Inter-University Centre
for
Astronomy & Astrophysics

(Muktangan Vidnyan Shodhika)

Activity Booklet

Annular Solar Eclipse

(26 December, 2019)

IUCAA

This booklet entails activities that can be performed during a solar eclipse. Teachers from schools and junior colleges can perform these experiments that involves both theoretical and hands-on work. They can further incorporate the same in their classroom sessions. This booklet is designed in such a way that it requires one to work out the mathematics of the intermediate steps which involves high school level mathematics. This year's annular solar eclipse is an opportunity for teachers and even students to give a try in astronomy as it requires nothing special but physics and mathematics which is already being taught in schools.

We are looking forward to this year's one of the rare astronomical events. Hope, you do as well.

Activities & experiments on solar eclipse

List of Activities

<u>Activity 1</u>: Observing Eclipse Using Pinhole Projector

Observing a solar eclipse with naked eyes can be dangerous and therefore should be observed using equipment or tool which can make the observation safe. One of such equipment is a Pinhole Projector, which is easy to make and use for other astronomy based activities.

Let's see how to make a pinhole projector.

Aim: Making a pinhole projector.

Material: Two black chart papers, butter paper, duct tape, pin

Procedure: 1. First, fold a black chart paper in cylindrical shape(a pipe shape) and join the ends with tape. Now you get a paper cylinder.

2. Fold another black chart paper but this time, the diameter of this pipe should be a little less than the first one such that it can be easily inserted in the bigger pipe.

3. Cover one of the open ends of the small pipe with butter paper which will act as a screen where you can see the projected image of the eclipse.

4. Cover one of the open ends of the bigger pipe with a black card sheet. Make a pinhole either circular, triangular, square or star shaped at the centre of this circular sheet.

Fig.1.1

Fig.1.2

5. Insert the small pipe into bigger one and now pinhole projector is ready to use. Move the smaller pipe accordingly to get a sharp image.

6. You can also make all such shapes on a single card sheet(See fig. 1.1 and fig. 1.2) and project the image of the Sun during an eclipse.

Note: The size of different shaped pinhole doesn't need to be very small and could be cut out in sizes that are comfortable to cut with.

Points to Ponder:

1. When you point a pinhole projector at the Sun with different shaped holes, do you see different shapes of the eclipse or just the circular(if total or annular)? Think over it!
2. How does pinhole projector work?

Activity 2: How do we know if it is an annular solar eclipse?

This year on December 26, 2019, annular solar eclipse will occur but can we prove whether it is going to be an annular solar eclipse or total. Let's find out with geometry and trigonometry.

Aim: To determine the condition for an annular solar eclipse.

Material: Pencil and Geometry box.

Procedure: 1. As we know that a solar eclipse occurs when the Moon covers the Sun's disc. Try to make a schematic of the whole system as shown in figure 2.1

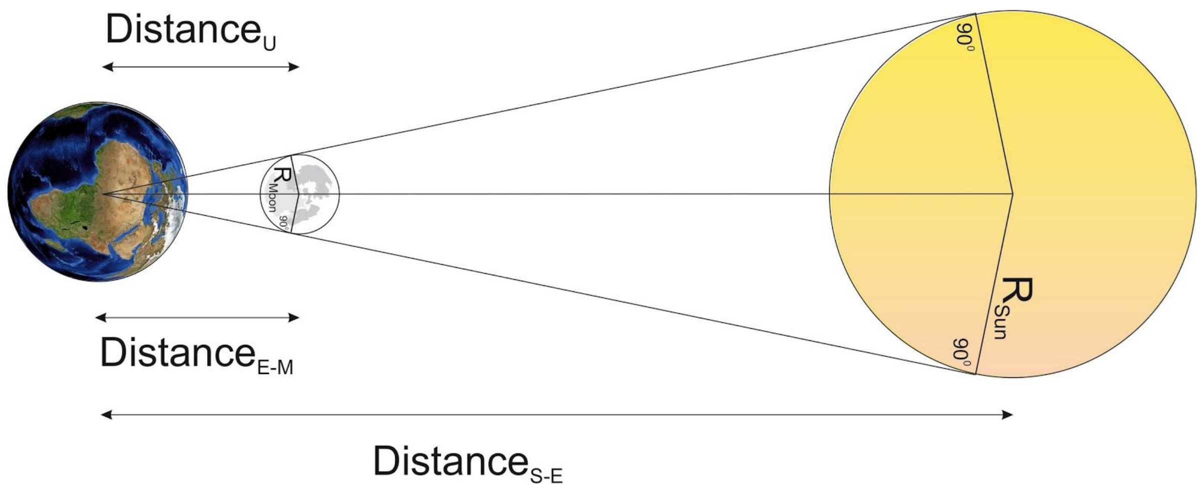

Fig. 2.1

2. In the case of a total solar eclipse, the umbra distance ($Distance_U$) should always be greater than the Earth-Moon distance ($Distance_{E-M}$) so that the Moon's Umbra(Dark shadow region) could fall on the Earth. (See Fig. 2.1)

3. In the case of an annular solar eclipse, the umbra distance ($Distance_U$) is less than the Earth-Moon distance ($Distance_{E-M}$) so the Moon's Umbra(Dark shadow region) does not fall on the Earth. (See Fig. 2.2)

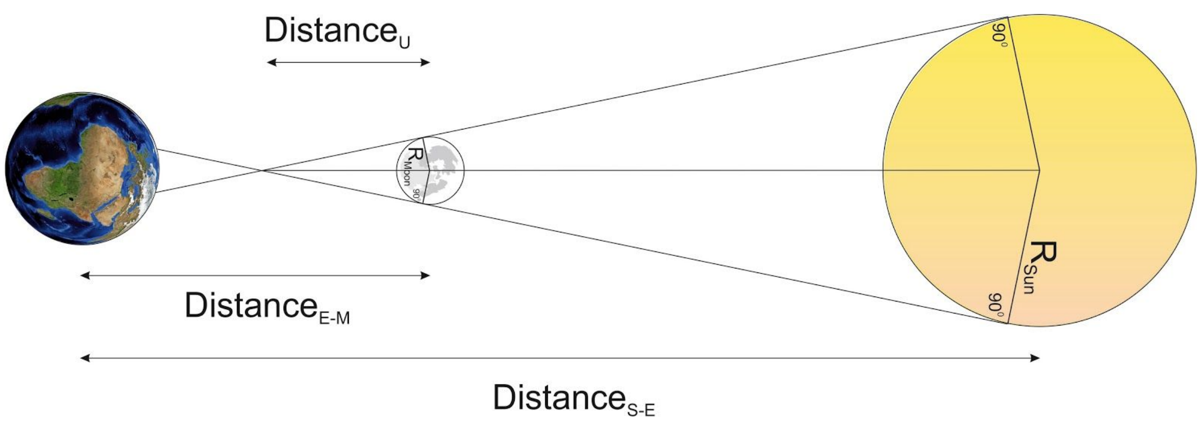

Fig. 2.2

4. Using a very simple activity, you can understand the above points. Extend your hand a little and try to cover any light bulb with your thumb. This is the same situation as in the case of a total solar eclipse. The shadow cast by your thumb is reaching your eyes. Now stretch

your hand a little more and you will notice that your thumb is not able to cover the bulb completely. This is the same situation as in the case of an annular solar eclipse.

During an annular solar eclipse, the Moon is farther away in its orbit and thus it won't cover the Sun's disk completely and hence we don't observe total solar eclipse that time. Is varying Earth-Moon distance the only condition for an eclipse to occur?

5. Using geometry(See Fig. 2.1) try to find the Umbra distance using the relation between all the five parameters i.e R_{Sun} , R_{Moon} , $Distance_U$, $Distance_{E\text{-}M}$, $Distance_{S\text{-}E}$. Finally, the relation comes out to be as follows:

$R_{Sun} / (Distance_{S\text{-}E} + Distance_U - Distance_{E\text{-}M}) = R_{Moon} / Distance_U$

Where R_{Sun}: Radius of Sun

$Distance_{S\text{-}E}$: Distance from Sun to Earth

$Distance_U$: Distance from the Moon to the end tip of Umbra region

$Distance_{E\text{-}M}$: Distance from the Moon to the end tip of Umbra region

R_{Moon} : Radius of the Moon

Note: Take the Sun-Earth and Earth-Moon distance as on the day of the annular solar eclipse. You can find these distances using Stellarium or using authenticated online sources. Also, the derivation of the above-mentioned equation can be derived using basic trigonometry and above mentioned solar eclipse schematic(See fig. 2.1)

6. If the value of $Distance_U$ is less than the $Distance_{E\text{-}M}$ than it would be an annular solar since the tip of the umbra region ends before it reaches the Earth. See Fig. 2.2

7. Hence, we can see in which case an annular solar eclipse will occur.

Activity 3: Calculating the magnitude and obscurity of a solar eclipse

The magnitude of an eclipse is the fraction of the Sun's diameter occulted by the Moon. And obscurity or eclipse obscuration is defined as the fraction of Sun's surface area occulted by the Moon. The magnitude of an eclipse tell us about the duration of totality. More the magnitude more would be totality.

Aim: To calculate the magnitude and obscurity of a solar eclipse.

Material: Pencil and Geometry Box

Procedure: 1. In the last activity, we calculated a condition for the occurrence of an annular solar eclipse in which geometry and trigonometry helped us a lot apart from online resources. Here, we are going to perform a similar calculation based activity but a little advanced knowledge of trigonometry is required this time. Make sure to refer good reading material for the same.

2. When we talk about occultation, we need to consider the apparent sizes of the Sun and the Moon. Hope this makes sense. You can find these sizes as on the day of the eclipse, using Stellarium and other authenticated online resources.

3. Now, let's see the geometry and final equations in finding the magnitude and obscurity for a general case of solar eclipse:

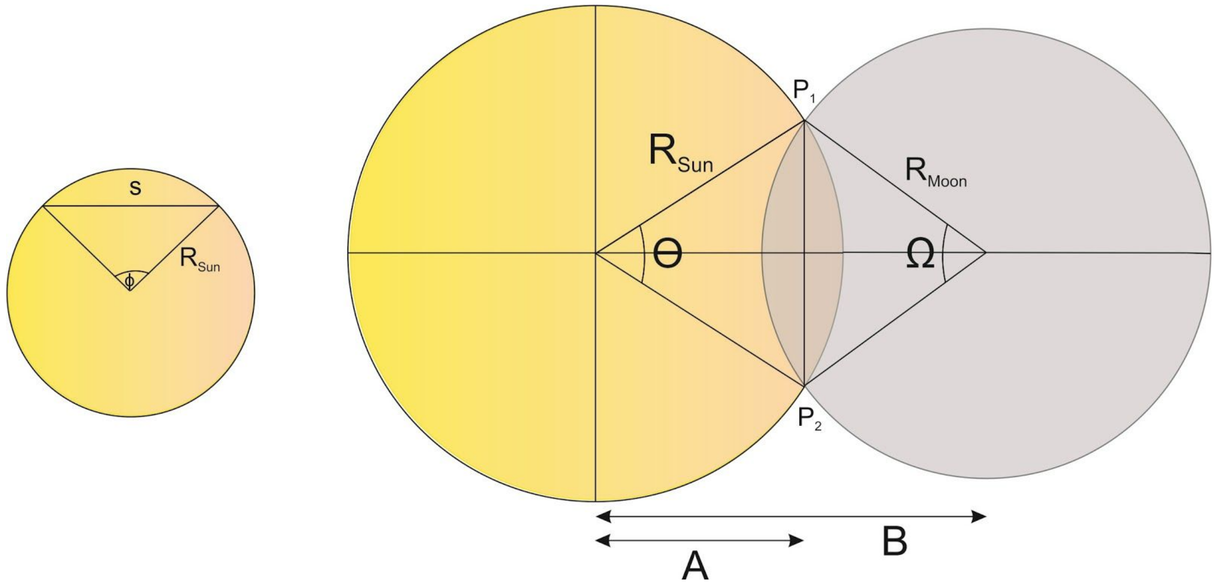

Fig. 3.1(Left) & 3.2(Right)

4. The area of segment 'S'(see fig. 3.1) can be calculated as follows:

$$S = \tfrac{1}{2} R^2_{Sun}(\phi - \text{Sin}\phi)$$

5. The secant P1P2 is at:

$$A = (R^2_{Sun} - R^2_{Moon} + B^2) / 2B$$

6. The angles Ω and Θ from fig. 3.2 can be calculated as follows:

$$\text{Cos}(\Theta/2) = A/R_{Sun}$$

$$\text{Cos}(\Omega/2) = (B\text{-}A)/R_{Moon}$$

7. After finding the above parameters, you can make a computer simulation of a solar eclipse. But for now, you can calculate the magnitude of the eclipse using equation below:

$$\text{Magnitude} = (R_{Sun} + R_{Moon} - B)/2R_{Sun}$$

can you calculate the magnitude for the annular solar eclipse?

8. Obscurity(%) can be calculated as follows:

$$\text{Obscurity} = [R^2_{Sun} + R^2_{Moon} + (\Omega + \Theta) - (\text{Sin}\Omega + \text{Sin}\Theta)]\times 100/2\pi R^2_{Sun}$$

9. The value of magnitude vary from 0 to 1 i.e in case of no eclipse and total solar eclipse respectively. In case of an annular solar eclipse, this value is generally greater than 0.9 and less than 1

10. The obscurity of an eclipse or obscuration is taken in terms of percentage. 0% is when no eclipse will occur and 100% is when total solar eclipse will occur. In case of the annular solar eclipse, this value is generally above 90% but less than 100%

11. This activity does not consider the effect of limb darkening(What's that?) while calculating these two parameters. If you are interested to learn calculations considering this effect. See this: http://robertnufer.ch/06_computing/eclipse_dimming_doc.pdf

12. For better understanding of magnitude and obscurity in an interactive way, see this: https://www.geogebra.org/m/SnZ7QGTJ

Note: All angles in this activity are taken in radians.

Activity 4: How to photograph a solar eclipse using a smartphone

When we observe such events even once in our life-time, we would want to make the best out of those opportunities.

Why not take this opportunity and capture the upcoming annular solar eclipse with your smartphone.

Aim: To take a picture of the annular solar eclipse.

Material: Smartphone, Tripod stand(optional), Stopwatch, Solar filter, a telephoto lens(optional).

Procedure: 1. The last two activities were mostly theoretical but this activity is hands-on one in which you will be using your phone instead of a heavy and costly DSLR for astrophotography. Apart from the phone, make sure to use high quality material, especially the solar filter.

2. Though there are numerous ways to photograph a solar eclipse including projection method but here we will directly capture images. Make sure to know the exact time of totality(If any) from your place. Use **Solar Eclipse Timer** app by Foxwood Astronomy for the same.

3. Once you know, prepare your set up well in advance. In setting up the equipment, first you need to put solar filter film over telephoto lens. You can get such film from an ISO certified solar viewing goggles.

4. It is advised to at least have a **telephoto lens**(eg. MobiTrip 12x Universal Optical Zoom Mobile Telescope Lens kit) to get better resolution images from your phone. You can easily get such lens from amazon, flipkart etc. and it costs around INR 1000.

A 12X telephoto lens. **Image Credit:** amazon.in

5. Fix the phone on a **Gorilla Tripod** stand with telephoto lens clipped on the phone camera. You can buy this tripod for INR 200 at amazon.in

Universal Gorilla Tripod stand. **Image Credit:** amazon.in

6. Turn on the HDR if available in your phone camera. While clicking pictures, don’t put camera on autofocus, instead, put it on manual mode. Make sure to focus the Moon.

7. Now adjust the exposure until you see the most detailed view of the eclipse. Before finally taking images of the eclipse, do as much practice as possible by photographing the Sun along with an artificial moon and all the setup as mentioned above.

8. You may be wondering about all those settings that may not be available in your android phone. Don’t worry you can do this by installing **Camera FV-5** app.

9. On the day of the annular solar eclipse, make sure to test all the equipment well in advance. Wear a solar view goggle while pointing phone towards the sun during actual activity. If not then point the Sun by looking at the phone screen. Finally, take as many images as possible.

Note: Annularity of solar eclipse will be visible in india from specific locations. If in case you are unable to travel to those sites, still you should consider photographing partial solar eclipse if visible from your place.

Activity 5: Calculating the Moon distance using parallax

There are different ways to find out the distance to the Moon which also include the projection method. But in this method you need to know the size of the Moon which can only be known from data we have in our textbooks and other resources. Using Parallax you don't need to know the size of the Moon even.

Parallax is a method to measure large distances, such as the distance of a planet or a star from Earth. It is based on measuring two angles and the included side of a triangle formed by the star.

Aim: To Calculate the Moon distance using Parallax on the day of the annular solar eclipse.

Material: Stellarium Software

Procedure: 1. This activity can be performed using astronomical instrument but that require both instrument and the background knowledge of local and universal coordinate system and much more. So here, we will take help from a computer software called Stellarium. It is very easy to use as it comes with guide and can be taken into practice for future astronomical events.

2. Let us first try to understand the geometry of the eclipse. According to fig. 5, if we can find out this parallax angle(ϕ), we can easily do the rest of the calculations with basic trigonometry.

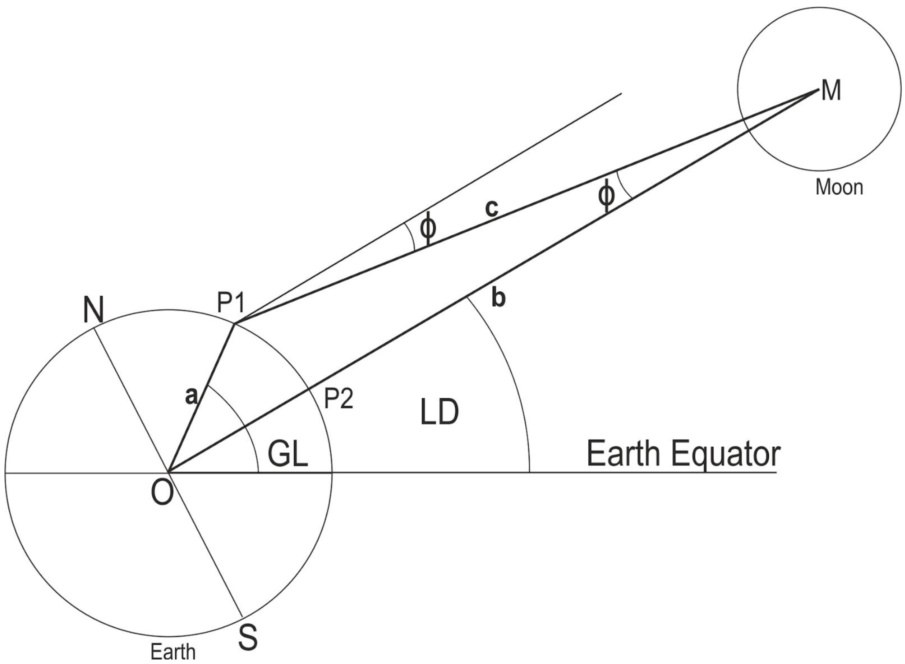

Fig. 5

Where: P1 and P2 are two different places on Earth

GL: Geographical Latitude of P1

LD: Lunar Declination from P2

ϕ: Parallax angle

At the time of maximum annular solar eclipse i.e when we see the Moon and Sun forming a perfect ring. The observer at P1 and P2 will see the Moon at different declination angle. Thus, only one observer will observe a perfect ring and the other will observe a partial solar eclipse. If can know the declination of Moon at these two places say P1 be Pune(place of partial eclipse) and P2(Coimbatore) and latitude of P1 then we can calculate:

1. The parallax angle
2. Distance to Moon

3. First, we will use stellarium and try to find out the declination of the Moon at the time of annular(maximum) solar eclipse(See Image below). Text highlighted in the image 5.1(below) tells us the declination, time and location from where the maximum annular solar eclipse can be observed.

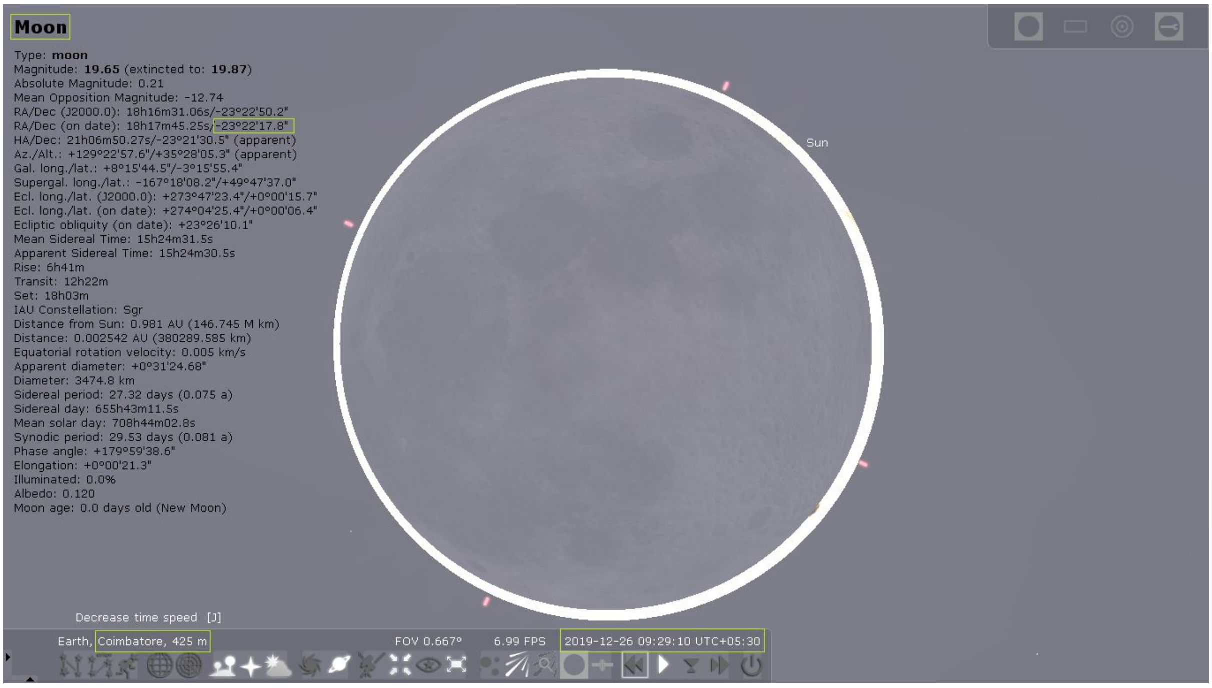

Image 5.1

4. Similarly, find the declination of your place(if partial eclipse is visible). In this case, I have chosen Pune(See Image 5.2).

Image 5.2

5. Find the geographical latitude of Pune and radius of the Earth from an authenticated source.

6. From fig. 5, we can see a triangle $\triangle OP1M$ with side a,b and c. Now, using Sine relation we can write:

$$\frac{Sin\,P1}{b} = \frac{Sin\,M}{a} = \frac{Sin\,O}{c} \tag{5.1}$$

from fig. 5, $Geographical\ Latitude(P2) - Lunar\ Declination\ at\ P1 = O$ (5.2)

and $a = Radius\ of\ Earth$ (5.3)

Since ϕ will be very small, we can say: $c = b$ (5.4)

where 'b' is nothing but distance to the Moon.

7. Now using equation 5.2, 5.3 and 5.4, can we rewrite the 5.1 equation?

So here it is: $\frac{Sin(Geographical\ Latitude - Lunar\ Declination)}{Distance\ to\ the\ Moon} = \frac{Sin\ \phi}{Earth\ Radius(a)}$ (5.5)

8. Now in equation we don't know ϕ. So here we will use stellarium to find ϕ. As shown in the Image 5.1, we can find out the Lunar declination from both the place at the time of maximum annular solar eclipse. Which would difference of both declination:

So $LD(at\ P2) - LD(P1) = \phi$ (5.6)

9. So, finally using 5.5 and 5.6 we can find out the distance to the Moon.

<u>**Activity 6**</u>**:** Does acceleration due to gravity changes during solar eclipse?

Aim: To determine if acceleration due to gravity on Earth changes during a solar eclipse.

Material: A simple pendulum consisting of a metal ball(e.g 0.5-2 kg) with known mass hanging from a laboratory clamp stand(1-2 m high) using a strong massless thread(0.5-1 m), stop watch, long ruler, chalk or markers.

Procedure: 1. First, place the laboratory clamp stamp at a leveled surface and hang the pendulum. Choose a place such that wind does not affect the motion of the pendulum. See Fig. 6.1

Fig. 6.1(For reference only)

2. Mark the pivot point on the clamp from which the pendulum is hanging to make sure the setup and especially the arm of the clamp is not moving down during the oscillation of the pendulum.

3. Measure the length of the string in all the five phases of the experiment. These phases would be; Before the eclipse to first contact, first to second contact, second contact to totality

of the annular solar eclipse(i.e when you see a perfect ring), totality to third contact and third to fourth contact. See Fig.6.2

4. Start the experiment before the first contact and take the reading of first phase till the first contact occurs. First contact is nothing but the beginning of the eclipse when Moon just touches the limb or edge of the Sun.

5. The reading include the time(in seconds) taken by the pendulum to complete say '20' oscillations and length of the string. The length of the string would almost be the same in all phases unless you want more data with varying string length during each phase for better results. In that case, take an average of multiple(if any) readings taken in single phase.

6. In second, third, maximum and fourth contact repeat the same thing and note down the time for 20 oscillations.

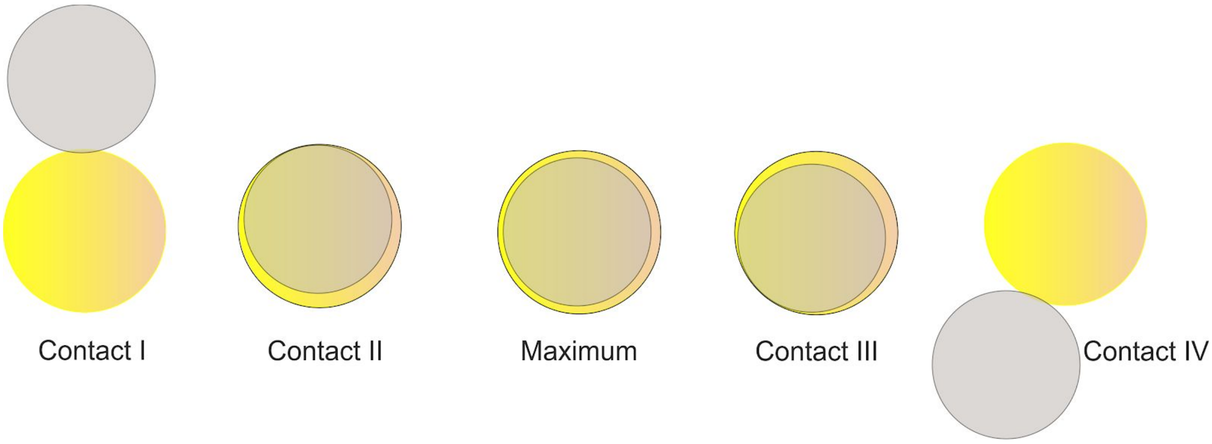

Fig. 6.2

7. Now as we know, time period for a simple pendulum with small amplitude can be expressed as:

$$T \approx 2\pi\sqrt{\frac{L}{g}} \qquad (6.1)$$

8. Equation (6.1) can also be written as:

$$g = (2\pi)^2\left(\frac{T^2}{L}\right) \qquad (6.2)$$

Where; g: Local gravitational acceleration

T: Time period of oscillation

L: Length of the string or cord

9. You can find the value of local gravitational acceleration at https://www.sensorsone.com/local-gravity-calculator/. If you count 20 oscillations say in 40 seconds, then the average time for each oscillation would be 2 seconds. This would be the T which you will use in the formula.

10. Since the above equation is valid for small amplitude, therefore make sure to start swinging the pendulum keeping the amplitude small such that maximum angle from vertical line i.e θ_0 should be less than 1.

11. Make a table as shown below to record the data:

Place of Experiment	Value of g(m/s^2) Phase I	Value of g(m/s^2) Phase II	Value of g(m/s^2) Phase III	Value of g(m/s^2) Phase IV	Value of g(m/s^2) Phase V

12. Lastly, you can plot the value of ‘g’ against each phase and see how acceleration due to gravity changes throughout all the phases.

13. Total time from first contact till the fourth contact will be eclipse duration. Make sure to verify your eclipse duration from predicted one for your place. In case if the variation comes out to be more than ±10 seconds, then the data taken is not good for this experiment. You can use ‘Time The Sat’ app to note down the timinings.

14. It is suggested and if it is possible, try to perform this experiment with more than one pendulum setup which would require more people.

<u>Activity 7</u>: Cap making: Solar eclipse observation using telescope

Observing a solar eclipse with telescope can be dangerous to the eyes as you can become blind. With a telescope, light gathering capacity gets multiply in contrast to our eyes. So, either use proper solar filter in front of the telescope tube or use projection method. Solar filter can be slightly costly. So, we can make a low cost telescope cap for the telescope.

Let’s see how to make a cap for telescope!

Aim: Making a telescope cap for solar eclipse observation.

Material: Two black chart papers, solar filter, duct tape, scissor, glue

Procedure: 1. First, cut a strip of black sheet a little wider than the circumference of telescope tube and keep width 100 cm or 4 inches.

2. Then role the strip over the front side of the tube and paste it with duct tape. Now ring of the paper is ready. See Fig. 7.2.1

3. Now, using pencil make a circle on the second chart paper of diameter equal to the diameter of the telescope tube

4. Mark one small circle of 1.5 inches diameter on bigger circle and cut the same(See Fig 7.1)

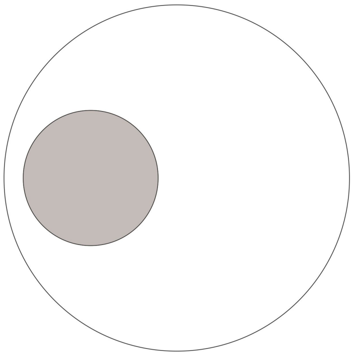

Fig.7.1

4. Just take out that ring one inches above the tube, then cut it into strips (see Fig. 7.2.2).

Fig. 7.2.1

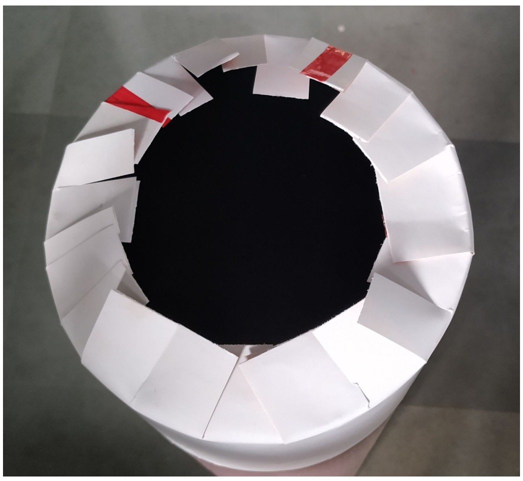

Fig. 7.2.2

5. Fix the circular sheet over the ring using glue. And now your telescope cap is ready. See Fig. 7.3

Fig. 7.3

5. You can fix a solar filter(silver in colour) as shown in Fig. 7.3 for safe solar observation.

6. If you can't get solar filter, you can use projection method for the observation. In that case, point the telescope towards the Sun without looking into eyepiece directly, instead put a white sheet and project the eclipse phenomenon on the paper screen.

Activity 8: How do we know if moon causes solar eclipse?

Most of us know that moon covers the sun's disk during a solar eclipse. How do we know it is the Moon? While observing a solar eclipse and especially during totality, the object covering the Sun looks black as no sunlight is reflected from it. Can we prove that is the Moon only and not something else? Although there are numerous ways to prove it. Let's do it using modeling the Earth-Moon system.

Let's see how this works.

Aim: To prove it is the moon that covers the Sun during a solar eclipse.

Material: A thick black big sheet, a long stick, glue

Procedure: 1. For modeling Earth-Moon system, we first need to calculate the scaled sizes and distance between them.

2. The ratio of radius of Earth to the moon is approximately 4 which tells us that the Earth is about 4 times bigger than the moon.

3. The ratio of Earth-Moon distance to Earth's radius on the day of the annular solar eclipse will be:

$$\frac{D_{E-M}}{R_E} \simeq 60$$

Where: $D_{E\text{-}M}$ = 381037 km(on the day of the annular solar eclipse i.e December 26, 2019)

R_E = 6371 km

4. Let's take the radius of our moon disk model to be 15 cm, the earth disk would be 60 cm. The distance from earth-moon in our model will come out to be 60 times the above ratio i.e 3600 cm or 36 meter.

5. Now, you can cut a 15 cm radius moon from chart paper and fix it using glue on a long stick.

6. On the day of the annular solar eclipse and at the time of annularity i.e observe this disk from a distance of 36 meter and see if both the moon and moon model looks the same in size. If yes, that means it is the Moon.

7. But hey! where to use earth disk? Well, the person observing that moon disk from 36 meter away represents Earth in this modeling.

Note: 1. You can choose the radius of the moon disk as convenient. Then, accordingly the distance in the model will change.

2. In this activity, we have assumed that data related to the object(here moon) is correct. And we can see that our model works. If it would have been anything other than Moon, how come two objects be in same orbit and still we don't seem them in the sky.

3. Moreover, we have understood the motion of the Moon around Earth and thus we can predict very precisely future eclipses.

Activity 9: How to find the latitude of your place during daytime

In one of our previous activities, we calculated the distance to the moon using parallax where we had to use latitude. In case, if you want to calculate latitude instead of finding it online, in books etc. you can do it. How? Let's see.

Aim: Finding latitude of your place using Sun.

Material: A long pencil, 30cm ruler, marker(chalk etc.), timer, large sheet of paper

Procedure: 1. Place the pencil upright on level ground in the sunlight and mark the centre of its base. Make sure the pencil is not tilted.

2. Precisely mark the tip of the shadow cast by the pencil at specific intervals of time (eg. every 3 min). Start shadow marking at 11:00 hrs and stop at 13:00 hrs as local noon for all the places in India lies b/w this time range.

3. Once all markings are done, measure the height of the pencil above ground. Now remove the pencil and then join each marking point to the centre of the pencil base (see Figure 9.1 for reference)

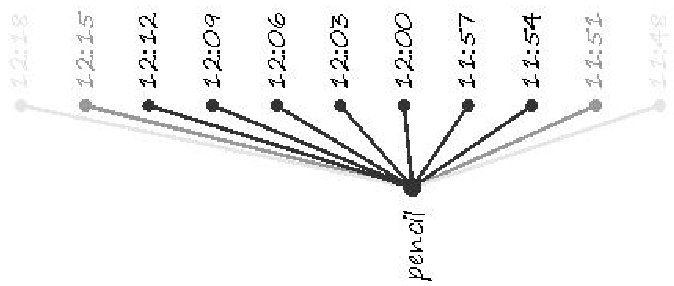

Fig. 9.1

4. The above figure is just a representation of what your markings may look like. By measuring the length of each shadow, you will find the shortest along with its time. This time is the local time of your place.

6. Draw a right angle triangle on a large sheet of paper keeping opposite side = shortest shadow length and adjacent side = height of the pencil above ground with angle (S) as shown in Figure 9.2.

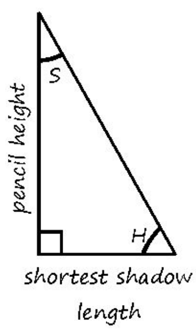

Fig. 9.2

7. Now, using a protractor, measure the angle (S) and Angle (H) which is the height or altitude of the Sun above the local horizon.

8. This height (H) can be written in terms of Solar Declination(SD) and Geographical Latitude (GL) of your place as follows:

$$GL = 90 - H + SD \tag{9.1}$$

9. Using the above equation, you can find out the latitude of your place in the daytime.

Activity 10: Sun Spectrum: Fraunhofer lines

Most of us have seen rainbow sometime in our life and it's beautiful. Have you ever wondered, what that beautiful band of colors is all about? It is called as Spectrum or band of light coming from the Sun. But if you could get a chance to see a rainbow very closely, you will find numerous black lines throughout the band. These black lines are called Fraunhofer lines. These are nothing but absence of different wavelengths of light which happens due the absorption from molecules present in the earth's atmosphere. So, can we see these absorption features using artificial objects such as a CD or prism. Yes, we can, let's find out how?

Aim: To form sun's spectrum using a diffraction grating and observe features

Material: A small mirror, written CD, cardboard box, paper cutter, glue, cello tape

Procedure: 1. we need to make a setup which can be made using the above listed material. We call this setup, spectroscope.

2. In making a spectroscope, first we will need a small cardboard box similar to the one shown below. You can make one or get it from the market.

Image 10.1

3. As shown in the image below, fix the mirror, white screen, CD cut out piece and make a slit in the box. For reference, the length of the box is given so as to get an idea of dimensions of other objects.

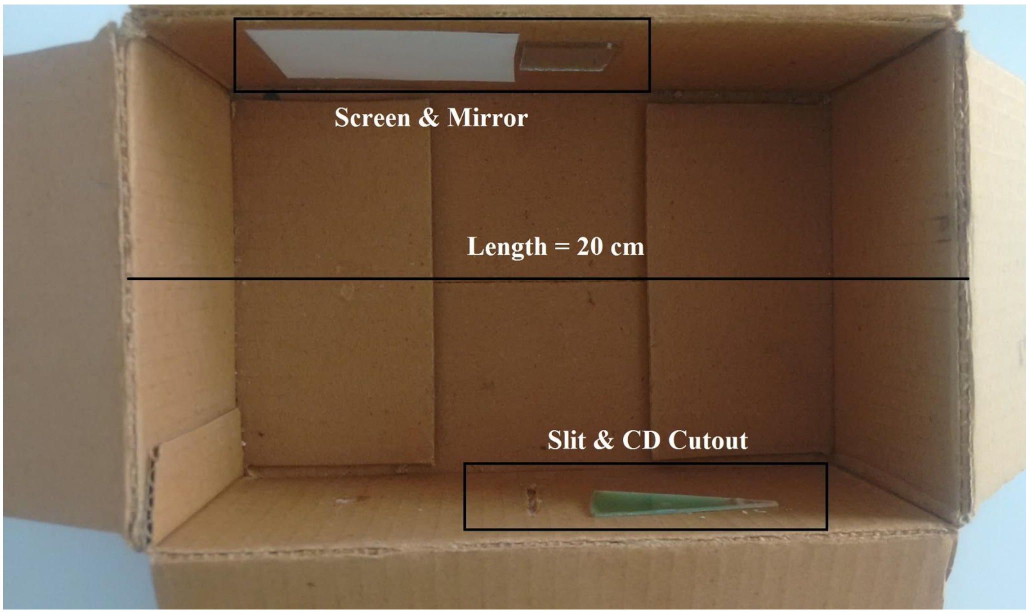

Image 10.2

4. Now, point the slit to the Sun and close all the lids of the cardboard box except the one with the wall at which screen and mirror are fixed. By closing the lids, you can avoid excessive sunlight entering the box and making spectrum look fade.

5. Now, one has to adjust the box while observing through it in such a way that light coming through the slit falls on the mirror.

6. In case if the spectrum is not sharp i.e black lines in the rainbow are not visible properly and distinctly, then move the screen ahead towards the wall at which slit and CD is fixed. Make sure the CD is coming in the way of slit and mirror.

7. Those black lines or absorption features, which you can see in the spectrum, could tell you about the atmospheric composition of our planet Earth.

Note: Please don't look at the sun directly while pointing the spectroscope towards it even during the solar eclipse.

Major references:

1. stellarium.org

2. Camera FV-5 Lite

Credits

Content Design

Shivom Gupta

Special Thanks

Surhud More

Samir Dhurde

Tushar Purohit

Atharva Pathak

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