OBSERVING LIGHT:
SHADOWS AND REFLECTIONS

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Are shadows completely dark? Are there some shadows that are darker than others? What do a mobile phone camera and the human eye have in common? Are there any natural pin-hole cameras? How many mirrors do we need to see our right hand appear as it would to others? In this article, the author explores many simple ways in which the teaching of light can link everyday observations to concepts using shadows and reflections.

Introduction

It is always a challenge to build curiosity, motivation, and a basic understanding of any topic in science. A popular trend worldwide 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 our own 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 meant to be 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, which 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. Studying light is an opportunity for teachers to enthuse students about science, by relating it to observations that they can themselves make and think about. This article covers two basic topics, shadows and reflections. These occur 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.

Shadows: not completely dark!

One way to think about the shadow of an object – say a duster – is to imagine that a small creature, say an ant, sits on a wall. Take a look at the image below to understand the positions of the Sun, the duster and the ant. We can ask what the ant would see if it were at different positions with respect to the duster and the Sun. 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? (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.)

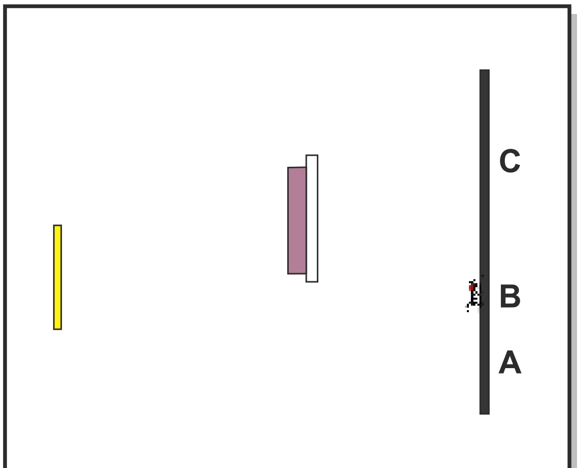

Figure 1: The yellow line on the left represents the Sun. The ant on the wall at C cannot see any part of the Sun. The ant at A can see the whole Sun. The ant at B can see part of the Sun. It lies between the darkest part and the fully lighted part. This is the fuzzy edge of the shadow.

The next experiment surprises even practicing scientists. Hold two pencils in the sunshine, at a time near noon, so that the shadows fall on the ground more than a metre from the pencils. By moving one pencil over the other, one can make the shadows overlap, and then again come apart. Surprisingly, the shadow is darker just before and just after the overlap, and becomes brighter when there is a full overlap! One can also hold the pencils crossed, in which case the darkest portion of the shadow is not at the intersection, but on either side. This is explained in Figure 2, from the point of view of an ant on the ground. So, this is actually a useful way of thinking about shadows!

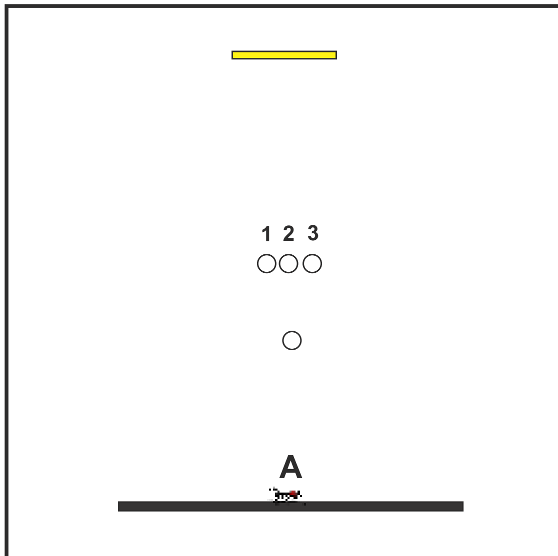

Figure 2: Overlapping the shadows of 2 pencils. When the moving pencil on the left is at position 1 or 3, then the ant at A sees a larger part of the Sun covered. When it is at position 2, the pencils cover each other, and more of the Sun is visible. This explains the increase in light at A, when the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

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

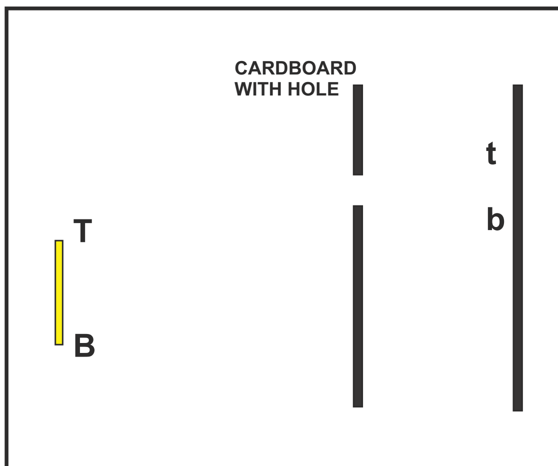

Figure 3: How a small hole in a piece of cardboard makes an inverted image of the Sun. The point t on the upper side of the wall receives light from B, the bottom of the Sun. The point b on the lower side of the wall receives light from T, the top of the Sun. This arrangement only works if the hole makes 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.

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. 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.

The circular patch is an image of the Sun. This observation is the basic principle behind a pinhole camera, shown in Figure 3.

Students can easily make this simple toy for themselves. This is also a good way of introducing 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 each direction. 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 chip, which is like the retina, with wiring connecting the chip to a computer, pretty much like the optic nerves going to the brain! It also has software to make the upside down picture, right side up. Our brains seem to have this as well.

Figure 4a: Circular patches of light, which are images of the Sun made by natural pinholes (gaps between leaves) in the shade of a tree. Image courtesy http://nivea.psycho.univ-paris5.fr/FeelingSupplements/ExperimentsWithCameraObscura.htm

Actually, this pinhole experiment is carried out for us naturally, when we go and look at the shade of a tree. As Figure 4a shows, we often see circular patches of light. This happens even though the gaps between the leaves through which the Sun shines have irregular shapes. During a partial eclipse of the Sun, which can be seen from most places in India about once in every decade, the circles become crescents, making it clear that we really are seeing images. December 26th, 2019 is the next date on which a partial eclipse will be visible from India, and the next date following this one will be on June 21st, 2020 (monsoon clouds may spoil the view of this one). Figure 4b shows a spectacular set of shadows of the eclipse of May 20, 2012, visible from the US. In this case, the moon left a ring shaped part of the Sun visible!

Another interesting aspect of shadows is revealed when one looks at the moon through binoculars (even though moonlight is much weaker than sunlight, one should be careful of the glare). The picture of the full moon (in Figure 5a) does not show any shadows. The half-moon (in Figure 5b) however, shows clear shadows of mountains and craters. It is a more interesting picture, although poets have sung praises of the full moon. We all know that shadows are long when the Sun is low

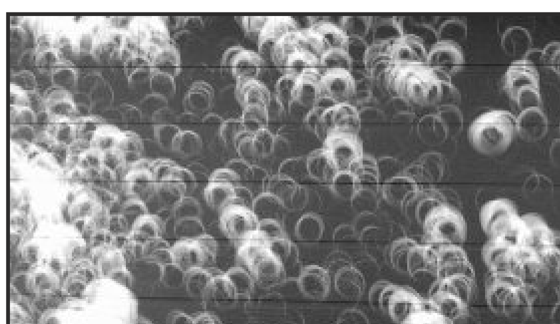

Figure 4b: Pinhole images of the Sun taken during the eclipse of May 20, 2012. Source: Image of the eclipsed Sun, taken from Carson City, Nevada. Photographer Dean Altus http://media.komonews.com/images/120521_eclipse_shadow_lg.jpg

on the horizon, and disappear when the Sun is overhead. So it is not surprising that we don't see shadows near the centre of the full moon. If one were sitting there, the Sun would be overhead. Near the edge of the full moon, the mountains do cast shadows. But these are invisible from the same direction as the Sun! At half moon, this problem is not there, and the shadows are plain for us to see.

Figure 5a: A photo of the full moon. Notice that we don't see any shadows even though there are mountains and valleys. Acknowledgment: "FullMoon2010" by Gregory H. Revera - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:FullMoon2010.jpg#/media/File:FullMoon2010.jpg

Figure 5b: 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. Acknowledgment: "Lune nb" by I, Luc Viatour. Licensed under CC BY-SA 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Lune_nb.jpg#/media/File:Lune_nb.jpg

These are just some examples involving shadows, which can be used to provoke observation and discussion. Such examples are not meant to replace the textbook and classroom teaching, but, rather to create some enthusiasm to understand taught concepts. In higher classes, these experiments can help one appreciate how simple, but general, concepts, like rays of light, enable us to understand so many things around us.

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. The unfortunate name, 'lateral inversion', is given to this change. This is unfortunate, because, actually, what is reversed in the mirror is the direction in which the person is looking! The other two directions remain the same. For example, 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 is not just a point of language, but can be a matter of life and death. A surgeon operating on a patient should definitely be clear when saying "left" - does this mean the patients left, or the surgeons own?!

It is true that a single mirror does not show us as we appear to others. This is particularly clear to a person wearing a garment, like a sari, which goes over one shoulder; or shirts, which have pockets 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. As you move your right hand away from you, the image also moves its right hand away from itself! A simple way of understanding this is given in Figure 6.

Even stranger is the experience when one looks into three mirrors, each placed at 90 degrees to the other two. The geometry of this would be like two walls and the floor meeting at the corner of a room. It is therefore called a 'corner reflector'. Any ray of light, coming from any direction, into the corner reflector, is sent back in the same direction (Figure 7a). 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 actually also very useful. Such reflectors are used on highways, especially near the edge of a dangerous curve. At night, the headlights of an approaching car

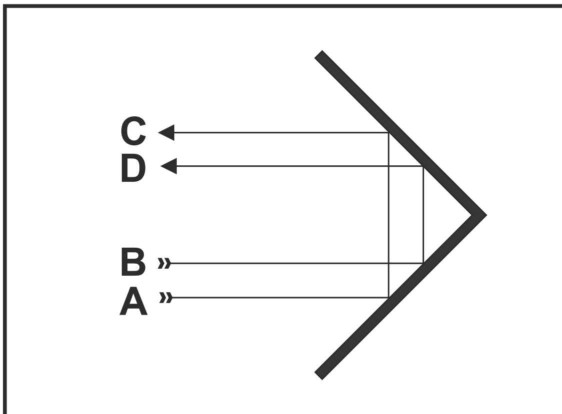

Figure 6: Reflection from a pair of mirrors making an angle of 90 degrees with each other. As the person standing in front of the mirror moves the right hand from B to A, the hand of the reflected image which is on the opposite side moves from C to D. This means that it is also seen as a right hand moving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

illuminate the reflector, and it sends light back to the driver as a warning. This is a very efficient arrangement. It needs no power, and only sends light where it is needed. A more dramatic example is of a corner reflector, set up by American astronauts on the moon during the Apollo mission (Figure 7b). Using this, scientists were able to send a beam of laser light to the moon from a telescope on earth, and get the returning beam back, at the same telescope. Because the light was a short pulse, they were able to measure

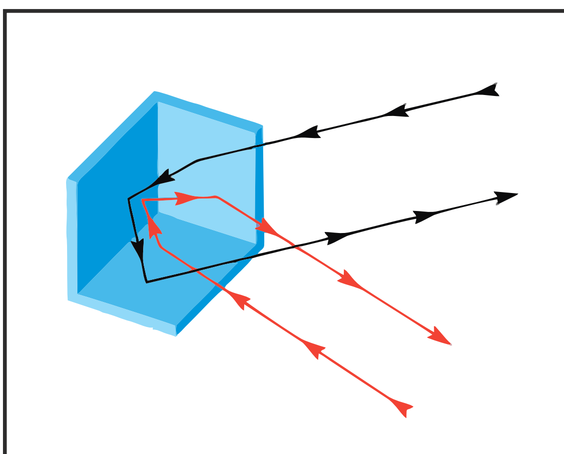

Figure 7a: An arrangement of three mirrors meeting at a corner. Light coming from any direction is sent back in the same direction.
Acknowledgment:
http://en.wikipedia.org/wiki/Corner_reflector#/media/File:Corner_reflector.svg

the time taken (about 2.5 seconds) and, hence, the distance to the moon, very accurately.

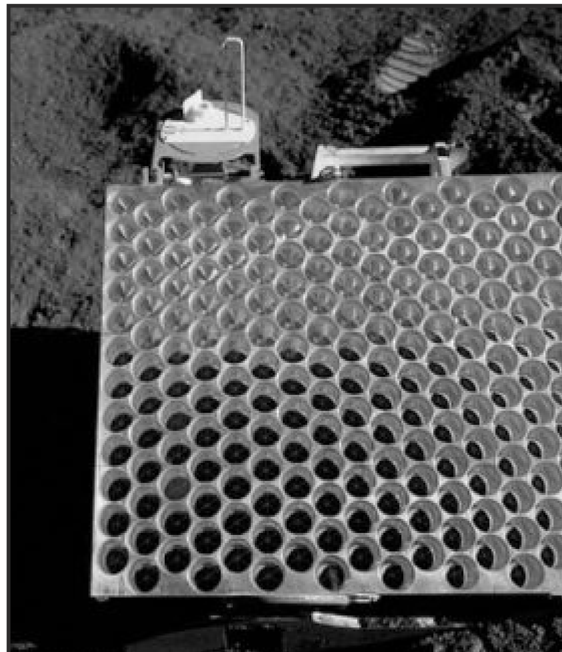

Figure 7b: A set of corner reflectors placed on the moon by astronauts on Apollo 15. This allowed very accurate measurements of the distance to the moon, and how it changes with time. Courtesy: NASA, USA

Nowadays there is great interest in using solar energy. One interesting method of using mirrors to bring sunlight from a large area to a small one, is shown in Figure 8.

Figure 8: A power plant in Spain, which 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. Acknowledgment:
http://en.wikipedia.org/wiki/PS10_solar_power_plant#/media/File:PS10_solar_power_tower.jpg

The last two examples show how a simple topic, like reflection, is important in today's space and energy technology.

Conclusion

Today's students will live in an age of far more advanced technology than their teachers. Many of these will involve light. That is why the United Nations has declared 2015 as the international year of light and light based technologies. Lasers are already used for cutting in industry. They are used by doctors to reshape the cornea of the eye to correct vision. 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. Those students, who make a career in science or engineering will learn much more about light. But everyone can, and should, appreciate some of the most basic principles of light, a few of which have been brought out in this article.

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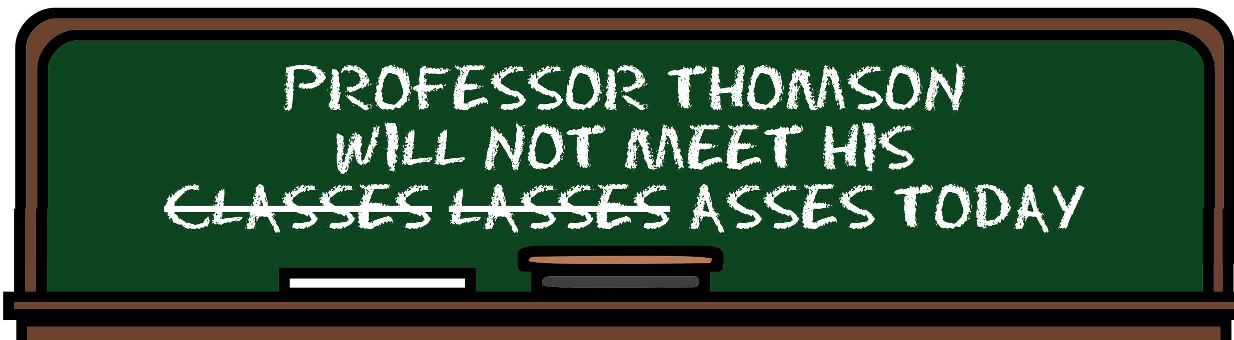
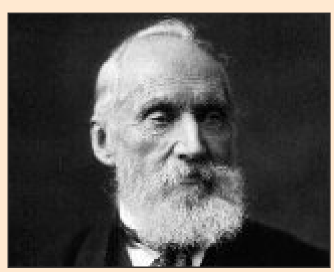


Sir William Thomson, a mathematical physicist and engineer, was a professor of Natural History (now called Sciences) at the University of Glasgow. He was an eccentric professor with a great sense of humour, full of drama and theatrics, and so, well admired by his students. Once when he could not take his lecture due to another commitment, he left a notice for his students on the lecture room door! "Professor Thomson will not meet his classes today".



A group of students decided to have some fun at the professor's expense. They carefully erased the "c" from the note - "Professor Thomson will not meet his lasses today", and waited to see his reaction. When they returned to see the note, it read, "Professor Thomson will not meet his asses today"- the fun loving professor had erased the 'l'!

The eccentric Professor Thompson is none other than Lord Kelvin who was born as William Thompson, and later received the title Baron Kelvin of Largs. He was knighted by Queen Victoria for his Trans-Atlantic telegraph project. He was the electrical engineer responsible for laying the first successful transatlantic telegraph cable in 1866. Although he is also noted for his work on the mariner's compass, he is best known for his discovery of the Kelvin temperature scale.

Contributed by: Geetha Iyer. Source: Science Education Review,Vol 1, No.2-2002 (Robacker, cited in Folino, 2001)

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