SUN WONDER!

Non-trivial concepts through day-time astronomy experiments with self-constructed equipment

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Our Sun is visible during school hours, as long as the sky is relatively cloudless. Equipment that we can easily construct ourselves can be used to conduct simple observations and make measurements related to the Sun, from which insights into the world of astronomy, the workings of the Sun, pin-hole cameras and imaging, can emerge. A few examples of these activities are described here, with pointers to external text and video resources.

Astronomy is Inspirational, but....

Enchanting is the sight of the Milky Way on a moonless night. Mesmerising are the photographs of the distant universe, brought home to us via the Internet by powerful telescopes like **Hubble, Spitzer** and **Chandra.** The sky is accessible to everyone and is a 'universal laboratory'. However, school hours are nearly always during day-time. Combine this reality with the scourge of light pollution, and practical star gazing within regular school curricula is virtually ruled out - with one exception. Our nearest star, the Sun, can play 'laboratory' during school hours! Thus, learning science by doing and discovering can indeed happen with day-time astronomy experiments.

Cautionary Note [1]

The Sun should not be stared at directly - it could harm our eyes. The projection of the Sun's image described in the activities below is one of the safe methods of viewing the Sun.

Activity 1: Find the Day-time Moon!

Materials needed: A notebook for recording observations.

Conditions: Need to be out in the open with a fair part of the sky, including the Sun and the Moon visible, at least off and on, i.e., a relatively clear sky.

Background: Our Moon appears to shine brightly in the sky because it is lit up by the Sun. Since the Moon orbits around the earth once every 29 days or so, different parts of this illuminated side of the Moon are visible to us on different days, which we call 'Phases of the Moon'. Another effect of the Moon's orbit around the earth being once every several days is that, the Moon is sometimes visible at night, and some times during the day. Indeed the Moon is bright enough to be seen clearly against even the bright blue day-time sky. Finding the day-time Moon is an activity that can be a precursor to more in-depth activities that teach lunar orbits, eclipses etc. using models, or observations during day as well as night.

Observational activity:

1. Locate the Moon in the day-time sky.
2. What is its shape? Note down the rough shape in your log book with the date and time of observation.
3. What is the orientation of its shape w.r.t. the horizon/sky-line directly below it?
4. What is its location in the sky relative to the Sun? (South-East? North West?).
5. Point one straight arm at the Sun and another at the Moon. What is the approximate angle made by your arms?
6. Follow the path of the Moon in the sky by observing it at intervals of about 30-60 minutes, and repeat observations.
7. Repeat these observations over subsequent days.
8. Using the lunar orbit diagram in Figure 1, can you explain your observations over a period of a few days?

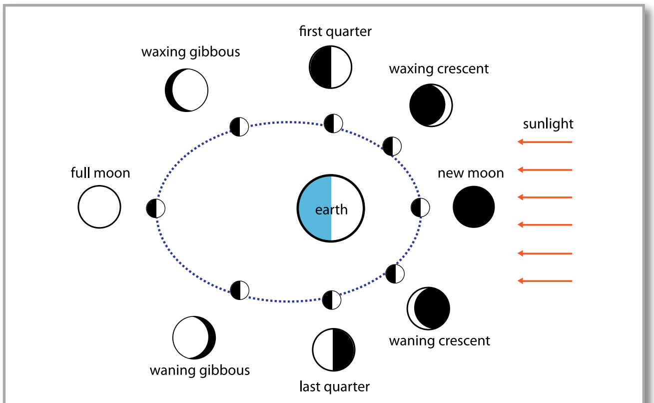

Figure 1. Lunar Orbit.

Note: The Moon will be visible in the mornings a few days after full Moon and in the afternoons a few days before full Moon. Be sure to arrange the first of these observations when the Moon is visible along with the Sun. Ideally, the observations should be continued through the lunar cycle so that the days when the Moon is not visible in the day-time sky are also noted. Students can then be encouraged to make observations during the day as well as night (at home) and relate their results to the explanation for the phases of the Moon that they study from their textbooks. Prior scheduling and planning of the activity can be done using lunar calendars, which are readily available on the internet[2].

Observing site	Date	Time	Sky condition	Angle between Sun and Moon	Shape of the Moon
School Playground	Sun 20 Mar 16	13:00	Clear		
School Playground	Mon 21 Mar 16	15:00	Partially cloudy		
Local Park	Sun 20 Mar 16	11:00	Partially cloudy		
School Playground	Wed 23 Mar 16	11:30	Mostly clear, passing clouds		

Table 1. An example of an observation template that can be used to track the moon.

Activity 2: A Magic Mirror

Materials needed: A plane mirror of size about 3cm x 3cm; thick black paper of size about 15cm x 15cm (the size depends on the size of the mirror you have - see the instructions); a circular coin; a pair of scissors; adhesive; a small ruler; measuring tape; a notebook for recording observations.

Conditions required: Skies clear enough for the Sun to be visible (at least off and on) and an open area with not too much of the sky obstructed.

Construction of the magic mirror:

Step 1: From each corner of the black paper, cut out a square piece of size 5cm x 5cm with the cuts parallel to the edges of the paper, so as to leave a piece shaped like a large 'plus' sign (see Figure 2).

Step 2: Cut out shapes of a square, a circle (using the coin to draw it), a star and an equilateral triangle from the outer square segments of the 'plus'. These shapes should be smaller than the size of the mirror.

Step 3: Fix the mirror onto the central square area of the 'plus' with adhesive.

Step 4: Fold each of the square segments with the cut-out shapes over the mirror, so that you have four flaps to act like masks on the mirror.

The Magic Mirror is ready!

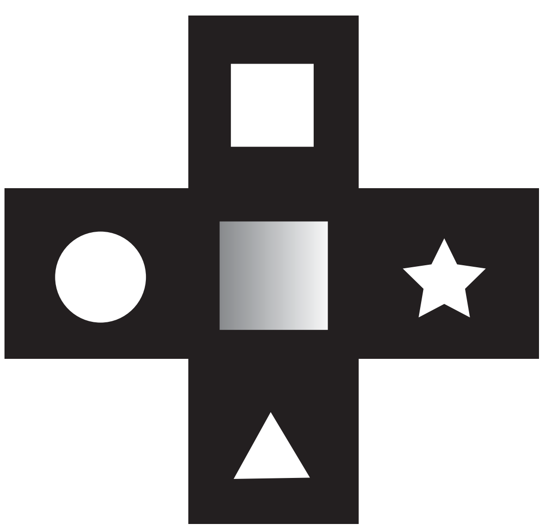

Figure 2. Black paper cut into a 'plus' shape, with the square mirror pasted in the centre; and shapes of a square, circle, star and triangle cut out of the four outer segments. Credits: Navnirmiti 2013.

Usage: Take the magic mirror outdoors to a spot where the Sun is visible. Hold the mirror out to 'catch the Sun' and experiment with the position and tilt of the mirror to reflect the bright patch of sunlight onto a nearby surface about a metre away. The surface could be a wall, a sheet of paper held by a friend, or the surface of a person's clothing.

Next, fold each of the flaps of the magic mirror over the mirror to cover it, and observe the effect on the shape of the bright patch. No surprises here: the shape of the bright patch will take the shape of the mask - whether square, circular, triangular or star-shaped.

Now for the surprise: increase the distance between the mirror and the projection surface to about 8-10 metres. If a person's clothing was used as the surface to project the bright patch made by the Sun, then the person's back should be turned towards the mirror to avoid accidental projection of the Sun onto her eyes, which could be blinding. Observe what happens to the shape of the bright patch. Regardless of the shape of the mask (whether square, circle, triangle or star), the patch is always circular! Fold the triangular mask onto the mirror, move the surface back and forth, and observe the bright patch change from triangular shape when nearby to circular when far away[3]. Repeat this for the square and star-shaped masks.

Explanation: The circular patch is the image of the Sun! This can be convincingly demonstrated by doing a similar experiment with light from a bright lamp, or a torch light, in a well-darkened room [4]. At a large enough distance from one of the walls of the dark room, the mirror projects an image of the lamp/torch light. The idea of a pin-hole camera [5] has been known for centuries and has been extensively used to image scenery with large depth of field. Following the pin-hole idea, holes made in cardboard can be used to project an image of the Sun [4, 6 7]. 'Pin-holes' also occur in nature, e.g., the holes made by gaps between leaves of a tree [7]. The Magic Mirror behaves like the mirror-analogue of such a pin-hole when reasonably distant from the wall/screen of projection [8]. Even though the mirror is much larger than a 'pin-hole' as we think of it, what is key to the 'magic' is not the size of the hole/mirror itself but the ratio between this size and the distance to the projecting screen, which should be large. The idea is expanded upon in the next activity.

Activity 3: Ball-mounted Solar Projector

Materials needed: A medium-sized stiff plastic toy ball; some sand to fill the ball; a (used) ring of sticking tape, or a tennikoit ring, or a stable flat cylindrical container (without its lid and a diameter about half that of the ball) for the base of the mount; a small mirror (about 3cm x 3cm); a piece of stiff paper slightly larger than the mirror; sticking tape; a pair of scissors and paper cutter; a coin; a notebook for recording observations.

Conditions for observations: A reasonably clear sky with the Sun visible at least off and on.

Construction of the Ball-mount and the Solar Projector:

Using the cutter, roughly mark four sides of a 2.5cm x 2.5cm square-shape on the ball and cut through three of the sides to create a square-shaped hole with a square 'flap' (see Figure 3). Use the hole to fill the ball with sand (somewhat more than half-full), which serves to weigh the ball down. Close the hole with the flap, and seal it off with sticky tape. Place this ball on the base of the mount (used ring of tape, or cylindrical container). You can feel that the ball can be rotated smoothly around on the base, but stays firmly in position when left alone.

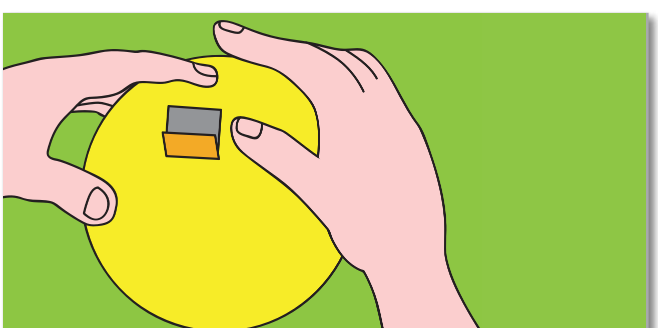

Figure 3. Cuts made on the ball using a cutter to create a square-shaped hole with a 'flap'. Credits: Suraj Zameen Par video series [9].

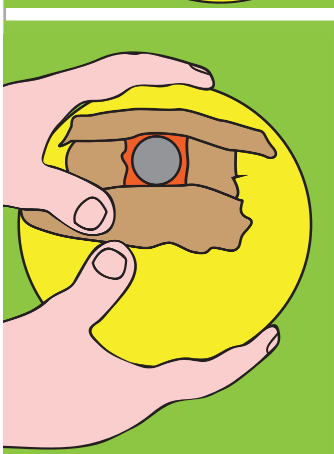

Figure 4. Mirror with a paper mask (circular hole) stuck firmly onto the ball. Credits: Suraj Zameen Par video series [3].

Using the coin, mark a circle of about 2 cm diameter in the centre of the stiff paper. Cut out this circle carefully and neatly to make a circular mask for the mirror. Apply some adhesive around the edge of the circular cut-out and stick the paper on the reflecting face of the mirror carefully, so that the cutout circle is roughly in the centre of the mirror. Make sure that no excess adhesive is left on the part of the mirror that is visible through the circular hole. Now paste the masked mirror carefully and firmly onto the ball using sticky tape. Make sure that the circular hole is not covered by the sticky tape.

Your Solar Ball-mounted Projector is ready!

Usage: Place the ball projector on its mount at a spot on the ground outdoors. Experiment with rotating the ball and pointing the mirror so as to catch the Sun, and cast its image onto some vertical surface, such as a wall or a screen. Note that the further this surface is from the ball, larger is the image of the Sun, but lower is the brightness contrast, and, therefore, lower the visibility.

Observational activities:

- How does the image change when you change the distance between the projected image and the projector?
- What happens to the image of the Sun with time (several minutes) if you keep the projector still?
- What is the direction of motion of the image with time (right or left? top or down? eastward or westward)?
- Manipulate the ball-mounted projector so that the Sun's image is thrown onto a wall inside a room (through its door, or a bar-less window). Observe the increase in contrast between the Sun's image and the surrounding area.
- If the room is further darkened using black curtains on its windows, ventilators and other openings, the contrast can be further enhanced.
- Mount a large sheet of light-coloured paper on the projected surface so that you can mark the shifts in the position of the Sun with time of day, day after day, etc., on the paper.
- Place the projector at exactly the same spot at the same time on the following day. What is the position of the Sun's image relative to the previous day?

- Can you see any dark splotches within the Sun's image? Do they move with respect to the edge of the image over time? These may be Sun spots[10]!

Notes on the Equipment

The mount: The heavy weighed-down ball when mounted on a ring is not only very stable, but playing around with pointing it also gives the participant a feel for what is known in astronomy as the 'alt-az' or altitude-azimuth mount. This is one of the mounts used for astronomical ground-based telescopes, wherein mechanical drives enable circular movement of the telescope around two axes, the first of which is parallel to the ground (thus changing the tilt or altitude of the direction in which the telescope is pointing) and the second being perpendicular to the ground, which enables changing the 'azimuth' of the direction in which the telescope is pointing. All directions/points in the sky that are above the horizon are thus accessible to the telescope using a combination of these two independent movements.

The projector: The principle was introduced in the previous activity. The mirror masked by a circular hole behaves like a 'pin-hole' when the screen onto which the image of the Sun is projected is relatively far away. It is important to remember that (a) larger the size of the hole, further the screen needs to be for the pin-hole effect; (b) larger the hole, greater is the amount of light that is gathered (giving a brighter image) but also lower is the sharpness of the image (noticeable at the edge of the image or if there are Sunspots or a planet transit); (c) the further the screen is, the larger is the image of the Sun, but lower is the brightness contrast of the image relative to its surrounding area on the screen. There are thus some trade-offs, and the students should be encouraged to experiment with changing the size of the hole and the distance of the screen to identify these trade-offs themselves.

For the same distance between the mirror and the projection screen, placing the screen in a darkened room increases the brightness contrast between the image and its surrounding areas, thus enhancing clarity for the observer. The darkened room can be made to function as the data gathering studio with sheets of paper mounted on the projection wall for marking the Sun's position and movement. Once the projector has been played with, the other advantage of its design becomes apparent: 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, which makes it very convenient.

Figure 5. Two children using a solar projector. Credits: Sejal Chevli and Navnirmiti Learning Foundation.

Notes on the activities

Playing with different shapes and sizes for the mirror mask, and the distance of the projection screen brings home the idea of pin-hole projection. A mirror mask with a hole of about 2 cm diameter and a projection screen 30 metres away in a darkened room works well. Tracking and recording the movement of the Sun's projected image illustrates the daily, day-to-day and seasonal movements of the Sun with respect to us. Occasionally the surface of the Sun exhibits sunspots[11]. The ability to see sunspots requires reasonably large sunspots to be present and reasonably high sharpness of the image. Daily satellite images of the Sun, which show us whether or not discernible hotspots are visible, can be found on the NASA/SOHO website[10]. Sunspots are planet-sized regions on the Sun with very high magnetic fields and therefore higher magnetic pressure, which inhibit the convective heat from reaching the surface of the Sun. Hence these regions are slightly cooler, and therefore appear quite a bit darker, than the surrounding surface of the Sun.

Conclusion

Astronomy is a delightful way to introduce things that are really faraway and **really** big, yet amenable to the laws of physics as we earthlings understand them. This introduction to our universe does not necessitate the night-sky and can be done with several day-time experiments during school hours, and can therefore be part of the school curriculum.

Acknowledgements

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