016	11:00	Partially cloudy		
School playground	Wed 23 Mar 2016	11:30	Mostly clear, passing clouds		

Box 2. What is a pinhole camera?

It is a camera without a lens, but with a pinhole-sized aperture through which it focuses all light rays within the smallest possible area to produce an inverted image. Such cameras occur in nature too. One example is that of the gaps between the leaves of a tree (see **Fig. 3**).

Fig. 3. Natural pinholes. The crescent-shaped patches of light seen in the shade of the tree are images of the Sun (during a partial solar eclipse) made by natural pinholes (gaps between leaves).

Credits: Thayne Tuason. URL: https://commons.wikimedia.org/wiki/File:Solar_Eclipse_August_21_2017.jpg. License: CC-BY.

Students can construct such a camera by themselves. All this requires is a light-proof box with a small pinhole-sized aperture on one side and a film on the other. When the aperture of the camera is focused on an object, the light reflected by the object enters the box through the pinhole and forms an inverted image on the film.

construct devices act like analogues of a pinhole camera (see **Box 2**).

What does an image of the Sun look like? Start by drawing your students' attention to the shape of the bright patch projected on the screen (see **Activity Sheet IV: Study the Sun with a Magic Mirror** and **Activity Sheet V: Study the Sun with a Mounted Solar Ball Projector**). This is an image of the Sun. Occasionally, your students may observe some dark splotches within this patch. These may be sunspots (see **Box 3**).

Your students may wonder if the shape of the image they see is a result of the circular paper mask on the mirror. This can be disproved using the magic mirror. Regardless of the shape of the mask (circular, triangular, square, or star-shaped) on this mirror, the patch remains circular. This is because the patch is an image of the Sun (see **Box 4**).

Getting a good image of the Sun will depend on three factors: (a) the size of the hole in the mask; (b) the distance of the imaging device (magic ball or mounted solar ball projector) to the projection screen; and (c) the darkness of the room with the screen. The larger the size of the hole in the mask, the further the screen needs to be to get a pinhole-like effect. But the larger the size of the hole in the mask, the more the amount of light the mirror in these devices gathers. While the image produced on screen is bigger and brighter, it has less clarity. The darker you make the room (for example, by using dark curtains to cover all the windows, ventilators, and other openings), the clearer the image appears to the observer. Let your

Box 3. What are sunspots?

While they may look like spots, these are really planet-sized areas on the surface of the Sun. Each such spot has a strong magnetic field (the strength of these magnetic fields is much stronger than anywhere else on the Sun and about 2500 times that of the Earth). The strength of the field inhibits the rise of hot new gas from the core of the Sun to its surface. Consequently, these areas are much cooler than surrounding areas and much darker in appearance (see **Fig. 4**). You can read more about sunspots here: https://annex.exploratorium.edu/sunspots/research2.html.

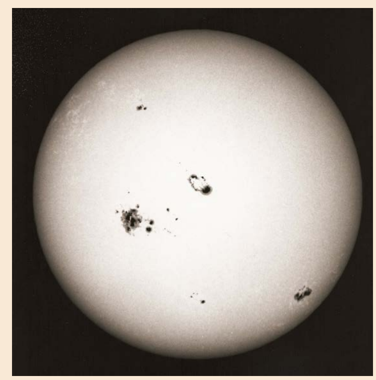


Fig. 4. The Sun with dark sunspots.

Credits: Hans Bernhard (Schnobby), Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Sun_with_sunspots.JPG#file. License: CC BY-SA 3.0 DEED.

To increase the likelihood of seeing sunspots, check out the daily satellite image of the Sun on the NASA/SOHO website (URL: http://sohowww.nascom.nasa.gov/data/realtime/hmi_igr/512/). Plan the activity on a day when you can see discernible sunspots on these images. Keep in mind that the possibility of seeing sunspots increases if they are reasonably large in size and you can get a reasonably sharp image of the Sun.

students experiment with changing the size of the hole in the masks, the distance between the device and the screen, and the darkness of the room. Encourage them to use observations from these experiments to identify tradeoffs between these factors and the clarity of the image for themselves. This exercise will help bring home the idea of pinhole projection. A mirror mask with a hole of about 2 cm diameter and a projection screen 30 metres away in a darkened room produces a clear sharp image.

A darkened room can function as a data-gathering studio. Mount sheets of paper on the projection wall and encourage your students to use these to track and mark the Sun's position and movement over several days. This can be used to introduce them to the day-to-day and seasonal movements of the Sun. In this context, a mounted solar ball projector offers some advantages. Regardless of the position of the Sun in the sky, the path from the projector to the screen can remain roughly parallel to the ground. This makes the projector very convenient. Mounting the heavy, weighed-down ball on a ring makes the projector more stable. This can increase the clarity of the image produced on the projection screen. Playing around with pointing this device at the Sun can also give students a feel for what astronomers call altazimuth (or 'alt-az') mounts (see **Box 5**).

Box 4. How do we know that the circular patch projected on the screen is an image of the Sun?

This can be convincingly demonstrated by a simple indoor experiment. Darken a room to allow light to come in from only a single small hole and fall on a clear wall. If someone holding a bright lamp were to stand outside the room and face the hole, you would see an inverted image of the lamp projected on the wall. If the person standing outside swung the lamp, the orientation and intensity of the image on the wall would change, but the shape would remain the same. It would also remain the same if you changed the shape of the hole through which light enters the room. This is what happens when you use the mounted solar ball projector to get an image of the Sun. The shape of the Sun's image would not be affected by a change in the position of the Sun in the sky or a change in the shape of the mask covering the mirror.

Box 5. What is an altazimuth mount?

It is a simple mount used to support and rotate instruments, like ground-based telescopes, along two axes: (a) a vertical altitude axis, and (b) a horizontal azimuth axis (see **Fig. 5**).

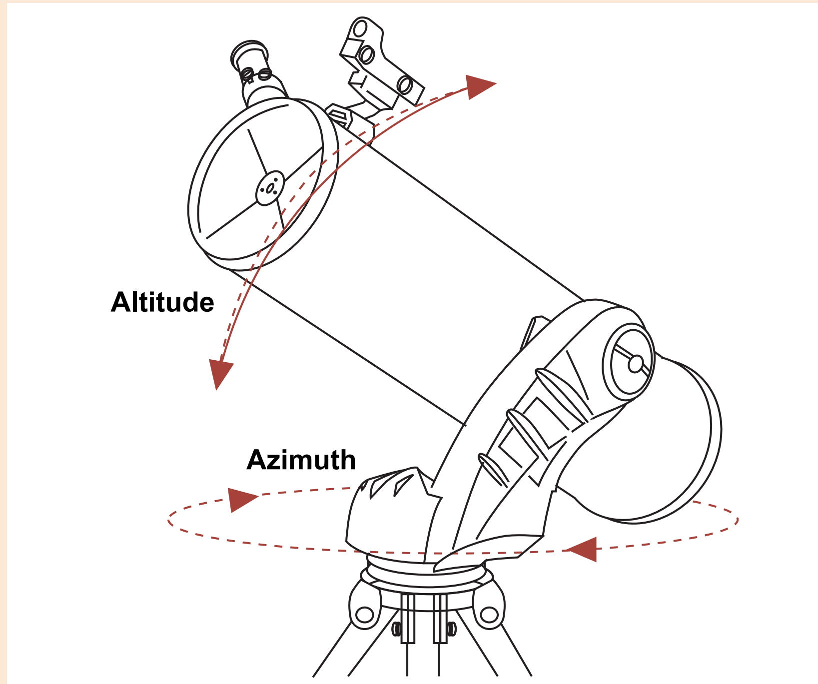


Fig. 5. An example of an altazimuth mount.

Credits: Adapted from BBC Sky At Night Magazine's: 'What's the difference between an equatorial mount and an altazimuth mount?' authored by Ninian Boyle. URL: https://www.skyatnightmagazine.com/advice/difference-equatorial-altazimuth-mount.

When used in the construction of the ball projector, it allows students the flexibility of two kinds of circular movements—up and down and from the left to the right. A combination of these mount movements allows students to observe the Sun in any direction or point in the sky above the horizon without having to move the entire setup to do so.

Parting thoughts

Astronomy is a delightful way to study heavenly bodies that are very far away and very big, yet amenable to the laws of physics as we on Earth understand them. Through daytime astronomy with self-constructed equipment, we can introduce students to the study of such bodies during school hours. Constructing and working with their own equipment and making their own observations can help students develop a less abstract and much stronger understanding of related concepts in the school curriculum.

Key takeaways

- Students can engage with astronomy during school hours through simple activities and self-constructed equipment.
- Locating the daytime Moon and recording its position on each day of a fortnight can help students map the phases of the Moon and track its movement relative to the Earth.
- Projecting an image of the Sun on a screen and tracking its movement can help students capture day-to-day and seasonal changes in our position relative to the Sun.
- Constructing and using a magic mirror and a mounted solar ball projector to view the Sun can give students a feel for the tools astronomers use to study objects in the sky.

Acknowledgements: The 'Magic Mirror' and 'Mounted Solar Ball Projector' were designed and developed by Navnirmiti, India, during Navnirmiti's Suntrek at Solar Maximum (2000) and the Transit of Venus Campaign (2004) respectively. These and other daytime astronomy experiments are available on the Navnirmiti website: www.navnirmitilearning.org. Demonstrations of these activities can be found on the Navnirmiti YouTube channel. These videos are produced by Vigyan Prasar in association with Navnirmiti Learning Foundation and Bharat Gyan Vigyan Samiti, Karnataka. I would like to thank the lead designers of Navnirmiti Learning Foundation—Vivek Monteiro and Geeta Mahashabde—for our discussions on this theme.

Notes:

1. This article was first published in i wonder…, June 2016, pp. 77-82. The original draft can be found here: https://publications.azimpremjiuniversity.edu.in/1257/. The version included in this issue has been reviewed and modified for school teachers. It includes new material and five activity sheets.
2. Source for the image used in the background of the article title: Sun vs Moon. Credits: Dino Abatzidis, Flickr. URL: https://www.flickr.com/photos/atomicshark/727649411. License: CC-BY-NC-SA 2.0 DEED.

Additional resources:

1. One example of a lunar calender: https://stardate.org/nightsky/moon.
2. More information on safe viewing: Suraj Zameen Part 13: Safe Viewing. URL: https://www.youtube. com/watch?v=-Xdy5TOi2E4.
3. More information on pinhole cameras: Suraj Zameen Part 2: Pin Hole. URL: https://www.youtube.com/watch?v=H0ythHRZsXc.
4. More information on solar ball projectors: Ball Mirror. URL: https://www.youtube.com/watch?v=6vK5hZaO0l0.
5. More information on magic mirrors here: Suraj Zameen Part 3: Magic Mirror. URL: www.youtube.com/watch?v=oLMyv0zZavA.

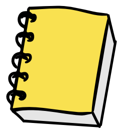
References:

1. Young M (1972). 'Pinhole Imagery'. American Journal of Physics, 40 (5), 715-720.
2. Monteiro V (2004). 'Measuring the Universe with a String and a Stone'. Navnirmiti. URL: https://navnirmitilearning.org/wp-content/uploads/2021/07/Measuring-the-Universe-With-a-String-and-a-Stone-%E2%80%93-Transit-of-Venus-Experiment-2004.pdf.
3. Monteiro V (2008). 'Sun-Earth experiments: Activity Cards for Day Time Astronomy'. Navnirmiti. URL: https://navnirmitilearning.org/wp-content/uploads/2021/07/Sun-Earth-Experiments-Activity-Cards-for-Day-Time-Astronomy.pdf.
4. Nilsson T H (1986). 'Pinhead Mirror: A Previously Undiscovered Imaging Device?'. Applied Optics, 25 (17), 2863-2864.
5. Nityananda R (2021). 'Observing Light: Shadows and Reflections'. i wonder... (6), 46-50.

Prajval Shastri is an astrophysicist. Her core research interest is in empirical investigations of supermassive black holes. Acutely aware of her privilege of being paid to be fascinated by the universe, she is continually amazed by the passion of amateur astronomers. Her core angst is discontent with early science education. When this article was first published, Prajval was working at the Indian Institute of Astrophysics (IIA), Bengaluru. She can be contacted at prajval.shastri@gmail.com.

ACTIVITY SHEET I : FIND THE DAYTIME MOON

Materials you will need:



A notebook for recording observations

Conditions you will need:

You will need to be out in the open under a relatively clear sky. A fair part of the sky, including our Sun and Moon, needs to be visible at least on and off.

Observe and explore:

- The Moon in the daytime sky.
- What is its shape? Note down the rough shape in your log book with the date and time of observation.
- What is the orientation of its shape with respect to the horizon or skyline directly below it?
- What is its location in the sky relative to the Sun (for example, is it to the southeast or northwest of the Sun)?
- Point one straight arm at the Sun and the other at the Moon. What is the approximate angle made by your arms?

Observing site	Record 1	Record 2	Record 3	Record 4	Record 5
Date					
Time					
Sky condition					
Shape of the Moon					
Orientation of the shape of the Moon to the horizon					
Location of the Moon relative to the Sun					
Angle between the Moon and the Sun					

Repeat these observations:

- At intervals of about 30-60 minutes on the same day.
- Over subsequent days.

Explore and discuss:

Think about the lunar orbit. Does it explain the changes you have observed in the moon over a period of a few days?

Contributed by:
Prajval Shastri, who is an astrophysicist. She can be contacted at: prajval.shastri@gmail.com.

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ACTIVITY SHEET II : CONSTRUCT A MAGIC MIRROR

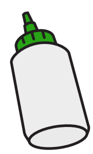
You will need:

A squarish plane mirror about 3 cm x 3 cm in size

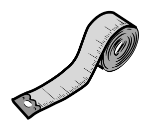
Thick black paper about 15 cm x 15 cm in size

A circular coin

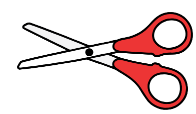
A small ruler



Adhesive



Measuring tape



A pair of scissors

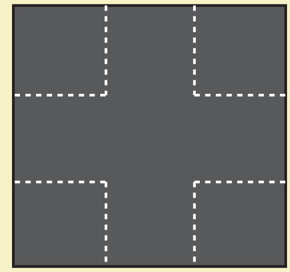
Construct:

1. From each corner of the black paper, cut out a square piece of size 5 cm x 5 cm with the cuts parallel to the edges of the paper. This will leave you with a piece of paper shaped like a large 'plus' sign. The arms of the plus will be squarish in shape.
2. Draw a geometrical shape on each of the squarish arms of the plus-shaped paper. Each of these shapes need to be smaller in size than the size of the mirror. Cut each of these shapes out. For example, cut out:
   a. A square from the top arm of the plus
   b. A circle (using the coin to draw it) from the left arm of the plus
   c. A star from the right arm of the plus
   d. An equilateral triangle from the lower arm of the plus
3. Use some adhesive to fix the mirror in the area at the centre of this plus-shaped piece of paper.
4. Each of the square arms can be folded over the mirror. Try doing this one-by-one. Observe how the cutout shapes act as differently shaped masks. Your magic mirror is ready to use!

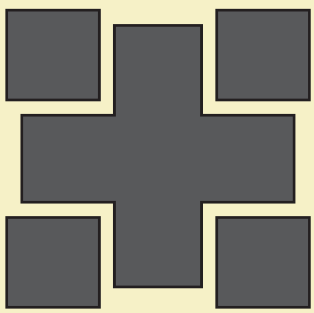
Contributed by:
Prajval Shastri, who is an astrophysicist. She can be contacted at: prajval.shastri@gmail.com.

Construction of a Magic Mirror: A Pictorial Guide

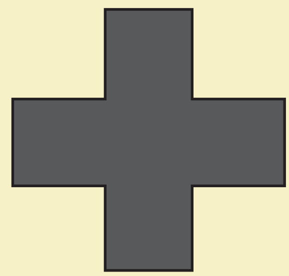
1. Take a square of black paper.



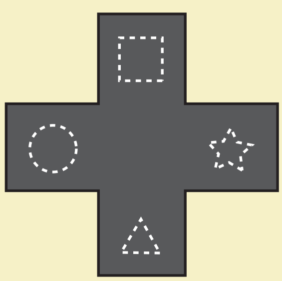
2. Draw four squares of equal size at the four corners of the paper.



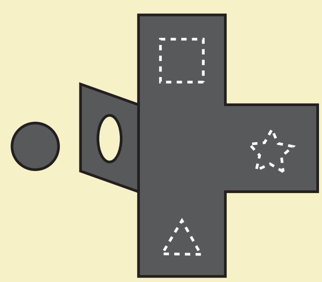
3. Cut out the four squares of paper from the four corners.



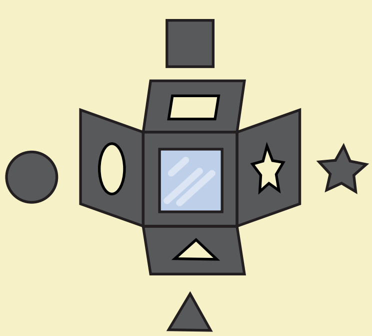
4. You will end up with a paper shaped like a plus.



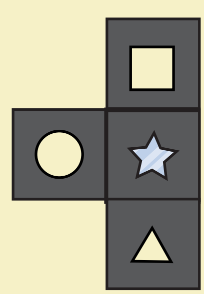
5. Draw outlines of four different shapes, one on each of the arms of the plus-shaped paper.



6. Cut out the different shapes from the arms of the plus. Each of these arms will act like a mask.



7. Stick the square mirror at the centre of the plus-shaped paper.



8. Fold the masks over the mirror one by one. The mirror will be visible through each of the cutout portions.

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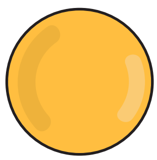
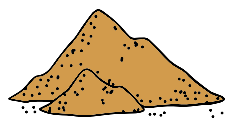
ACTIVITY SHEET III : CONSTRUCT A MOUNTED SOLAR BALL PROJECTOR

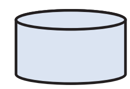
You will need:



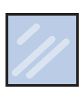
A medium-sized stiff plastic toy ball



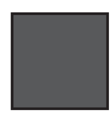
Some sand to fill the ball



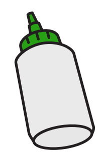
A used ring of sticking tape, a tennikoit ring, or a stable flat cylindrical container (without its lid and with a diameter that is about half that of the ball)



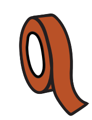
A small mirror (about 3 cm x 3 cm)



A piece of stiff paper slightly larger than the mirror

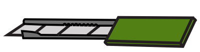


Adhesive



Sticking tape

A circular coin



A paper cutter

To construct the projector:

1. Draw a 2.5 cm x 2.5 cm square on the plastic toy ball.
2. Use the paper cutter to cut through three sides of this square to create a squarish flap.
3. Use the hole to fill the ball with sand. The ball should be a little more than half full. This will help weigh the ball down.
4. Close the hole with the flap and seal it off with sticky tape.
5. Mount this ball on the ring in such a way that you can rotate it smoothly around the ring but it stays firmly in position when left alone.
6. Use the coin to mark a circle of about 2 cm diameter in the centre of the stiff paper.
7. Use the paper cutter to cut the paper out of this circle. What will be left behind is a piece of card paper with a circular hole at the centre.
8. Use adhesive to stick the mirror to the piece of card paper in such a way that the circular hole in the paper is positioned roughly at the centre of the mirror. Ensure that none of the adhesive covers the reflecting surface of the part of the mirror that is visible from the circular hole of the card paper.
9. Use sticky tape to stick the 'masked' mirror firmly onto the ball. Ensure that the sticky tape does not cover the reflecting surface of the unmasked part of the mirror. Your mounted solar ball projector is ready!

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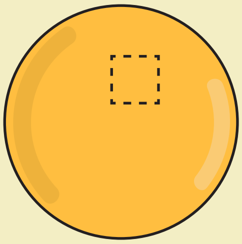
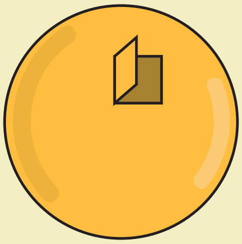
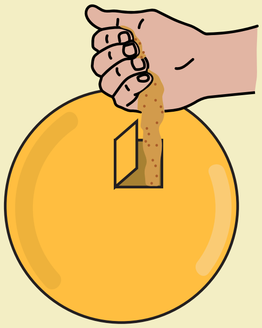
Construction of a Mounted Solar Ball Projector: A Pictorial Guide



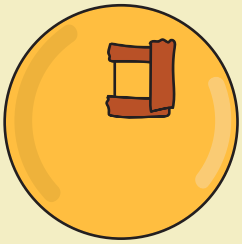
1. Draw a square on the plastic ball.



2. Cut the ball along three sides of the square to create a flap.

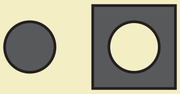


3. Pour sand into the ball through the flap.



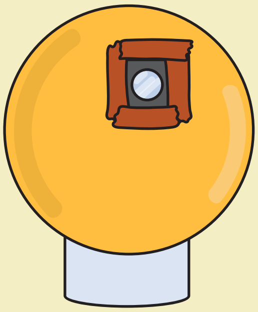
4. Close and seal the flap with tape.

5. Use a coin to trace the outline of a circle on a square piece of black paper.



6. Use the paper cutter to cut out the circular piece from the paper.

7. Use the adhesive to attach the mirror to the black paper.



8. Use tape to attach the 'masked' mirror to the ball.

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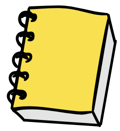
ACTIVITY SHEET IV : STUDY THE SUN WITH A MAGIC MIRROR

Materials you will need:



A notebook for recording observations

Conditions you will need:

Skies clear enough for the Sun to be visible (at least on and off) and an area open to leave you with not too much of your view of the sky obstructed.

What to do:

1. Take the magic mirror outdoors to a spot where the Sun is visible.
2. Hold the mirror out to 'catch the Sun'. Experiment with the position and tilt of the mirror to project the bright patch of sunlight onto a surface about a metre away. This surface could be a wall, a sheet of paper held by a friend, or the surface of a person's clothing. If you project it on a person's clothing, ensure that the person's back is turned towards the mirror. This is to avoid blinding them by accidentally projecting the Sun into their eyes.
3. Fold the square mask over the mirror to cover it. Observe the effect this has on the shape of the bright patch.
4. Increase the distance between the mirror and the projection surface to about 8-10 metres. Again, observe the effect of this distance on the shape of the bright patch.
5. Remove the square mask and fold one of the other masks over the mirror. Repeat steps 3 and 4. Do the same with each of the remaining masks.

Projecting through	What does the patch look like?
The mirror	
The mirror covered with the square mask	
The mirror covered with the circular mask	
The mirror covered with the star-shaped mask	
The mirror covered with the triangular mask	
The mirror covered with the triangular mask moved to a greater distance from the projection surface	

Think about:

- Do you see a pattern in the shape of the patch when it was observed through different masks or at different distances from the projection surface? If yes, how would you explain this pattern?
- Let us assume that the patch you are observing is an image of the Sun. How would you verify this assumption?

Contributed by:
Prajval Shastri, who is an astrophysicist. She can be contacted at: prajval.shastri@gmail.com.

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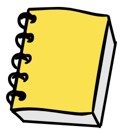
ACTIVITY SHEET V : STUDY THE SUN WITH A MOUNTED SOLAR PROJECTOR BALL

Materials you will need:



A notebook for recording observations

Conditions you will need:

A reasonably clear sky with the Sun visible at least on and off.

Position:

- Place the ball solar projector on its mount at a level spot on the ground outdoors.
- Experiment with rotating the ball and pointing the mirror to catch the Sun and cast its image onto some vertical surface, such as a wall or a screen.

Observe and record:

- How does the image change when you change the distance between the projector and the projected image?
- Keep the projector still for a few minutes. In what direction does the image move (right-left, top-down, or east-west)?
- Manipulate the projector so that the image is thrown onto a wall inside a room (through a door or a barless window). How does the contrast between the image and the surrounding area change? What happens to this contrast when the room is further darkened by covering windows, ventilators, and other such openings with black curtains?
- Leave the projector in the same place. Observe the image at different times of the day and on different days. Is there a change in the image? In what way does its position change? Mount a large sheet of light-coloured paper on the projected surface. Use this to mark shifts in the position of the image.
- Can you see any dark splotches within the image? Do they shift in position (with respect to the edge of the image) over time?

Think and discuss:

- Let us assume that the patch projected on the vertical surface is an image of the Sun. Do your observations support this assumption? How?

Contributed by:
Prajval Shastri, who is an astrophysicist. She can be contacted at: prajval.shastri@gmail.com.