OBSERVING LIGHT: SHADOWS & REFLECTIONS

RAJARAM NITYANANDA

Are shadows completely dark? Does the human eye have anything in common with a mobile phone camera? How many mirrors do we need to see our right hand appear as it would to others? This article explores many simple ways of teaching concepts related to 'light' by linking them with everyday observations on shadows and reflections.

It is always a challenge to build curiosity, motivation, and a basic understanding of any topic in science. A popular worldwide trend is to bring in technology — computer animations and demonstrations, with specially designed equipment. This trend attempts to overcome the sense of familiarity and boredom, which comes with early exposure to mass media and the internet, and is now catching on in schools in India.

There is no doubt that technology has value in creating interesting learning experiences. But this article is about the oldest technology — live (meaning not virtual) observation. Simple observations are not a second-best option that one engages with because of a lack of online or lab resources. They are valuable even to students who have access to virtual resources, because ultimately science is about the real world. First-hand experiences can help a student connect to the more abstract developments that school science must cover in later years. Without such a connection, even students who do well in existing school systems may find it difficult to apply what they learn from books and lectures to new situations. Even if one first learns the theory, it really helps to see it being put into practice, and use observation to build connections. The observations suggested here are not just for students in middle school, but for anyone, teachers included, who has not tried them.

Light appears early in the school science curriculum. This is natural — vision is one of our most powerful senses. Two basic topics under light — shadows and reflections — are covered in all textbooks, with the usual ray diagrams showing light travelling in straight lines from the source. This is already a virtual experience — students do not always connect the figures with what they see, but know that the diagrams have to be reproduced in tests and interviews. However, studying light can be an opportunity for teachers to enthuse students about science by building connections to observations that they can themselves make and think about. How do we do this?

Shadows — not completely dark!

One way to think about the shadow of an object, say a duster, is to imagine what a small creature, say an ant, sitting on a wall would see if it were at different positions with respect to the duster and the Sun (see **Fig. 1**). If a point on the wall is dark, it means that the ant sitting there finds that the Sun is completely blocked by the object. As we move it away from this point on the wall, we notice that the edge of the shadow of the duster is not sharp. This observation is what illustrates the so-called **penumbra**. 'Penumbra' is just a name. Isn't it better to say that as the ant crawls past the edge of the shadow of the duster, it moves from the region where the Sun is completely covered, to one where it is partially covered (the penumbra), and finally to one from where it can see the entire Sun?

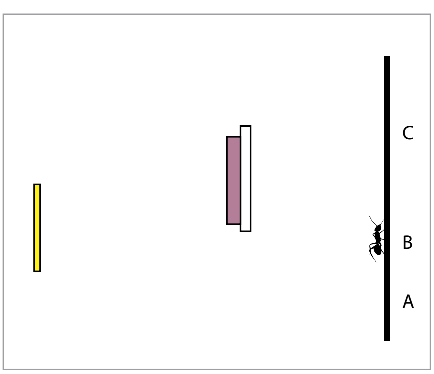


Fig. 1. Are shadows completely dark? The yellow line to the left of the image represents the Sun. When the ant on the wall is at C, it cannot see any part of the Sun. When it is at A, it can see the whole Sun. When the ant is at B, it can see that part of the Sun that lies between the darkest part and the fully lighted part. This is the fuzzy edge of the shadow.

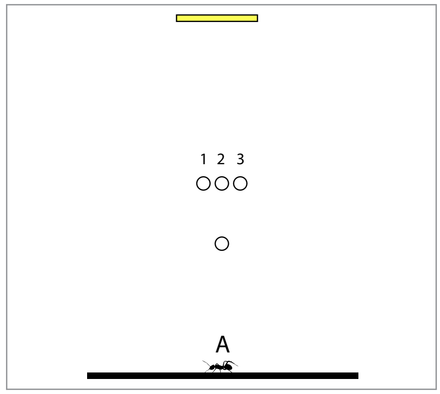


Fig. 2. Overlapping pencil shadows. When the moving pencil is at position 1 or 3, then the ant at A sees a larger part of the Sun covered. When it is at position 2, the pencils cover each other, and more of the Sun is visible. This explains the increase in light at A, when the shadows overlap.

(It is wise to imagine this, rather than actually going under such a shadow and looking at the Sun oneself. Looking directly at the Sun can damage the eye).

Another experiment you can do with this method surprises even practicing scientists. Hold two pencils in the near noon sun in such a way that their shadows fall on the ground more than a metre away. By moving one pencil over the other, you can make the shadows overlap or come apart. You'll notice that the shadow is darker just before and just after the overlap, and becomes brighter when there is a full overlap. Similarly, when you hold the pencils crossed, the darkest portion of the shadow is not at the intersection, but on either side. Again, looking at this from the point of view of an ant is a useful exercise. The darkness of the shadow in each of these cases depends on how much of the Sun the ant can see (see **Fig. 2**).

What lies between the shadows?

Let us now look at the opposite of a shadow. When light passes through a hole in a piece of cardboard, we get a bright region inside the shadow. We expect a square hole to give us a square patch of light, a triangular one to give a triangular patch, etc. This is what we see when we place the cardboard close to the wall. But when the hole is small (say about 3 millimetres in size), something interesting happens as we move away from the wall. At a distance of about half a metre, the patch of light starts looking more circular. At a distance of about a metre, we see an almost circular disc, even though the hole may have been a triangle. What's more — the size of the bright patch starts increasing. As you may have guessed, the circular patch is an image of the Sun (see **Fig. 3**). This observation is the basic principle behind a pinhole camera. Students can easily make this simple toy for themselves (see **Box 1**).

We can see this pinhole experiment occurring naturally in the shade of a tree. This explains why the Sun, shining through irregularly shaped gaps between the leaves of a tree, leaves circular patches of light in the shade. During a partial eclipse of the Sun, which can be seen from most places in India about once every decade, the circles become crescents (see **Fig. 4**). This makes it clear that we really are seeing images of the Sun.

Another interesting aspect of shadows is revealed when one looks at the Moon through binoculars (even though

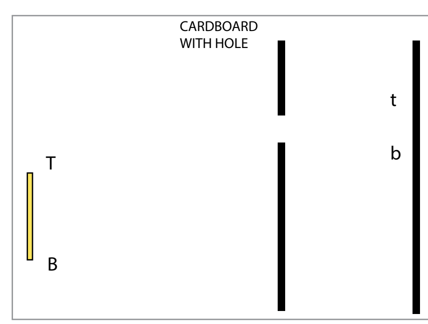
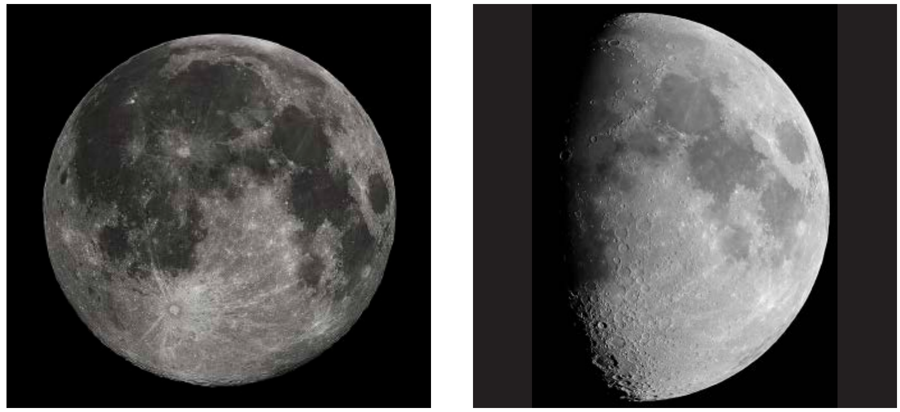


Fig. 3. How a small hole in a piece of cardboard makes an inverted image of the Sun. The point t on the upper side of the wall receives light from B, the bottom of the Sun. The point b on the lower side of the wall receives light from T, the top of the Sun. This arrangement only works if the hole makes an angle smaller than that of the Sun as viewed from the wall. If the hole is very close to the wall, the lighted portion on the wall takes the shape of the hole.

Box 1. Using a pinhole camera to introduce the human eye:

A pinhole camera is a good way of introducing students to the workings of the human eye, the basic tool for all our observations. The eye is a beautiful collector of light which shows the brightness and colour of light from all directions. This is what we call a picture or image. In fact, the camera in mobile phones, which many students will be familiar with, is more like the eye than earlier film-based cameras. It has a human retina-like chip. This is connected to a computer through wiring that resembles the optic nerves going to our brain. The computer has software to turn the upside-down picture right-side up. Our brains seem to have this as well.

Fig. 5. Shadows on the Moon.



(a) A photo of the full Moon. Notice that we don't see any shadows even though there are mountains and valleys.

Credits: Gregory H. Revera. URL: https://en.wikipedia.org/wiki/File:FullMoon2010.jpg. License: CC-BY-SA.

(b) A picture of the half Moon. Note the clear shadows near the boundary between the lighted and dark part. An observer located there would see the Sun close to the horizon and, hence, shadows would be long.

Credits: Luc Viatour. URL: https://commons.wikimedia.org/wiki/File:The_Moon_Luc_Viatour.jpg. License: CC-BY-SA.

moonlight is much weaker than sunlight, one should be careful of the glare). Unlike the full Moon, the half Moon shows clear shadows of mountains and craters (see **Fig. 5**). To understand this, ask your students if they've observed any change in the length of their shadows in the Sun at different times of the day. We know that our shadows are long when the Sun is low on the horizon, and disappear when the Sun is overhead. Now, imagine we were sitting near the centre of the full Moon. The Sun would be directly overhead, and our shadow would disappear. The mountains on the Moon do cast shadows near the edge of the full Moon, but these are invisible when viewed from the same direction as the Sun. Since this problem does not exist at half Moon, the shadows are plain for us to see.

Doing it with mirrors

We now turn to mirrors, which fascinate most children, until they grow up and start taking them for granted. Most of us are aware that a mirror shows us a person whose left hand is like our right hand. This change is called **lateral inversion** — an unfortunate

Fig. 4. Natural pinhole optics. These crescent-shaped patches of light are images of the Sun made by natural pinholes (gaps between leaves) in the shade of a tree.

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

name, because what is reversed in the mirror is the direction — left or right — in which the person is looking. Our top and bottom are not interchanged. Our languages define left and right with respect to the direction in which a person is looking, but define top and bottom with respect to the earth. This 'inversion' may seem like a point of language, but can be a matter of life and death. A surgeon operating on a patient should definitely be clear what they are referring to when they say *"left"* — do they mean the patients left, or their own?

That a single mirror does not show us as we appear to others is particularly clear to a person wearing a garment, like a sari, which goes over one shoulder, or a shirt, which has a pocket on one side. To see yourself as others see you, use two mirrors, placed at 90 degrees to each other. If you have not looked into such a set up before, it can be a strange experience to see the image moving its right hand away from itself as you move your right hand away from you (see **Fig. 6**).

It can be even stranger to look into three mirrors, each placed at 90 degrees to the other two. The geometry of this

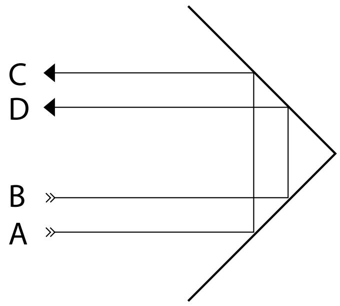


Fig. 6. Reflection from a pair of mirrors making an angle of 90 degrees with each other. As the person standing in front of the mirror moves their right hand from B to A, the hand of the reflected image (which is on the opposite side) moves from C to D. This means that it is also seen as their right hand moving away. With a single mirror, the image would appear to move the left hand in the same direction.

Credits: Rajaram Nityananda. License: CC-BY-NC.

set up would be like that of two walls and the floor meeting at the corner of a room. It is, therefore, called a **corner reflector**. The corner reflector sends any ray of light, coming from any direction, back in the same direction (see **Fig. 7**). What does one see when one looks into such an arrangement? No matter where one goes, one sees one's own eye in the corner. This is not just a curious trick, but can actually be very useful. Such reflectors are used on highways, especially near the edge of a dangerous curve. When the headlights of an approaching car illuminate the reflector, it sends light back to the driver, warning them. This is a very efficient arrangement because it needs no power, and only sends light where it is needed.

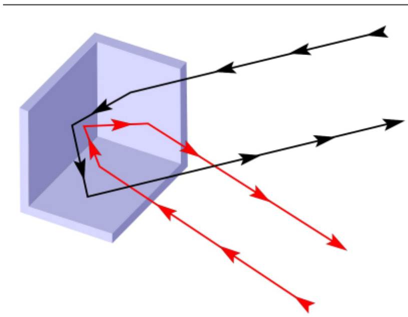


Fig. 7. An arrangement of three mirrors meeting at a corner. Light coming from any direction is sent back in the same direction.

Credits: Chetvorno. URL: https://commons.wikimedia.org/wiki/File:Corner_reflector.svg. License: CC0.

A topic as simple as reflection can play a very important role in today's space and energy technology. One dramatic example is of a corner reflector set up by American astronauts on the Moon during the Apollo mission (see **Fig. 8**). Scientists used this to send a laser beam to the Moon from a telescope on earth, and catch the returning beam with the same telescope. Since the beam was a short pulse, they were able to measure the time taken (about 2.5 seconds) for it to cover this distance and arrive at a very accurate measure of the distance to the Moon. Another interesting application of mirrors is to bring sunlight from a large area to a small one. This has been used to harness solar energy (see **Fig. 9**).

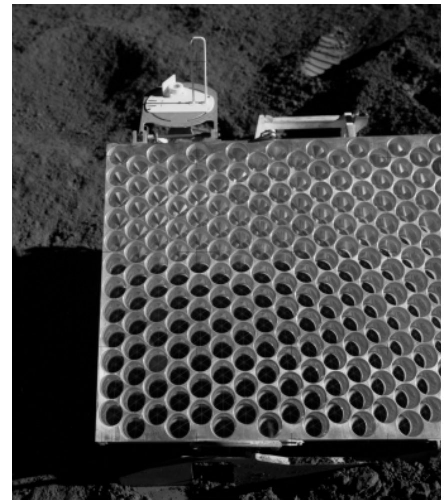


Fig. 8. A set of corner reflectors placed on the Moon by astronauts on Apollo 15. This allowed very accurate measurements of the distance to the Moon, and how it changes with time.

Credits: NASA, USA. URL: https://commons.wikimedia.org/wiki/File:ALSEP_AS15-85-11468.jpg. License: CC-BY.

Conclusion

Today's students will live in an age of far more advanced technology than their teachers. It is likely that many of these technological advancements are likely to involve light. Even today, lasers are used for cutting in industrial applications, and correcting vision by reshaping the cornea of the eye. Light carries most of our phone conversations and internet surfing over optical fibres. Many new, wonderful, and useful things are bound to come of our understanding of light in the future too.

Fig. 9. A power plant in Spain uses energy from the Sun, instead of coal, to produce the steam that runs its generators. Because of the dust in the air, one can actually see the path of the Sun's rays.

Credits: afloresm. URL: https://commons.wikimedia.org/wiki/File:PS10_solar_power_tower.jpg. License: CC-BY.

Students who make a career in science or engineering will learn much more about light, but everyone can appreciate some of the most basic principles of light. This article shares only some examples involving shadows and reflections, which can be used to provoke observation and discussion. Such examples are not meant to replace the textbook or classroom teaching, but rather to create some enthusiasm to understand taught concepts. When shared with students from higher grades, these experiments can help one appreciate how simple but general concepts, like those related to the rays of light, can help us understand many things around us.

Key takeaways

- The topic of light appears early in the school science curriculum since it connects to vision, one of our most powerful senses.
- While students are able to reproduce key concepts and ray diagrams in tests and interviews, they are not always able to connect these with their real-world experiences.
- Simple observations and first-hand experiences of shadows and reflections that students can themselves make and think about can provoke discussion and enthuse them about science.
- Exploring everyday applications of light-related concepts, such as pinhole cameras and corner reflectors, can help students connect to more abstract developments in the school science curriculum.

Note: Source of the image used in the background of the article title: https://www.shutterstock.com/image-photo/little-child-plays-his-self-reflection-47335690. Credits: manzrussali.

Rajaram Nityananda is currently teaching at the Azim Premji University, Bengaluru. Prior to this, he was at the Raman Research Institute (RRI), Bengaluru. He has been the Chief Editor of Resonance, journal of science education, for one term (~ three years). Much of his research work has been theoretical — in areas of physics relating to light and to astronomy and, hence, involving mathematics and/or computation. Rajaram enjoys collaborating with students and colleagues — many of them experimenters, and many outside his own institution.