Explaining the Motion of Heavenly Bodies:Part -1

Why do we say that the earth is a sphere which rotates on its axis once in 24 hours?

Uma Sudhir

This is the first part of a series of articles that look at some concepts usually covered in primary school in what can only be called a perfunctory manner. At the end of this series, we shall consider the wisdom of introducing *and* finishing this topic in primary school. These concepts are actually wonderful examples of the process by which knowledge is constructed and verified in the realm of science, and my attempt is not only to explain in some detail how these ideas came about, but also to share experiences of some activities which can be used to convey these ideas to learners. These activities are in no way original; they have been collated from a variety of sources[1], but have been tried out with different groups of learners. One major learning from all my attempts at getting learners (teachers and students) to grapple with these concepts is that it takes time for them to be assimilated, and it is best to do them over extended periods of time with breaks. Another thing to remember is that concepts from many other topics and disciplines need to be made use of, so at times it is necessary to proceed on the assumption that those concepts are a given. Spiralling, that is, revisiting concepts at higher levels at later stages is often talked of as a pedagogical tool, but it is hardly ever used for these ideas. But a few essential points covered in higher classes that reinforce these concepts will also be mentioned, but not gone into in detail.

My approach has always been to state the claims of the heliocentric model and ask the group to proceed with the assumption that this is the correct view. In essence this is to repeat the main statements made in the textbooks – (i) the spherical earth rotates on its axis (which is tilted at an angle of 23.5°*[2]) once in 24 hours and revolves around the Sun once in a year; (ii) the moon revolves around the earth, and the phases of the moon; (iii) all other planets revolve around the Sun; (iv) the revolution of the earth around the Sun in combination with the tilt of its axis results in different seasons in different parts of the earth & (v) the rotation of the earth gives rise to the apparent motion of all heavenly bodies (over a period of 24 hours) except for the North Star because the axis of the earth points towards it. The aim of the session then becomes that of understanding why this view came to be accepted as true.

I have split this up into a number of articles because there is so much to be covered, but these concepts are all interlinked. So in places, I will also be mentioning connections to ideas which will be gone into in detail later. One should be aware that these questions will come up en masse, but we need to patiently address them one by one.

If you look at the original edition of the Bal Vaigyanik series, there were activities to be done over the entire year with regular observations being made of shadows (their direction

---

[1]One of the best sources for a variety of experiments is, of course, the Bal Vaigyanik. If possible, one should carry out all the experiments in the chapters related to astronomy.

[2]* Do we ever talk about what is the base from which this angle is measured? *Note to Himanshu – this question is included to stress how incomplete our discussion on the solar system is, it can be deleted.*

and length), the moon and its phases, etc. While ideally this would be the best way to approach this topic, given time constraints this is often not possible even during a series of workshops, and more importantly the fact that given the ubiquitous phone and television in everyone's hands and homes, most people have not noticed what is happening in the sky.

We say that the earth is a sphere, but what do they actually think?

Numerous studies have been done on the range of alternate ideas that children (and perhaps adults, maybe even teachers) have about the earth, and the motion of the Sun, moon, stars and planets around the earth. Sandarbh has carried articles by Rashmi Paliwal and Yemuna Sunny (Sandarbh 1.20; 2.43) and Deepak Verma (Sandarbh 13.63) which convey the gist of these alternate conceptions. But before one starts on this topic, it is best to elicit from the group what they think. Most will parrot the textbook statements, so they need to be asked to describe their models elaborately. Then these will need to be deconstructed so that they realise what the shortcomings of their mental models are. Now how do we proceed towards the currently accepted understanding that the earth is a sphere [3]?

How is the idea of a spherical earth matched with lived experience?
It has been observed that one of the ways is to interpret this to mean that we live inside a hollow, spherical earth with the dome of the sky forming the skin of the sphere which has the Sun, moon etc. moving across it. One of the ways in which this idea can be challenged to ask them about what they have heard about different time zones in different countries, and how this will fit in with their 'world-view' – where does the Sun go when it sets, and how is late in the evening for someone in California when we are waking up in the morning. This does not mean that they will immediately change their ideas, but we can move on to a new mental model only when we realise that the one we cherish is inadequate.

The Earth as a Sphere:

Activity 1: Imagine that we were to stand on a football, would we be able to observe the sphericity of the ball? Now imagine that we were to stand on a ball with a radius of 1 m, would we still be able to observe its curvature? Would the curvature be the same as that seen while standing on the football? Imagine standing on bigger and bigger balls – a ball the size of the room, another the size of the building, then one the size of the mohalla or village. The group will be able to easily figure out that the curvature would keep diminishing as the size of the sphere increases.
{Be sure to have an illustration for this; not sure if giving a link to an animation (if available) is enough.}

So we are not able to discern by any simple or direct observation that the earth is a sphere, then what is it that gave rise to this idea? Records we have of ancient Greek ideas[4] tell us that two sets of observations mutually reinforced a spherical earth as opposed to the flat earth of our daily experience. There is much more, and now we have more 'pieces' of evidence; but let us look at the easily accessible ideas before we go into the others.

---

[3]The earth is not an exact sphere, but we shall go into that later. The article by Isaac Asimov (galat, yani kitna galat? Sandarbh 84.07) is an excellent resource.

[4]It might not seem fair to attribute all of this ancient knowledge to the Greeks, most ancient civilizations had developed quite extensive descriptions of the motions of heavenly bodies and how to predict various special events like eclipses. Unfortunately, Greek ideas were recorded and transmitted through various routes and formed the basis for the growth of the modern understanding and so I am sticking to their narrative.

First, as a sea-faring nation made up of many inlets and islands too, the Greeks had seen that when a ship sails away, the sails are visible long after the decks disappear. And this was a constant regardless of the direction in which the ship was setting sail. And similarly, when one was on a ship, the first indication of land were the tall mountains, the beaches and the port came into view much later[5]. This could be not be explained if we assumed the earth to be flat, because if there are no obstructions, there is nothing to prevent us seeing the base of any feature (building or tree or mountain) at the same time as we see its top. So the curvature of the spherical earth was used to explain these observations. Not only this, if we have an unimpeded view to the horizon in all directions, then we can see that it forms a circle (this can be observed in the plains too if we stand in the middle of fields with no trees).

Nothing beats the lack of obstructions in the sea (or maybe even a large lake or a broad river like the Brahmaputra), but even when we travel on land, some similar observations are possible. For example, if we travel towards the hills (especially the Himalayas), we can see the tall mountain ranges much before we see the foothills at the bottom. Or if we are going towards a city, then the tall buildings become visible from quite far away. When one goes to Dewas, the hill of the Devi can be seen from quite far away and one can gather one's belongings in preparation for getting off the train or bus!
{Illustration here to show a tree, and the same tree with a bus in front of it; when we can see the top of the tree, we can also see the bus that is blocking our view of the base of the tree; but this is not the case when we look at distant mountains, they appear on the horizon, but we cannot see any structures below at all.}

Second, numerous observations of lunar eclipses over many hundreds of years had led the Greeks to conclude that not only were these eclipses caused by the shadow of the earth[6] falling on the surface of the moon, but also that since shape of this shadow was always an arc of a circle, the earth had to be a sphere. Here, their superior knowledge of geometry came into play since they knew that the only solid shape whose shadow would always be a circle (or part of a circle) was a sphere (*picture*). This was regardless of the direction from which the light fell on the object and the angle at which the screen was placed (that is, even if it wasn't always exactly perpendicular to the rays of light).

Activity 2: Use either sunlight or a torch to experiment with the shapes of the shadow formed by various objects. Rotate each object to see how the shape of its shadow changes. Also change the angle at which light falls on the screen to see how this affects the shape of the shadow. It can easily be seen that the shadow of a plate goes from a full circle to a thick line as one rotates it, but the shape of the shadow does not change at all for a ball. If ones uses a rubber ball with a spoke through it, then the spoke can be used to rotate the ball so that the shadow of the ball can be seen cleanly. Using a hand to hold the ball confuses the shape of the shadow!

Box: Modern additions to the evidence for the earth's sphericity:
Of course, now we have satellite pictures taken from all angles and positions above different parts of the earth, and even photographs taken from the moon, which show a disc. And since only a sphere

[5]This was in contrast to what was observed when one looked at the skies. If one were to travel east or west, there was no apparent shift in the positions of the stars; but if one were to travel to the north or south, then the stars seemed to shift in the opposite direction. That is, if one were to travel far enough to the south, then the stars that were overhead in one's hometown shifted more and more northwards. More about this in later articles.

[6]Eclipses, both lunar and solar will be covered in a later article.

would appear as a disc regardless of the angle of viewing, the earth can now be accepted as a sphere, we can see it! *Illustration – photographs here.*
But about a hundred and fifty years ago, a nearly ten kilometre long straight stretch of a river (or its canal) in England was used to calculate the curvature of the earth. It was done in this manner – three poles were kept at different distances in a straight line. All of the poles showed the same height above the level of the water (and since this was a calm river, there were no waves to hinder these measurements), but when looked at from afar, the middle one appeared be to higher than the ones on the sides. Or if the poles were looked at from one side, the closest one looks higher than the others. Many variations of this experiment were carried out and corrections had to be made for the effects of atmospheric refraction too.
{Illustration for this?}

The Earth as a Sphere that Rotates on its Axis:

Now we move on to the next counterintuitive idea – that the earth which is so stable (unless we have lived through an earthquake) is not actually stationary. Once again, our senses deceive us, the earth seems flat, but is actually a sphere, and it is not standing still but rotating (and revolving around the Sun, but we shall take this up later). In order to fully appreciate the concept that the apparent motion[7] of all heavenly bodies can be explained by the earth spinning on its axis once a day and going around the Sun once a year (with caveats for the motion of the moon (and its phases) and the planets), we need painstaking observations over many, many years. But here, we bring out Occam's razor and say that though we can prepare a model in which what we see is actually what is happening with the daily rising and setting of the Sun, moon, stars and planets with slight variations through the year(s) being caused by their motion around a stationary earth, a lot more simpler idea is to have a) the earth spinning on its axis to explain the daily changes and b) the motion of the earth and other planets around the Sun to explain the changes that are observed in the sky over the year(s[8]). In this first installment, we shall just talk about the spinning of the earth on its axis.

Activity 3:

So we start with a model of the earth (it is best to use a globe, but at a stretch a ball will also do; if using a globe it is best to remove it from its base and avoid complications of the tilt of its axis for the moment) and say that it is its rotation that makes it appear that the Sun rises in the east and sets in the west. Designate some point (say a fan) or a person in the room as the Sun and get the participants (it is best if they work in small groups of four or five each so that free discussions are possible) to spin the earth so that the 'Sun' appears to rise in the east and set in the west[9]. If viewed from the level of the equator, the earth can be made to turn from left to right or right to left (the same, if viewed while looking down upon the north pole would have the earth respectively turning counter-clockwise or clockwise; this is difficult to digest, but the same motion if viewed looking down upon the south pole would appear to be clockwise and

[7]What do we mean by apparent motion? Like when we sit in a train and perceive trees to be moving backwards – this is apparent motion because it is actually we who are moving.

[8]It is actually the change in position of the other planets with respect to the stars in the background over a period of months to years that require the heliocentric model, but that complication is being reserved for the last article.

[9]With younger students, it might be best to place them on India (if a globe) or mark a spot on the ball and ask them when the 'Sun' would be visible from this position. And then get them to turn the 'earth' so that the 'Sun' rises and sets appropriately.

anti-clockwise respectively : hence the importance of stating one's point of view!). Get the participants to work out the 'correct' way that the earth is turning.

Direction of the Earth's Rotation:
The commonly used statement is that the sun appears to rise in the east and set in the west because the earth rotates from west to east. This is one way of describing the rotation of the earth. But one must remember that the directions that we think of as universal actually apply only on the earth. Historically, the directions were recognised and named based on firstly the direction in which the sun rises (east) and sets (west) and later the discovery of a star which does not change its position at night gave us north even when the sun was not to be seen.
But the description of the direction of rotation as being clockwise or anti-clockwise can be applied to any rotation. The only thing to remember here is that here one has to mention the point from where the observation is being made. It is slightly confusing at first, but imagine a clock in which the mechanism is transparent and we can see the hands of the clock from behind too, then the hands will be seen to move counter-clockwise!
Hence the emphasis here and in later articles too that the direction of the earth's rotation if we look at it from outer space looking down upon the north pole would be anticlockwise, while if we were looking down at the south pole, the earth would now appear to be rotating clockwise.

The timings for sunrise and sunset do not change that much from one day to the other, so taking the time from one sunrise to the next to be 24 hours, and not going into extreme variations in day-length, we can say that if roughly the time when the Sun appears in the east to when it sets in the west is 12 hours, then it would be overhead at noon[10] roughly six hours after it rises in the east. What does this tell us about how 'fast' the earth rotates? It completes one rotation in 24 hours. Given that a circle is 360°, this means that it turns 15° in an hour. We can use this to look at various constellations at night and check whether they too move by the same amount after an hour. There is no need to measure angles accurately, a rough estimation is all that is required. Since, during the course of a single day, all heavenly bodies appear to move at this same rate (it is slightly different for the moon, but more on that later!), Occam's razor makes an appearance to tell us that it is simpler to assume a constant rotation on part of the earth with all other heavenly bodies staying put instead of making all of them run circles around the earth :-)

So the motion of the Sun and other stars (the ones that are nearly overhead; one would get confused if one were to pick stars or constellations too much to the north or south!) can be explained by the spherical earth spinning on its axis. As mentioned earlier, the motion of the moon is not so easily explained, and its phases are an additional complication, we shall look at this in the next article.

[10]Once again, the full discussion will come later. When we talk about the effect of the tilt of the earth's axis on day length throughout the year, we will also talk about how the position of the Sun in the sky changes through the day and through the year in greater detail. So the Sun is not always (perhaps never) overhead at noon (and there may be a difference between local noon and noon according to the clocks), but for now we will take that as a given.

Hindi Translation Published in SANDARBH issue 147, July-August, 2023
Sandarbh is a bimonthly resource magazine published by Eklavya Foudantion