Why do day length and seasons change, and why is this different in different parts of the world? Explaining the Motion of Heavenly Bodies:

Uma Sudhir

We saw in the last article how different constellations and stars are seen at different times during the night over the course of a year. But what about the position of the Sun, other than its daily commute from east to west, are any other changes to be observed if we note its position over longer periods? It is difficult not to have noted that the sun does not rise and set from exactly the same point every day throughout the year. You might have also noticed that the sun shines into the the house for only some days of the year around noon. In most parts of India, it is not very congenial to be out in the open during the day in summer, but in winter you might have noted that the sun is not overhead, and your shadow is not beneath your feet at noon. You might have also noted the change in day length with seasons. How is all this to be explained? Let us start by looking at some data.

How does the position of the sun change from day to day over the year?
Obviously, these patterns can only be discerned if observations are made over many years. So it might seem trivial to reduce this to a few observations made over a couple of months. But it is best to at least observe for oneself that the sun does not always rise exactly in the east and set exactly in the west each day, and that the sun is hardly ever overhead in the middle of the day (I am purposely not using the word noon here, if we go by the clock, the sun might or might not be at its highest point during the day at noon; more about this later).
In this article, we shall look at sun-rise and sun-set timings at different places in India to see how this changes from one place to another over the year, and how this is different in different places even on the same day because we have agreed to adhere to a single time zone all over the country. But before we do this, we shall look at how sun-rise and sun-set timings will also change from one place to another when we look at many different countries too, and what we can deduce about the peculiarities of the earth's motion around the sun from this.

Activity 1: Locate the following places on a large map of India and try and figure out why the sun rises earliest in Dibrugarh.
Sunrise & Sunset Timings:
As on 21st March:

Place:	Sunrise	Sunset
Kanyakumari	6.24	6.31
Srinagar (J&K)	6.34	6.43
Jamnagar (Gujarat)	6.54	7.01
Dibrugarh (Assam)	5.15	5.21

Is the length of the day the same in all the places?

Now look at that data from a different month:
As on 21st June:

Place:	Sunrise	Sunset
Kanyakumari	6.04	6.40

Srinagar (J&K)	5.20	7.45
Jamnagar (Gujarat)	6.06	7.37
Dibrugarh (Assam)	4.16	6.08

Where is the sun rising first? Is the day length different now? What might be the reason for this?

Consider the data for two more months:
As on 21st September:

Place:	Sunrise	Sunset
Kanyakumari	6.10	6.17
Srinagar (J&K)	6.18	6.30
Jamnagar (Gujarat)	6.38	6.48
Dibrugarh (Assam)	4.58	5.09

As on 21st December:

Place:	Sunrise	Sunset
Kanyakumari	6.29	6.08
Srinagar (J&K)	7.32	5.25
Jamnagar (Gujarat)	7.25	6.10
Dibrugarh (Assam)	5.56	4.20

Is there any kind of a pattern to be seen in the variation in sun-rise and sun-set timings and the length of the day in these four places?

The length of the day changes from month to month, and the longer days are associated with hot weather. In this article, we shall also look at the link between the terms like longitude and latitude that you learn in geography and the variation in the position of the sun in the sky over the course of a year and why we have different seasons during the year. And though I suggested in my first article that you try out all the activities in Bal Vaigyanik, we will cover a couple of essential ones now. These will lay the basis for the discussions to follow.

Activity 2: Fix a long stick in the middle of a large open area so that it stands upright. The area should be such that it receives sunlight during most of the day and shadows of trees or tall buildings don't fall on the stick. This can also be done on the terrace of your building. Start as early in the morning as possible and mark where the shadow of the top of the stick falls every half an hour. The sun is supposed to be overhead at noon, so note where the shadow falls every 10-15 minutes after 11 am. Is the shadow shortest at noon? If the sun is right overhead at noon, then no shadow should be formed, is this so?

Does the Sun rise and set in the same place everyday?
My uncle's house in Bhopal faces east, and there is a water-tank right in front of the house. My uncle has very proudly told me several times how ideal this is for sitting on their verandah and having tea in the mornings. In summer, the sun rises behind the water-tank, so their verandah is in its shade and it is cool enough to sit out. And in winter, since the Sun rises to the south-east, they can soak up the mild sunshine while they enjoy their morning tea.
Similarly, our office in Indore was on the first floor and we had a balcony facing the south. In winters, this balcony would get the sun during the day and we would often stand there and warm up. In

summer, since the sun was mostly overhead, and there was another floor above, the rooms didn't get very hot.

Leave the stick fixed in the same position and try and note how the length of its shadow changes – make this observation at least once every fifteen days for about two months. If possible note this over the entire year. Also note the point where the sun rises and sets each day – does this remain constant or does it change over time? Is there any pattern and does this get repeated?

How to figure out the day-length while using a globe with a torch throwing light on one side:
Hold the sphere in one hand such that light from a torch falls on one side (this is best done at night, but a dark corner of a room will also do). Spin the globe with your other hand and note how any one point on the globe has light from the torch falling on it for some time (day) and for some time, this point on the globe is on the side away from the torch (night). Since it is difficult to spin the globe at a consistent speed, how does one figure out the length of the day?
One easy way is to note the position of the equator – this imaginary line divides the earth into two equal halves – the northern and southern hemispheres. Now take either hemisphere, and note how much of this is lit up by the light of the torch. If half of the hemisphere is lit up, then the day and nights are of equal lengths. If more than half of the northern hemisphere is lit up by the light from the torch, and light is even falling on the north pole, then the days are longer than the nights.

The change in day-length can be observed all over the world. Let us look at the data from a few more places, and see if there is any pattern to how day-length changes in different parts of the world.

Activity 3: Locate the following places in a large map of the world and go through the data for sun-rise and sun-set timings given for each place:

Alice Springs, Australia (23°42'S / 133°53'E)	(GMT + 9.30 hours)
Misool, Indonesia (1°52'S / 130°10'E)	(GMT + 9 hours)
Kikai, Japan (32°25'N / 130°00'E)	(GMT + 9 hours)
Harbin, China (45°46'N / 126°37'E)	(GMT + 8 hours)
Greenwich (51°29′N 0°00′E/W) England	(GMT)

As on 21st March:

Place:	Sunrise	Sunset
Alice Springs, Australia	6.38	18.44
Misool, Indonesia	6.23	18.29
Kikai, Japan	6.23	18.31
Harbin, China	5.35	17.46
Greenwich (England)	6.01	6.14

As on 21st June:

Place:	Sunrise	Sunset
Alice Springs, Australia	7.16	17.56

Misool, Indonesia	6.20	18.21
Kikai, Japan	5.13	19.30
Harbin, China	3.43	19.26
Greenwich (England)	4.43	9.21

As on 21st September:

Place:	Sunrise	Sunset
Alice Springs, Australia	6.25	18.30
Misool, Indonesia	6.09	18.15
Kikai, Japan	6.07	18.18
Harbin, China	5.18	17.34
Greenwich (England)	6.44	7.02

As on 21st December:

Place:	Sunrise	Sunset
Alice Springs, Australia	5.44	19.20
Misool, Indonesia	6.10	18.24
Kikai, Japan	7.17	17.18
Harbin, China	7.11	15.51
Greenwich (England)	8.03	3.53

Now answer the following questions:
a) How does the length of the day vary in each of these places? Which has the greatest variation – that is, the shortest day and longest day amongst these places?
b) When Harbin has the longest day, do the other places also have longest days?
c) By how many hours does the day length change through the year in each of these places? Is there any pattern in how the length of the day changes from place to place, is there any connection with their geographical location?
d) Where do you find the least variation in day-length?

In order to understand why the day-length varies in this manner, we have to figure out how the earth revolves around the sun. And it is here that the importance of the tilt of the earth's axis finally comes in. We shall go into what this 23 1/2 degrees that we have been told about from childhood means shortly. First, let us make the earth go around the Sun :-)

Activity 4: Take the globe off its stand and hold it such that its axis of rotation is vertical. Keep a source of light in the centre of an open area (this is best done at night or in a dark room), and take the earth (the globe) around this light (the Sun) in a circle. Mark four points at equal distances along the periphery of this circle (see illustration) and at each point note whether the day length is the same or different in various places.

The axis of the earth is tilted at an angle of 23 1/2 degrees:
What does this mean?
This number 23 1/2 degrees is thrown at us in childhood almost before we learn to measure angles. And when we do learn to measure angles, we come to know that we need two lines to make an angle

to be measured. So for this 23 1/2 degrees, one line is the axis of the earth, which is the other line, how do we define it?
This is something which is never gone into in our textbooks and school teaches us not to ask difficult questions and disrupt the classroom, so I doubt if any of us knew this in primary or middle school.
We saw that if we hold the axis of the globe vertical while taking the earth around the sun, the day-length does not vary, and the 23 1/2 degrees is measured from this vertical line. And this vertical line would be the perpendicular to the plane of the earth's orbit.
All the planets go around the Sun on the same plane which is why all the planets are visible within the zodiac belt itself, and when one can see three or more planets, they all appear to be in a line. And so we can measure the tilt of the axis of other planets from the perpendiculars to this same plane. And the tilts vary, the axis of rotation for Uranus has a tilt of almost 90 degrees!

Activity 5: Now fix the globe back on its stand or base. You will see that the axis of rotation is now fixed at a certain angle. Point the axis in one direction (that is, the top of the axis at the north pole of the globe can be made to point at a fan inside the room or some other feature like a clock or light). Making sure that the axis stays in this same orientation while moving the earth around the Sun. Not take the globe around the source of light and in the same four positions as before, note whether the portion of the northern hemisphere lit up is equal in area to the dark portion. If it is more or less than the dark portion, then check if the situation in the southern hemisphere is the same.
Now answer the following questions:
a) In all the positions, is the length of the equator which is lit up the same or different from the length in the dark? You can use a string or a tape-measure to measure this length. What does this tell you about how the length of the day changes in places on or near the equator through the year?
b) Is there any position in its orbit around the 'sun' where no light falls on the north and south pole during an entire 24 hour period (that is, when you spin the globe one entire rotation)?
c) In positions where the day-length is more in the northern hemisphere, does the portion in the dark increase or decrease as you look at places towards the north as compared to the places near the equator? How does this relate to the data about day-lengths in various places given in Activity 3?

Does the axis of the earth wobble? That is, does it point in different directions at different times of the year?[1]
To a first approximation (see the footnote), the axis always points in the same direction. If we extend the line of the axis beyond the north pole into outer space, this line will reach the North star. This is why the North star is always seen in the same position in the sky when we observe it at night.[2] *So from simple observation, we know that the earth's axis is stable.*
Then we saw that we cannot explain the variation in day-length at different places at different times of the year unless we tilt the axis of the earth while it revolves around the Sun and keep it pointing in the same direction all the time.
Further, when we learn about the law of conservation of angular momentum, we can see how much force would be required to keep changing the direction of the earth's axis. The spinning of the earth gives it the required stability!!

As you can see, by doing this activity, one can make sense of all the facts we are taught in school about the poles having a six-month long day, places where the sun never sets on the day of

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[1]The precession of the earth's axis means that the axis does wobble a tiny bit, but this slight change cannot be observed over the course of a few years, so for the purpose of this article, we can state that the axis always points at the north star if we extend the axis from the north pole into space. A full discussion on this would require an article of its own.

[2]See the box on latitudes and longitudes.

the summer solstice, etc. All this happens just because the earth's axis is tilted at an angle of 23 1/2 degrees from the perpendicular to its plane of revolution!

Latitudes and Longitudes:

In the earlier box, I had mentioned that we see the North star in the same position all night every night. But when we travel to a new place to the south or north of where we live, we will see that the North star now occupies a new position, but it remains in this new position all night and every night. In fact, if we keep going northwards, the North star will rise higher and higher above the horizon till it ends up overhead when we reach the north pole. What about when we go towards the south? Then the North star dips lower and lower towards the horizon in the north till it disappears below the horizon. Ideally, this will happen when we reach the equator, but given the light pollution these days, we will lose the North star in the haze a few degrees north of the equator itself.

So the latitude of the place where we live actually tells us how many degrees above the horizon the North star will be seen. So in Harbin, the North star is almost 45 1/2 degrees above the horizon.

What about in Alice Springs? Once we cross the equator while going south, we will no longer have the North star in our sky at night. In the southern hemisphere, the axis points not towards a single star as it does in the northern hemisphere, but towards a cluster of stars in the shape of a cross. This constellation is called the Southern Cross and is used to find directions just the same as we use the North star over here.

What about Longitudes? In the beginning of this article, we saw that the Sun rises first in Dibrugarh because it is the eastern-most point given in the list. We know that the earth takes 24 hours to complete one rotation, that is turn 360 degrees. That is, it takes 1 hour to turn 15 degrees. The earth has been divided by lines running from the north pole to the south pole corresponding to this time taken for one rotation. But instead of 360 degrees, they start with 0 degrees in a place called Greenwich in England[3] and are numbered 1 to 179 degrees east and west. The 180 degree line is the international date-line, that is, the arbitrary line which decides when a new days starts :-) For political reasons, this is a zig-zag line since some islands in the Pacific ocean didn't want to be the last place where a new date starts and so moved the line westwards!

Each place initially used to calculate its own time using the local longitude, India itself had more than one time zone. But running the railways required some coordination when everyone was using different times, so the Indian Standard time uses the longitude 82 1/2 degrees east of Greenwich. Any place in India falling on this longitude will find that local noon (when the Sun is at the zenith, not necessarily overhead) is the same as noon by the clock. But places to the east of this longitude will find that the Sun has dipped to the west at 12 noon, and for places to the west, the Sun is still in the eastern half of the sky when the clock says 12 o'clock. The nearly two-hour difference between the sun-rise or sun-set times between Dibrugarh and Jamnagar tells us that India is nearly 30 degrees (two hours) from east to west!

Seasons too owe their existence to this same very tilt of the earth's axis. Longer days mean that more heat is gained during the day than is lost at night and so summers are hotter or at least warmer than winter. And the northern hemisphere has its winter while it is summer in the southern hemisphere and vice-versa. But, then why is it not hottest as we go nearer to the poles, why are the hottest regions of the earth closer to the equator where the day length does not exceed 14-16 hours?

[3]Greenwich is 0 degrees reflecting the one-time dominance of England in the world. When maps were first made, each country used to draw themselves in the centre (hence the name Mediterranean Sea which means the sea in the middle of the earth, a name given by the Greeks!) and for a long time, some maps used the Paris longitude as 0 degrees too, but the rise of the British Empire meant that Greenwich 0 degree came to be used all over even long past the death of the same Empire.

Activity 6: Take a PVC pipe with a diameter of about 10-15 cm and cut it diagonally (see illustration). This would give an ovoid shape at one end of the pipe and a circle at the other end. Draw outlines of both these shapes on graph paper and compare their areas. Which is greater?

Activity 7: This is best done with a laser-pointer, but remember to be very careful while using it, make sure that the pointer is never switched on when turned towards anyone's face. Take a globe and place it on a table so that it is at a comfortable height. Now hold the laser-pointer such that the beam is parallel to the surface of the table and move it up and down so that the light falls on different parts of the globe. Note in which areas the light falls in the shape of a circle and where this is elongated into an ovoid shape. What is happening at the equator and what happens as the beam moves towards either of the poles?

We can think of the light from the laser beam falling on the globe or the area covered by the end of the PVC pipe as energy coming from the Sun. One unit of energy depicted by the thickness of the beam or the cross-section of the pipe is being spread out over different areas. When the area is less, that means the per unit energy falling on that area is more. Hence, in the places towards the poles, where the sun is never directly overhead, even though the length of the day is more, since the sun's energy is spread over a greater area, the temperatures never go very high. You must have also noticed that in summer, when the sun is overhear near noon, it feels impossible to be out in the sun while the slanting rays of the sun in the winter feel very comforting.

There is one more confusion that is prevalent, caused by the misleading illustrations in textbooks and the statement that the path of the earth around the sun is not a perfect circle and so the earth is closer at times to the Sun during a part of the year. This gives the impression that we have summer when the earth is closer to the sun. The biggest objection to this is, of course, the fact that when it is summer in the southern hemisphere (the earth is closest to the Sun some time in the first week of January), it is winter in the northern hemisphere. In order to overcome this confusion, it is best to look at a scale model of the sun, earth and moon with the distances between them also at the same scale. Take a look at the following table which gives all this data and also the sizes and distances when a scale of 1 lakh km = 1 cm is taken.

	Sun:	Earth:	Moon:
Diameter (in km)	13,92,684	13,462	3480
Distance from the Sun (closest) (in km)	-	1471 lakh	-
Distance from the Sun (farthest) (in km)	-	1521 lakh	-
Distance from the earth (in km)	-	-	3,84,400
Size (diameters) in Scale model (1 lakh km = 1 cm)	14 cm	0.13 cm	0.03 cm
Distance from the Sun in Scale model (1 lakh km = 1 cm) (closest)	-	14.7 m	-
Distance from the Sun in Scale model (1 lakh km = 1 cm) (farthest)	-	15.2 m	-
Distance from the earth in Scale model (1 lakh km = 1 cm)	-	-	4 cm

So if we prepare a scale model[4] of the solar system using these sizes, the sun would be about the size of a musk-melon which is an average 15 metres away from the earth which is the size of a mustard seed (and the moon is 1/4 of this!). At this scale, even though the actual difference between the closest and farthest distances from the Sun seems huge, the percentage difference is not much. So it is not this difference which is causing the change of seasons on the earth. It is all because of the earth's axis being tilted, and nothing else.

Even though the Sun is so much bigger than the earth and the moon, it is an interesting coincidence that because the Sun is so much farther away, the apparent sizes of the Sun and the moon when we look at them from the earth is nearly the same (the orbit of the moon around the earth is also not a perfect circle, so sometimes it is closer to the earth and appears bigger (so-called super moon)) – about 1/2 degree. Because of this, when the moon sometimes ends up exactly between the sun and the earth, we get a solar eclipse. But we shall discuss eclipses in detail in the next article.

But before I wind up this article, I would like you to think about one more issue. You have seen the number of threads that have fed into developing our understanding of the earth, its rotation and revolution and the movement of various heavenly bodies in our skies. Don't you think it is worth seriously debating if this entire topic can be taken up in primary school and assumed to have been understood by the children so that it is never again taken up in middle or high school.

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[4]Permanent scale models of the entire solar system have been made in various countries like Sweden, Canada and Australia and might be well-worth a visit – suggest a field-trip for your students to see one of these :-)