# SIGNS OF THE ZODIAC

DEEPAK KHEMANI

# SIGNS OF THE ZODIAC

DEEPAK KHEMANI

PUBLISHED BY
BHARAT GYAN VIGYAN SAMITHI
NEW DELHI
FOR
COSMIC VOYAGE PROGRAMME
JOY OF LEARNING CAMPAIGN

SIGNS OF THE ZODIAC
DEEPAK KHEMANI
IIT MADRAS


| | | |
|---|---|---|
| FIRST EDITION | : | JANUARY, 1995 |
| PUBLISHED BY | : | BHARAT GYAN VIGYAN SAMITHI<br>WEST BLOCK 2, WING-6,<br>RK PURAM, SECTOR-1,<br>NEW DELHI - 110066<br><br>FOR THE COSMIC VOYAGE PROGRAMME<br>OF THE JOY OF LEARNING CAMPAIGN |
| DESIGN & ILLUSTRATIONS | : | KAMAL LODAYA, DEEPAK KHEMANI |
| COVER DESIGN | : | M. BASHEER AHMED |
| PRINTED AT | : | SUDHARSAN GRAPHICS |
| PRODUCTION | : | FINELINE, MADRAS |

# Part 1 Night and Day

*It was a fine evening in the month of March. Brinda was going for a walk with her uncle Vivek. On the way they met Shirish uncle, who was returning from a bridge match.*

VIVEK: Hello, Shirish, how was your match?
SHIRISH: We lost! Had a lot of bad luck. I think it is a bad period for Aquarians ...
VIVEK: Oh! You and your Sun signs! Why don't you simply admit that you didn't play well?
SHIRISH *(laughing)*: Maybe we did, maybe we did not...

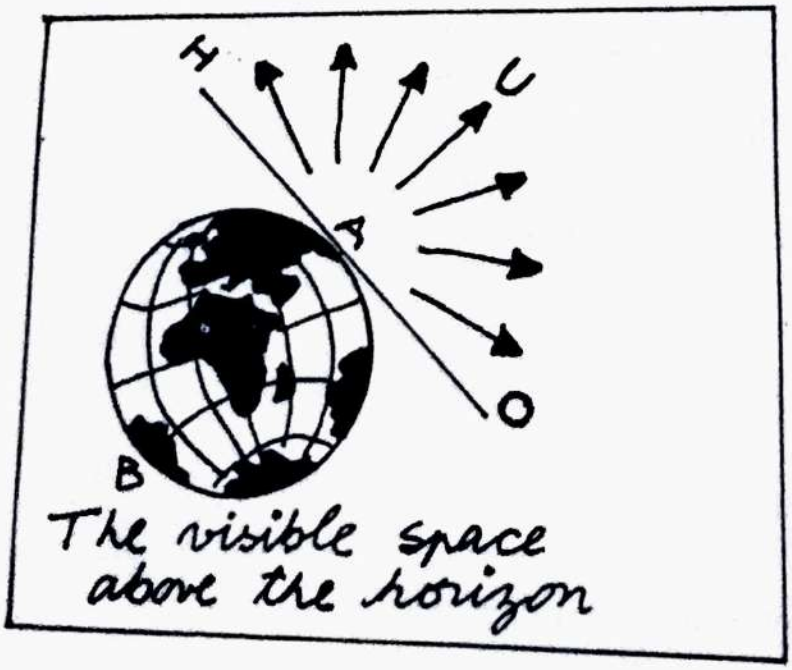
*Patting young Brinda on the head, Shirish went off, while Brinda and Vivek continued towards the beach. The mention of Aquarians had aroused Brinda's interest and she pestered Vivek to tell her more. Vivek began by saying that the signs of the Zodiac were related to the position of the 'heavenly bodies'. It is because of the motion of the Earth and the planets, that we see different patterns in the sky over the year.*

VIVEK:. It's like when you are sitting in a train, the trees outside appear to be moving.

BRINDA: Yes, I remember I read that in my Geography book. Day and night, summer and winter all happen because of the movement of the Earth. Only, it is so confusing ...

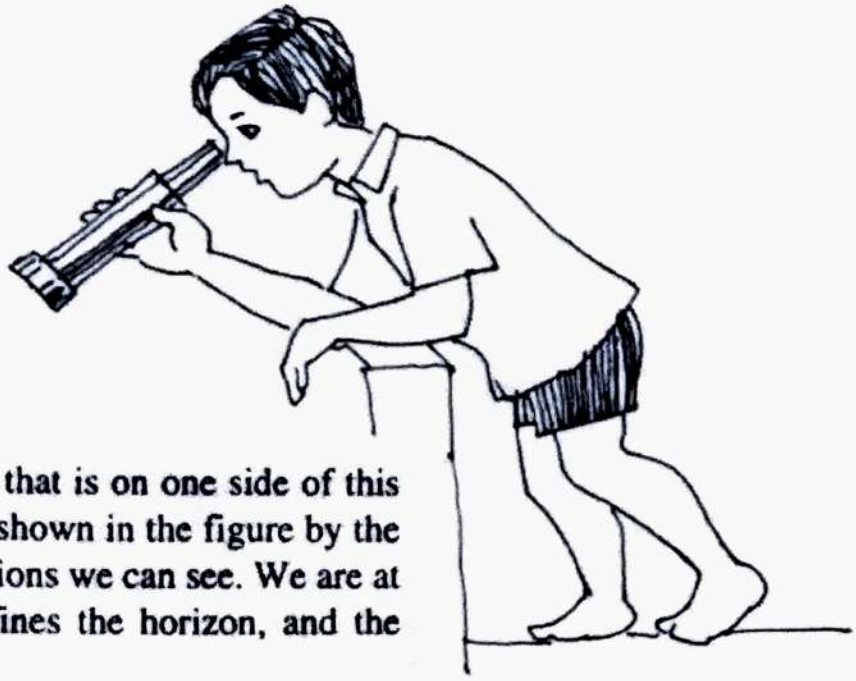
VIVEK: No, it's not. Come, let me explain it all to you. So, tell me, where should we begin?

BRINDA: At the beginning!



The visible space above the horizon

*And they sat down near the sea on a rock. The Sun was still a little high in the sky, and a gentle breeze was blowing in from the sea. Vivek took out a pad from his sling-bag, which he always carried, and drew the following figure, explaining how the plane defined by the ground is a tangent—which he called HO—when seen from a side. He held up the paper so that looking at it from the side one could see only a line.*



VIVEK: Right? Now everything that is on one side of this plane can be seen by us. This is shown in the figure by the arrows going out in all the directions we can see. We are at the point A. The plane HO defines the horizon, and the direction U is right above us.

BRINDA: Is it the same thing as saying that we can see everything above the ground?

VIVEK: Well, sort of...

BRINDA: But then what are the things that we cannot see? All the sky is above the ground, isn't it?

VIVEK: No, remember that the Earth is round! For example, we cannot see anything on the point B on the Earth. This could be in Brazil! In fact, as you can see in the diagram, we can see exactly half of the Universe at any one time.

BRINDA: What are the little circles you are drawing?

VIVEK: I'm just trying to put in some stars into our picture. The dotted lines are only to show the pattern. Of course there are no such lines actually in the sky!

*Vivek drew a similar figure, and some little circles connected with dotted lines, as shown on the following page. He also drew a small picture of the Sun.*

BRINDA: Oh! You've drawn the stars also like the Sun.

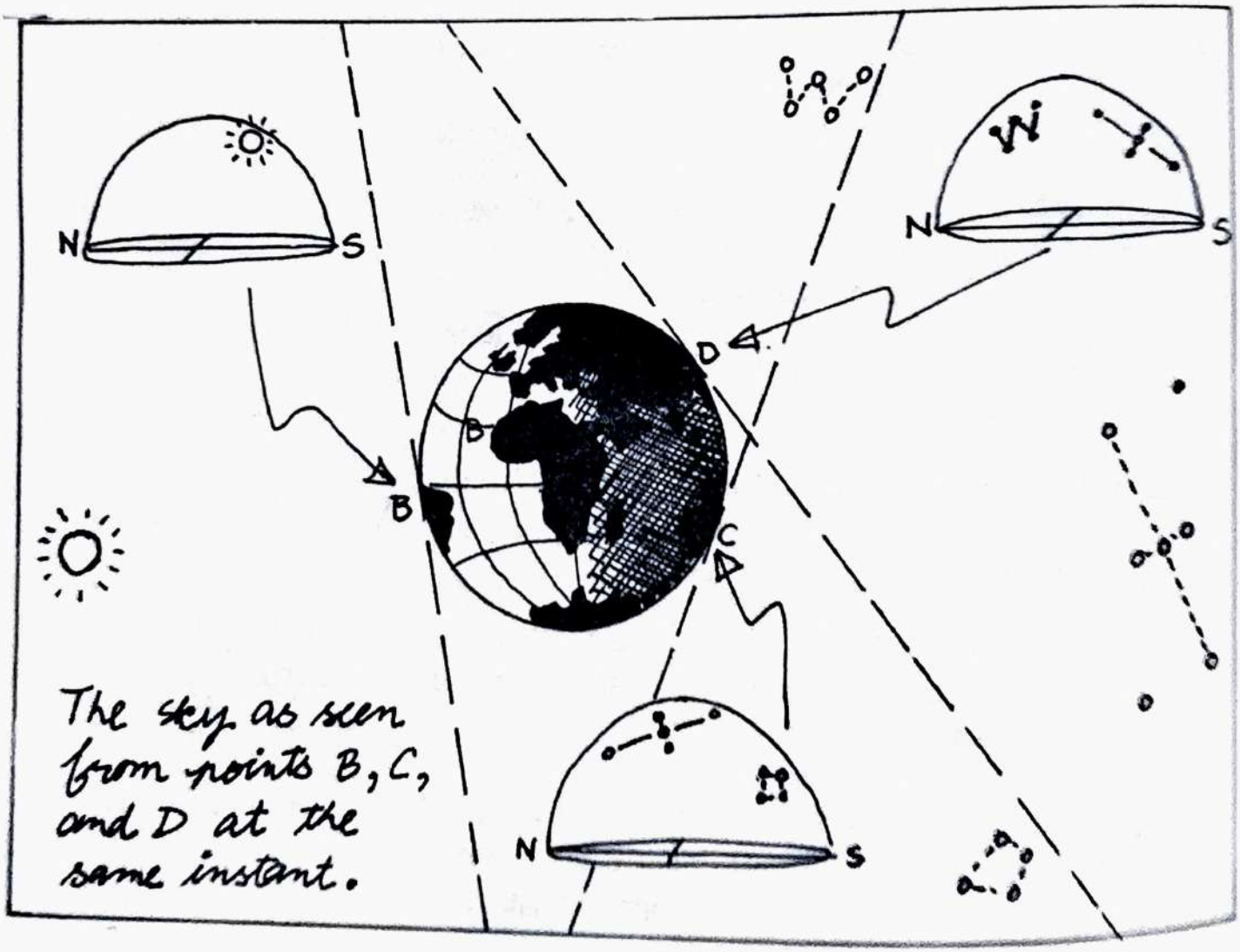
VIVEK: Yes, I have drawn them as we see them. In fact they are much much bigger.

BRINDA: And much much farther away.

VIVEK: Okay. Now let's try and see how the sky will look like from three points B, C, and D. Point B is in Brazil, point C is in Australia, and point D in Japan. What can a person standing in Brazil see right now?

BRINDA *(looking carefully at the picture)* : The Sun!
VIVEK: That's right! Now imagine a giant soap bubble around you. It's like a dome, through which you can see the entire sky above you. You can imagine that the Sun and the stars are on the dome.

*And he drew the figure for point B, with the Sun in the sky.*

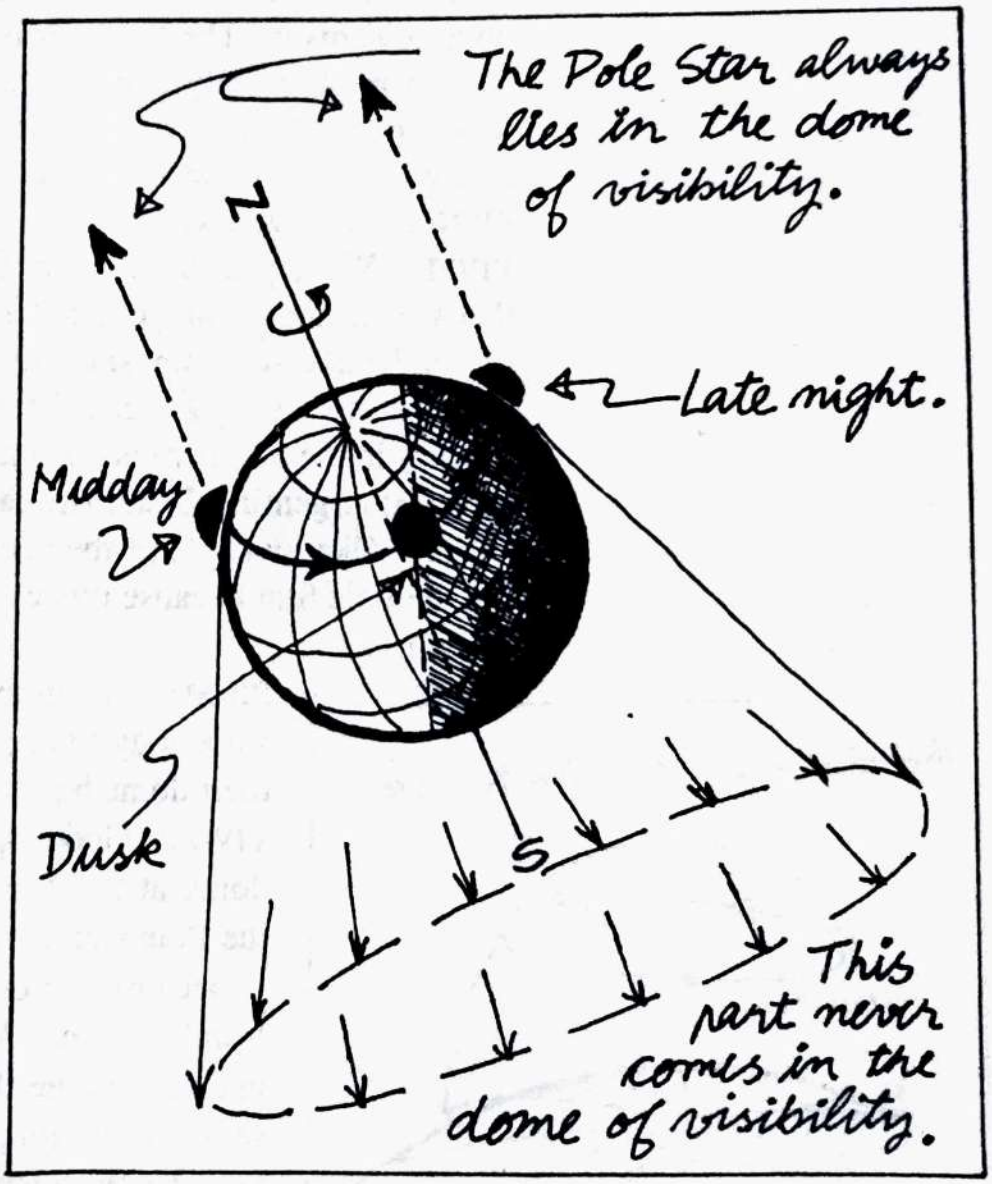


VIVEK: Fine. Now let us look at what the person in Japan can see. He can see this group of stars which look like a W. And he can see this group of three and four, which we call Orion, but he cannot see the group of four. So his dome will look like this.

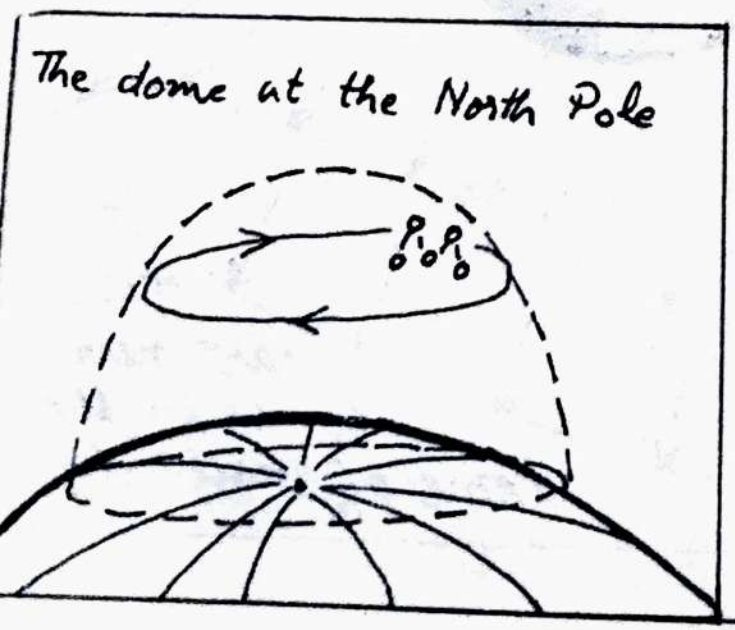
BRINDA: Yes, I see. And somebody in Australia can see Orion and also this group of four! But not the W...

VIVEK *(drawing another figure)*: So far so good! Now let us think of a rotating Earth. As the Earth rotates our dome of visibility moves. The path taken by a point in India is shown here. We see that during the day we are facing the Sun. But as the Earth rotates we move towards the darker side. At dusk we are about to cross over. And during the night we move through the region where we cannot see the Sun.

BRINDA: And then we can see the stars... Yes, I see. So as the Earth goes



round we can see everything at some time or the other?
VIVEK: Well, nearly everything. That depends on where on Earth you are. Have you heard of the Pole Star?
BRINDA: Yes, and also the Great Bear which points to it.
VIVEK: We call it *Dhruva* The arrows that I am drawing point towards it. The Pole star is also known as the North star since it is exactly in the North always. This is because it is in line with our axis of rotation. You can see from the figure that from India you can always see the Pole star.
BRINDA: Even at daytime?
VIVEK: Well, you could have. Only our Sun is so bright that we cannot see any other stars in the day. But this part of the Universe I am shading never comes above our horizon and we never see it. Now, tell me the name of a country in the Southern hemisphere.
BRINDA: Argentina, South Africa, New Zealand...
VIVEK: Okay, okay! All the people living there can never see the Pole Star because it *never* comes into their dome of visibility.




BRINDA: Hmmm, okay. But what about somebody living at the North Pole? Won't their dome be a bit funny?
VIVEK: Good question! Let's draw the dome at the North Pole. You can see that the Pole star always stays directly up! This is because the dome does not move about. It only rotates! As a result the stars also go in circles in the sky, and they always see the same sky rotating them. Let's draw the path that the W constellation, Cassiopeia, takes

in the sky for the people at North Pole.

BRINDA: It's like when I look up and go round and round!

VIVEK: Yes, you've understood it exactly!

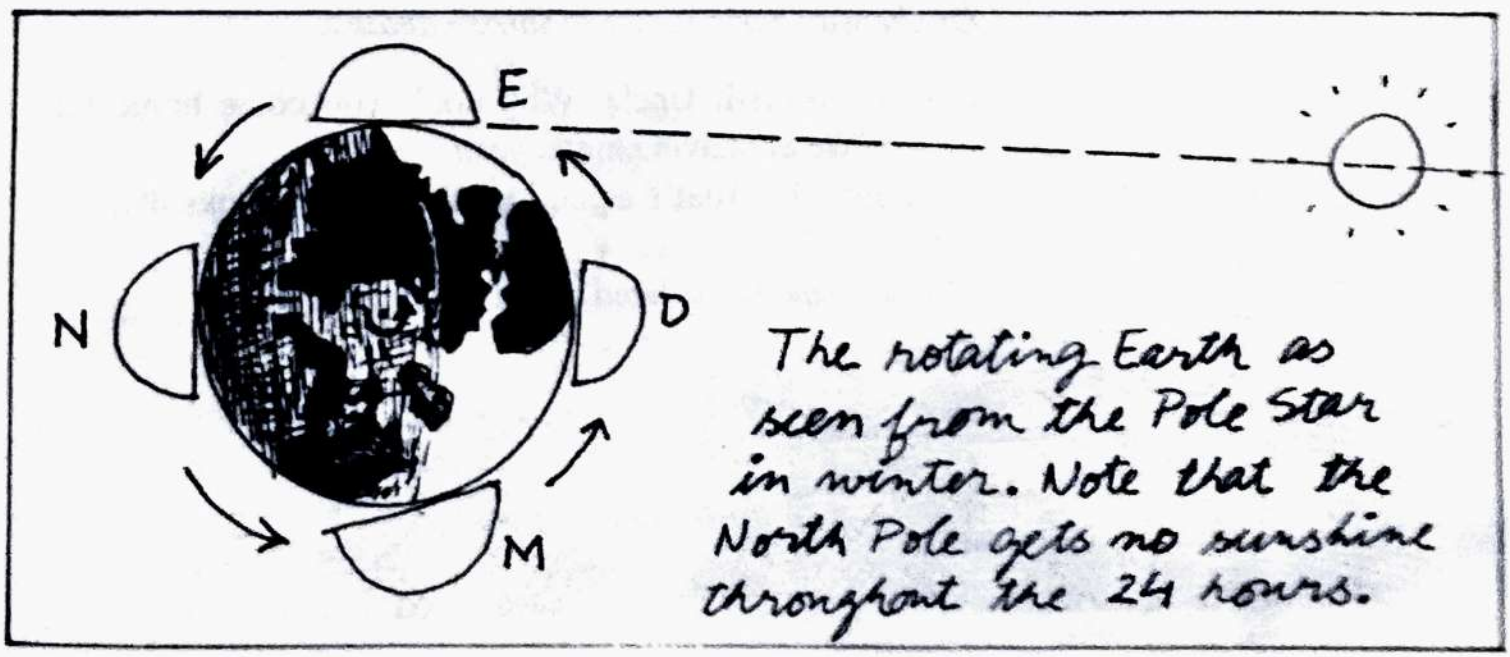
BRINDA: But still, your diagrams are a bit difficult to understand!

VIVEK: I know. That is because we are trying to draw three dimensional pictures. But supposing you were to look at the Earth from the Pole Star. Then it would look like this.

VIVEK: As the Earth rotates your dome moves along with you. When you are at M the Sun is just about to come into your dome, and it is dawn. At D the Sun is directly overhead. When you are at N it is the middle of the night. And at E it is the evening, when the Sun is at the horizon, like now.

BRINDA: Aha! How beautiful it looks!

VIVEK: Yes! At this point only half of the Sun comes in




The rotating Earth as seen from the Pole Star in winter. Note that the North Pole gets no sunshine throughout the 24 hours.

our dome, like in this figure.

BRINDA: Yes, I see...

VIVEK: But don't forget that right now the Sun must be directly overhead somewhere else, and at some other place it must be rising now.

BRINDA: Yes, and my friend Aparna in Australia must be fast asleep, because it must be the middle of the night there!

VIVEK: Right! And it's time for us to go home too.

BRINDA: But, what about the signs of the Zodiac?!

VIVEK: Yes, yes. I'll explain that too. But first we must return home.

BRINDA: Oh! you can see the Moon too!

VIVEK: It's a nice crescent, isn't it? I think I'll explain the movement of the Moon also. But dinner first.

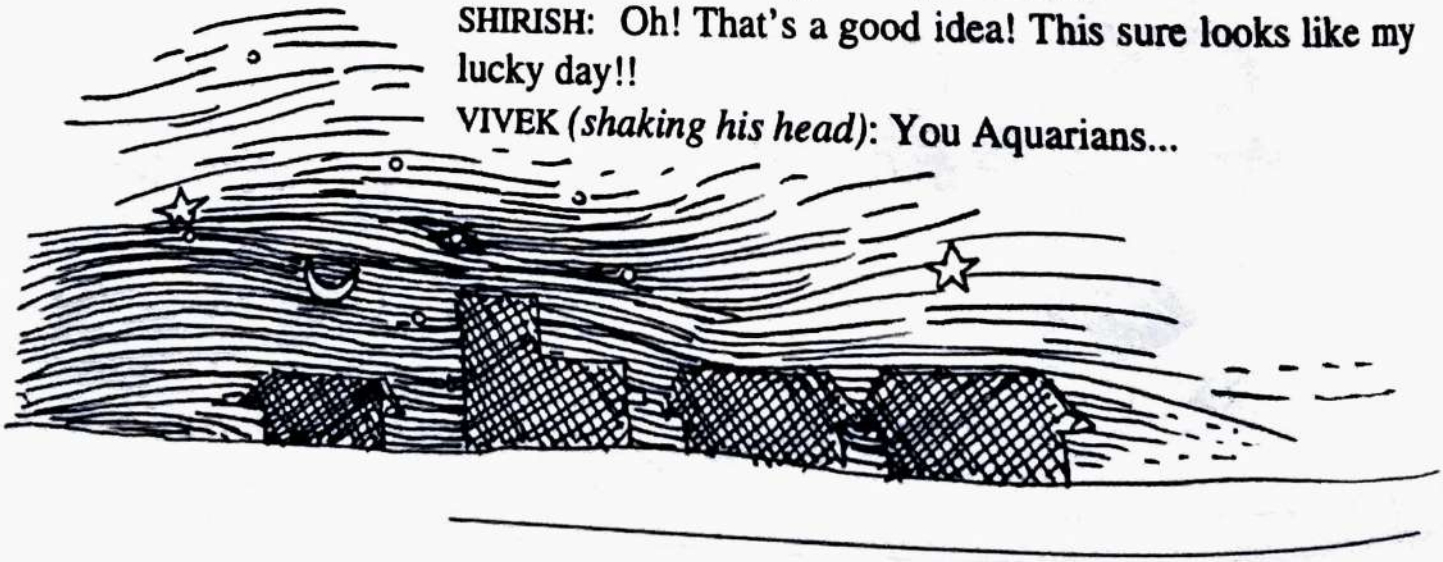
BRINDA: Yes, I'm also feeling quite hungry. And Mummy is making *methi parathas.*

*On the way home they met Shirish again...*

BRINDA: Shirish Uncle, Why don't you come home for dinner. We are having *methi parathas...*

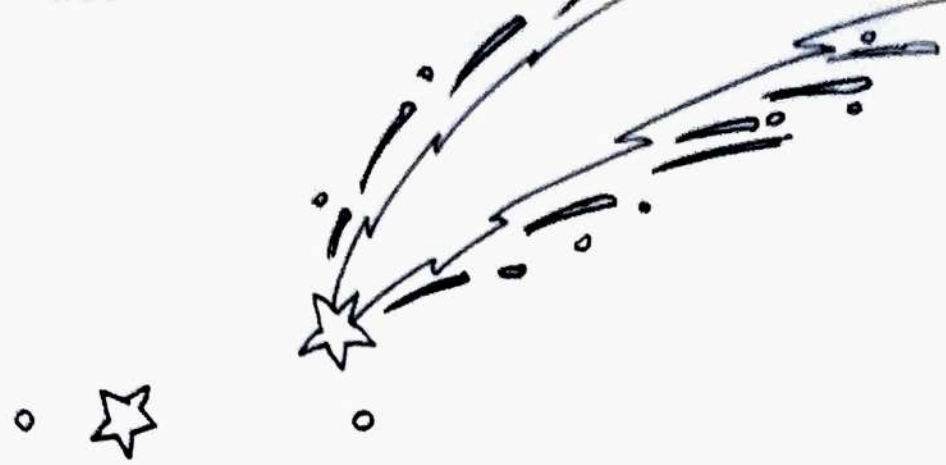
SHIRISH: Oh! That's a good idea! This sure looks like my lucky day!!

VIVEK *(shaking his head)*: You Aquarians...

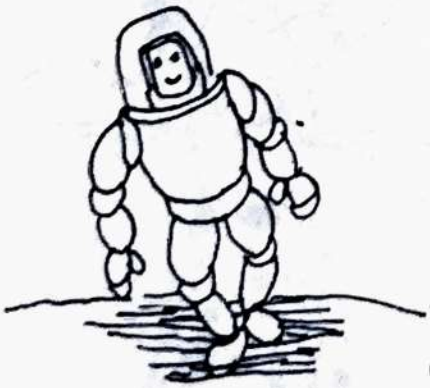


## Part 2 Phases of the Moon

*After a feast of methi parathas they came out on the terrace to enjoy the cool night breeze...*



VIVEK: Look, the Moon is also about to set!
BRINDA (*musing..*): Yes! But the Sun just set a little while ago. It's only 9 p.m. now! I thought the Moon *comes up* in the night...
VIVEK: Not always. Sometimes it rises in the night, sometimes in the day. Sometimes early morning, sometimes in the evening.
BRINDA: Is that so? How is that?
VIVEK: Why don't you try and figure it out.
BRINDA: Okay, let me see... The *Sun* rises and sets because the *Earth* rotates. And the Moon too must rise and set for the same reason...
VIVEK: That's right.
BRINDA: But why doesn't it rise and set everyday at the same time like the Sun? Let's see... morning... evening... Yes! I know! Because it doesn't stay in the same place!
VIVEK: Brilliant! But why doesn't it stay in the same place?
BRINDA (*thinking for a while*): Is it because the Moon goes round the Earth?
VIVEK: Absolutely! Come, let's work out the details...

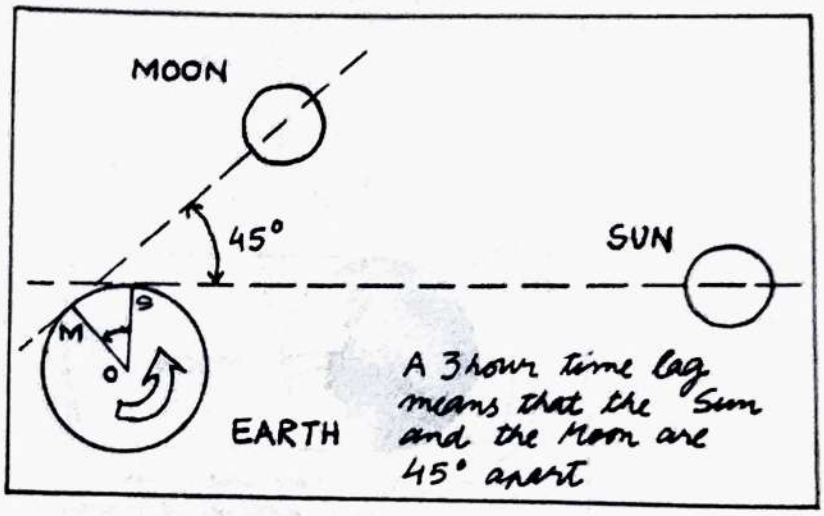


*And they moved the chairs below the lamp. Brinda went in to get the writing pad and when she returned Shirish was with her.*

SHIRISH: Ah! That was a good dinner! Listen Vivek, look at this hand I played in today's bridge match...
VIVEK: Later, later. We have more important things to discuss now. Come Brinda, let's start with today's situation. The Sun set around 6 p.m., right? And now at 9

o'clock the Moon is going down. The Sun set when we were at point S. Now we are at point M.

*He drew the following figure.*




VIVEK: Okay? Now let's get mathematical. Can you tell me what is the angle SOM?

BRINDA: How do I know?

VIVEK: See, we were at S at 6 p.m. After 3 hours we are...

BRINDA: Let me try... In 24 hours when the Earth goes around we cover 360°. So in 3 hours we cover 45°. So ∠ SOM = 45°?

VIVEK: You are right. In general it helps to remember that every one hour the Earth rotates by 15°, and every degree takes 4 minutes. Okay, now can you tell me where the Moon will be tomorrow at this time?

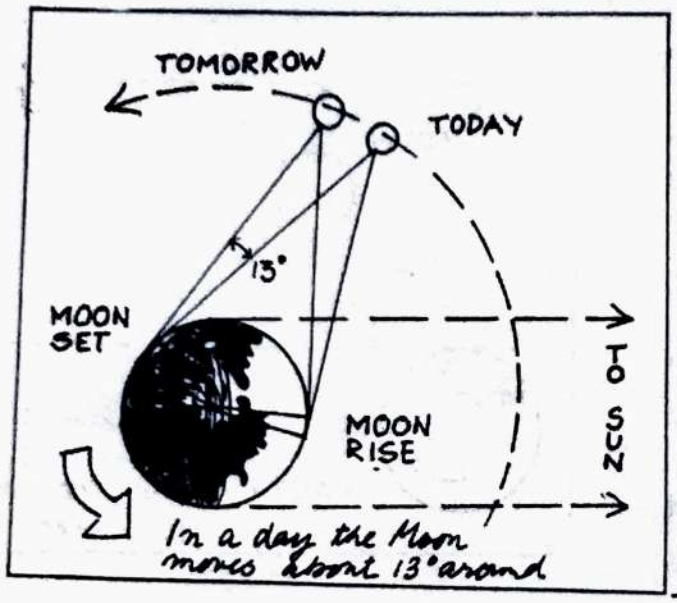
BRINDA (*after some thought*): No, you tell me.

VIVEK: See the Moon goes around the Earth in 27.3 days, covering 360°. So in one day it will cover 13.18° - say about 13°.

BRINDA: 13° in one day. That means it needs (24× 60)/13.18 or 109 minutes for every degree. So, the Moon moves roughly about 1° every 2 hours...

VIVEK: Right, and tomorrow the Moon will be another 13° away.

*And he drew the figure below.*




BRINDA: How do you know it moves in this direction? Why not in the other direction?

VIVEK: Good question. We know this because tomorrow it will set a little *later* than today. Can you tell me when it will set tomorrow?

BRINDA: Let's see. We have to cover 13° more than today. 1° takes 4 minutes. So we need $13 \times 4 = 52$ minutes more.

VIVEK: Excellent! So the Moon will set about 9.52 p.m.! Actually this is not exact, because the Moon moves in an elliptical orbit...

BRINDA: I see. Everyday the Moon will set a little later than the previous day. That means it will also rise later, isn't it?

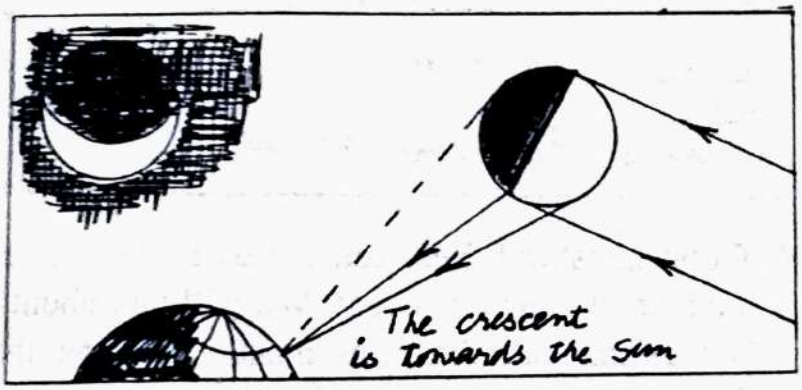
VIVEK: You're right. You can see that both today and tomorrow, at moonrise the Sun is high in the sky.

BRINDA: Yes I remember that sometimes you can see the Moon in the day also.

VIVEK: Like the crescent we saw today evening.

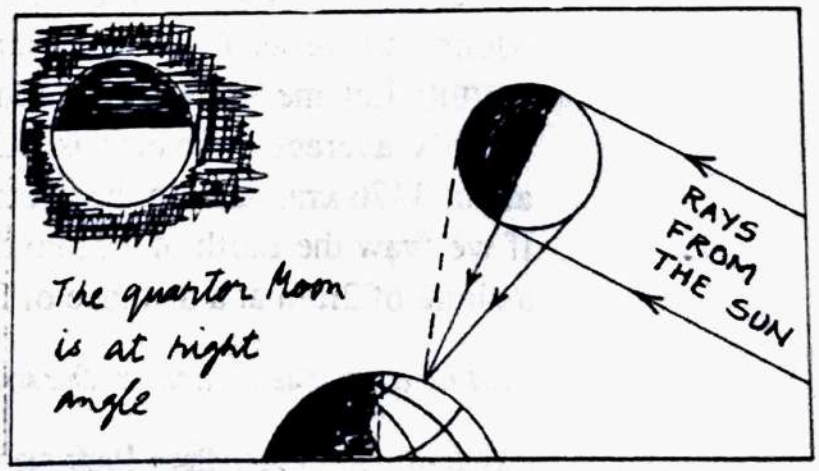
BRINDA: It was beautiful! Tell me, Vivek uncle, why does the Moon change its shape like that? Sometimes it is a full round, sometimes a crescent, and sometimes only half...

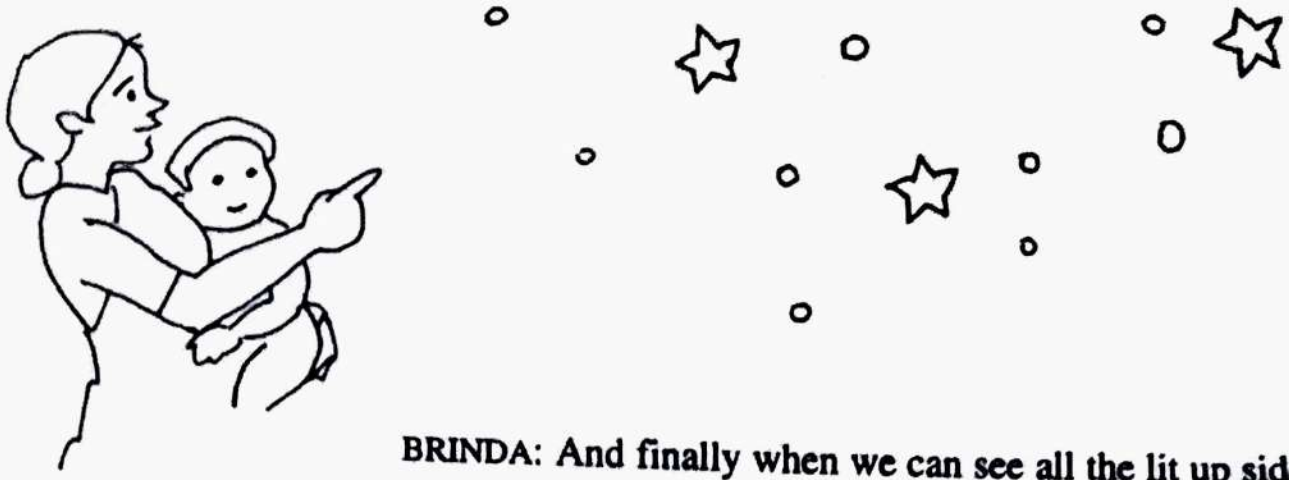
VIVEK: Actually the Moon does not change at all. It is also a sphere like our Earth. It shines in the light of the Sun. At any time one half of the Moon is lit by the Sun. But depending on its changing position we see only part of the lit surface. Like in today's Moon we could see only a little of the lit part, as we can see in this figure.



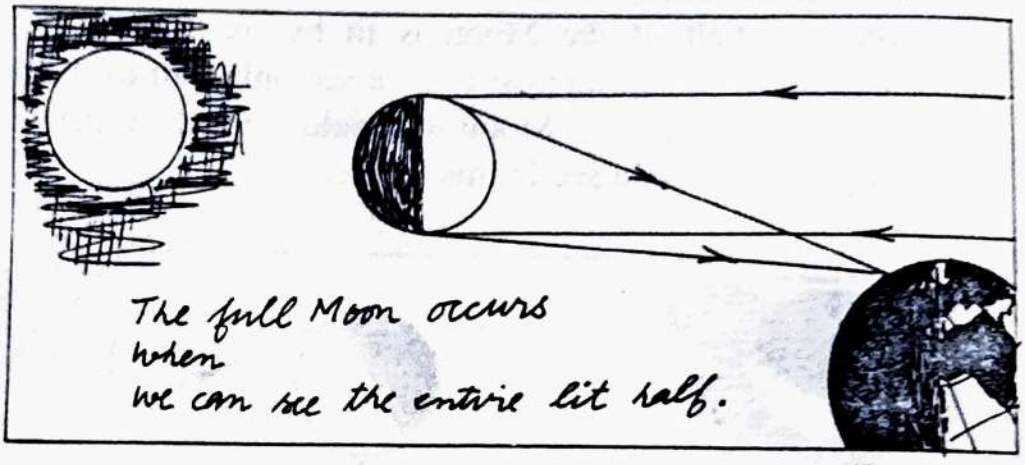

BRINDA: Tomorrow, will it be bigger?

VIVEK: Yes. The process of the Moon growing is called *waxing*. In about four days, when it is at right angles to the Sun, we will see it has a half disc.





BRINDA: And finally when we can see all the lit up side, it will be a full moon!But won't the Earth come in the way and block the light?



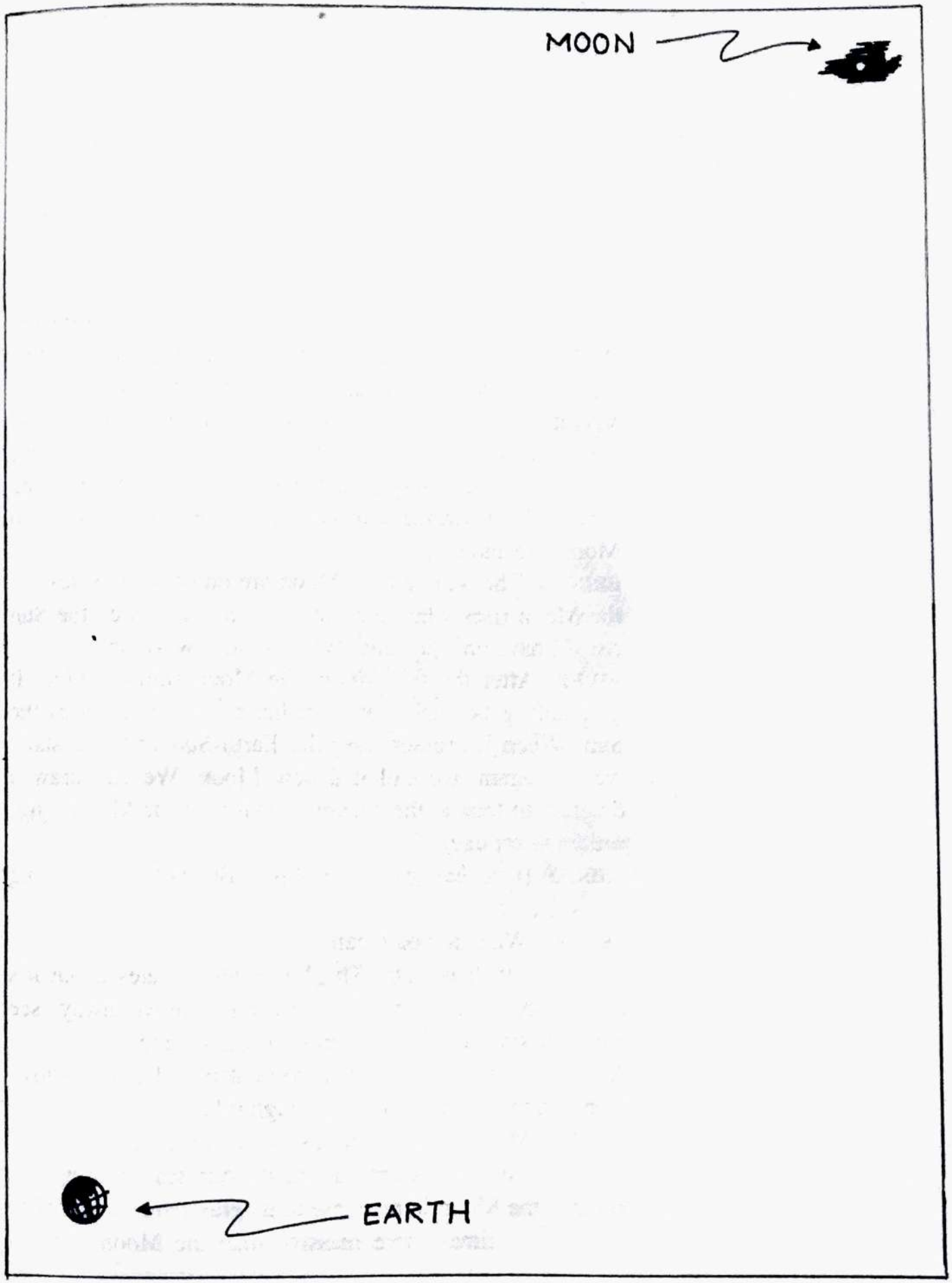

VIVEK: Good question! Yes, sometimes it does, and we have an eclipse. It is a rare event. We will talk about that later. It's true that our diagrams make us think that it should always happen. But that is because they are not to scale.

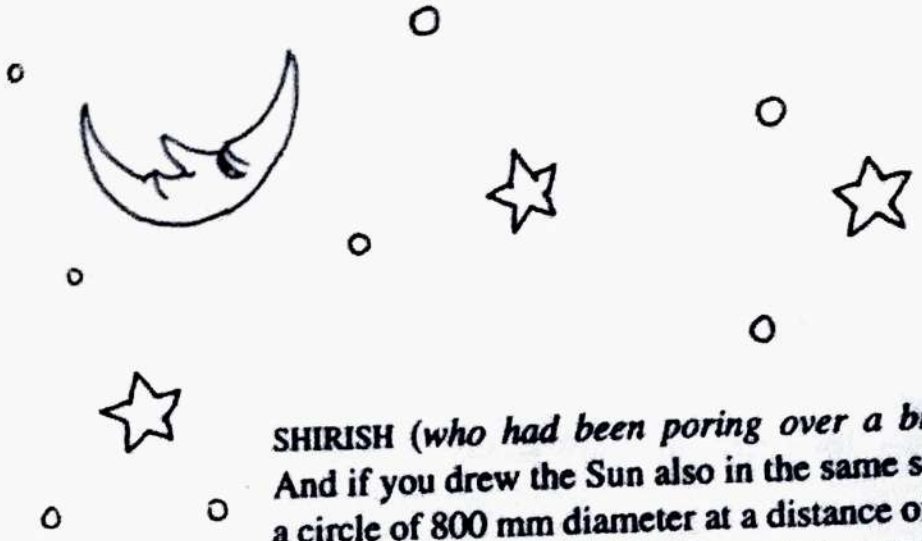
BRINDA: Yes, I know the Sun is much bigger than the Moon, but we see them as the same size...

VIVEK: Let me draw the Moon and Earth to scale. The Earth's average diameter is 12756 km. The Moon's is about 3476 km, and on the average it is 384,404 km away. If we draw the Earth of 7.5mm diameter, the Moon will be a circle of 2mm at a distance of 22 cm.

*And he drew the figure on the following page.*

BRINDA: Oh! Here they look so far apart!


MOON
EARTH



SHIRISH (*who had been poring over a bridge problem*): And if you drew the Sun also in the same scale it would be a circle of 800 mm diameter at a distance of 86 meters...

VIVEK: Yes, and that would certainly not fit on this page! That is why we don't draw pictures to scale. The universe is mostly *vast* empty space with a few objects floating around. Now Brinda, can you tell me when does the full Moon rise and set?

BRINDA: The Sun and the Moon are on opposite sides. So the Moon rises when the Sun sets and sets when the Sun rises! I have one question. What is the new Moon?

VIVEK: After the full Moon, the Moon starts *waning*. It gradually gets smaller and smaller as it goes towards the Sun. When it crosses over the Earth-Sun line and starts waxing again, we call it a new Moon. We can draw a diagram to look at the changing phases of the Moon. *(figure on next page)*

SHIRISH (*who had got interested* ): But not the changing faces! Ha ha.

BRINDA: What do you mean?

VIVEK: Shirish is right. The Moon also rotates about it's axis in about 27.3 days. As a consequence we always see the same side. That's an interesting coincidence!

SHIRISH: Actually it is not a coincidence! Do you know, Brindavanam, why do we have high tide?

BRINDA: Mmm... I read about some Tidal forces...

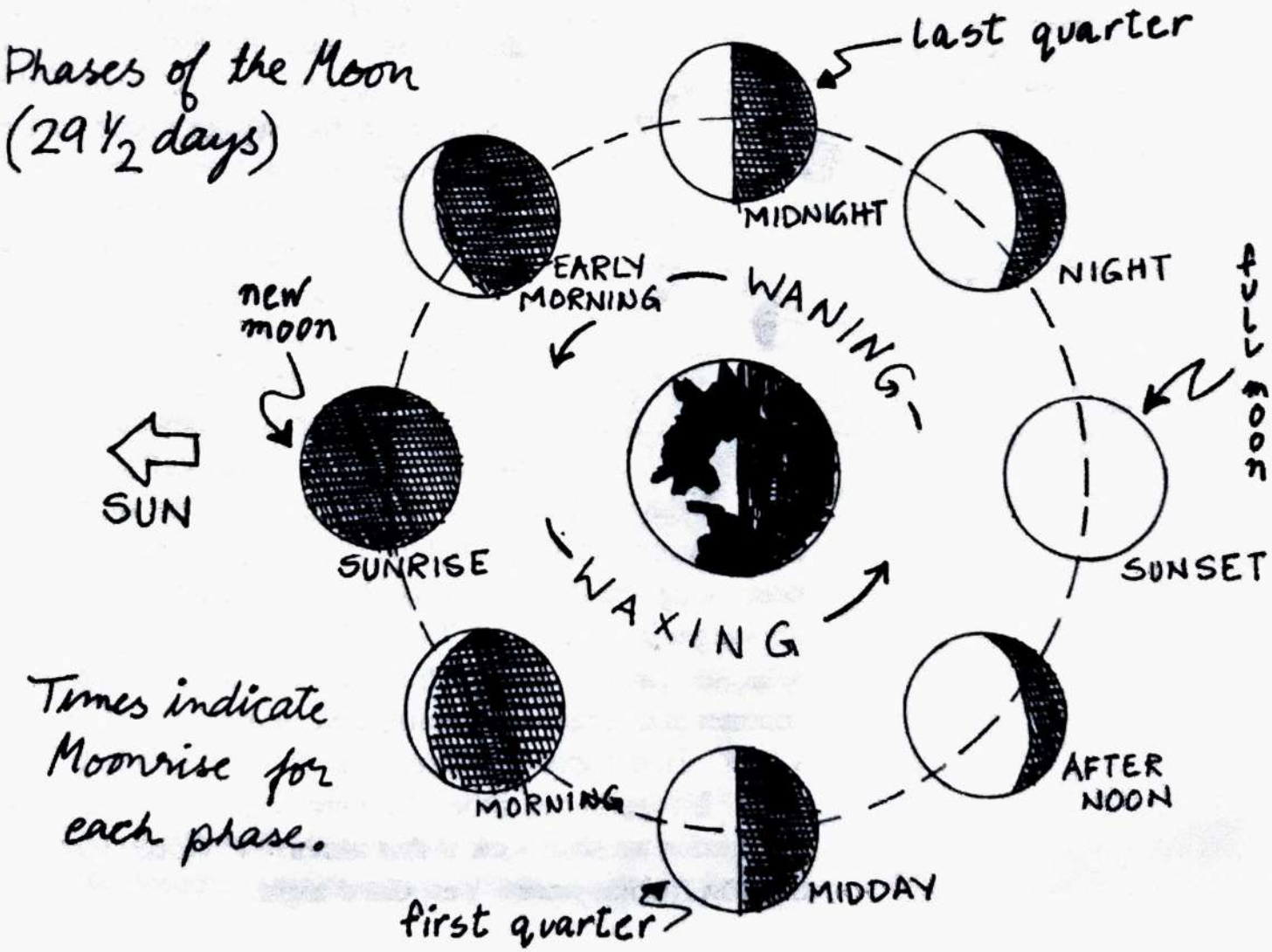
SHIRISH: High tides are caused by our seas bulging out towards the Moon in response to its gravitational pull. The Earth is 81 times more massive than the Moon. Conse-

quently the effect of Earth's pull on the Moon is more pronounced. First, it causes the Moon to bulge out about 60 feet..

**BRINDA:** You mean like an egg?

**SHIRISH:** Right. Secondly, under the "spell" of the same gravity the bulging side keeps facing the Earth!

**BRINDA:** Aha... I see the gravity of the situation!

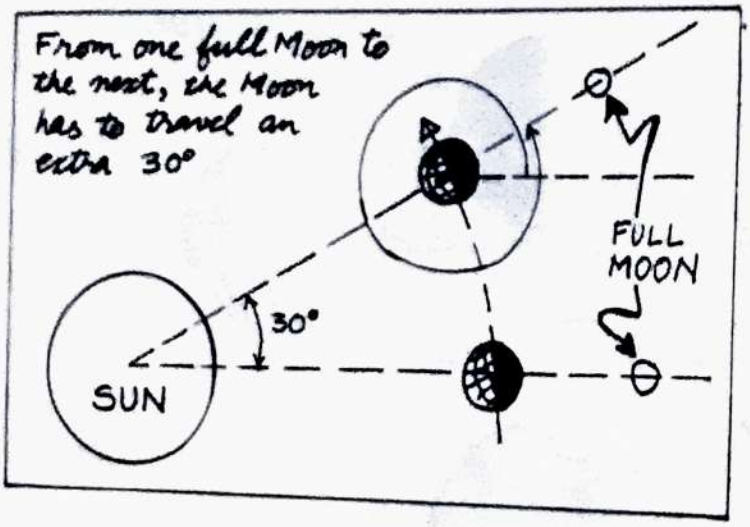


SHIRISH: Okay, let me ask a question. How much time does it take from one full Moon to the next?

BRINDA: Why! Doesn't it take 27 days?

VIVEK: No. Actually it takes a little longer. The *synodic month*, which is the period between full Moons, is about 29.5 days.

BRINDA: Is that so? Why is that?




VIVEK: It happens because the Earth is also going round the Sun Remember that the full Moon occurs when the Moon is on the opposite side of the Earth from the Sun. Now, as we see in this diagram, by the time the Moon goes around the Earth, the Earth itself has moved around the Sun by about 30°. That is about a twelfth of 360°. So the Moon has to travel a little bit extra to come bang opposite the Sun.

BRINDA: I see. That extra time is 27.3/12 days... You know, a thought occurred to me just now. According to your diagrams the day should be 12 hours long and the night also. But why do we say the days are longer in the Summer?

SHIRISH: (*with a smile*): Indeed! And *why* do we have summer and winter and autumn and spring?

VIVEK: That happens because the Earth's axis is a little tilted. It's getting a little late now. But if *you* have the *inclination* we shall look at that tomorrow! Good night!

BRINDA (*with a yawn*): Yes. Good night.

## Part 3 The Four Seasons

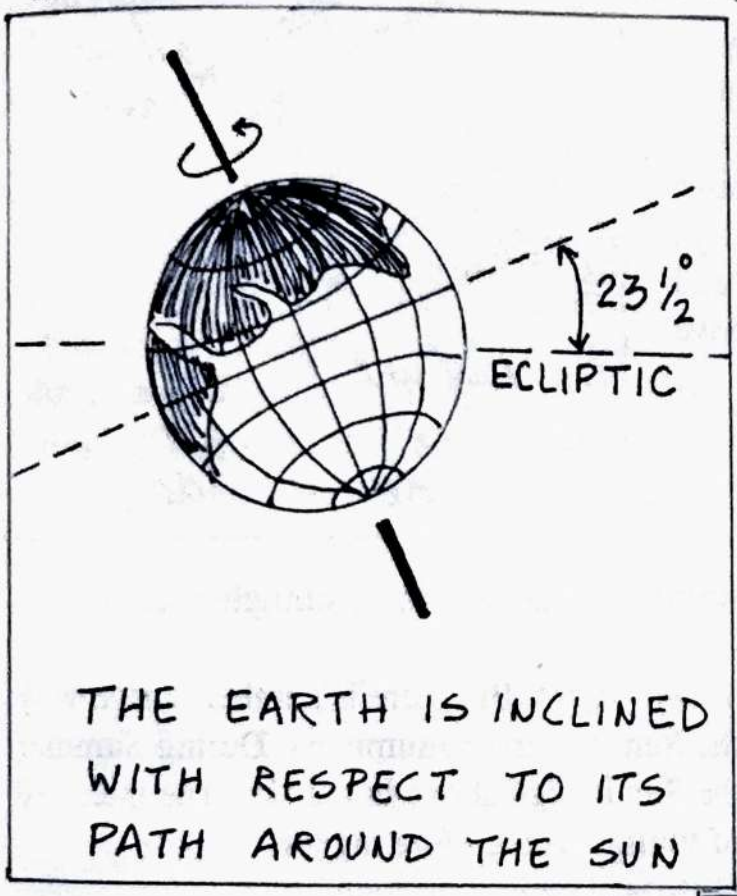
*Brinda eagerly rushed back from school, and found Vivek engrossed in some Western classical music. She shook her head amusedly.*

BRINDA: Aha, the Italian composer you are always listening to... what is his name again?
VIVEK: Antonio Vivaldi. Hulio Brinda! So you're back!

*She put her schoolbag away with her other books and went for a wash. Vivek put out lunch on the table. They finished eating. Brinda switched on the fan in the hall and they sat listening to the music.*

BRINDA: Vivek uncle, shall we talk about Summer and Winter?
VIVEK: And Spring and Autumn... The four seasons that define the year.
BRINDA: Meaning?
VIVEK: Well, how long is a year?
BRINDA: I know, it is 365¼ days.
VIVEK: But why 365? Why not 100? That's a nice round number.
BRINDA: Because, in one year the Earth goes round the Sun.
VIVEK: Okay. But how did our ancestors know that? In fact many of them believed that it is the Sun that went round the Earth everyday!
BRINDA: Oh! So the four seasons... you mean they...
VIVEK: Yes. For early man the year was the largest period of repetition known. Just like day and night define a day, repeating seasons define a year. In due course of time, people also started recognizing the *yearly* cycle of patterns in the sky.
BRINDA: I see.
VIVEK: In fact the Roman calendar which is common now, was meant to be such that Spring begins on March 21st. But do you know *why* do the seasons occur?
BRINDA: Yes, I know, because the Earth is inclined...
VIVEK: You mean the axis of Earth's rotation is inclined.

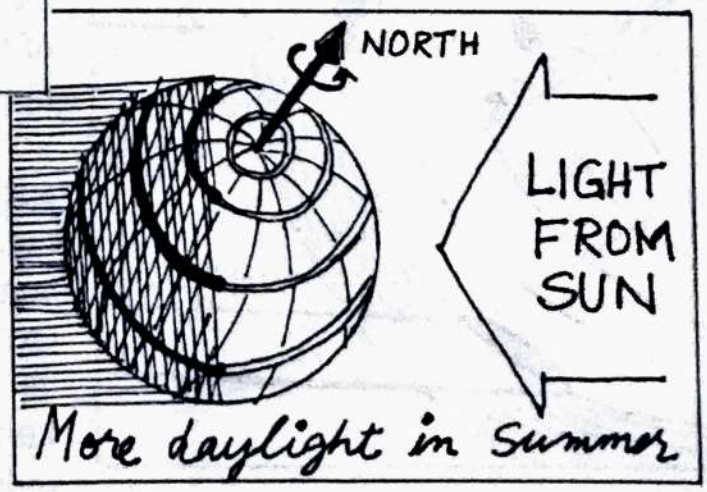
See, the path of the Earth around the Sun defines a plane, which we call *the Ecliptic*. The plane defined by our equator is inclined at an angle of 23½° with respect to it.




BRINDA: But how does that cause the seasons?

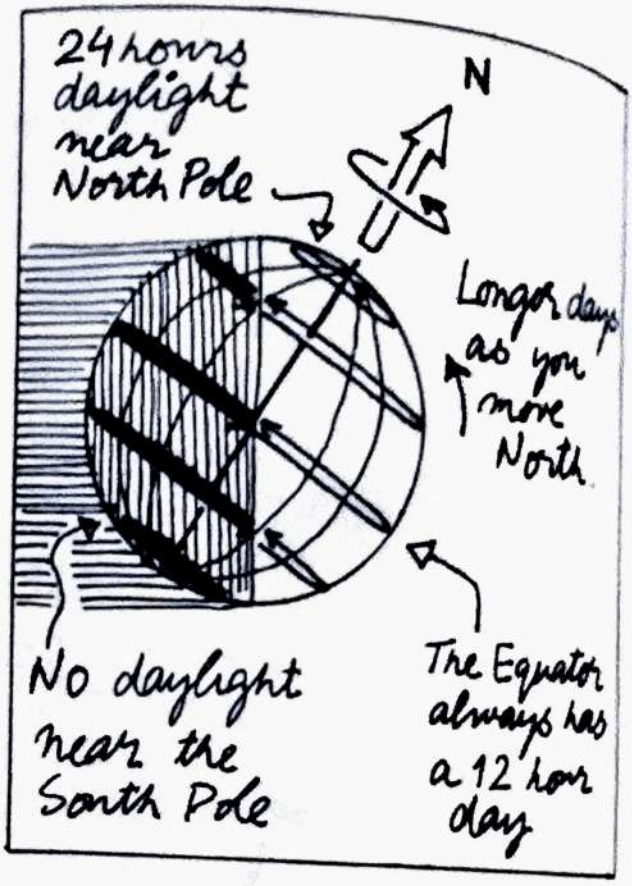
VIVEK: Summer happens when the axis is inclined towards the Sun. Our days are longer and therefore we get more Sunlight.

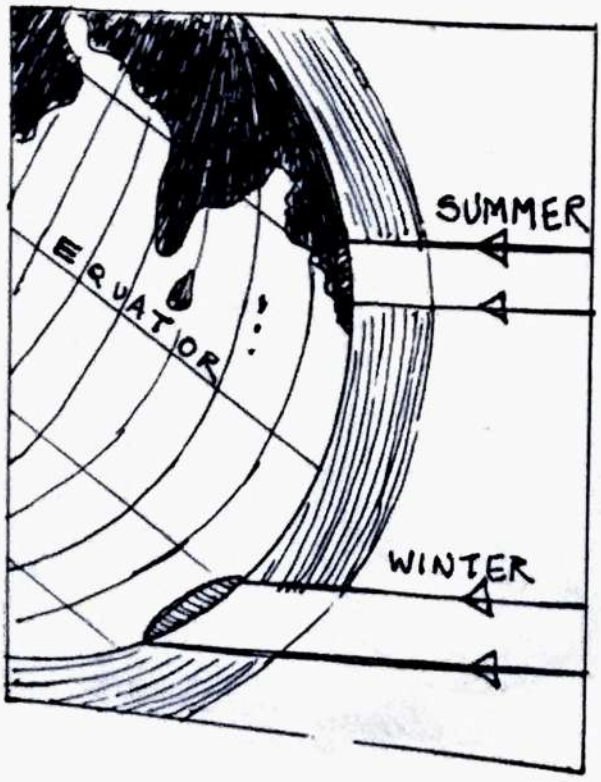
*Vivek drew the diagram on the right.*



BRINDA: From your diagram it looks like some people always have daylight!

VIVEK: It's true. As we move north the days get longer, and as we move south they get shorter, like in this diagram




BRINDA: I see.. and more sunlight means more heat.

VIVEK: Right. But there is another reason why the Sun is *hotter* in summers. During Summer the Sun is high above in the sky. The intensity of sunlight is therefore higher.

BRINDA: I don't understand...

VIVEK (*drawing the figure*): See, the same amount of sunlight falls upon a lesser area during summer than in winter. Therefore it's hotter.

BRINDA: And also during winter the path through the atmosphere is longer...

VIVEK: Quite right! Therefore less heat is absorbed in the atmosphere during summer.

BRINDA ( *after some thought...*): The path of the Sun must be changing over the year then?

VIVEK: True.

BRINDA: And... at the North Pole the Sun doesn't set at all!

VIVEK: Only in Summer. In winter it doesn't rise at all. In fact it rises and sets *once* every year.

BRINDA: That's funny...

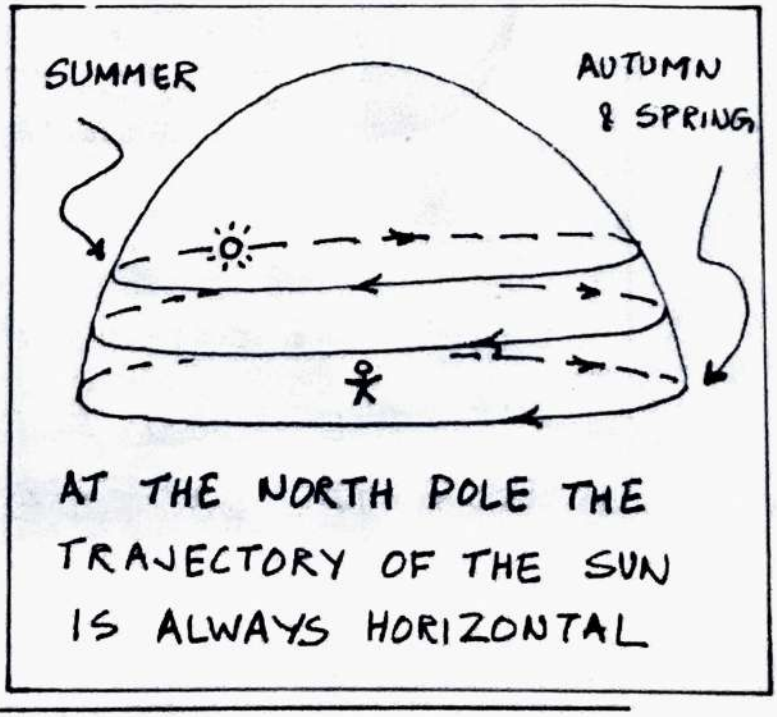
VIVEK: Not really. The path the Sun follows in the sky depends upon the latitude. At the Equator, which is latitude 0°, it goes up vertically at 90° and comes down straight.

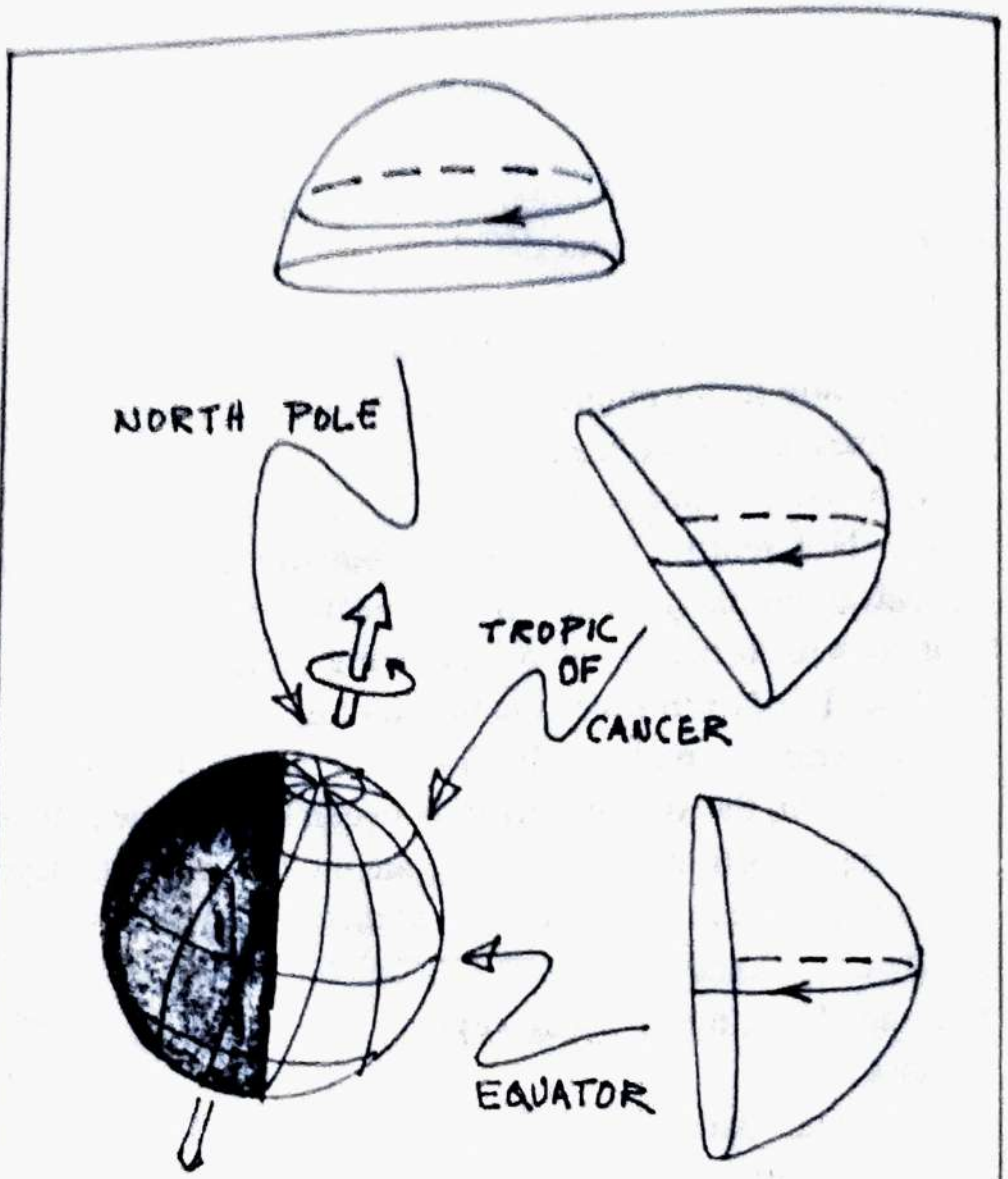
BRINDA: The North Pole is at 90° latitude...

VIVEK: And the path of the Sun is inclined at 0°! It just goes round in the sky. At any in between latitude the path is inclined proportionally. The diagram on the following page shows the trajectories of the Sun at different latitudes..

BRINDA: And with the changing seasons...?

VIVEK: The path just *shifts* without changing the angle. Which means at the North Pole the path shifts down, until it goes below the horizon in Autumn. Like in this diagram.

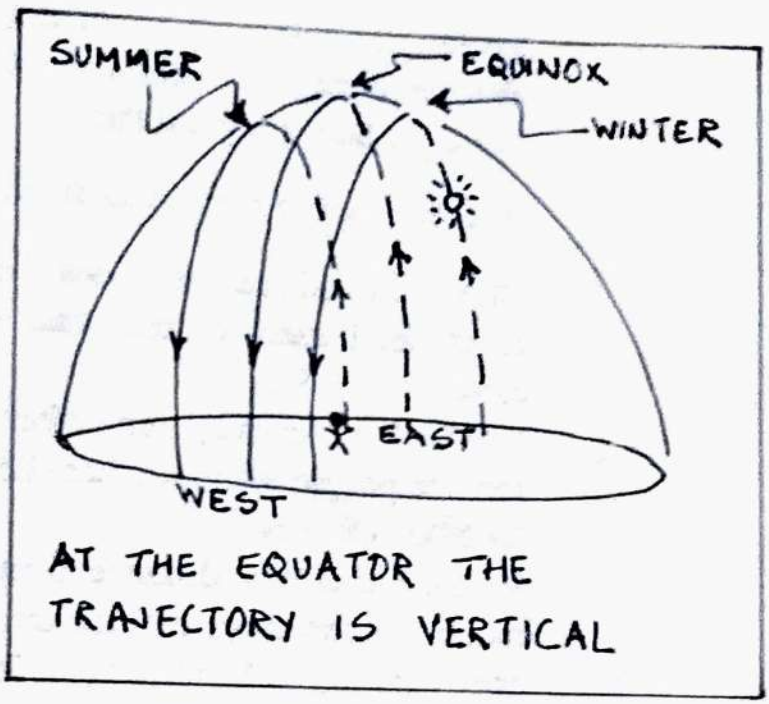





THE TRAJECTORY
OF THE SUN DEPENDS
UPON THE LATITUDE ON EARTH

BRINDA: And at the Equator?

VIVEK: There also it shifts to a parallel position. We can draw its changing trajectory. During the Equinoxes it climbs the highest in the sky. A similar thing happens for any other place. Do you know what are the Tropics of Cancer and Capricorn?




BRINDA: Yes, the latitudes of 23 1/2°.

VIVEK: Let's draw the diagram for the Tropic of Cancer. During the Summer Solstice the Earth is most inclined towards the Sun, right?

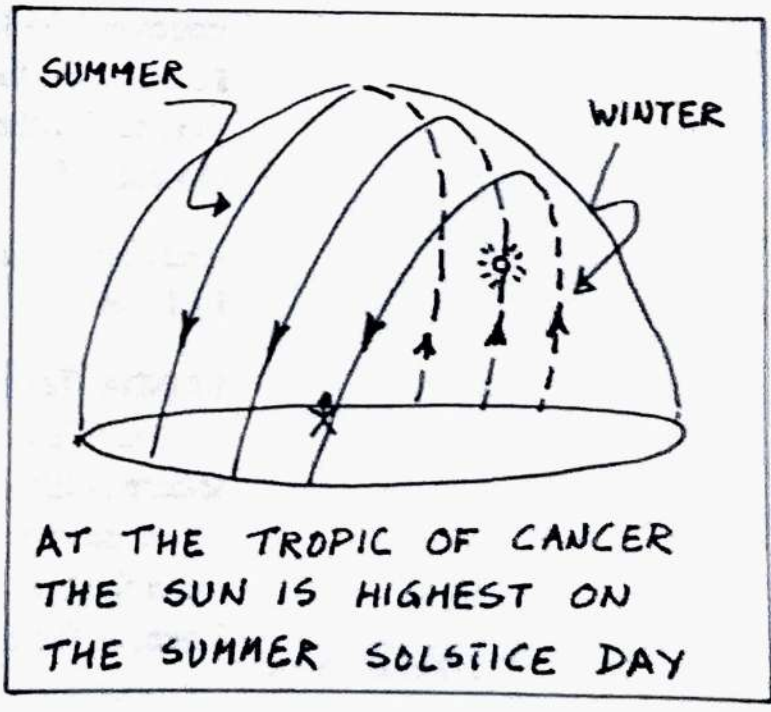
BRINDA: Right.

VIVEK: This is the only day the Sun is *directly overhead* at noon there. After that the Sun's path starts moving South...

BRINDA: And at higher latitudes the Sun never comes overhead?

VIVEK: Correct. And at lower latitudes the highest point comes sometime in between.

BRINDA: It must be hottest then...



VIVEK: It must be... In Madras we have the *Agninakshatram* during the middle of May. I think it must be because the Sun is highest then.

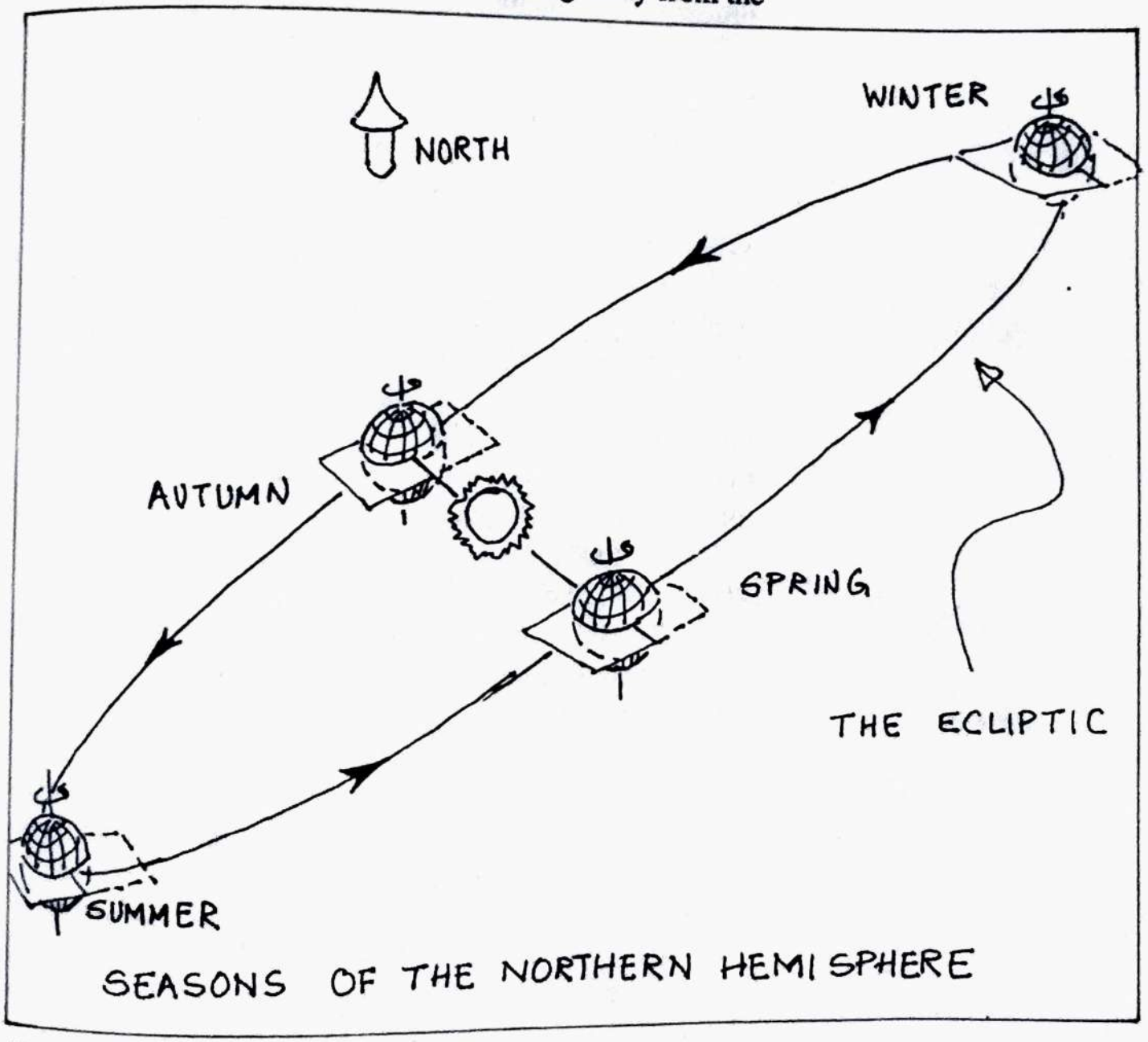
*And they looked ruefully at the fan trying to do it's best.*

BRINDA: I had read in a book that the orbit of the Earth is elliptical. I used to think that summer is when we are closest to the Sun.
VIVEK: No. Anyway, remember that when *we* have summer the people in the southern hemisphere have winter.
BRINDA: Oh, yes.
VIVEK: Also, the distance from the Sun does not vary much. Astronomers call the *average distance* to the Sun one Astronomical Unit, or AU. It is about 150 million kms. Now the maximum distance is only 1.017AU, and the minimum is 0.983AU.
BRINDA: So the Earth's orbit is *nearly* circular...
VIVEK: Further, it may interest you, the Sun is actually closest in January, and the farthest in July.

*And they pondered over this for a while. Meanwhile Shirish had come in ...*

BRINDA: Tell me Vivek uncle, what are equinoxes?
VIVEK: Well ... we have summer when the northern hemisphere is tilted towards the Sun. Right? The point when the tilt is most is called the Summer Solstice. On that day at noon the Sun is directly overhead at the Tropic of Cancer. Then, as the Earth moves along its orbit around the Sun the tilt decreases. Look at the following diagram. The plane defined by the Equator is also tilted. The Autumnal Equi-

nox occurs when the line defined by the intersection of this plane with Ecliptic points to the Sun. The axis is neither towards the Sun, nor tilted away, but it is tilted sideways. As the Earth moves on the axis starts tilting away from the




SEASONS OF THE NORTHERN HEMISPHERE

Sun, till it is most tilted on the Winter Solstice. Then is starts tilting back and we say that Spring begins on the Vernal Equinox.

BRINDA: And one more year begins!

VIVEK: Curiously, while March 21 *is* an important date, we don't begin our years on that day. You know the year is not exactly 365 days long...

BRINDA: Yes, it is 365¼ days. That is why we have a *leap year* once every four years.

VIVEK: Right, it was started by Julius Caesar. But that is still not accurate enough. There is an error of about 11 minutes. Due to which the Spring Equinox had actually shifted to March 11 by the sixteenth century. It was then that Pope Gregory II made the new calendar. He began by renaming October 5, 1582 as October 15. Further he said that only century years divisible by 400 will be leap years.

BRINDA: So, 1700, 1800 and 1900 are not leap years, but 1600 and 2000 are...

VIVEK: Yes. The year as defined by the *Gregorian* calendar is 365.2425 days long, which is quite close to the actual tropical year of 365.2422 days. The error now is only one day in 3300 years.

SHIRISH: Okay, now can you tell me how long is a year?

BRINDA: Why, Vivek uncle has been just telling us that?!

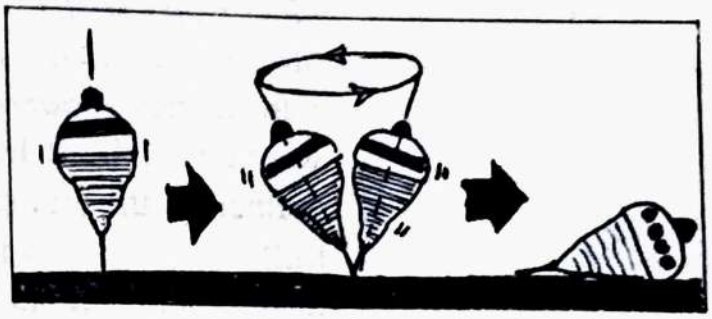
VIVEK (*musing*): I think what Shirish is hinting at is that the Earth does not go completely around the Sun in a year...

BRINDA: It doesn't?

SHIRISH: No. Let me explain why... Remember that we want the year to be such that the Spring or Vernal Equinox always occurs on March 21st.

BRINDA: Right.

SHIRISH: And the Equinox occurs when the Earth's axis is neither tilted towards the Sun, nor away from it. Normally this would happen at the same location with respect to the Sun as the Earth goes round. But in actual fact the axis does not keep still. It wriggles around like the axis of this top.

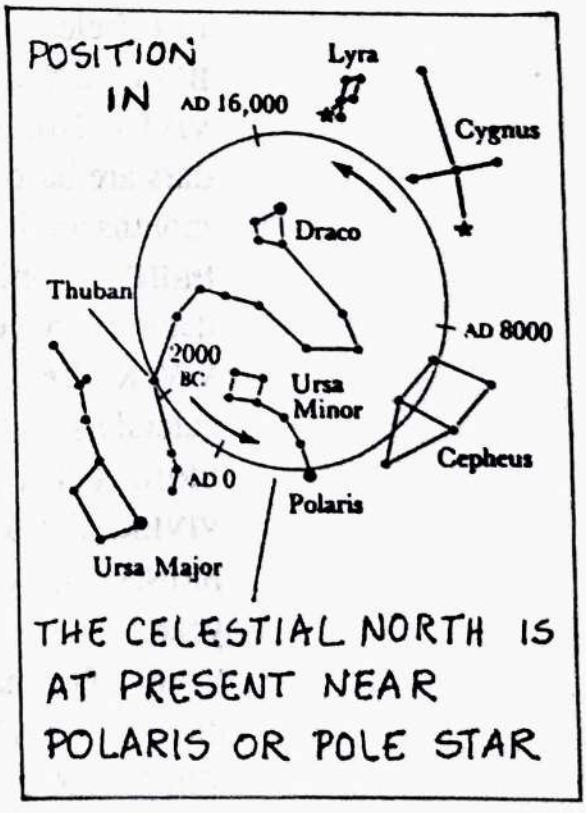


*He took out a top and spun it. Initially the top was rotating fast, quite still in one place. But gradually it started wobbling before eventually coming to a stop.*

SHIRISH: You saw how the axis of rotation of the top was itself moving in a circular fashion? This motion is called *precession.* Now our Earth also precesses as it rotates.

BRINDA: You mean the Earth's inclination is not always 23½°?

SHIRISH: Yes. It precesses slowly, completing one circle in 26,000 years. As a result of which the Pole Star is not always in the geographical North, which astronomers call the *north celestial pole.* This figure shows the movement of the celestial pole (to which the axis points) over the centuries....




BRINDA: I see, but how does that affect things?

SHIRISH: Remember, we are interested in the Spring Equinox? Now this precession causes the location of Equinox to shift a little by the time the Earth goes around the Sun. This happens because of the changing angle of the axis.

BRINDA: I see! So the Equinox does not happen at the same *place* every year.

SHIRISH: Yes. One full revolution of the Earth around the Sun defines a *sidereal year*. It is exactly 365.2564 days, which is a little longer that the tropical year, the one defined by the four seasons.

BRINDA: I see... so in one year the Earth goes a little less than full circle around the Sun!

SHIRISH: Yes, in about 20 more minutes it would finish the full circle.

BRINDA: What about the Moon? Doesn't it matter?

VIVEK: Not in the Roman calendar. But our Indian Calendars are based on the Lunar month. Unfortunately 12 lunar months are less than a year.

BRINDA: Oh! That's why Deepawali occurs on different dates every year!

VIVEK: Yes. And to keep pace with the seasons Indian calendars add an extra month every few years.

BRINDA: The *adhika masam*, huh?

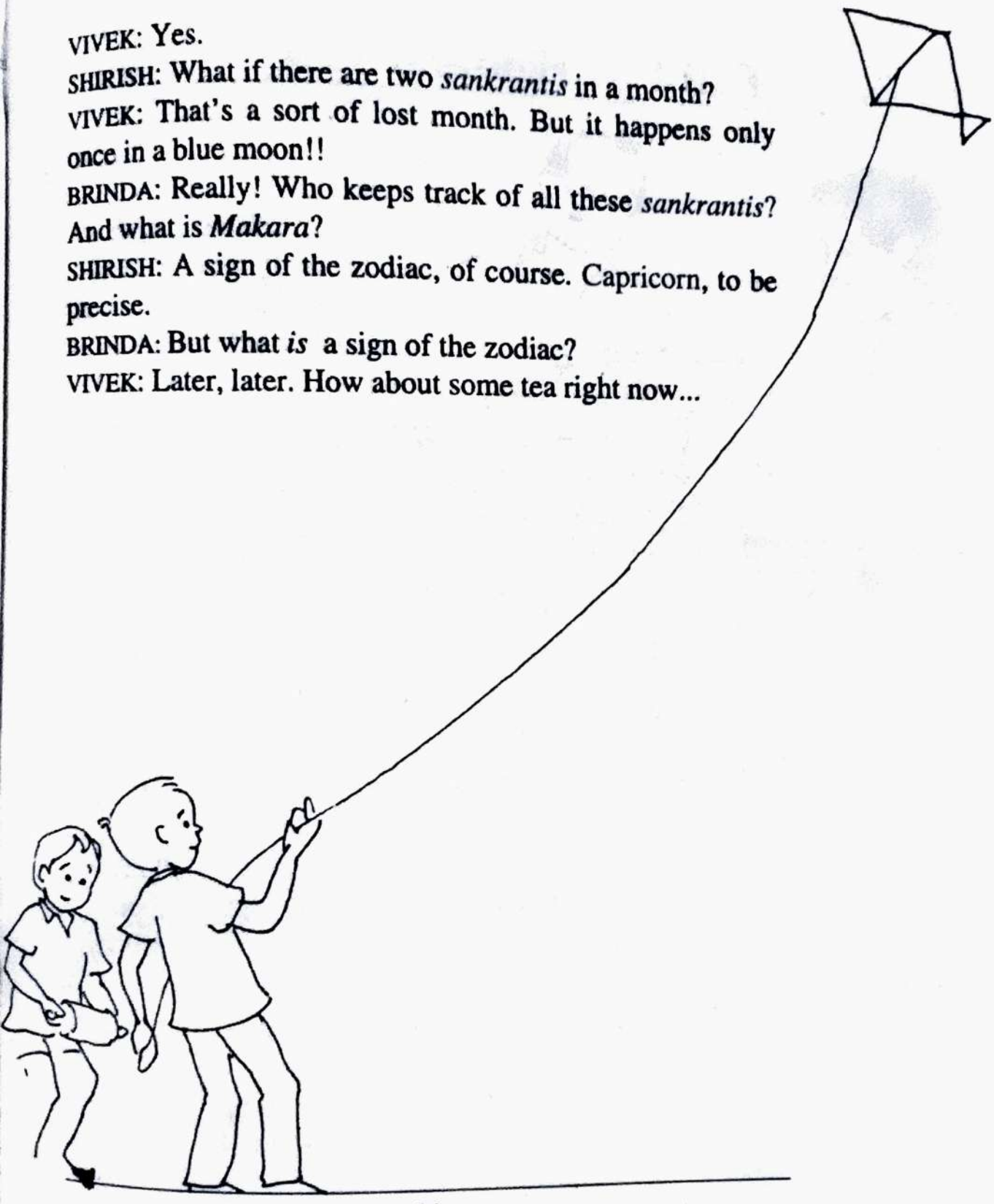
VIVEK: You know of *Makara Sankranti*, don't you?

BRINDA: Of course! Shirish Uncle flew so many kites this year ...

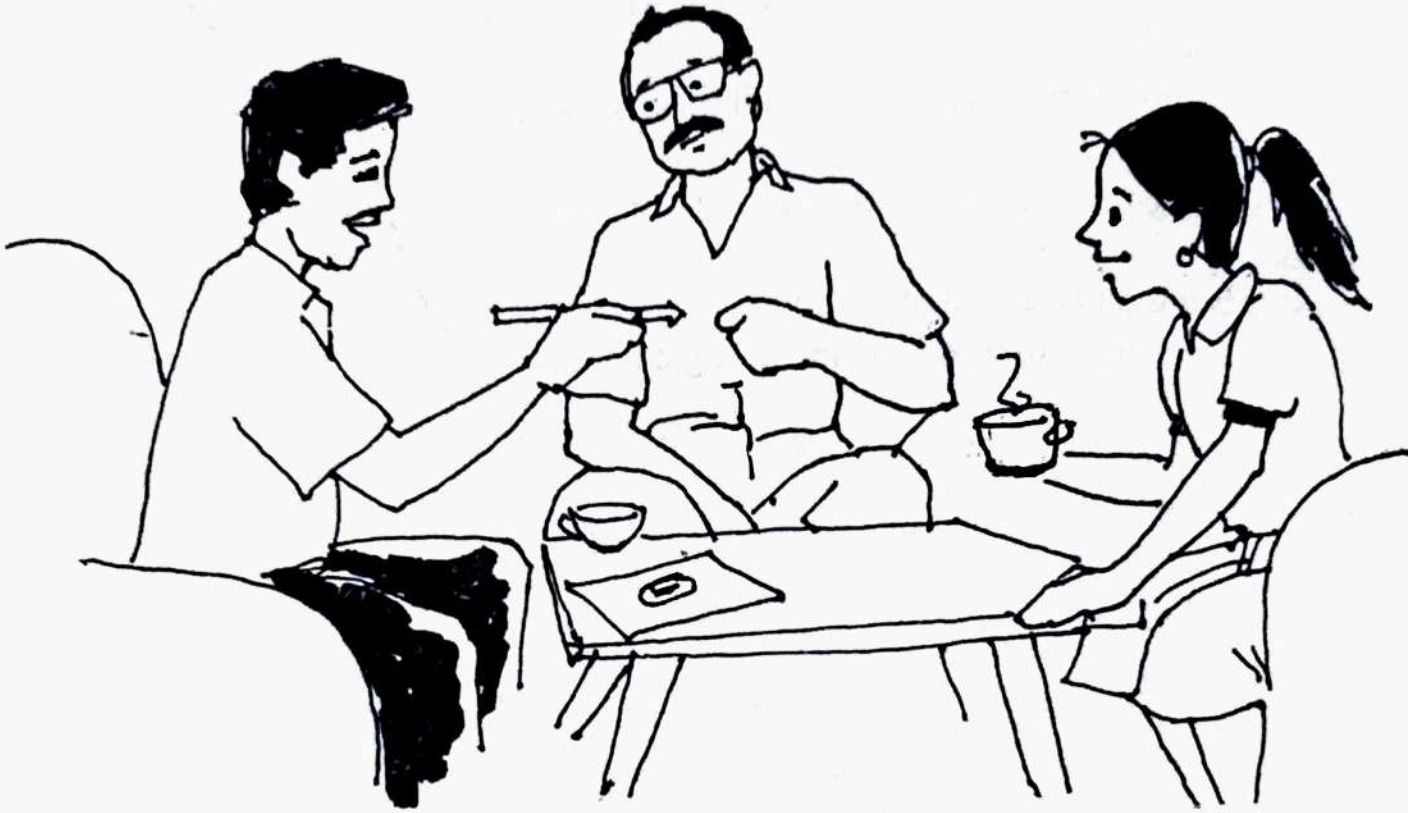
VIVEK: Normally, there is a *sankranti* every month. When there is none, that month becomes an extra month.

SHIRISH: Really? So that's the explanation?

VIVEK: Yes.
SHIRISH: What if there are two *sankrantis* in a month?
VIVEK: That's a sort of lost month. But it happens only once in a blue moon!!
BRINDA: Really! Who keeps track of all these *sankrantis*? And what is *Makara*?
SHIRISH: A sign of the zodiac, of course. Capricorn, to be precise.
BRINDA: But what *is* a sign of the zodiac?
VIVEK: Later, later. How about some tea right now...



# Part 4 Hide and Seek



*Many things have been thrown light upon, sometimes aided by Shirish's diversions. The three of them are sipping tea...*

BRINDA: Vivek uncle, you had said you would tell me why the Moon doesn't block the Sun's light on New Moon ...

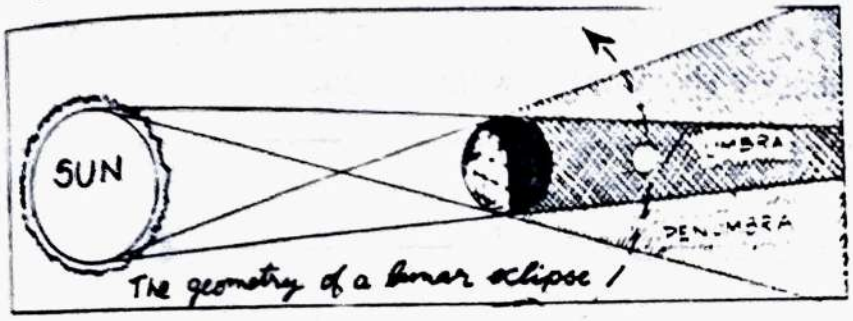
VIVEK: But it does, sometimes, Brinda! That is when we have a *Solar eclipse*. This happens when the shadow of the Moon falls on the Earth. The Sun vanishes from the sky and it becomes dark for a while.

SHIRISH: That's when *Rahu* or *Ketu* eats it up!

VIVEK: In our mythology Rahu and Ketu have a grudge against Rahul and Ketul.

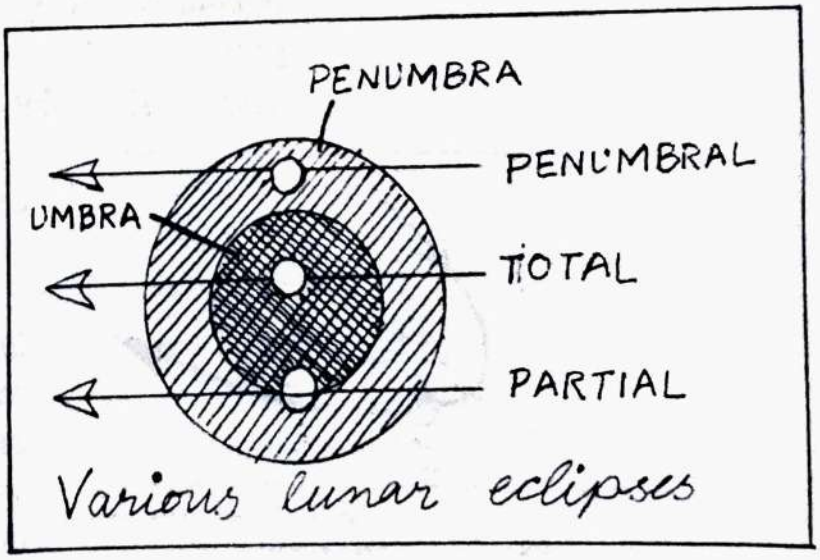
BRINDA: *Ketul* is the Moon, right?
VIVEK: Yes! And so we also have *Lunar eclipses* in which the Moon vanishes. This happens when the shadow of Earth falls on the Moon. Remember, the Moon shines in the light of the Sun.

*He pulled out a pad and drew the following figure.*




BRINDA: *(Thinking for a while...)* Then a Lunar eclipse should happen every full Moon!! But it doesn't!
VIVEK: Good thinking! But it is a little complicated to understand why it doesn't happen that way. Listen carefully...

*And he drew another figure.*



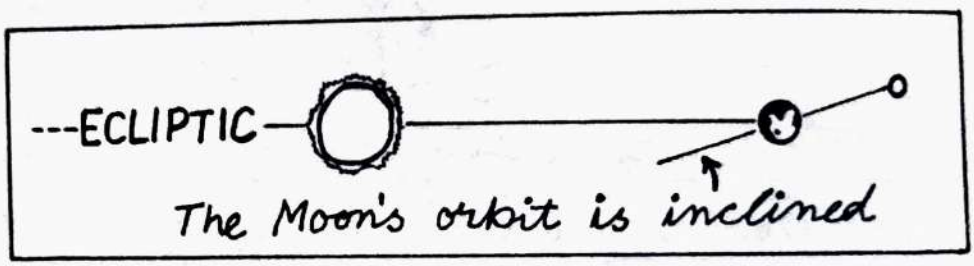

VIVEK: First let's get the basics clear. The Earth's shadow has two regions. One we call the *Umbra*. This is the dark part where there is no sunlight at all. The second part is the *Penumbra*, where only a part of the Sun shines. When the Moon passes through the Umbra we get a *total Lunar eclipse*. If the Moon passes through the

Penumbra we get a *penumbral Lunar eclipse.* The Moon is still visible. It just looks a little dimmer. If it passes *partly* through the umbra we get a *partial Lunar eclipse.*

SHIRISH: And when it passes through neither we have no eclipse. Ha ha.

BRINDA: But why sometimes this and sometimes that...?

VIVEK: The first reason is that the Moon's orbit does not lie in the Ecliptic. It is inclined by about 5°. So the full Moon can occur above or below the Ecliptic...

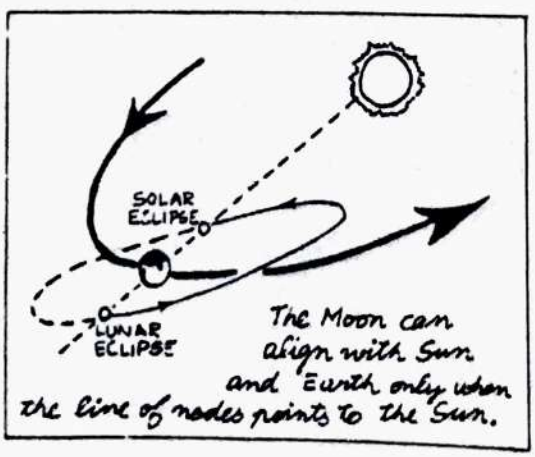



SHIRISH: *That* is when we have no eclipse...

VIVEK: Yes, or if it is near the Ecliptic it passes through the shadow. The Sun, Earth and the Moon are in a straight line.

BRINDA: And we have an eclipse.

VIVEK: The points where the Moon's orbit cuts the Ecliptic plane are called the ascending and descending nodes.



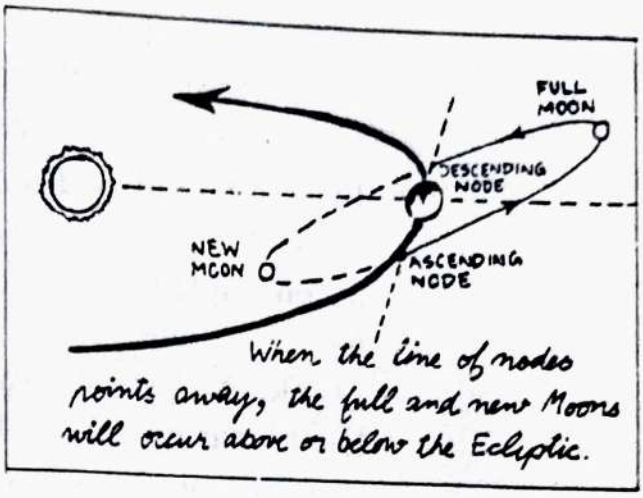

SHIRISH: What we call Rahu and Ketu.

VIVEK: The line joining them is called the *line of nodes.* When this points to the Sun we can have an eclipse...

BRINDA: *Can* have?

VIVEK: Yes, remember that the Moon must be present there. It can come in line with the Earth and Sun only at one of

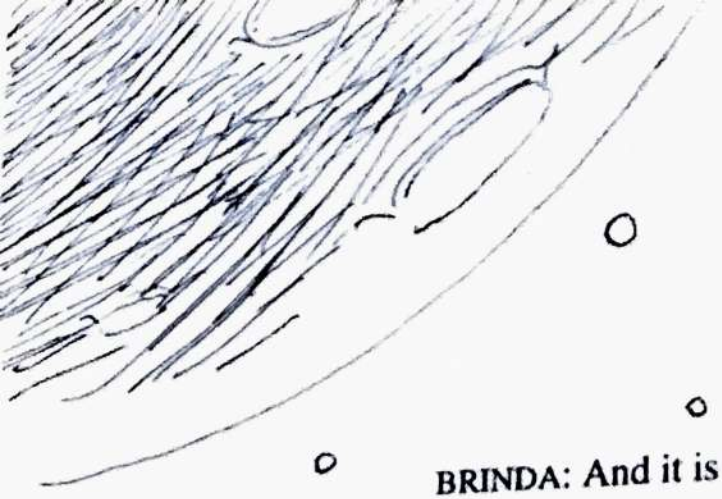
these nodes. So it must be a Full Moon.
SHIRISH: Or the New Moon.
VIVEK: That would be a Solar eclipse. But we will come to that soon. And when it doesn't point to the Sun, the Moon will be above or below the Ecliptic.
BRINDA: Okay. So this line of nodes must point to the Sun... But doesn't it point to the Sun at the same time of the year? Like the Equinoxes? So the eclipse must occur on the same day every year ...




VIVEK *(laughing)*: You are right. It *should* have. But like the Equinoxes again, the line of nodes also *precesses*!
SHIRISH: Like this. Imagine this coin represents the orbit of the Moon....

*And Shirish twirled a one rupee coin on the floor. It danced about for a while before settling down.*

VIVEK: Yes, quite like that. Because of the precession, the line of nodes rotates once every 18.6 years or so.
BRINDA: I see...
VIVEK: As a result it takes exactly 346.6 days after which the line of nodes again points to the Sun. This period has been known to man for a long time. It is known as the *eclipse year.*



BRINDA: And it is used to predict eclipses?

VIVEK: Yes, you can compute the time from one Lunar eclipse to another one.

SHIRISH: And one Solar eclipse to another one.

BRINDA *(eagerly)*: Can I do it too?

VIVEK: Yes, of course. Let's say you have a Lunar eclipse. Now the next lunar eclipse will have to be during a full Moon. Right?

BRINDA: Right.

VIVEK: So it must be after some number of *lunar months*. Each lunar month is 29.5 days. If it happens after $n$ lunar months, that means it will happen after $29.5\times n$ days..

BRINDA: But *how many* lunar months?

VIVEK: Remember the line of nodes must again point to the Sun. And it does so every 346.6 days, or an eclipse year. Let us say it takes $m$ eclipse years to the next full Moon. Therefore $346.6\times m$ must be equal to $29.5\times n$. The solution is when $n = 223$ and $m = 19$, and the above product is 6585 days. This is called a *saros*.

BRINDA: So it takes 6585 days from one eclipse to the next?

VIVEK: Well, actually, it means that if you have an eclipse today, you will certainly have a similar one after 6585 days.

SHIRISH: But you won't be able to see that.

VIVEK: Why?

SHIRISH: Because the saros is actually 6585.3 days long. That extra ⅓ means that the Earth will be 120° away from this position. So in fact you have to wait for three saros.

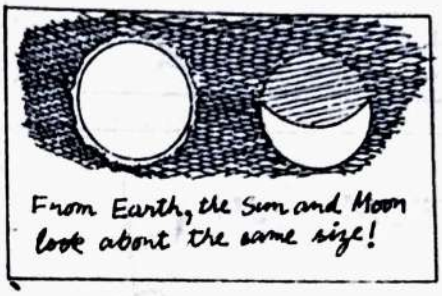
BRINDA: That's a long time. More than 54 years!

VIVEK: Yes, but there are many such *families* of eclipse periods. In fact we have an eclipse almost every year.

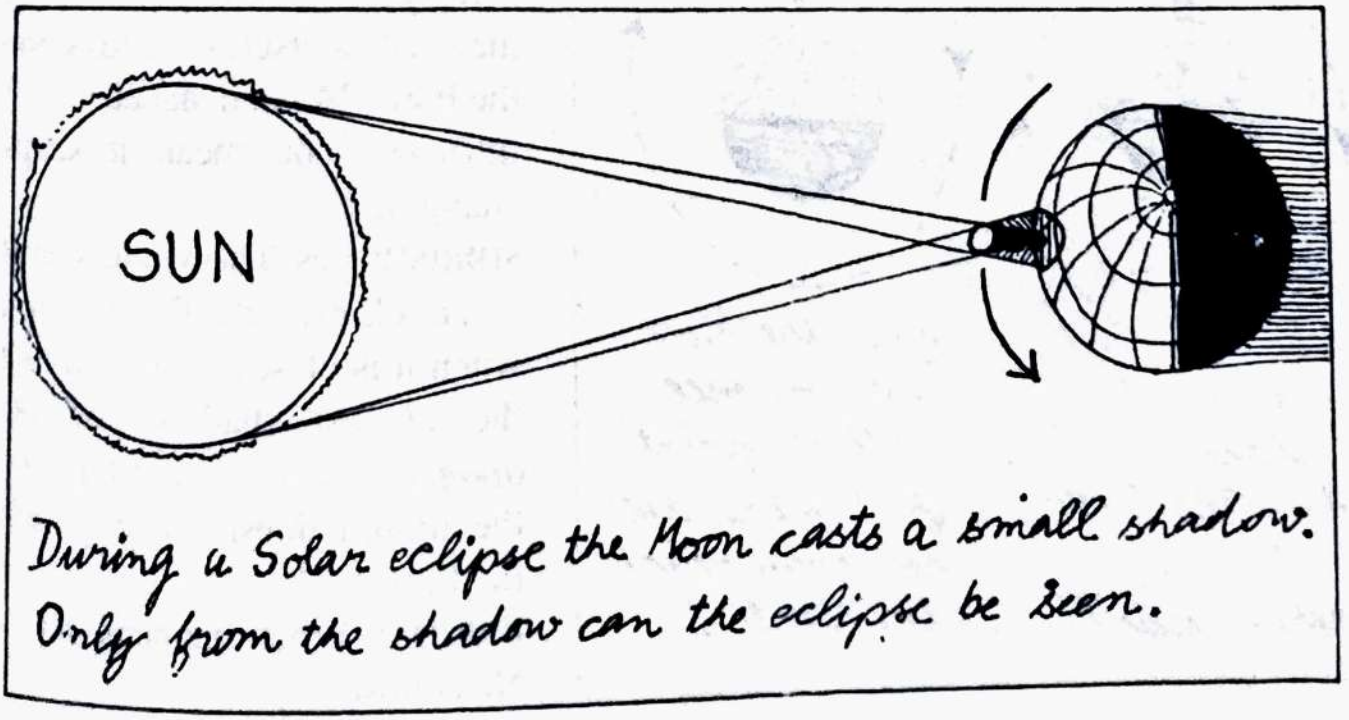
SHIRISH: There are at least two, and not more than five Solar eclipses every year. In 1935 there were five Solar eclipses. Lunar eclipses can be as many. But both together cannot be more than seven.

BRINDA: Oh! So many... How come we never see them?

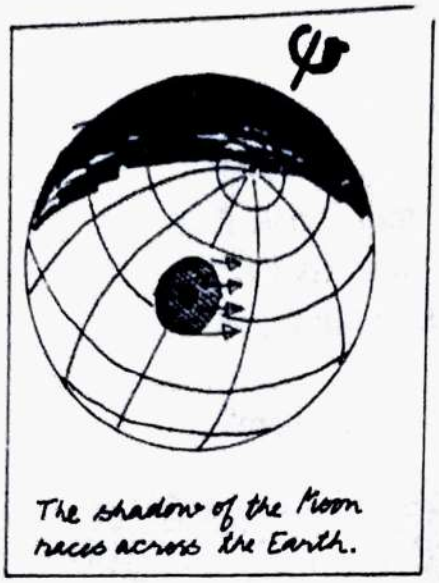
SHIRISH: Look at this diagram. From Earth both the Sun and the Moon look about the same size. Both are about ½° across the sky. This means that the tiny Moon can actually hide the Sun. But for the same reason the umbra of the Moon's shadow barely reaches the Earth. Only people standing in that region can see the total eclipse. The



From Earth, the Sun and Moon look about the same size!




During a Solar eclipse the Moon casts a small shadow. Only from the shadow can the eclipse be seen.

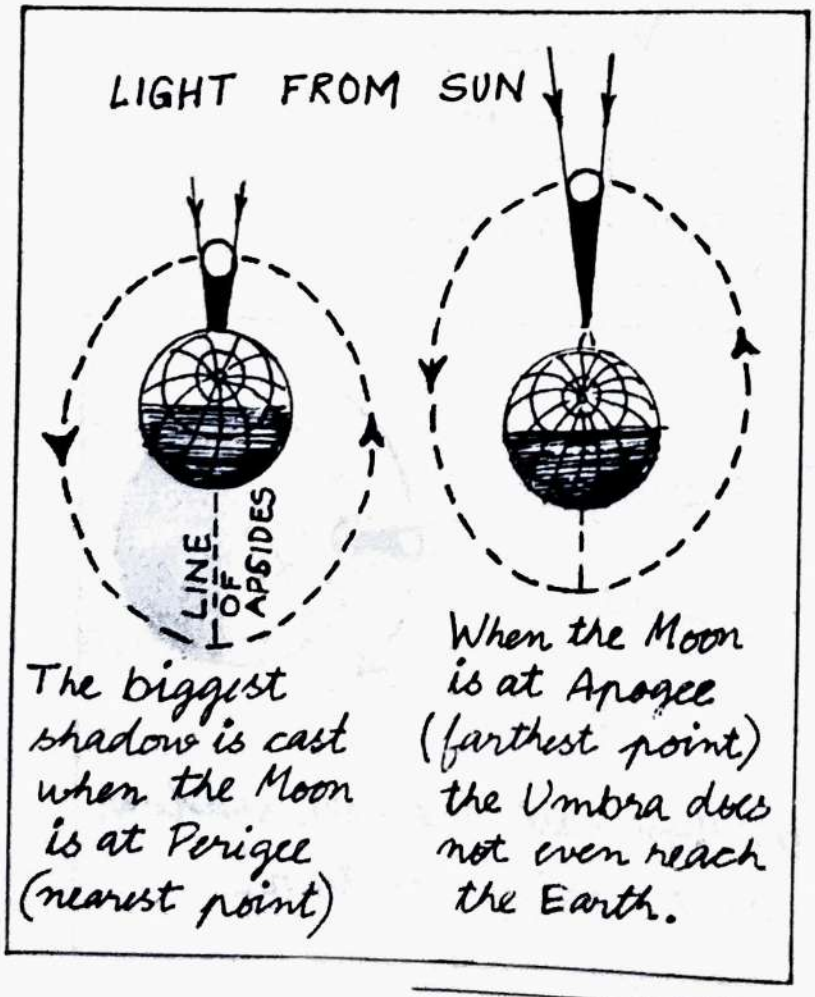


The shadow of the Moon races across the Earth.

penumbra is a little bigger. People in this region can see a partial Solar eclipse.

BRINDA: And the others cannot see it?

SHIRISH: Not only that, the Earth's rotation and the Moon's movement causes the shadow to race across the Earth, faster than 1700 km per hour. So you get to see it only for a short time. Totality never lasts more than 7½ minutes. Typically it is much less.




BRINDA: Why is that?

SHIRISH: Well for one thing, you have to be at the centre of the umbra to see it the longest. Some scientists try and do that by chasing the umbra in an aeroplane! Secondly the size of the shadow itself depends upon the Earth-Moon distance.

BRINDA: You mean it keeps changing?

SHIRISH: Yes. The Moon's orbit is an ellipse. At the *perigee*, when it is closest, it would cast the biggest shadow. At the *apogee*, when it is the farthest, the umbra doesn't even reach the Earth!

BRINDA: What happens then? No eclipse?

SHIRISH: Then the Moon looks a little smaller than the Sun, and cannot quite hide it. What we get is an *Annular Solar eclipse*. Look, this book *Universe* by William Kaufmann has a picture of the annular eclipse seen in Costa Rica in 1974.

BRINDA: Oh! How beautiful it looks. Do we know when the next annular eclipse will be?

SHIRISH: The Moon must be at the apogee, right? Now, the line joining the apogee and the perigee is called the *line of apsides*.

BRINDA *(with mock horror)*: Don't tell me that too rotates.

SHIRISH *(laughing)*: Yes, in fact it does. Once every 8.85 years. Using that we know that the next annular eclipse is going to be on April 29, 1995.

BRINDA: Oh, really! How exciting!

SHIRISH: Unfortunately, we in India cannot see that. You will have to go to Peru.

BRINDA *(dejectedly)*: Oh no ...

SHIRISH: But don't worry. We have a total eclipse coming in October 24th, 1995. The eclipse will be visible from much of India, and it will be *total* on a line from Bikaner to Calcutta.

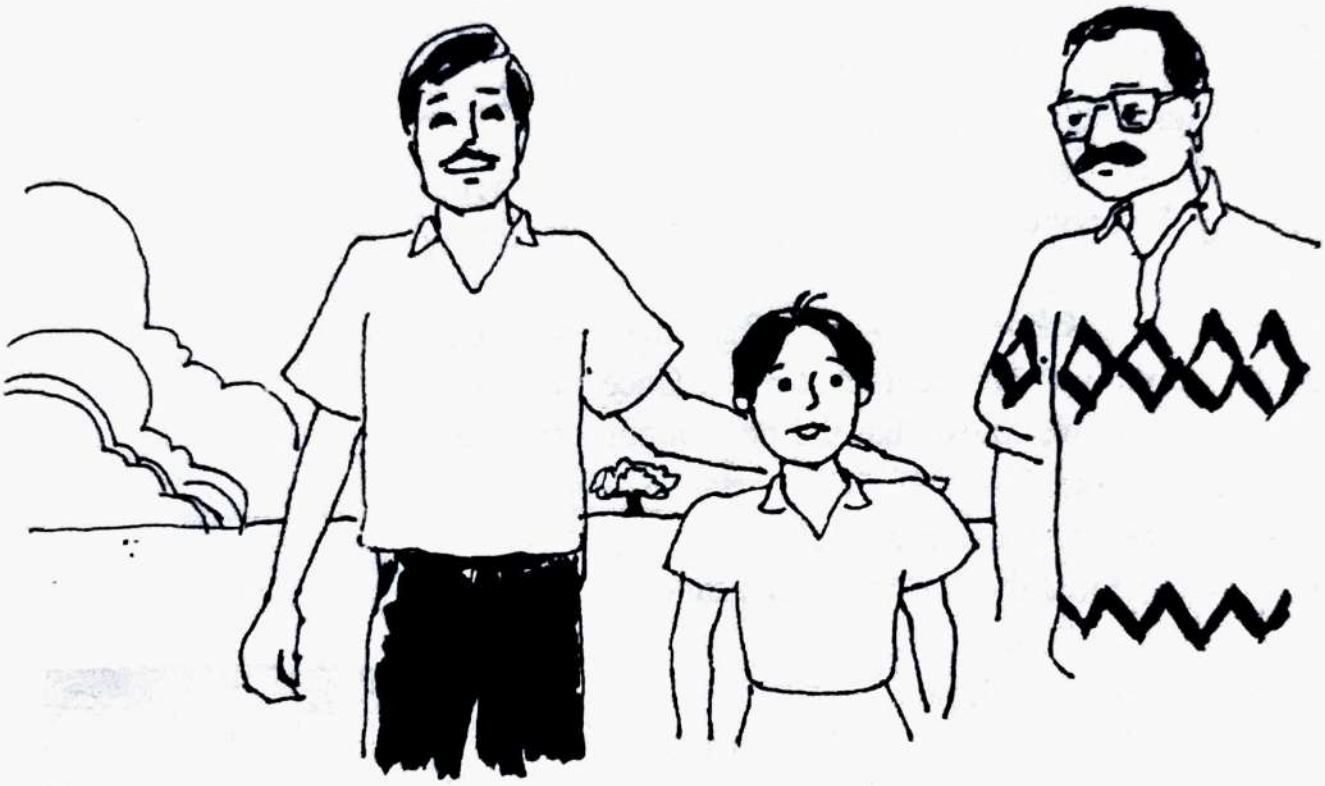
BRINDA: Really! Vivek Uncle, can we go and see it? We can visit Mihika in Calcutta!!

VIVEK: Mmm ... Let's see ... October 1995 ...Yes, that's a nice idea. We should plan for it.

BRINDA: Yippee!! ...

*Brinda ran off in excitement to tell her friends Rahul and Ketul, and found them fighting as usual...*

## Part 5 Twinkle twinkle...



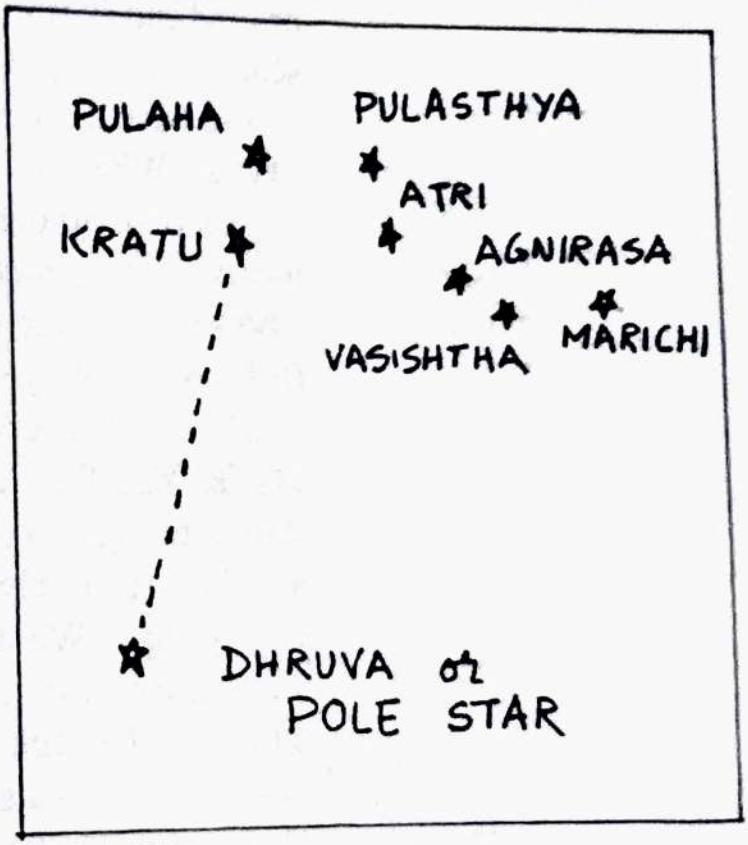
*The Sun and Moon had so far eclipsed any talk of stars. Finally, on a clear starry night, our friends were able to break away and turn their attention towards the "distant" cousins of our Sun. As they went for a post dinner stroll...*

BRINDA: Do you think anybody has been listening to our conversation?

VIVEK: Why?

BRINDA: Rahul was saying that someone has been writing about us in a magazine called Jantar Mantar...

SHIRISH: Good! We'll be famous.
BRINDA: But Rahul was unhappy about it.
SHIRISH: Imaginary people, imaginary magazine... like Rahu and Ketu... Ha ha.
VIVEK: Come, let's talk of real things. Look, what a clear night it is.
BRINDA: Isn't that the Great Bear?
VIVEK: Yes, we call it the *Saptarshi*. It is also known as The Big Dipper. It is useful in finding the Pole Star. And there are the stars Castor and Pollux, of Gemini.
SHIRISH: That is your zodiac sign, Brinda!
BRINDA: But what *is* a zodiac sign!? You *must* tell me today!
VIVEK: Okay, here we go. First let me ask you a question. Do you have any idea how far the stars really are?
BRINDA: Well, I know that they are *very* far...
VIVEK: Remember, I had told you that if the Earth were a ball of diameter 7.5 mm, the Sun would be a ball of about 800 mm at a distance of 86 meters?
BRINDA: Yes, and the Moon was only 22 cm away.
VIVEK: Well, on that scale the nearest star we know, Proxima Centauri, would be about 24,000 km away.
BRINDA: Gosh! The nearest star! And there is *nothing* else in between.



VIVEK: Yes, it is over 60,000 times farther than the Sun, or 4.3 light years away.

BRINDA: That means light from there takes 4.3 years to reach here! It's lucky I don't have a friend there. If I said hello on the phone she would hear it only after 4.3 years!!

SHIRISH *(Smiling)*: 24,000 km would be more than halfway around the Earth. And remember this is at such a reduced scale, that if light were to take 4.3 years to reach here, it would have to *crawl* along at a speed of 0.176 cm/sec!

VIVEK: When in fact light travels 300,000 kilometers in one second. So our model is 1.7 *billion* times smaller.

BRINDA *(awestruck)*: And that is the *nearest* star...

VIVEK: Yes, there are stars as far away as we can see. Billions of light years away.

BRINDA: All around us?

VIVEK: Yes. But they are not spread uniformly. Millions of stars form a galaxy. And there are millions of galaxies. Our Sun is a relatively small star on the fringe of the Milky Way galaxy. We are about 25,000 light years away from the centre of our galaxy.

BRINDA: The Milky Way is not a constellation?

VIVEK: No, constellations have no *physical* significance. They are just patterns of stars we see in the sky. The stars do not have to be physically close to each other. Look at the figure on the following page for example. These 5 stars may be quite far away from each other. But when seen from the Earth they appear to form a pattern like "M".

BRINDA: I see, so constellations are only patterns as *we* see from the Earth...

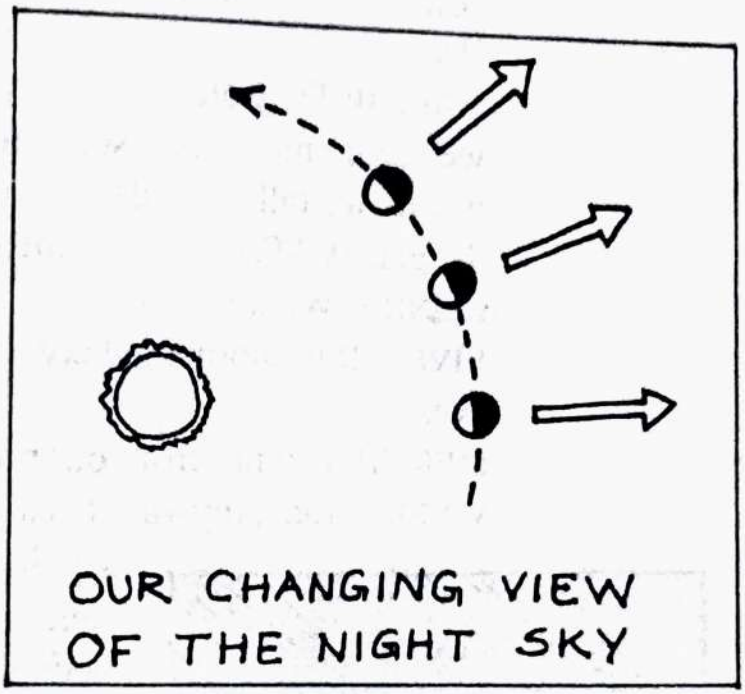
VIVEK: Yes, in ancient times, our ancestors noticed these

patterns in the sky. They also observed that these patterns are not static. They moved with the seasons. We can see from this figure that as the Earth moves along its orbit around the Sun, different parts of the sky are visible at night.

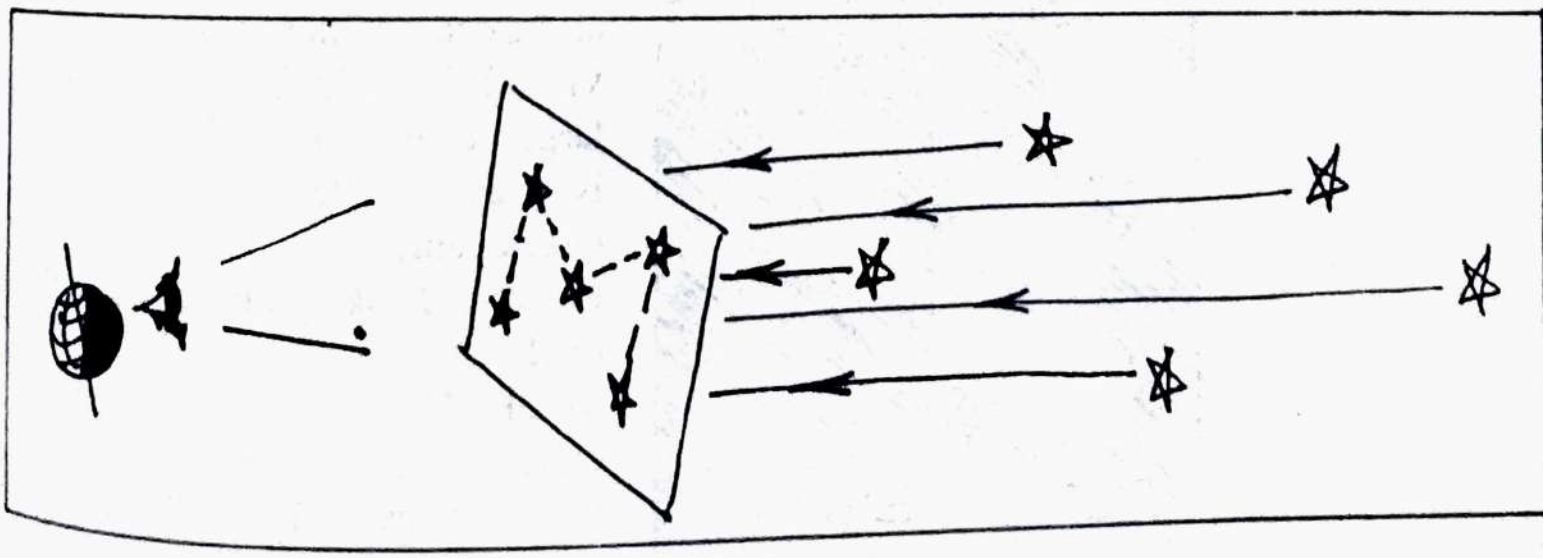
BRINDA: Yes! And after one year when the Earth comes back to the same place we would see the same patterns again.

VIVEK: That, in fact, is how our ancestors learnt to recognize a year.

*Brinda remembered the talk about length of the year. But she was not going to get diverted this time!*



OUR CHANGING VIEW OF THE NIGHT SKY



BRINDA: Ahem! About the zodiac signs...

VIVEK *(laughing)*: We are nearly there! There are about 6000 stars that the unaided eye can see. The more prominent ones among them form the constellations. According to modern charts there are 88 constellations in the sky.

SHIRISH: They are essentially used to *map* the sky. Just like we use countries and states to map the Earth. For example, just as we talk of Calcutta being in Bengal, we can talk of the galaxy M31 in Andromeda.

BRINDA: What is M31?

VIVEK: It is another galaxy. One we can see with our naked eyes...

SHIRISH: But not from our polluted cities.

VIVEK: True. Anyway it is a good example for our talk. We say M31 is in the Andromeda constellation. But in fact it is a full fledged galaxy in itself, far far away.


BRINDA: Okay. The Great Bear is also a constellation, right?

VIVEK: Right. In fact it is one of the largest constellations. In the charts it is usually called Ursa Major, its Greek name.

BRINDA *(Looking up)*: Look at that one!

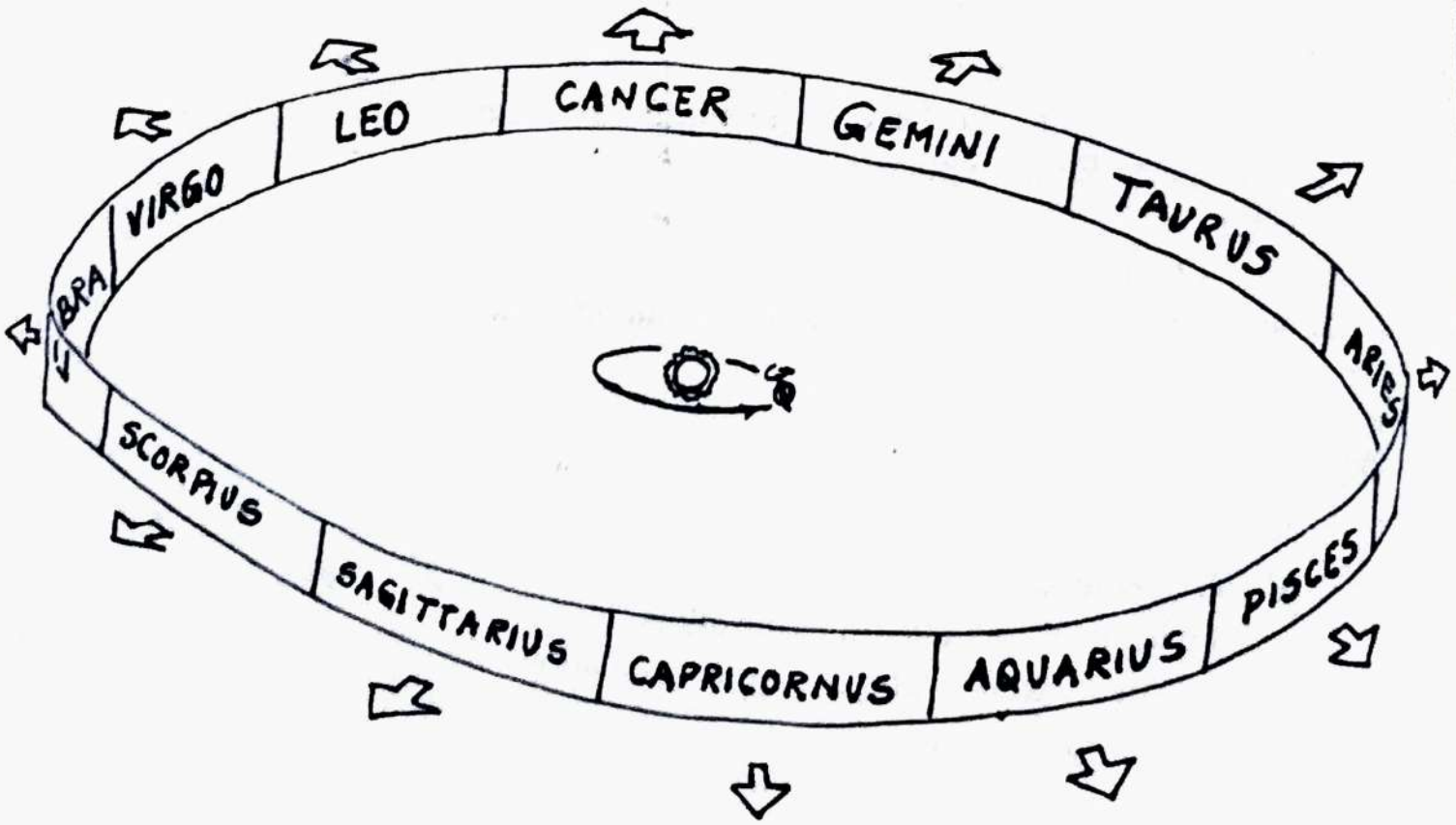
VIVEK: No, no. That is in fact a cluster, called Pleiades. We call them the seven sisters. They are actually a set of stars close together.

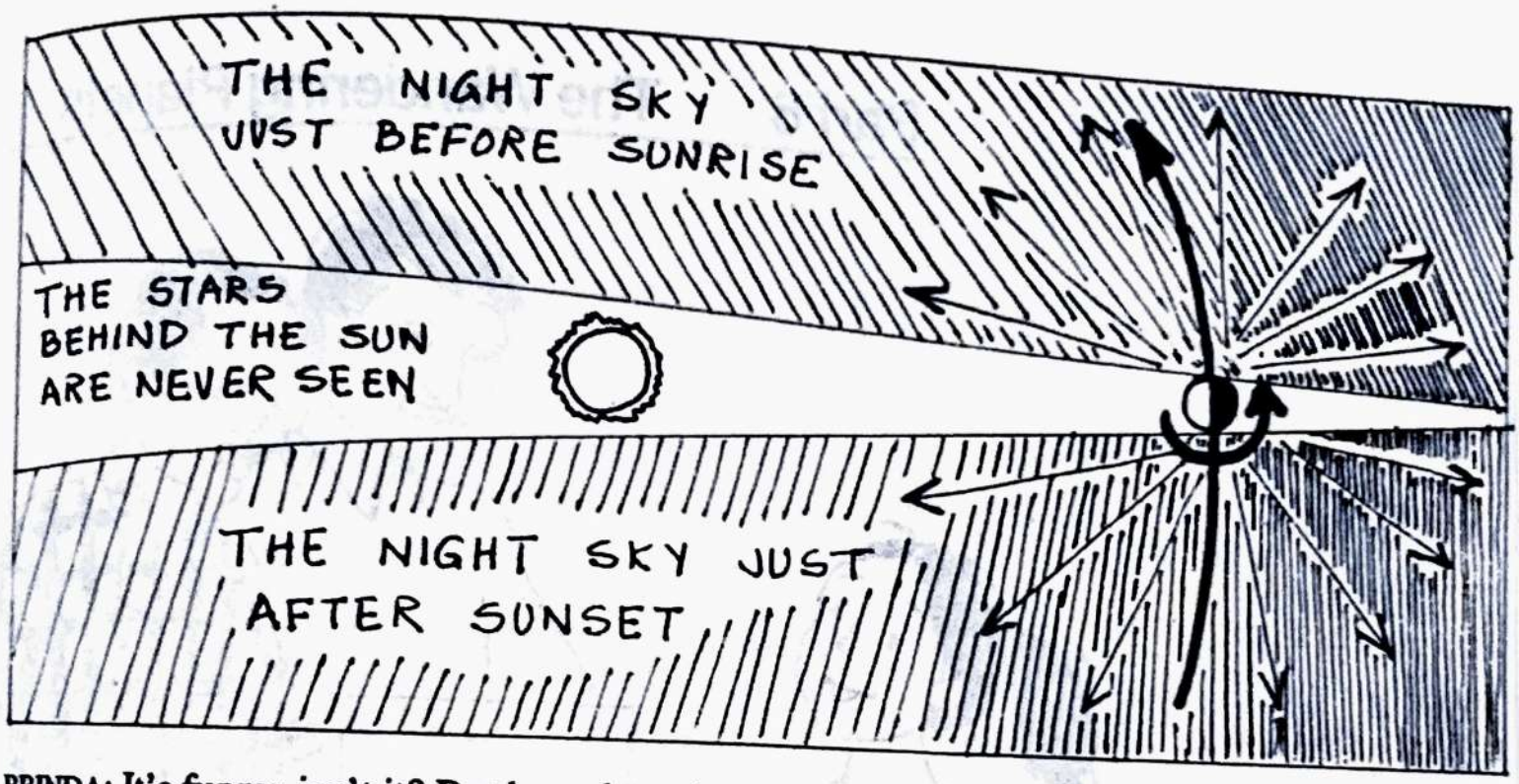
BRINDA: How does one know clusters from constellations?
SHIRISH: One just has to learn to recognize them. Perhaps someone is writing about them too in your imaginary magazine!
BRINDA: It's a real magazine! And a very good one.
VIVEK: Okay, okay. Let's get back to our zodiac signs. You know the word zodiac comes from Latin. It means "the living". There are 12 constellations of the zodiac.
SHIRISH: Their names are Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricorn, Aquarius, and Pisces.
BRINDA: Why are they special?
VIVEK: You remember that the orbit of the Earth around the Sun defines the Ecliptic plane?
BRINDA: Yes.
VIVEK: The 12 zodiac constellations lie in that part of the sky through which the Ecliptic passes. Imagine that there were twelve windows around the Ecliptic, as in the figure on the next page.
BRINDA: Then the constellation seen through each window would be a zodiac constellation!
VIVEK: Perfect! You got it.
BRINDA: But why are they called the Sun signs?
VIVEK *(After some thought)*: The twelve constellations are also known as the twelve houses.
BRINDA: With each house having a window?
VIVEK *(Smiling)*: Sort of... Now since the Sun is also on the Ecliptic it must be in one of the twelve houses. By Sun sign one means the house in which the Sun was at the time

of one's birth. So if you are a Gemini, it means that the Sun must have been in Gemini when you were born. This is according to the Western system based on the Sun.

BRINDA *(musing...)*: But that means Gemini must have not been visible in that period.

VIVEK: Yes! Curiously, it must have been the *only* zodiac constellation not visible then. In ~~June~~* August, its neighbour Cancer comes up early morning, and on the other side Taurus can be seen setting just after sunset.






BRINDA: It's funny, isn't it? But how does that matter?

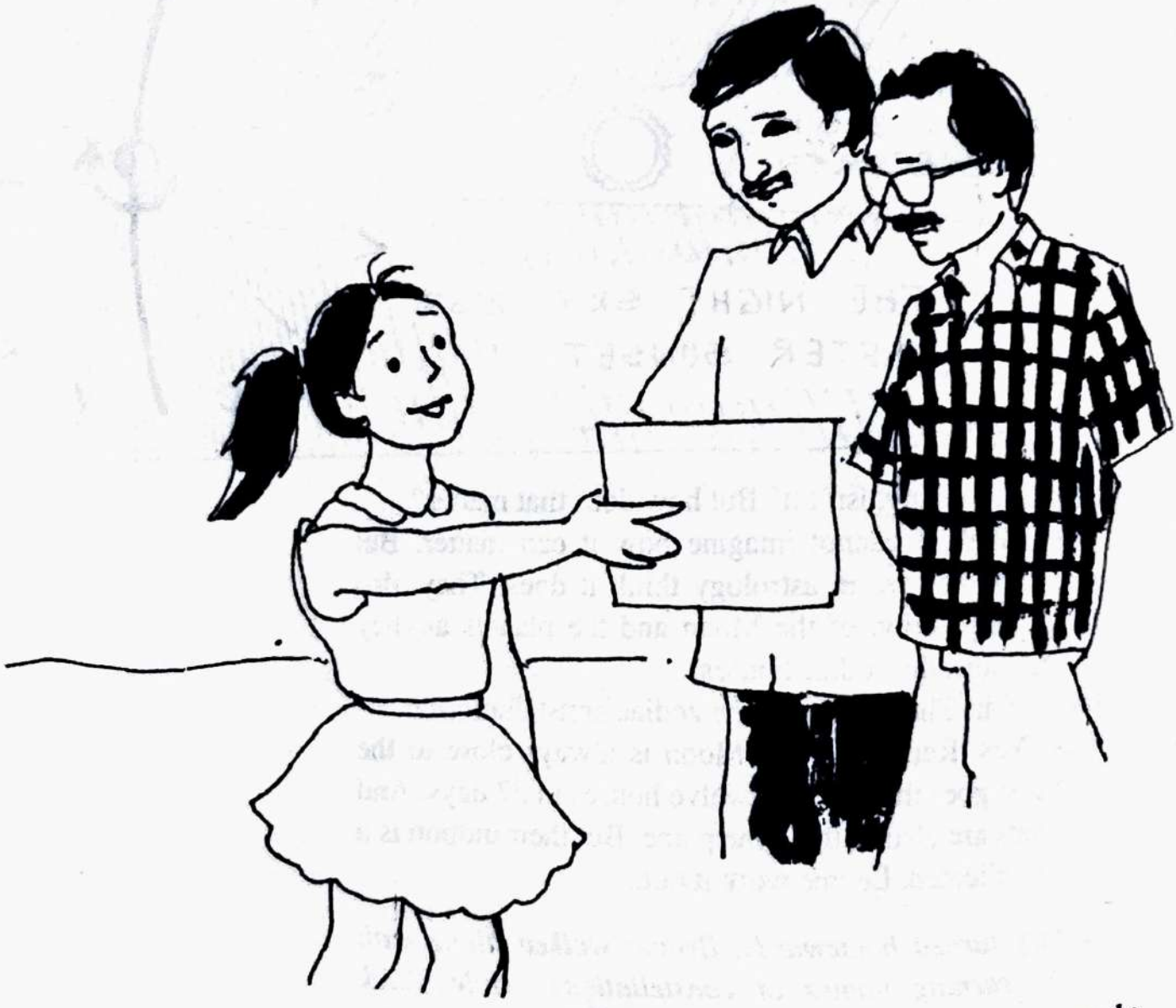
VIVEK: Well, I cannot imagine how it can matter. But people who believe in astrology think it does. They also look at the position of the Moon and the planets as they move amongst the zodiac houses...

BRINDA: Oh! They also visit the zodiac constellations?

VIVEK: Yes. Remember the Moon is always close to the Ecliptic. It goes through the twelve houses in 27 days. And the planets are also in the same plane. But their motion is a little complicated. Let me work it out...

*And they turned homewards. Brinda walked along with Shirish learning names of constellations, while Vivek pondered over the zigzag motion of the planets...*

# Part 6 The Wandering Planets



*Brinda had just learnt that the stars of the zodiac were the ones which could be seen along the ecliptic, which is the plane defined by Earth's revolution around the Sun. As the*

*Earth moved through the year the Sun appeared to visit different zodiac houses. Meanwhile as our three friends reached their own home...*

BRINDA: The planets are also in the plane of the Ecliptic, aren't they?

VIVEK: Yes, but as seen from the Earth their motion is not as simple as that of the stars.

BRINDA: Why is that?

VIVEK: All the stars are far far away...

BRINDA: Yes, I know.

VIVEK: To us it looks as though they are stuck on a "celestial sphere" which rotates around the Earth.

BRINDA: But it is the Earth that is moving!

VIVEK: Right. The important thing is that all the stars appear to move in step with each other. The planets on the other hand seem to follow paths of their own. That happens because they are closer to us.

BRINDA: Not because they are moving?

VIVEK: Actually, yes. The combination of their movement and closeness makes their motion as seen in the sky quite interesting. Do you know the names of the planets?

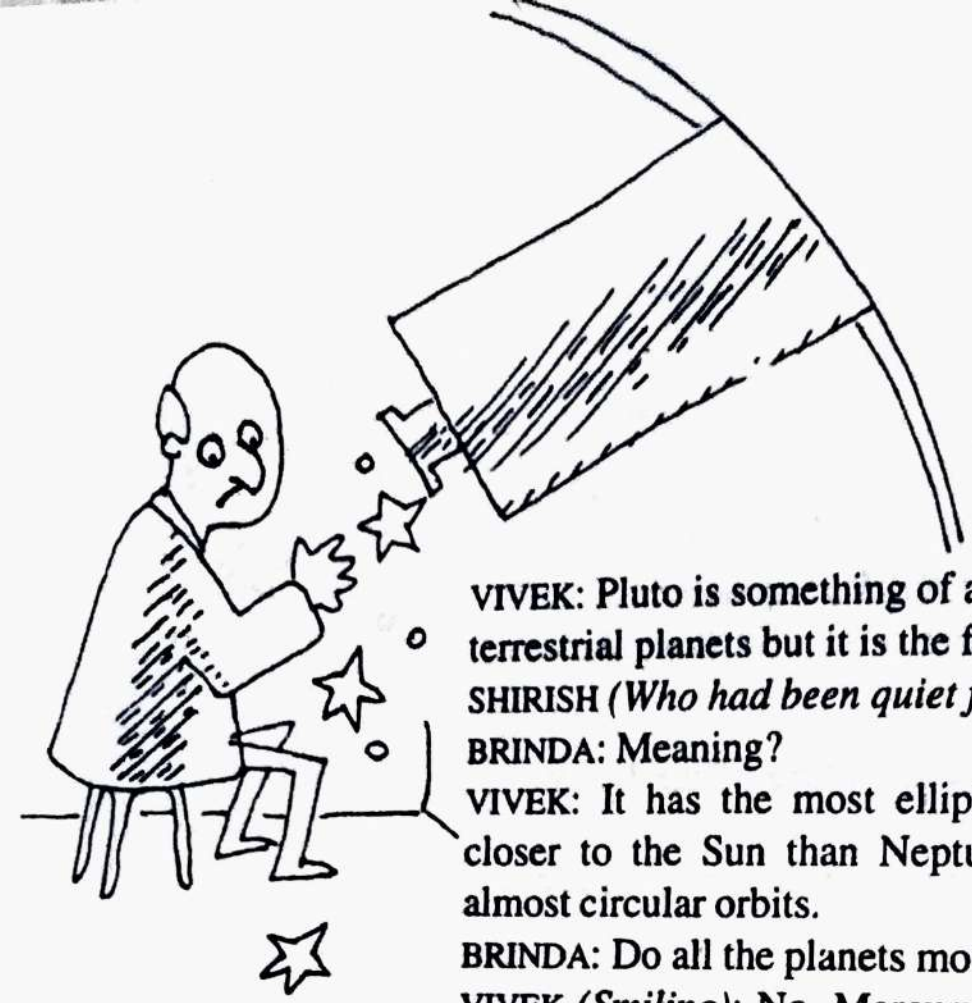
BRINDA: Yes. Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto.

VIVEK: That's right. The first four are bunched quite closely near the Sun and are called the *terrestrial* planets.

BRINDA: Terrestrial?

VIVEK: Because they are small, hard and rocky like the Earth. The next four are called Jovian planets. They are huge and gaseous like Jupiter.

BRINDA: And Pluto?



VIVEK: Pluto is something of an oddity! It is a little like the terrestrial planets but it is the farthest.

SHIRISH *(Who had been quiet for sometime)*: Not always.

BRINDA: Meaning?

VIVEK: It has the most elliptical orbit. Sometimes it is closer to the Sun than Neptune. All other planets have almost circular orbits.

BRINDA: Do all the planets move together?

VIVEK *(Smiling)*: No. Mercury takes only about 4 months to go round the Sun. As we move away from the Sun, the period of revolution increases. Jupiter takes about 12 years and Pluto takes about 248 years.

BRINDA *(Surprised)*: Oh, so long! So when can you see them?

VIVEK: It depends. There are two kinds of planets. Those closer to the Sun than our Earth, and those farther. Have you heard about the Morning Star?

BRINDA: Yes, and also the Evening Star.

VIVEK: In fact they are both the same.

SHIRISH: And not a star.

VIVEK: The names are used for Venus because it can be only seen in the evening or the morning.

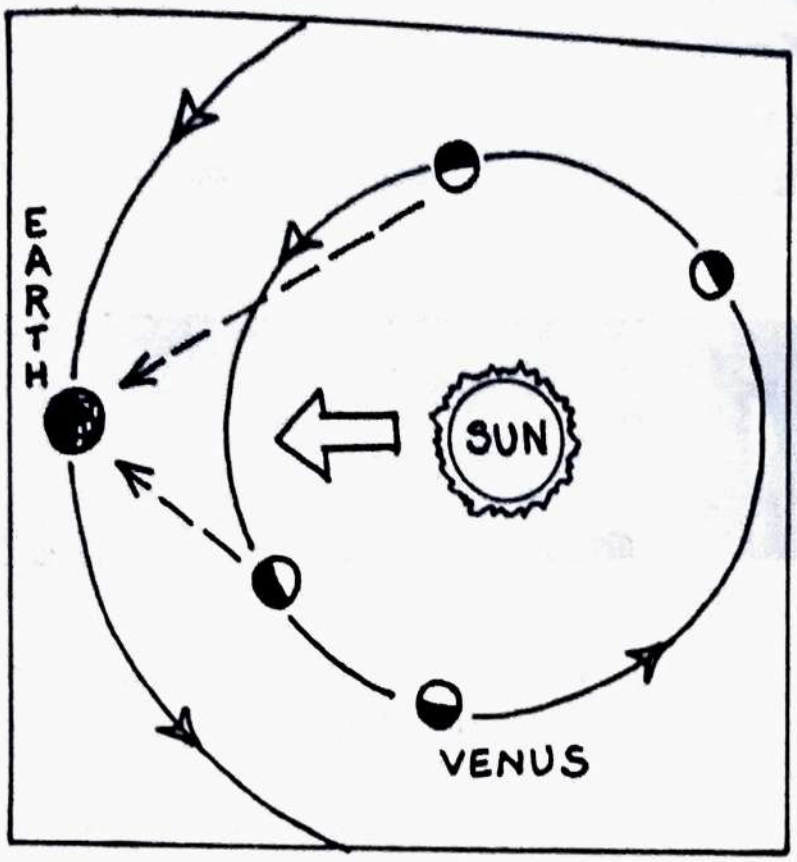
SHIRISH: But not both. And never in the middle of the night.

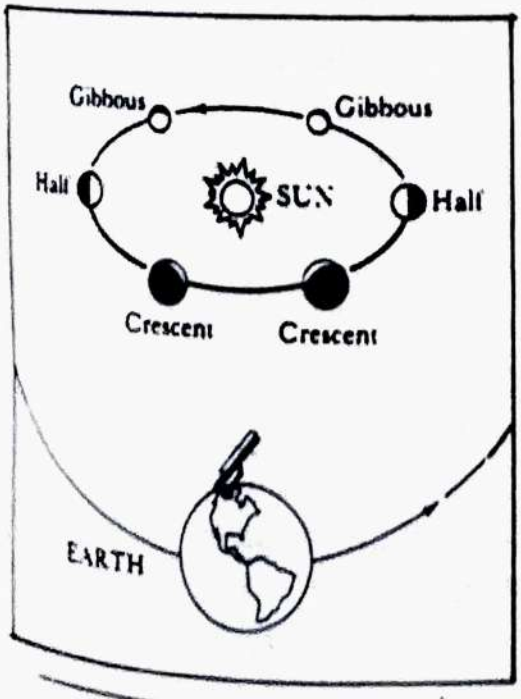
BRINDA: Really? Why is that?

VIVEK: Both Mercury and Venus, the inner planets, are like that. Look at the figure above. Their orbits lie inside the Earth's orbit. So wherever they are they will appear to be closer to the Sun. So you can only see them for a few hours after sunset or before sunrise.

BRINDA: Okay. So the Evening Star sets a little after the Sun..

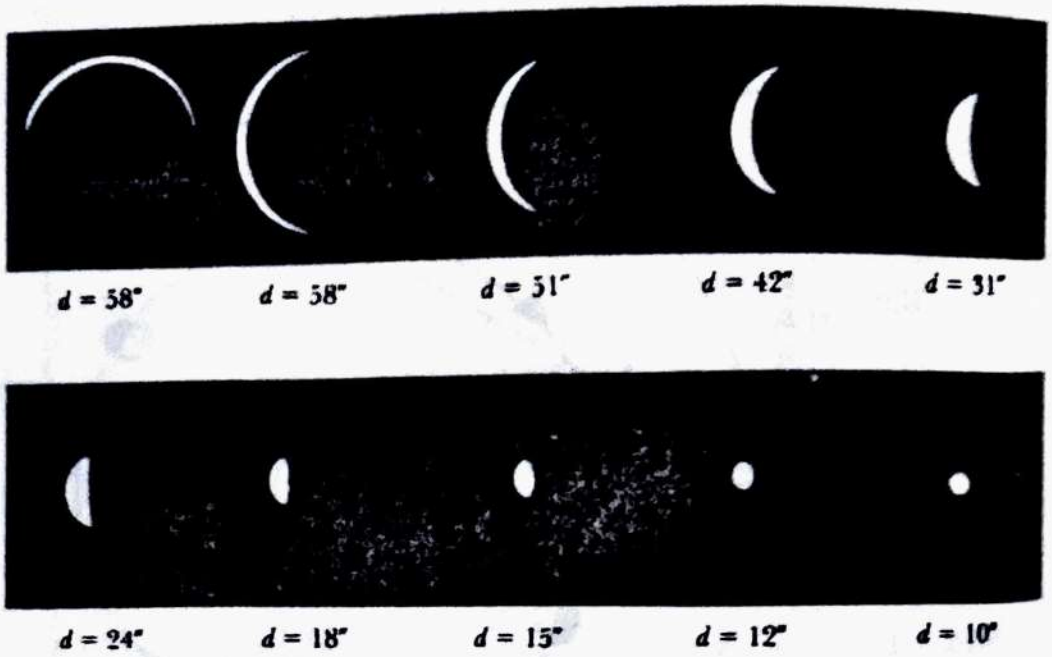
SHIRISH: Right. And the Morning Star rises a little before the Sun. It can be seen till the Sun begins shining.




VIVEK: If you watch through a telescope you can also see the "phases" of Venus. The next figure shows how it would look at different points.

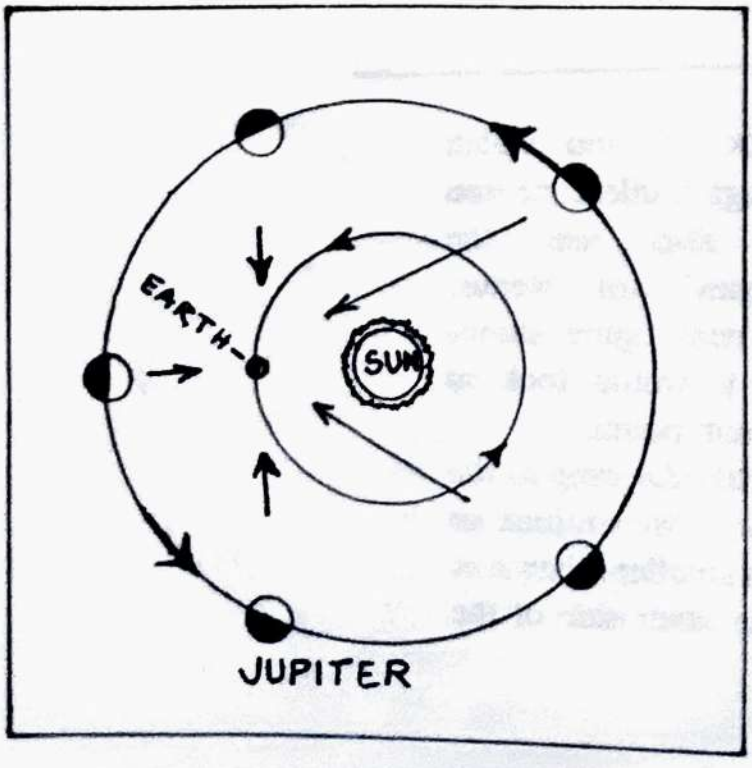
BRINDA *(Looking at the figure)*: Does it look so much smaller when it is on the other side of the Sun!




VIVEK: Yes! In fact this series of photographs taken through a telescope shows the phases and the size as seen from here. At the farthest point Venus is about six times smaller than when it is nearest.

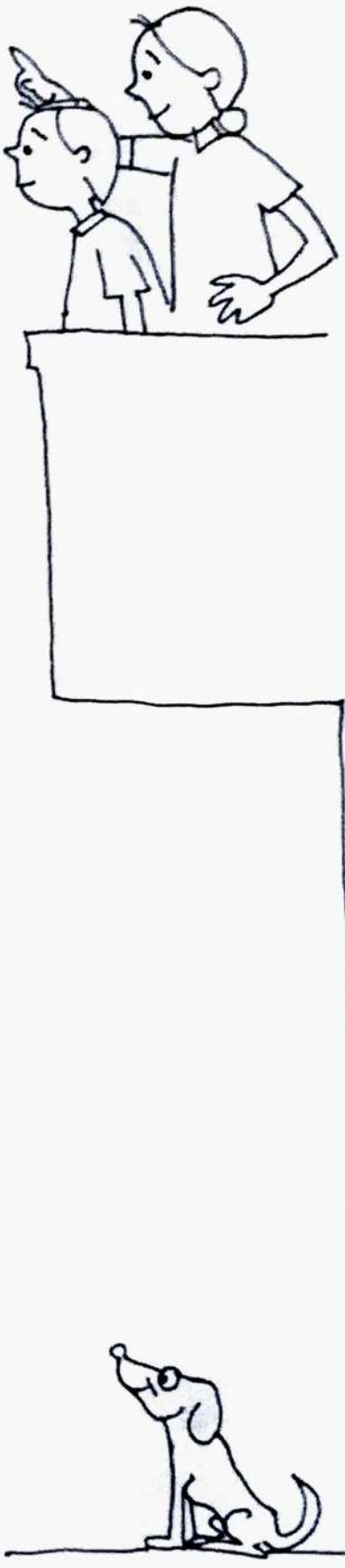
SHIRISH: But at the nearest point it is only a thin crescent. It is brightest when $d$ is about 40 arc seconds.

*Vivek then drew the diagram shown on the left.*




VIVEK: The rest of the planets, or the outer planets whose orbits lie outside the Earth's can be seen in any part of the sky.

SHIRISH: And therefore any time of the night.



VIVEK: True. Depends upon where the planet is.

BRINDA: But, Vivek uncle, why did you say that their movement is zig zag?

VIVEK *(After some thought)*: On any one day the planets also rise and set with the stars. But from day to day, the motion of the planet itself changes its position amongst the stars. We can notice this as the movement of the planet from constellation to constellation. But sometimes its motion can be quite dramatic. Let us take the example of Mars. It is about 1.5 times farther than the Earth from the Sun. And it takes about 1.9 years to go around. Okay?

BRINDA: So the Earth goes around faster!

VIVEK: Yes, now imagine both of them going around the Sun with Mars a little ahead...

BRINDA: ... and the Earth catching up.

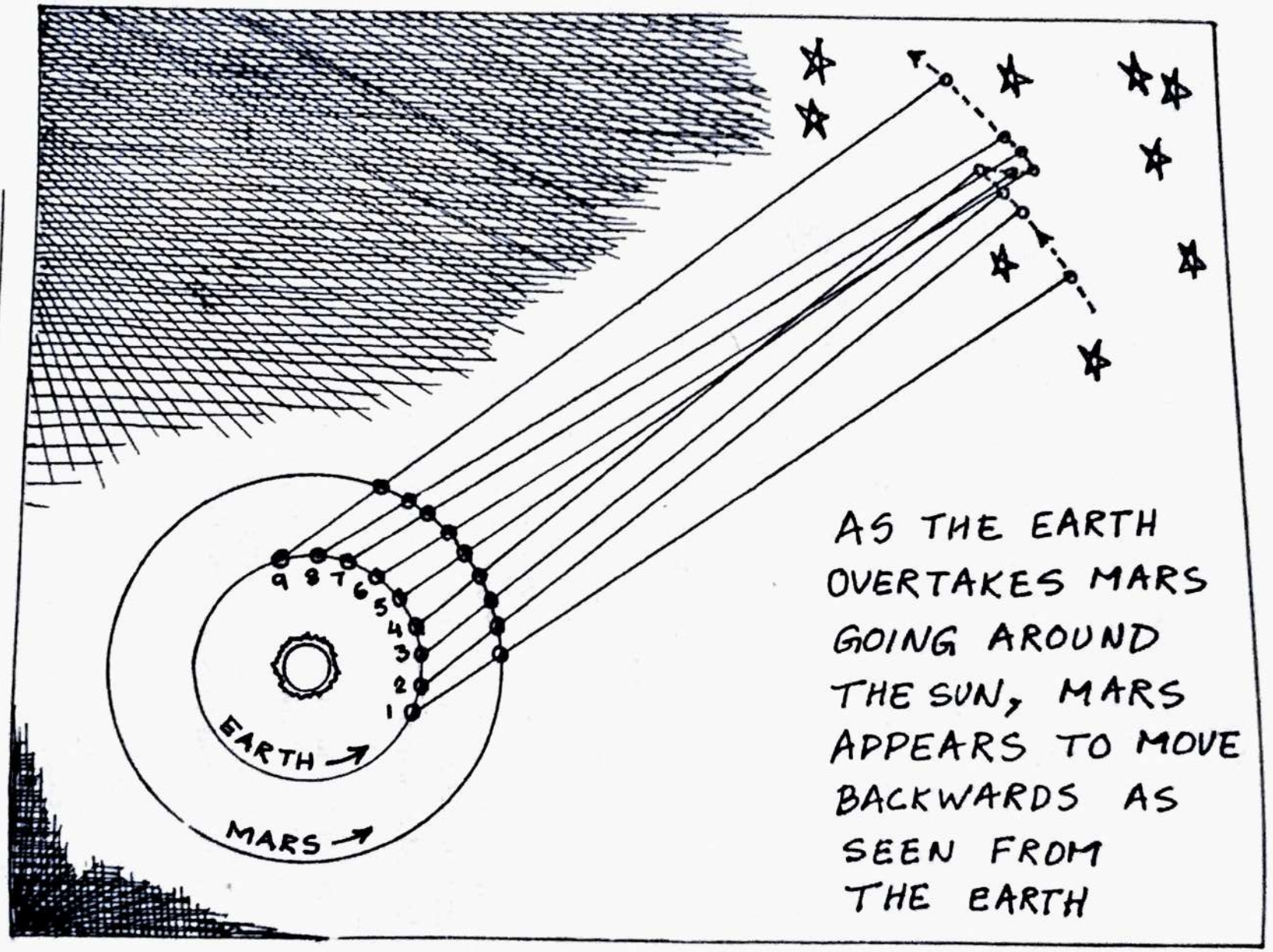
VIVEK: Look at the diagram on the next page. We will look at their positions as the Earth overtakes it and goes ahead. Let us start at point 1. Let us mark the position of both the Earth and Mars with 1. Then the line joining them shows where Mars will appear to be among the stars.

BRINDA: I see. So in this diagram you have drawn the stars as seen from the Earth?

VIVEK: Right! Now let us see the postion of both after a few weeks, at point 2. Drawing a similar line we can see that the position of Mars has shifted as seen against the stars.

BRINDA: Yes!

VIVEK: And so on ... you see that when we move from point 4 to 5 to 6, our Earth is overtaking Mars. During that period Mars *appears* to move backwards with respect to

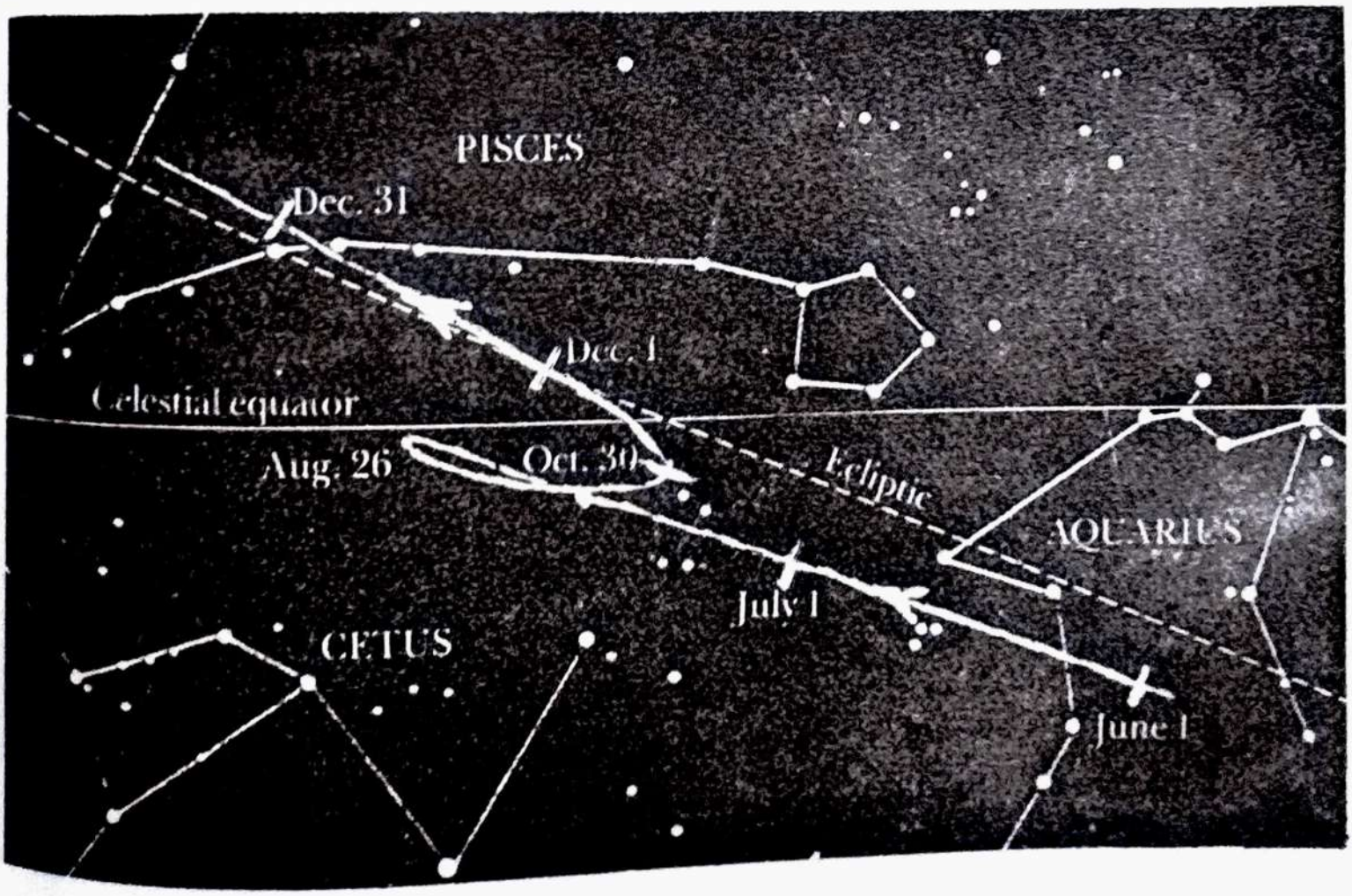

9
8
7
6
5
4
3
2
1
EARTH
MARS
AS THE EARTH OVERTAKES MARS GOING AROUND THE SUN, MARS APPEARS TO MOVE BACKWARDS AS SEEN FROM THE EARTH

the stars.

BRINDA: It is like when our train overtakes a truck on a road. It appears to move back against the distant trees!

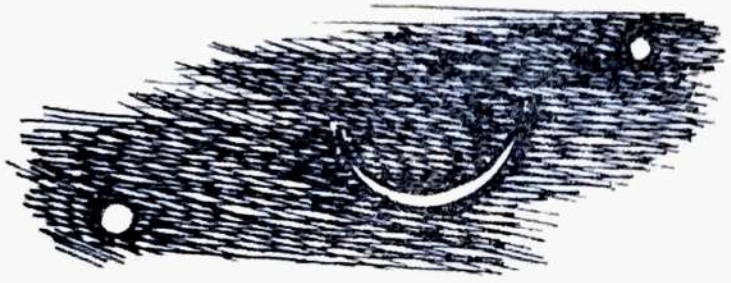
VIVEK: Brilliant! You have understood it perfectly. Then after point 6, Mars again appears to move forward. Look, this figure below shows the observed motion of Mars in the summer of 1988. From August 26 to October 30 it appeared to turn back towards Aquarius.

BRINDA: You know, last year on October 8th Shirish uncle



had shown me Venus, Moon and Jupiter close together like this.

*And she drew the following diagram.*



BRINDA: It looked so beautiful!

VIVEK: Aha! What a nice diagram you have drawn!

BRINDA: But I thought that the Moon should eclipse Jupiter and Mars then...

VIVEK: It does sometimes. The reason that it happens rarely is that all of these are very slightly removed from the ecliptic. Remember, the Moon's orbit is inclined by about 5°? That of Venus is about 3°, and Jupiter about 1°. So they don't always align. I think the planetarium is having a show on planets. Maybe tomorrow we can all go...

BRINDA: Hurray! Can I call Rahul also?

VIVEK: Sure!

-oOo-