Explaining the Motion of Heavenly Bodies: Part 2
Why do we say the moon goes around the earth?

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In the earlier installment of this series of articles, I discussed how we can arrive at a spherical earth, and how the rotation of the earth on its axis can explain the apparent daily motion of the Sun and the stars. The motion of the planets is more complicated and this cannot be seen unless observations are made over a period of several weeks to months. But the difference between the apparent motion of the Sun and the moon can be observed if we note the position of the moon at a fixed time over just two or three days. Not only is the motion of the moon slightly erratic when we look at the mostly regular motion of the Sun, it also looks slightly different each day going from nothing to a full moon in a fortnight. This article looks at how we need to move the moon around the earth, and what the effect of the illumination by the Sun is. It is best to start with actual observations and then try and figure out what this tells us about the motion of the moon.

Activity 1: Though the moon can be seen some time during the day or night on all days except the day of the new moon, it is best to make these observations just before or after the days of the full and new moon – and we can get these dates from any calender or almanac. Observations can be taken over three or four days (minimum of two days of observations will be required to follow what comes later, but is it better to have more so that you can have confidence in your findings!) and the following are to be noted (the shape of the moon on each day can also be noted, this can be used to discuss the phases of the moon later on):

Before full-moon:

1. Is the moon visible in the sky when the sun has just set?
2. Is it in the eastern sky or the western sky?
3. How high above the horizon is it? (A rough estimation of the angle above the horizon can be made.)
4. How does this change over the days that you are making the observations? Is the moon higher above the horizon or lower over the days leading to the full-moon?
5. What can you say about the time of moon-rise each day on the basis of these observations?

After the full-moon:

1. Is the moon visible in the sky when the sun has just set? How many hours after sunset is it seen in the sky? (If the horizon is not visible from the point where you are making your observations, you can just report how high above the horizon it is when you do see it each day.)
2. How does this change over the days that you make the observations? Is the moon rising later or earlier each day (night)?

After the new-moon:

1. Is the moon visible in the sky when the sun has just set?
2. Is it in the eastern sky or the western sky?
3. How high above the horizon is it?
4. What can you conclude about the time of the moon-rise each day on the basis of your observations?

Before the new-moon: (if you are observing the moon before the new-moon, you will have to look for it early morning, if possible starting at least half an hour before sunrise)

1. Is the moon visible in the sky before sunrise?
2. Is it in the eastern sky or the western sky?

3. How high above the horizon is it?
4. What can you conclude about the time of the moon-rise each day on the basis of your observations?

Observations of the moon taken over just two days at the same time (this time would vary based on whether you are looking at the moon before or after full or new-moon) is sufficient to make us realise that the rotation of the earth on its axis alone cannot explain the apparent position of the moon each day. With the Sun, when the earth completes one spin and gets back to the the starting point, the Sun is back at the same point in the sky[1]. But what about the moon? Whenever we look for the moon at the same time over two consecutive days, we find that it is not at the same place where it was the previous day (of course, the shape is also different, and we will be covering that too in this article). However, in little less than a month, we see the moon back in the same position and it is also of the same shape as before. What does this tell us about the how the moon might be moving?

First, if the moon is not in the same position in the sky after 24 hours, it needs to be explained by something in addition to the apparent motion of all the heavenly bodies being due to the rotation of the earth on its axis every 24 hours. And because the moon seems to get back to whatever position it was in after about a month[2], so the moon completes one revolution around the earth in that much time. But in which direction is the moon doing this circumambulation? And this can be fun to figure out based on the data we have collected on when and where we see the moon from one day to the next.

Activity 2: Take a small ball to represent the moon and a globe. Any point in the room can be used to represent the Sun, or else a torch can also be used. Use any set of data points collated in activity 1 and figure out the position of the moon from one day to the next. For example, if the earth, the moon and the Sun are in a straight line with the moon in the middle, you would not be able to see the portion of the moon that is illuminated by sunlight from the earth, and this is what happens on new-moon day. You would have noted that the day after *amavas*, the crescent moon is visible in the western sky just after sunset and this too sets within an hour or so. This means that the moon-set takes place only when the earth has turned for more than 24 hours. That is, if the position of the moon had not changed, it would have set at the same time each day. Since the moon is setting later, it means that when the earth gets back to the original position after 24 hours, the moon is still in the sky and it sets only after the earth has rotated a little bit more. In which direction would the moon have moved around the earth for this to happen? Counter-clockwise when viewed from the top of the north pole or clockwise?

Experiment with moving the moon both clockwise and counter-clockwise around the earth and work out whether the moon would rise and set later or earlier each day in both cases. Since this is fairly easy to work out, I will not reveal the answer here, but it is great fun for the groups to work this out and make sense of seemingly disparate data using a particular model. A similar approach can also be used to figure out the direction in which the earth revolves around the Sun. Once everyone is comfortable with thinking about how the moon goes around the earth, we can get down to figuring out how the moon's phases change over a month.

The direction of the moon's orbit around the earth:

[1]Well, not exactly, but we will go into that later.
[2]The time taken from one full moon to the next is 29.5 days, we will round it off to a month now so that calculations are easier.

As in the earlier article, here too we use the terms clockwise or anticlockwise to describe the motion of the moon around the earth, and here too it is important to remember that if we are looking at the earth-moon system from the north star (using a very powerful telescope!), that is, if we were looking down at the earth from a point above the north pole, the direction of revolution of the moon would be opposite of that observed if we were looking at the earth-moon system from a point above the south pole.

Activity 3: This activity can be done any time the moon is visible in the sky along with the Sun low on the eastern or western horizon. So this means 3-6 days after the new moon day if one wants this activity to be done in the evening. Mark the position of the moon in the sky and hold up a ball in the same direction such that sunlight falls on the ball. Obviously, the half of the ball towards the Sun will be lit up and the other half will be in shadow. But you will be able to see only a portion of this illuminated surface of the ball. Compare the shape of this portion with the phase of the moon. Try this on different days. And draw the shape of the illuminated portion of the ball and the moon's phase on each day. The change in shape might not be very apparent from one day to the next, but is very obvious if there is a gap or one or, even better, two days.

This activity gives us an indication of why we see the different phases of the moon over a period of a little less than 30 days. This understanding can be reinforced with the following activity.

When will the moon rise each day?

One of the common questions that come up during this session is why people have to wait so long to break their fast for 'karva-chaut', and I always say that the day chosen for the fast is a conspiracy :-)

Anyhow, a rough and ready calculation can be done to figure out when the moon will rise (or set) on any given day after the full moon or new moon. Since the moon takes 29.5 days to go from one full-moon to the next, we can take this as the time taken by the moon to complete one revolution around the earth. Since, this revolution can be taken to be a circle, it is covering 360° in (approximately) 30 days which means that it covers 12° in a day. Since we had earlier calculated that the earth turns 15° in an hour, this means that the moon will rise roughly 50 minutes later each day.

Since, on the day of the full moon, the moon on the opposite side from the Sun, we can take the time for moon-rise on that day to be the same as the sunset time (there will be slight variations, but this is roughly true). On the second day, the moon will rise around 50 minutes after sunset, on the third day around one and a half hours later, and so on. Since the moon is often not visible till it has risen a little above the horizon if your area is surrounded by hills or trees, you can imagine how painful the wait to see the moon on 'karva-chaut' would be. Recently, the group I was doing this session with came up with a suggestion of a fast on the day of 'karva-dooj' so that one could comfortably have one's dinner at the usual time!

Activity 4: We will need a globe, a small ball and a torch for this activity. A bigger ball can be used for the earth, but it is easier to locate oneself in a known location and try and figure out what would be visible from there so it is better to use a globe. First shine the torch (the Sun) so that its light falls on both the globe (the earth) and the ball (the moon). Move the ball around the globe, taking care that the ball is not coming in the shadow of the globe, and neither should the shadow of the ball fall on the globe[3]. It can easily be noted that half of the ball is always lit

[3]In this situation we would get an eclipse which we are not going to discuss at this point.

by the torch while half is in shadow. Similarly, half of the globe is lit by the torch (the portion of the earth where it is day) and half is in shadow (where the night has fallen). While moving the ball around the globe, it will become apparent that at different points, the moon will be visible for some time during the day and also during the night within each 24-hour period. However, when the moon is nearer to the Sun, we would not notice the moon except early in the morning or towards evening because when the Sun is high in the sky, we would not be able to look towards it (we should not even try because we would damage our eyes).
Next, place yourself on the globe and imagine what portion of the illuminated half of the moon would be visible to you. First work out the respective positions of the Sun, moon and the earth when the full moon is visible, and when the moon would not be seen at all. Next see if you can figure out in which position exactly half of the illuminated portion of the moon would be visible from the earth. Check if you are confident about working out each phase of the moon over the 30-day period.

Box : Why is a the full circle of the moon faintly illuminated when a crescent moon is seen and not on other days?
You might have noticed that when the quarter-moon (when half of the moon is visible, it is called quarter moon because it has completed a quarter of its circle around the earth) is seen after the new moon, the other half is fully dark and not visible at all. However, for around 4-5 days after the new moon, when the crescent moon is seen after the sky is sufficiently dark, a faint circle marks the full shape of the moon even though only a crescent is brightly lit. What is the source of this faint light falling on the moon?
Interestingly, this faint light is reaching us after multiple reflections – the earth too is illuminated by the Sun and like the moon, it reflects some of this light out into space (like we see all the other planets because of the sunlight that they reflect). In the crescent phase, some of the earthlight is reflected towards the moon which then reflects this back towards the earth! This faint light from the earth makes for excellent viewing of the craters on the moon if one has a fairly basic telescope.
With the quarter-moon, the light being reflected off the earth does not go towards the dark portion of the moon and hence we see only half the moon.

Once we have figured out the motion of the moon around the earth and exactly how much it moves each day, we can also understand why the full-moon does not rise exactly as the Sun sets every time (the full moon would have risen exactly with the setting of the Sun in some part of the earth; but by the time the sun sets for us here in India, the moon had not yet reached the exact opposite position or had already crossed it). And this also explains why Eid gets to be celebrated on different days in different parts of the world (if the crescent moon is too close to the Sun when it sets in a particular country, the moon might set soon after, it might not be dark enough to see it before the moon too sets).

If you have any other questions about the moon (other than eclipses), please do write and ask.

[Wikipedia has a few videos showing how the phases of the moon are seen.]

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