Sun-Earth Experiments

Activity Cards
for
Day Time Astronomy

Developed and Written By

Dr. Vivek Monteiro
Geeta Mahashabde
Priyanvada Barbhai

Navnirmiti

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Sun-Earth Experiments : Activity Cards for Day Time Astronomy

Contact of Authors : vivekmonteiro@yahoo.com
geeta_uam@yahoo.com
priyanvada@gmail.com

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Navnirmiti
'Discover it ! '
3rd Floor, Priyadarshani Bldg.,
Padmavati Road, Opp. IIT Market Gate,
Powai, Mumbai - 400 076.
(022) 2578 6520 Telefax : 25773215
navnirmiti@yahoo.com

Navnirmiti, Pune
Gunavatta, 654 B, Shanivar Peth,
Ramanbag Chowk,
Next to Axis Bank, Pune - 411030
(020) 2544 2794 / 2447 1040
navnirmitipune@yahoo.com

www.navnirmiti.org
www.sunderstanding.net

1. EXPERIMENTS WITH A MAGIC MIRROR

1.1 Reflections with a mirror

Hold a small mirror in sunlight so that you can cast reflections with it.
Try to cast reflections at different places.
Can you get such reflections at night with a light bulb or tubelight as light source?

1.2 Make a Magic Mirror

Take three small mirrors with different shapes : round, square, triangle.
What if you have just have just a single mirror? How can you get different shaped mirrors with a single mirror?

Simple ! cover the mirror with a paper mask with the desired shaped hole cut in

1.3 Magic Mirror Experiment :

Hold the circular mirror outside in the sun. Reflect the sun light on your friend's shirt. What is the shape of the image on your friend's shirt? Repeat the experiment with the square and the triangular mirror.

We get a square shaped reflection with a square mirror, a triangular reflection with a triangular mirror .....

..... and circular with a circular mirror.

1.4 Now cast the reflections with all these mirrors on a distant wall (about 20 metres away) What do you see?

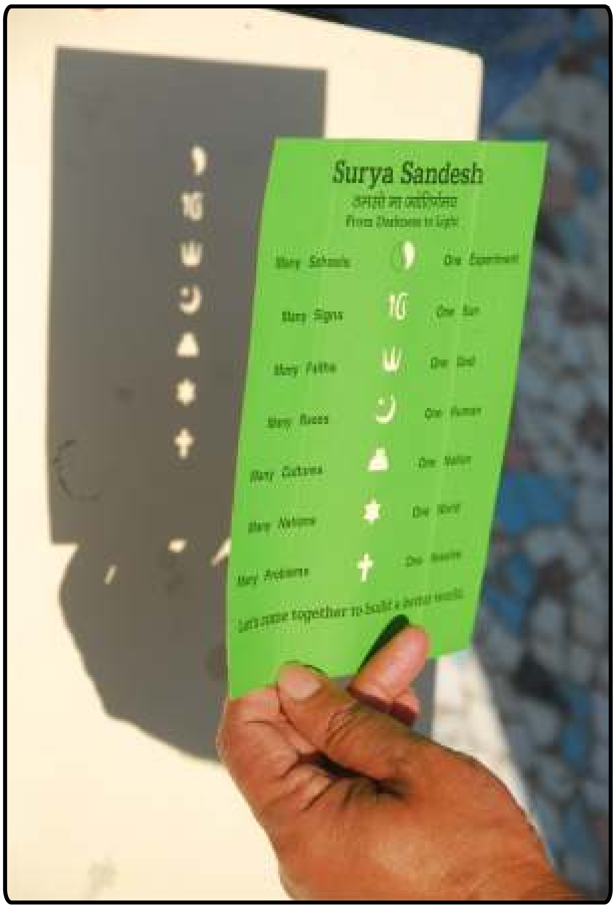
What are the shapes of reflections when you take projections over a long distance?

The image at a far distance is round even if the mirror is square or triangular.

WHY?

The answer to this question is in Activity cards 2, 3 and 4.
Use mirrors of various shapes to verify this.
You can study how the triangular image, nearby, becomes a circle as the distance is increased.

2. SUNCARD



2.1

Hold the Surya Sandesh Sun card close to the ground, in the sunlight. Examine the shadow cast by the card. You will see the various signs on the card projected on the ground.

Now slowly raise the card towards the sun as high as possible.

The different signs all become the same. They all become circles of light, circles of our broadening understanding. As you go higher and higher, the circles touch each other, an expression of unity, of coming together, of our essential oneness as human beings, as citizens of secular India and as citizens of planet earth.

WHY?

This is not a miracle, but a scientific phenomenon. The circles of light that you see are all images of the sun.
Therefore the poem on card has 'Many Signs, One Sun'.
They are round because the sun is round.

This effect is known as pinhole projection or pinhole camera.

3. PINHOLE PROJECTORS IN NATURE : TREE SHADE SOLAR TELESCOPE

Have you noticed, that on a sunny day, in the cool shade of a tree, you see, here and there, some bright discs on the ground?

These bright discs are images of a bright object in the sky. The images are formed due to 'the pinhole camera' effect.

To understand this, do the following experiment :

Take a card, about the size of a post card, and punch a small hole (about 5 mm in diameter) at its centre, as in the figure. There is one such card in the Terra Sun lab kit.

With this simple device you can get images of bright objects in a dark room. (Note : The small hole punched is what we call the "pinhole". In this case it is much thicker than a pin !)

3.1 Imaging a tubelight

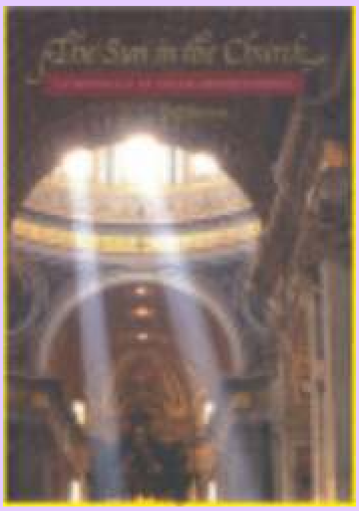
At night, when it is dark, keep only one tubelight 'on', and switch off all other lights. Stand near a wall which is most distant from the tubelight and hold the card with the hole about 15 cm from the wall. You will see the blurred image of the tube light on the wall inside the shadow of the card.

3.2
Repeat the experiment with a single bright open window as the object in an otherwise dark room. You will see that the blurred image of the window is upside down.

3.3
Now we can understand those round discs of light which we see in the dark shade of the tree : They are the images of the round sun with the spaces between the leaves acting as the pinholes. As the wind shakes the leaves, the circles disappear at one place and appear elsewhere.

3.4
In tall buildings with high roofs like railway stations, we can see the round image of the sun formed on the floor when sunshine streams in through a small hole in the roof.

3.5
The first solar telescopes were just these pinhole cameras in structures with high roofs , dark inside, with a small hole in the roof, and the image taken on the floor. There is one such pinhole projector chamber at the Jantar Mantar in Delhi. In Europe, especially in Italy, such 'telescopes' exist in churches.



4. BALL AND MIRROR SOLAR PROJECTOR

As we saw in the magic mirror experiments (card no.1), the reflection image of the sun by a plane mirror from a far distance is round even if the mirror is of any shape. WHY ?
Because this is an image of the Sun!
The image is round because the Sun is round!

It is difficult to hold the image steady when the mirror is held in your hand.
How to get a steady image? We need to fix the mirror on a stable mount. We need to be able to easily adjust the position of the image. How to achieve this?

4.1
Take a medium size plastic ball.
- Make a small hole and fill it with sand.
- Stick your mirror to the ball.
- Keep the ball on a ring.

You have made a low-cost, long-lasting, powerful sun projector!

The Ball & Mirror Solar Projector is by far the simplest method to project the sun's image, which works because the sunlight intensity is so strong.

4.2

Place the ball and mirror on a stool outside the room in the sunshine. Adjust the angle of the mirror so that it projects the sun into the darkroom on a white screen . Increase the distance of the mirror from the screen to around 30-40 metres. At this distance you will get a nice big image of the sun around 35 cm in diameter.

5. MAKE A PORTABLE DARKROOM

To get as clear and sharp an image as possible with your mirror and ball mount projector, the image should be taken in a room which is as dark as possible.

Here is how you can make a 'darkroom' which can be taken anywhere- a portable darkroom.

5.1 Take a large cardboard carton, like the carton of a TV set.

5.2 On one inside wall paste a sheet of white paper. This is your screen.

5.3 On the opposite side cut a circular hole which is about 30 - 40 cm in diameter. The rays of light will enter from this hole and fall on the screen.

5.4 Now seal the carton on all sides with tape, so that except for the hole there is no other opening for light to enter.

5.5. Now you have a portable darkroom. On one inside of the cube you have a screen. On the opposite side you have a hole for light to enter. There are four remaining side of the cube. On one of these sides with a knife cut a small flap which you can open and close as a window to observe the screen.

5.6 Your portable darkroom is ready for use. You can keep it on a stool anywhere and use it for public programmes in a playground or open space.

5.7. Improving the darkness : The darkness can be improved by the following method. Take another carton which is the same size as your darkroom carton. Seal it on all sides. Now cut holes on two opposite sides the same size and position as the hole cut for making the portable darkroom.. This 'two-hole' box can be placed directly in front of the aperture of the darkroom, touching it, so that all three holes are in a straight line. This will cut off more outside light and improve the darkness at the screen.

6. MAKE AND USE A TELESCOPING DISTANCE FINDER

6.1 Making the telescopic Distance Finder :

a.

Using two pieces of mount board to make two triangular shaped tubes such that one fits into the other telescopically. The fit should be smooth : not too loose and not too tight. If the inner tube is too loose add a few layers of PVC tape on the edges until you get a smooth fit. The side of the triangle should be around 10 cm to 11 cm.

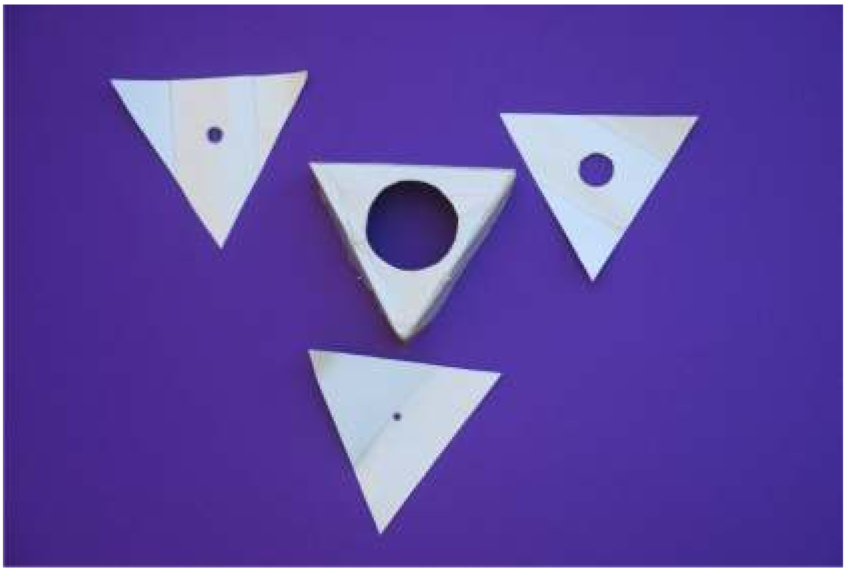
b.

Take a frooty pack and open it up , wash and dry it. Make a triangular cap like in the photograph, which fits onto the front of telescoping tube and can be fixed in place with a rubber band.

c.
In the centre of the frooty pack cap cut a circular hole of diameter 55 mm. This cap can now be used to keep in place different lenses, or different apertures, (each set in its triangular holder.)

d.
Make 4 triangular shapes out of frooty pack sheets which fit nicely into the cap, not too loose and not too tight.

e.
In one such triangular shape punch a hole of diameter 10 mm at the centre like in the photograph. In the other 3 triangular shapes punch holes of diameter 20mm, 5mm, 3 mm respectively. Now you have made a set of four apertures of 20mm, 10mm, 5mm and 3 mm.



f.
Fit one aperture to the front of your telescoping tube with the cap and rubber band.

Your telescopic distance finder is ready to use.

6.2 using your telescopic distance finder (TDF)

a.
Take a plastic ball and measure its diameter (say you obtain 140 mm). Keep it at eye-height at some distance from you.

b.
Fix a 10 mm aperture on your TDF and look at the ball through the TDF from the other end. Adjust the length of the TDF such that when you look from the eyepiece end of the TDF through the aperture, the plastic ball exactly fits into the aperture. Measure the distance from the aperture to your eye. Lets say this is 's'.

c.
Now you can calculate the distance 'd' from your eye to the ball as follows :

(Diameter of ball / Distance of ball)
= (Diameter of aperture / Distance of aperture)

140 mm/ d = 10mm/ s

i.e. d = s x (140mm/10mm).
Since we know s, we can calculate d.
Having calculated d, now actually measure it with your measuring tape, and see how accurate your calculation is.

Please note : The two results will be only approximately and not exactly equal.

6.3 Measuring the length of a playground :
Measure the height of your friend. Ask him/her to go to the other end of the playground and stand there. Use your TDF to look at him /her. Experiment with different apertures and adjust different lengths until your friend exactly appears to fit into the aperture as you look through it. Measure the length s of your TDF. Calculate the length of the playground and then actually measure it and see how accurate you have been.

7. USING THE TELESCOPIC DISTANCE FINDER (TDF) TO FIND THE RATIO OF SUN'S SIZE TO ITS DISTANCE FROM US.

7.1 You can use your TDF (card no. 6) to take a sighting on the sun, by fitting a solar filter on the aperture, or by wearing a solar filter to protect your eye. Never look at the sun (except just at sunrise or sunset) without protecting your eyes with a scientifically designed solar filter. Use a 5 mm aperture. Notice that when the sun exactly fits into the 5 mm aperture, the length of the TDF is again around 55 cm.

BUT THE SUN IS JUST A DISTANT BALL.

7.2
We can now calculate the ratio of the sun's diameter to its distance from us. (See activity 6.2)

Diameter of sun / Distance of sun

= diameter of aperture / distance of aperture from eye

= diameter of aperture / length of distance meter

= (0.5) / 55

= 1 / 110

This tells us that the sun is 110 times as far from us as it is wide.

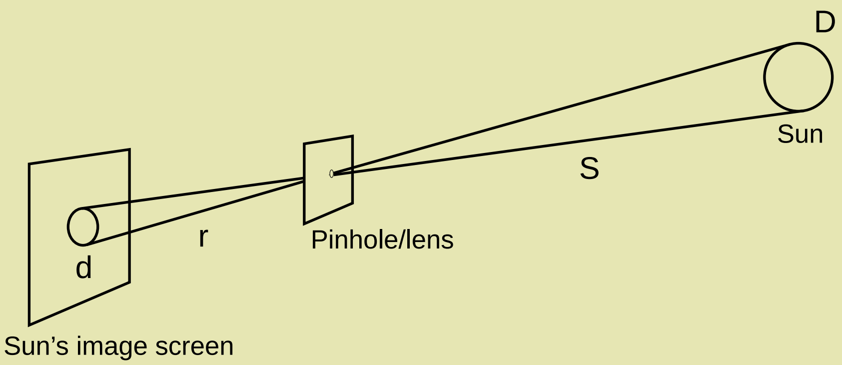
7.3

You can also do this experiment by holding a punched care (with a 5 mm aperture), covered with a solar filter, in your hand. Fit the sun exactly into the aperture by adjusting the distance between your eye and the sun. Measure the distance from the aperture to your eye when the sun exactly fits.

8.1

Using an opaque card with a hole at its centre as a pinhole projector, project the sun's image on the ground.

Measure the distance 'r' of the image from the pinhole . Measure the diameter 'd' of the image disc. (See fig) .Divide r by d. What is r/d ?



8.2

Increase the distance r between the pinhole and the ground. Measure it. The size of the image will increase. Again measure 'd' the diameter of the image disc. Calculate r/d.

Repeat the experiment for different 'r'. Measure and calculate r/d in each case. The result will always be around 100.

8.3

Project the sun with a convex lens, and bring the image into focus. Measure r and d. (In this case r= focal length of the lens). Calculate r/d. Again you will get a number close to 100.

8.4

Project the sun with the ball and mirror projector. Measure 'r' the distance from the mirror to the image, and 'd' the image diameter. Calculate r/d for different distances. The result will always be around 100. In fact if you do the measurements accurately the answer will be always close to 110.

Pinhole projector, convex lens, or ball and mirror- the result is always close to 110 ?

Why ?

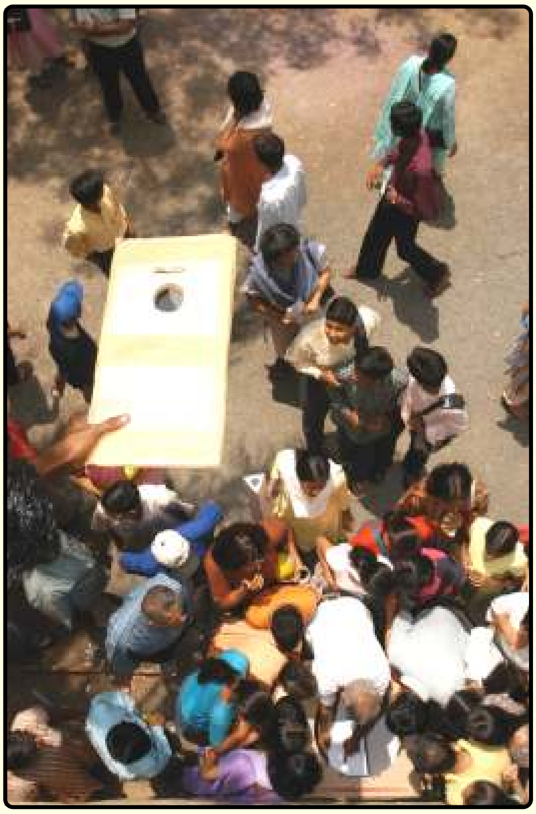
Because the sun is 110 times as far as it is wide.

Very Long Focal Length Lens :

It is commonly believed that a convex lens concentrates the light from the Sun. This however is true only if the focal length is small. As the focal length of the lens increases the size of the Sun's image increases. The relation is the same as for a pinhole projector.

Diameter of Sun's image = focal length of lens / 110.

For a very long focal length (VLFL), the diameter of the Sun's image can be quite large, larger than the lens itself. Navnirmiti has developed VLFL lenses with focal lengths of 4 metres and 10 metres. The second lens gives a large image of the sun more than 9 cm in diameter.



VLFL LENS WITH BALL MIRROR PROJECTION

We saw in activity card no. 9 that we can project a large image of the sun with a Very Long Focal Length convex lens. To get a sharp image of the sun on a screen, the distance between the screen and the lens will have to be equal to the focal length of the lens.

To obtain a sharply focussed image of the sun on the ground with a 10 metre focal length VLFL we will have to hold the lens on the terrace of a three storied building. This is not always possible, or convenient. A terrace which is at the correct height when the sun is overhead at noon, may not be suitable at 9 AM or 3 PM.

The mirror with ball mount gives us a simple way to project the sun with a VLFL lens anywhere and at anytime. It can give us the sun in a 'horizontal' position no matter where the sun is up in the sky.

10.1

Take an image of the sun on the screen with the mirror and ball first. Then hold the VLFL lens in front of the mirror such that the rays of light leaving the mirror pass through the lens. Move the screen till you get a sharp image.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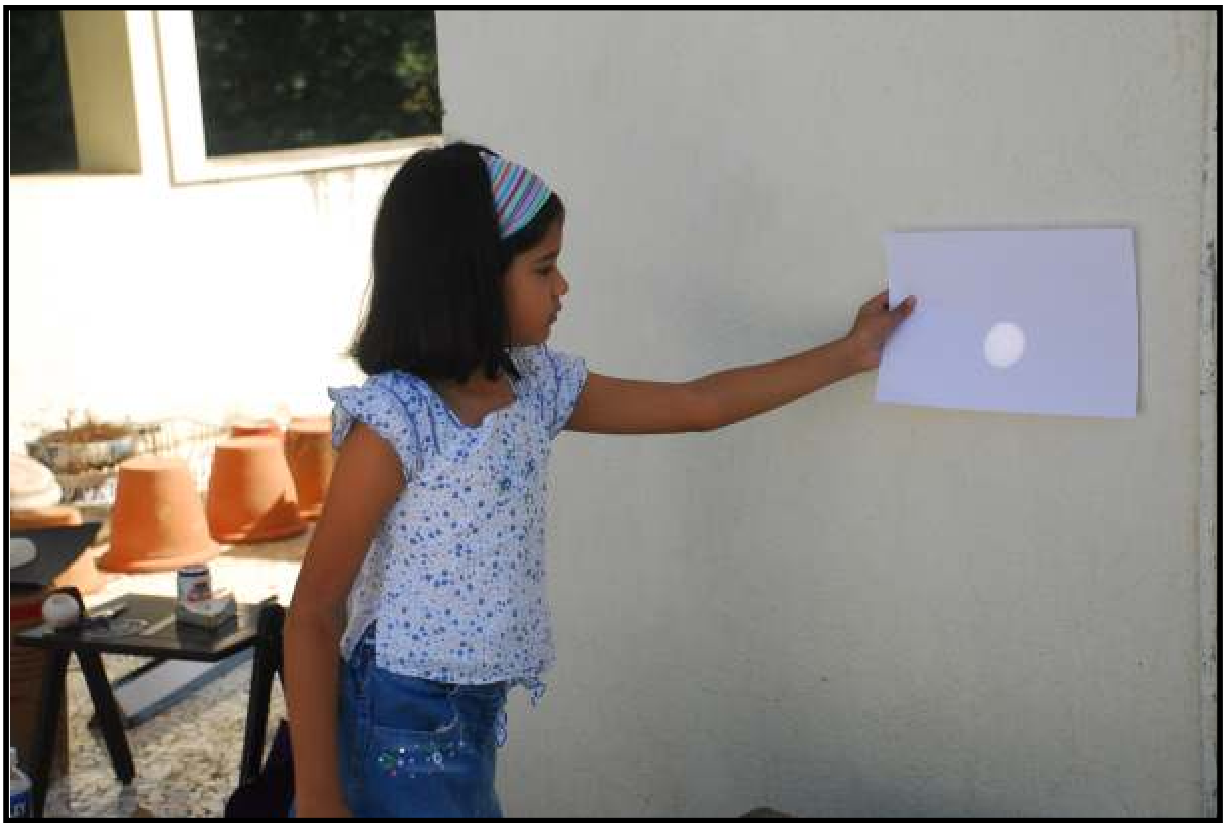
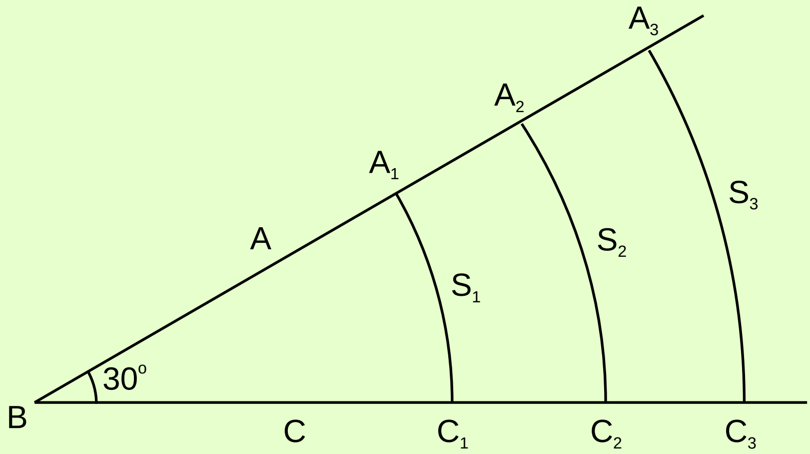


ANGLE AS RATIO OF ARC LENGTH TO RADIUS

11.1
Draw an angle ∠ ABC of 30°, as in the figure. Extend BA and BC as far as possible, on your sheet of paper.



With B as centre, use a compass to draw three arcs : S_1, S_2, and S_3.

11.2
Call the points where S_1 intersects BA as A_1, and where S_1 intersects BC as C_1.
Similarly, we have A_2 and C_2 as the points where S_2 intersects BA and BC.
We have similarly the points A_3, C_3 on S_3.

11.3

Measure with a string the arc length between A_1 and C_1. Call it x_1.
Measure with a scale the radius r_1 (the length of BA_1)

Similarly measure x_2, the arc length between A_2 and C_2. Measure r_2 = length of BA_2.

Measure x_3 and r_3.

11.4

Using a calculator, divide x_1 by r_1.
Divide x_2 by r_2.

Divide x_3 by r_3.

What do you notice ? (All three answers should be nearly the same)

Call this answer as 'ratio for 30° ' or ratio(30°)

11.5

Draw an angle of 60 degrees and repeat the same set of activities as in 11.1, 11.2, 11.3 and 11.4
i.e draw three arcs,
measure the arc lengths,
measure the radius for each arc length
Calculate the ratio by dividing arc length by radius.

What do you notice ?

You should get the same answers for all three ratios.
Call this answer as ratio (60°)

11.6

As in the above draw an angle of 90° and measure and calculate 'Ratio(90°)'

11.7

Compare ratio (30°), ratio(60°), ratio(90°).
If you have done all the above activities correctly, you should get

Ratio(30°) = 0.52
Ratio(60°) = 1.05
Ratio(90°) = 1.57

Notice that when you double the angle measure from 30° to 60°, you double the ratio 0.52 to 1.05. When you triple the angle, you triple the ratio.

11.8

What is the ratio for 360° ?

Now the arc length corresponding to 360° for radius r is just 2 x π x r i.e. 2πr.
So the ratio of arc length to radius is just 2 times p i.e. 6.28

11.9

So from the previous activities, we notice that when the angle increases, the ratio increases in the same proportion.

Secondly for any angle, this ratio is fixed.

Thirdly, if a ratio is given, there is only one angle for which this is the ratio. Equal angles have equal ratios.

We can therefore use the (arclength/radius) ratio as a measure of the angle.
This way of measuring angles is called the radian (another word for ratio) measure of the angle.

What is the radian (ratio) measure of 360° ?

What is the radian (ratio) measure of 180° ?

What is the radian (ratio) measure of 90° ?

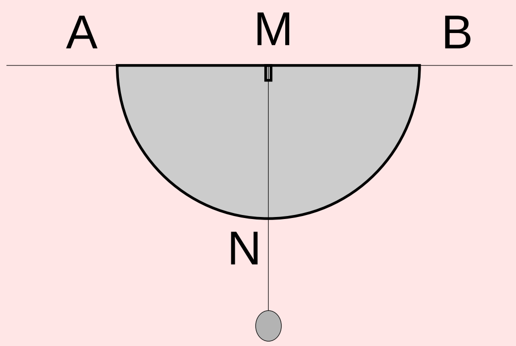
ANGLE DANGLE METER

Can you measure the angle made by the Pole Star with the horizontal ? Can you measure the angle of Venus or any other planet? Here is an instrument you can make it yourself, to measure the angles of celestial objects or of high places.

We call this instrument as an "Angle-Dangle Meter".

Because

- it helps us measure the angle
- it has a dangling pointer.



12.1

It is really quite easy to make an angle dangle meter.

You will need a stiff and flat piece of cardboard, or thin plywood, a piece of thin string and two small stones which act as weights at the two ends of the string.

- Take a piece of string about a metre long.
- Tie the two small stones, one at each end.
- Take the rectangular piece of stiff cardboard.
- Make a small notch at the middle of its upper edge.
- Hang the string from the notch so that the stones dangle, one on each side of the card.
- When the upper edge AB is parallel to the ground (i.e., when it is in horizontal position), the string and stones will dangle exactly along NM, the vertical.

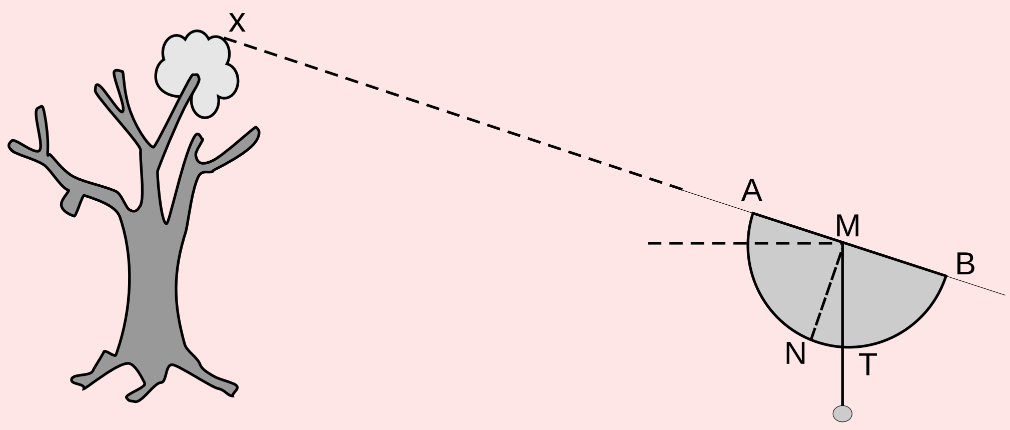
Using M as centre, draw a large semicircle on the cardboard with AB as diameter. The angle AMN and angle BMN are both 90 degrees. Divide the arc AN into 90 parts, each of 1 degree, using a protractor. Also divide the arc BN into 90 parts each of 1 degree.

Your angle dangle meter is ready to use.

12.2

Measure the angle of an object, let's say, a top of a tall tree.

a. Refer to the figure, keep your eye near Point B.
b. Hold the angle-dangle meter such that A, B and the top of the tree are in straight line.
c. Now, measure the angle NMT, by reading where the string cuts the arc BN.
d. This is the angle of the tree top with the horizontal.



12.3

Now, measure the angles for other interesting objects like the Pole star, Venus, a hill-top temple, tower etc.

12.3

To get an accurate measurement we need a stable mount for the angle dangle meter.

- Take a medium size earthen pot (Matka)
- Fill it with sand.
- Paste your angle-dangle meter to a flat wooden stick.
- Insert the stick into the sand in the Matka and pack it so that the stick does not move in the matka.
- Place the Matka on a ring base.
- Now, you can move the Matka to fix and then measure the angle.

13. THE EARTH IS ROUND

We learn in school that the earth is round. It is a large sphere hanging in space without anything attached, (like a balloon hangs in air, without anything attached).

How can we imagine this? Look at the moon. We can see (especially with the help of binoculars, or a telescope) that it is a sphere hanging in space. If we could go to the moon and stand on the moon looking at the earth, this is how earth would look:

A long time ago, people believed the earth was flat. It does look flat! They also thought that if someone was to go away off to the horizon, he (or she) would fall off the end of it.

Nobody knows who first discovered that the Earth is round and not flat.

We can experience the roundness of the earth by carrying out some experiments:

13.1

a. Go to a beach on the east coast well before sunrise alongwith a friend. Each one of you should carry a watch. Synchronise both the watches.
b. One of you should stand at the water edge and look ahead of you towards the horizon. The other should stand on the terrace of a nearby tall building and look towards horizon.
c. Clock the exact time when each of you sees the sunrise.
d. You will notice that the person on the building top will see the sunrise earlier than the one on the beach below.
e. In fact, you will also notice that clouds in the sky will become pink much before you see the sunrise. Why does this happen? That's because the cloud is higher in the sky and will get to 'see' the sunrise before you!

13.2

If Earth was flat, the cloud, the person on the terrace and the person on the beach would have seen the sunrise at exactly the same time. But, since the earth is round, people at different heights see the Sunrise at different times.

13.3

You can do a similar experiment at the time of sunset on a beach on the west coast. What did you observe? Who sees the tip of setting Sun last? Is it the person on the beach or on the terrace?

13.4

There is another interesting experiment you can do. For this, you will need a friend in an Eastern part of India (let's say Bhubaneshwar) and you can be at a Western part (Mumbai). Synchronise your watches and record the exact time when each one of you saw sunrise/ sunset.

You will notice that the sun rises and sets earlier in the east than in the west.

Why?

14. THE EARTH'S ROTATION

The sun rises and sets everyday. The moon and the stars also rise and set. The sky appears to revolve around us, along with all its heavenly objects like the sun, moon, planets and stars.

Many centuries ago, our ancestors discovered that the earth is a globe. We live on the surface of a large ball. (Activity card 13)

If the large ball was not still, but rotated, the skies would also appear to revolve to the people living on the ball, i.e. to us. (Even if the earth was not a ball, but in the shape of a cube, or any other shape, its rotation would make the sky appear to rotate).

We can experience this by the following experiment :

14.1

Make a large circle on the floor, say with radius 2 metres. You stand at the centre. Your friend stands on the circumference.
First, you stay fixed without moving. Ask your friend to start walking around you on the circumference of the circle. He will appear to 'revolve' around you. Lets say, your left is 'east', and your right is 'west'. Ask your friend to walk from your left to your right, along the circumference, to move from east to west. When he is in front of you, you will see him. When he is behind you, for half the time, you will not see him. Now imagine that your friend is the sun, and 'front' is 'up', and 'back' is 'down'.
Your friend, the sun, rises in the east, and sets in the west.
Half the time, you can see him, and it is day.Half the time it is night.

14.2

Next, ask your friend to stay still, without moving. Now you rotate yourself , without moving away from the centre of the circle. When you rotate from right to left, your friend will again rise in the east(your left) and set in the west. Half the time there will be day, and half the time night.

Is the sky revolving around us? Or is the sky stationary, only appearing to revolve, because we are on a rotating large ball ?

14.3
Around 350 BC, three ancient greek astronomers, Heraclides, Hicetas and Ecphantus, proposed that the earth rotates and this is why the sky appears to revolve around us. But this view was not accepted by the ruling scholars of the time, by Aristotle or Ptolemy, who maintained that the earth was the centre of the universe, and everything else revolved around it.

14.4
India's greatest ancient astronomer Aryabhatta 1 also maintained that the earth rotated, in the 5^{th} century AD.

In Aryabhatiyam he writes “Just as a man in a boat moving forward sees the stationary objects (on either side of the river) as moving backward, just so are the stationary stars seen by the people at Lanka (i.e. on the Equator) as moving exactly towards the west.”

Today all of us learn that we live on a rotating earth. But not until Copernicus and Galileo, was the view of a rotating earth accepted by everyone. For almost two thousand years, everyone, except a few people like Heraclides in Greece and Aryabhatta in Ancient India, believed that things are what we see. It took great courage and the sacrifice of people like Bruno to assert that things are not always what we see. What is in the sacred books may not be true. To arrive at truth we have to go beyond appearances.

15. LOOKING AT DHRUV TARA

15.1

Fix a straight thin tube along AB on your angle dangle meter (card no.12) . You should be able to see right through the tube at far away objects like stars.

15. 2.

At night, go out into the open and place your instrument on a high stool on its ring mount. Using it like a telescope, or like a rifle barrel, look through the tube and take aim on any star.

15.3

After fifteen minutes, look through the tube again without moving the ball. Now you cannot see the star. Why?

15.4

Look towards the north and identify the pole star (Dhruva tara) in the sky. Point your instrument to Dhruva tara when you look through the tube. After 15 minutes again look through the tube without moving the ball on its mount. You can still see Dhruva tara.

15.5

Even if you look through the tube after one hour, after two hours, after three days or three weeks, without moving your ball on its mount, you will always see Dhruva tara.

This is because Dhruv tara does not move in the sky at all. (In fact it moves just a little bit, which you can hardly see, but you might be able to observe this movement with a very thin tube.

15.6

All the stars and planets move in the sky except Dhruva tara. Why does Dhruva tara always remain fixed ? This is because the earth's axis, like the axis of a spinning top, always points in a fixed direction, and Dhruva tara happens to be in that direction. Secondly, because Dhruva tara is very very far away, so that even if the earth moves round the sun, that movement is very small compared to the distance of the sun and earth from Dhruva tara.

HOW MANY MINUTES IN ONE DAY?
MEASURING THE EARTHS RATE OF ROTATION.

All of us know that the earth rotates around itself once in a day. Now lets measure for ourselves, how many minutes there are in one day.

16.1
Let us see for ourselves the earth's rotation. Use a ball and mirror projector (card no. 4) to project the image of the sun on a wall at a distance of approximately 30 metres .

16.2
You will see that the suns image is not fixed, but moves. At thirty metres it will move almost 13 cm in one minute.

16.3
Measure as accurately as possible how much the image moves in one minute.

16.4
Measure as accurately as possible the radius of the circle in which the image is moving (this is the distance between the mirror and the wall- assuming that the wall is perpendicular to the rays of light coming from the mirror).

16.5
Calculate the circumference of the circle, which has the radius you have measured. We know how much the image moves in one minute.

16.6
Calculate how many minutes it would take to traverse the full circle.

Do you get an answer close to 1440 minutes ? Why ?

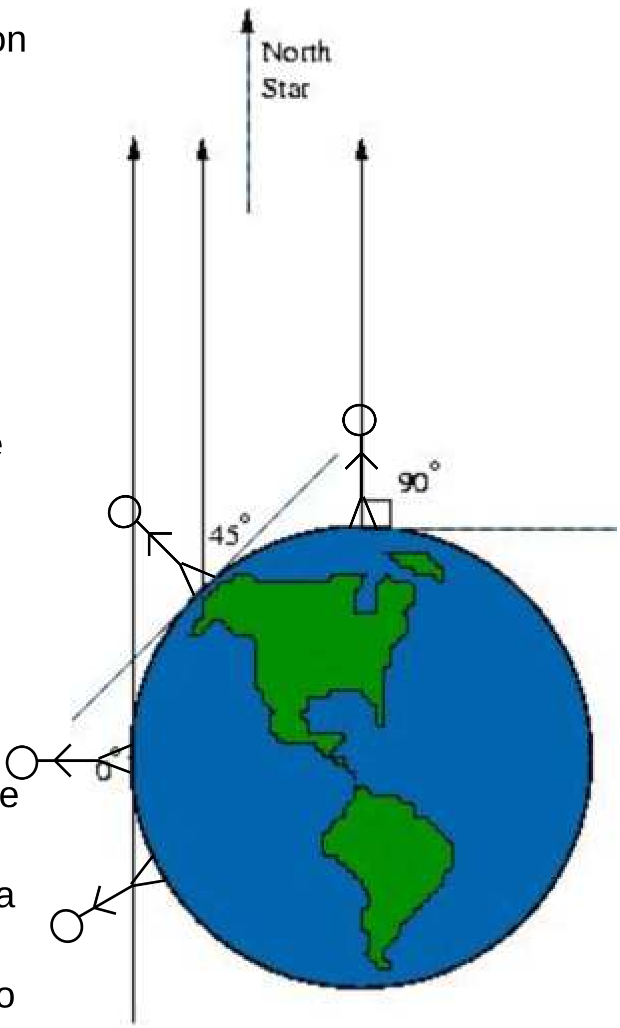
17. THE ANGLE OF LATITUDE

17.1 The angle made by Dhruv tara :

We can understand that we are standing on the curved surface of the earth by measuring the angle made by Dhruv tara above the horizon with your angle meter (card no. 12).

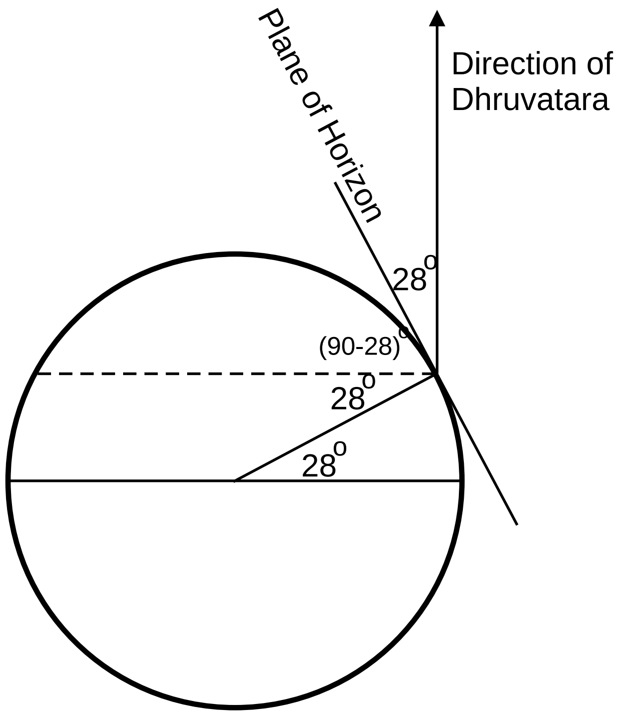
In Delhi we will get an angle of 28° . At Mumbai it will be around 18° . At Tiruvanantapuram Dhruv tara will be close to the horizon.

As you proceed north, the angle made by Dhruv tara with the horizon will steadily increase. When you reach the North pole, Dhruv tara will be directly overhead(see fig). If you go South the angle will decrease until you reach the Equator. A person standing on the equator will see Dhruv tara exactly on the horizon(see fig). If you go south of the equator, you will not be able to see Dhruv tara.



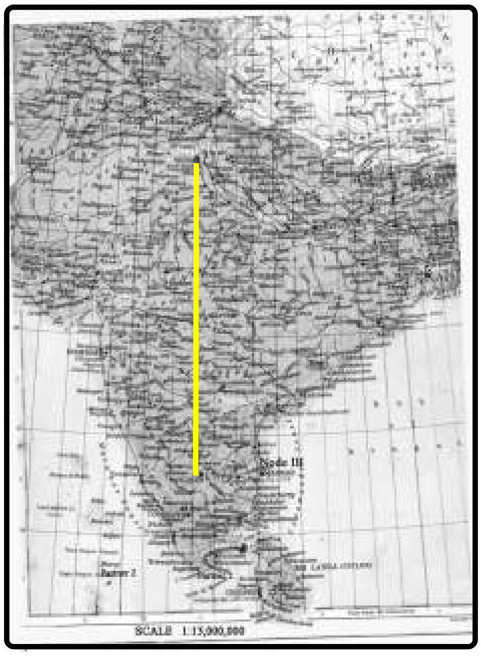
17.2 Measuring your latitude

Measure the angle made by Dhruv tara with the horizontal with your angle meter. Look up in an atlas, the latitude angle of the place where you live. The two angles should be equal. Why ?
Look at the following figure . It shows a man standing at latitude 28°. Can you see why Dhruv tara also makes an angle of 28° with the horizon ?



HOW BIG IS THE EARTH?
MEASURING THE SIZE OF EARTH BY MEASURING LATITUDES

18.1
Look at the following map of India.

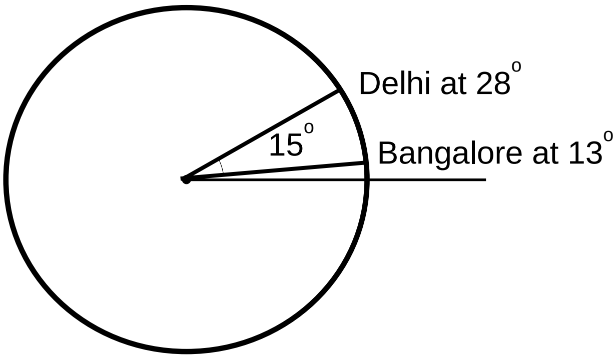


We observe that Bangalore and Delhi are almost exactly south and north of each other.

We observe that the distance between Bangalore and Delhi is around 1700 km as an airplane would fly.

We observe that the latitude of Bangalore is 13^{o} and the latitude of Delhi is 28^{o}.
The difference in latitude is 15^{o}.

18.2
Now we do a simple calculation . Look at the following figure. A difference of 15^{o} in latitude corresponds to an arc length of 1700 km on the circle. What is the circumference of the circle ? Easy.



The circumference corresponds to 360^{o}. It is equal to (360/15)x 1700 km

i.e The circumference of the earth is around 40,800 km.

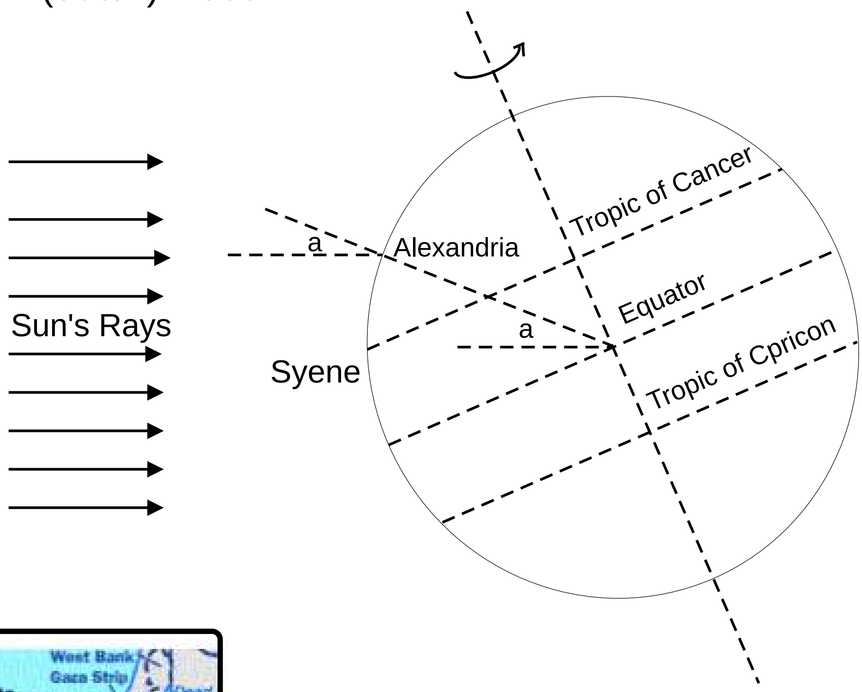
18.3

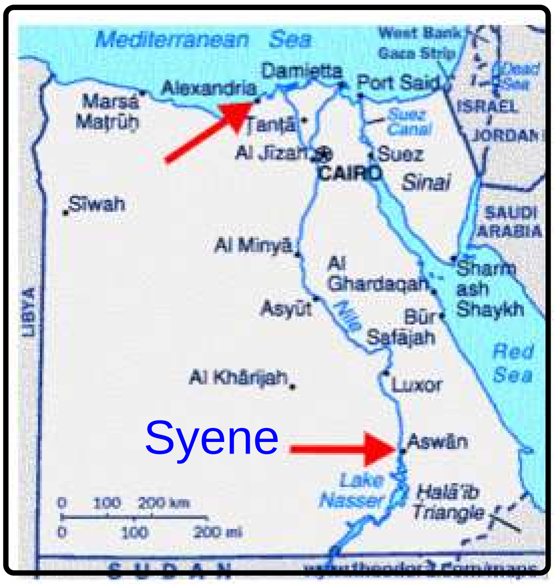
More than 2200 years ago Eratosthenes used a very similar method to calculate the circumference of the earth. He knew that on 21st June the sun was directly overhead at a place called Syene. On the same day, when it was highest in the sky at Alexandria, it was not overhead, but made an angle of 83° with the horizontal. This meant that the difference in latitude between Alexandria and Syene was 7 °.

He also knew that Alexandria and Syene were north-south of each other and at a distance of 800 km from each other.

So he calculated that the circumference of earth was equal to

$$(360/7) \times 800 \text{ km}$$





HOW BIG IS THE EARTH?

MEASURE EARTH'S SIZE, BYE MEASURING TIME

Do you have a friend in an Eastern part of India (let's say Bhubaneshwar) and you can be on the Western part. Both of you should be on approximately the same latitude.

19.1

Synchronise your watches i.e. set the watch at exact Indian Standard Time or TV time. Record the exact time when each of you saw the sunrise (lower tip of the sun when rising) or sunset (upper tip of the sun when setting).

19.2

What is the difference between the times of sunrise or sunset between these two different places?

Let's say, the Difference in hours = T

And the distance between two places = D

Hence, we can conclude that Earth takes time T to cover distance D on its circumference. Earth takes 24 hours to encompass its circumference.

We can calculate the approximate size of earth as follows

Size of Earth = (24 x D) / T

Note : This method will give you a correct answer for the circumference of earth only if you and your friend are both at the equator.

(But India is above the equator!)

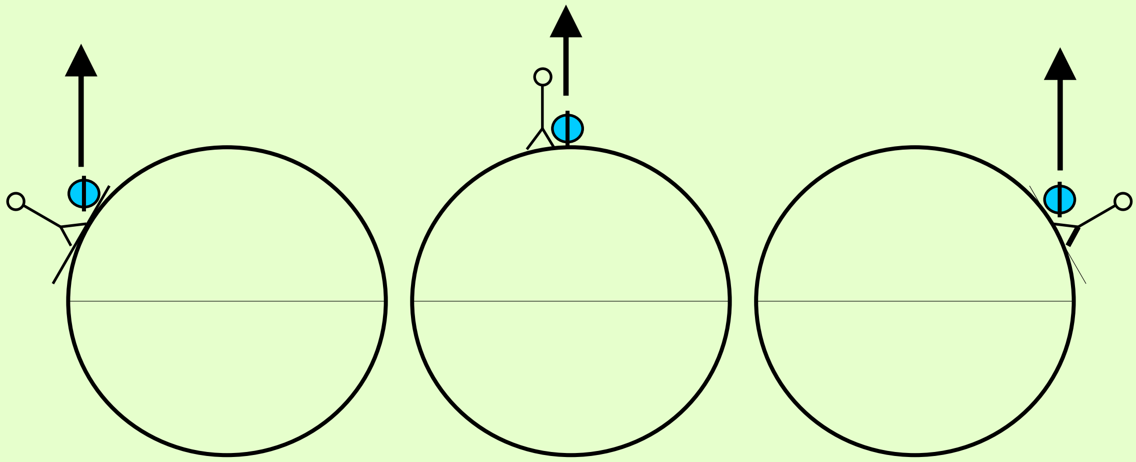
19.3

For those of you who have learned trigonometry :

You will have to divide your answer by sin (your latitude angle) to get the right answer.

Look up Sine tables to get the Sine of your latitude. You can find your latitude by doing the experiment on card 15.

GEOSYNCHRON



We learn in school that the earth rotates around its axis once in a day, and that it also revolves around the sun once in a year. A geosynchron model helps us to understand this.

To make a Geosynchron :-

1. Take a large Hollow spherical globe with holes at the north and the south poles so that you can see through.
2. You can use the plastic globe models of the earth or even a large plastic ball from any toy shop.
3. Set the globe on a ring mount and fix it such that you can see Dhruva tara when you look from the south pole, through the north pole.

4. Keeping Dhruva Tara in sight, rotate the globe so that the map of India is on top. Now, India on our Geosynchron is parallel to real India on the earth.
5. When it is noon in India, the sun will be right above our Geosynchron and it will be noon on our Geosynchron. In fact whatever time the sun is showing in real India, the same solar time will be seen on the India which is on our Geosynchron. Geosynchron means 'same earth time'. It could also be called a Samantar Prithvi or parallel earth.

By the simple act of fixing the line of sight of the tube onto Dhruva tara, we have created a parallel earth which remains parallel to the real earth not only as the earth rotates around its own axis, but also as the earth goes around the sun in one year.

EXPERIMENTS WITH GEOSYNCHRON :

22.1
Do this experiment outside in the sunshine. Place a geosynchron (card no. 21) such that its axis is parallel to the earth's axis. Rotate it so that India is on the top side. In this position (if you are doing the experiment in India), the geosynchron is exactly parallel to our Earth as it is situated in space.

22.2
Place a toothpick upright on India on the geosynchron with the sticky tape. Observe how the toothpick casts its shadow on the upper surface of the globe.
Fix a bamboo rod upright on the ground next to the geosynchron. Observe how it casts its shadow.
Do you see the similar triangles formed on the geosynchron and on the ground by the two poles and their shadows ?
This means that the solar time on the geosynchron is the same as the solar time where you are standing.

22.3
Observe in which countries the sun is rising on the geosynchron. The sun is rising in the same countries on our Earth.

22.4
Observe in which countries the sun is just setting.

22.5
Observe where it is night and where it is day.
You can imagine, that along that line which separates light from dark, millions of people are waking up, going to the bathroom, brushing their teeth, and getting ready to go to school or to work. Along another line on the other side of the globe, millions more are relaxing at home after a hard days work and watching TV, and getting ready for dinner. Enjoy your journey to the geosynchronous satellite thousands of kilometres above the earth in outer space. You are now looking at earth as it is seen from the geosynchronous satellite.

22.6
Find the point where the sun is exactly above on the geosynchron. At this point the shadow of an upright toothpick is of zero length. Move the toothpick around until you find this point. Alternatively make a small tube by rolling a piece of paper. Keep the tube upright at different points on the geosynchron. Find the point where the sun shines directly inside the tube till the bottom. This is the zero shadow point.
Note that as time progresses this zero shadow point moves.
Let us study how it moves with time.

Where is it at 12 noon (our time) ?

Where is it at 2PM (our time).

Notice that as time progresses in the course of a day, the zero shadow point moves longitudinally along a line of latitude. Every minute the longitude of the zero shadow changes a little.

22.7
This experiment must be done on the same day of the week, say Monday, for a few weeks, at a fixed time, say 2 PM. Mark the point of zero shadow at 2 PM on Monday for four weeks. Observe that these points lie on a line of longitude. As the days pass, and the earth revolves around the sun, the sun (at a fixed time of day) appears to move latitudinally along a line of longitude. Every day the latitude of the zero shadow point changes a little.

At any time of day and on any date of the year the zero shadow point is at exactly one place on the Geosynchron.

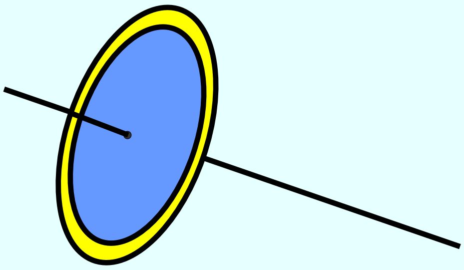
The zero point shadow is always moving. But at the same Time, and date , after one year, it will return to exactly the same place.

If we know where the zero shadow point is, we can know the exact date and time. The geosynchron is a kind of a day-date clock.

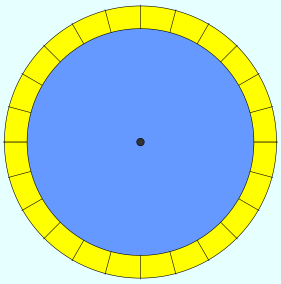
23. MAKE AN EQUATORIAL SUNDIAL

In your terrasunlab kit you have a disc with a hole punched at its centre. You also have a thin tube.
Any disc / circular rim can be used for this purpose (e.g. dhakkan of a bartan or bicycle rim)

23.1



23.2



Put the thin tube through the centre of the disc so that the tube is perpendicular to the plane of the disc. Place it as in the figure, such that when you look through the thin tube at night, you can see Dhruvatara. Your equatorial sundial is almost ready to use. It is in the correct position to tell the time. But first we have to make it into a usable clock, with a clock face.

Divide the circular rim of the disc into 24 equal parts, and mark the parts with a sketch pen. See figure. The sundial clock face is ready. The normal clock face circle is divided into twelve hours. This clock face has 24 hours.

23.3

Now keep the equatorial sundial in the same position as in the first activity (23.1), so that you can see Dhruv tara through the tube. The next morning, after the sun has risen, study the shadow cast by the tube on the face of the disc. In one hour the shadow moves from one marking to the next one.

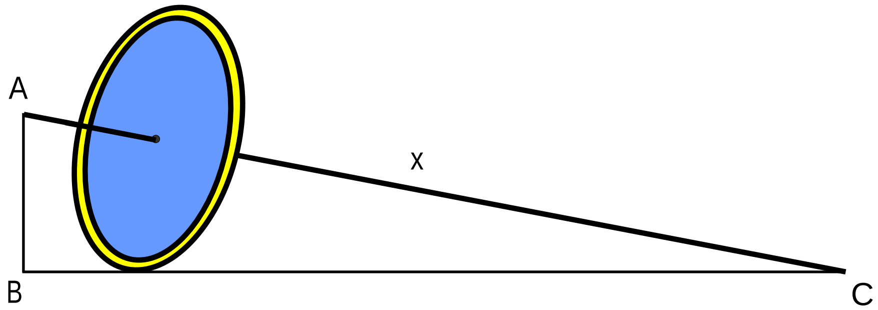
23.4

Now mark the divisions from 1 to 24 with a sketch pen. Keep the sundial in the correct position, and rotate the disc until the time shown by the shadow is synchronized with the time shown by your watch. Your sundial clock is ready.

It will never need to have its batteries changed. Whenever the sun shines, it shows the time of day.

If you want to put the rod pointing to Dhruvatara, but if because of trees or buildings, Dhruvatara is not visible, what will you do?

- Find the latitude of your place from your geography books, or internet. e.g. latitude of Pondicherry is : 11 degrees 56 min, which is almost 12 degrees.
- Measure the length of your rod which is passing through the disc (AC). Let it be x.



- In triangle ABC, CA should be pointing to Dhruvatara. It means that angle ACB should be 12 degrees.
-

sin ACB = AB/AC

sin 12 = AB/x

FInd AB.

- Adjust the position of the disc such that you get the required AB.
- Your angle ACB will then automatically be equal to your latitude.

- Remember that, 12 degrees is the latitude for Pondicherry. You will have to find and use the latitude of the place where you are.

EQUATORIAL SUNDIAL AS A SUNDUAL
SUN CALENDAR

24.1

As in Activity card 23, keep your equatorial sundial in the correct position, with the tube pointing towards Dhruva tara. In the previous activity card we were observing the shadow of the tube as it falls on the disc. Now we do the opposite. Observe the edge of shadow of the disc as it falls on the tube. If the sundial is placed accurately, we will observe that this shadow does not move even though the sun is moving from east to west.

24.2

Keep the sundial in the same position for one week. Mark the position of the shadow on the tube (Note: Not the shadow of the tube- the shadow on the tube) after one week. Notice that the shadow has moved from its original position. However, during the course of the day, the shadow remains almost stationary.

The movement of the shadow of the disc falling on the tube marks the passage of the days and the seasons. It is a calendar shadow.

The movement of the shadow of the tube falling on the disc marks the passage of the hours and minutes of the day. It is a clock shadow.

The equatorial sundial can therefore be used both as a clock as well as a calendar. It is a dual time teller. It is a Sundual.

25. THE MOON IS 110 TIMES AS FAR AS IT IS BIG

25.1

Do this activity on a full moon night. As in activity card no 6 take your distance finder with a 5 mm hole at its centre. Adjust its length until the full moon exactly fits into the aperture.

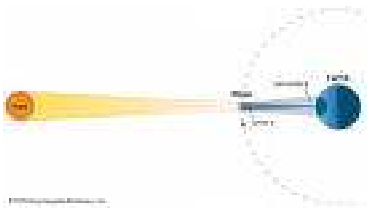
Measure the distance of the aperture from your eye at this point. It will be around 55 cm. This shows that the diameter of the moon divided by the distance of the moon from us is equal to ½ cm divided by 55 cm = 1/110.

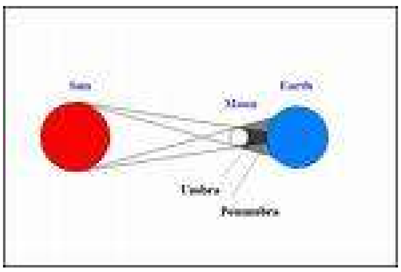
The sun is 110 times as far as it is big.
The moon is 110 times as far as it is big.

Why 110 for both sun and moon ? This is a complete coincidence. But because of this coincidence, total solar eclipses occur.

At the time of total solar eclipse, the moon covers the Sun fully.

Note: The orbit of the earth is not exactly circular. It is slightly elliptical. The orbit of the moon is also slightly elliptical. Therefore the ratio of distance to diameter changes from time to time. Sometimes, when the moon is further than normal, the ratio will increase beyond 110. The moon appears smaller than normal. If a solar eclipse occurs at such a time, it will be an annular eclipse.

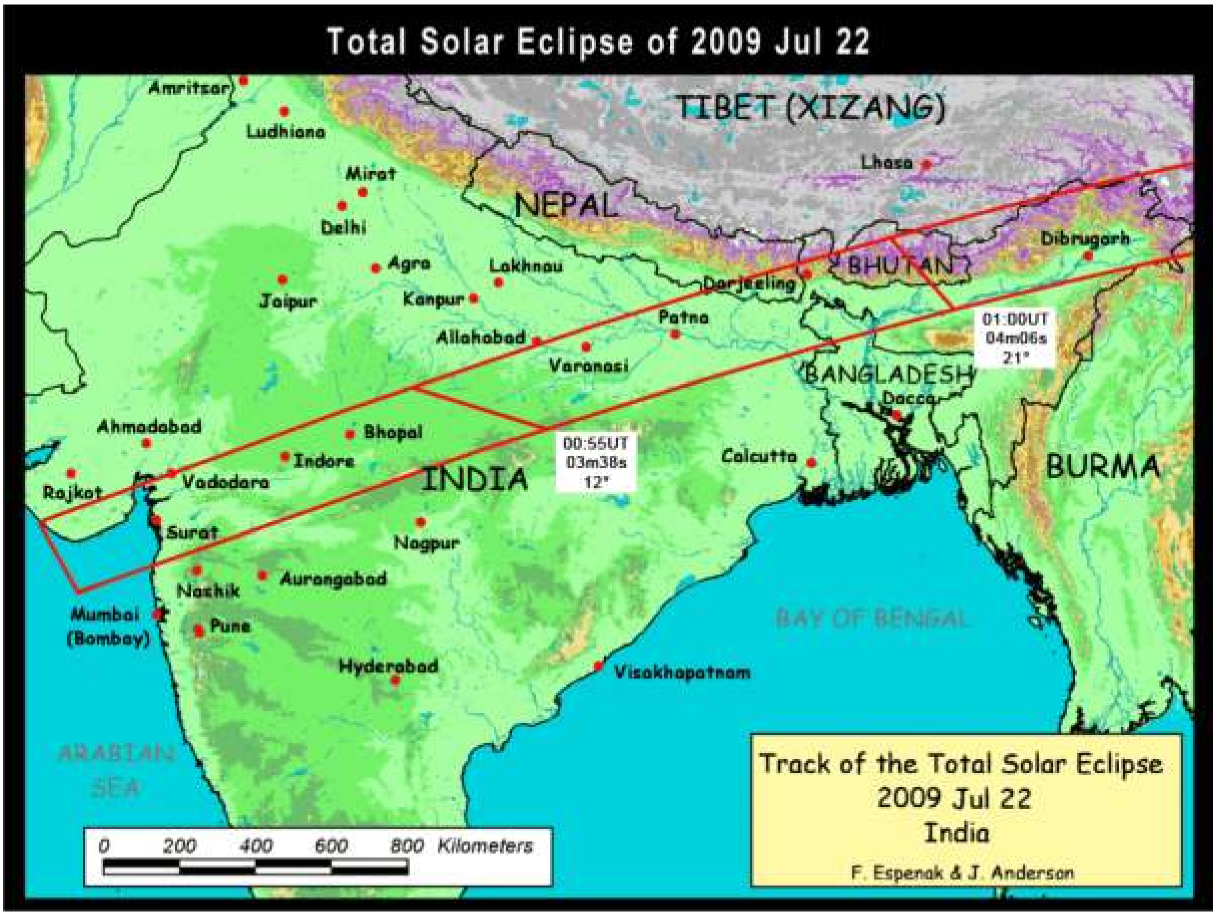




TOTAL SOLAR ECLIPSE

On July 22, 2009, just after sunrise, a total solar eclipse will be visible along a path that runs across the centre of India. The total solar eclipse will also be visible in other parts of the world like Myanmar, China and Korea.

Many cities like Indore, Bhopal and Patna lie in the path of totality.



When the sun rises it will not be a circular disc, but it will be seen as a crescent shape.

There is only one problem: July 22nd is mid monsoon and there is a very high probability that there will be clouds in the sky.

To observe the solar eclipse, you can use all the ways that you have learned to observe the sun (card numbers 3, 4, 10, 29) :

1. Pinhole projector,

2. Ball and mirror projector

3. Telescope projection

4. Using a certified solar filter for direct viewing

5. VLFL lens and ball and mirror projector

WHAT TO OBSERVE DURING A TOTAL SOLAR ECLIPSE

27.1
Observe the changing crescent shape of the sun as the moon progressively covers the sun.

27.2
Observe the shape of the sun in the patches of light which can be seen in the shade of a tree. Normally these are discs of light. During a solar eclipse, these appear as crescents.

27.3
Observe that shadows get sharper and clearer as the visible part of the sun gets smaller and smaller as it gets covered by the moon.

27.4
Just before totality observe the “Diamond Ring effect”

27.5
Observe Bailleys' beads

27.6
If you are fortunate enough that the sun is visible during the short few minutes of totality, observe the solar corona and its shape. The time of totality is the unique opportunity you have to observe the corona.

Solar Corona during eclipses of 1994, 1999, 2005 :

27.7
During totality look in the dark sky and see which stars and planets you can see.

27.8
Observe the behaviour of birds and animals during the solar eclipse.

Sun Spots :

- The combination of ball mirror solar projector and very long focal length lens will give you a sharp crisp image of the SUN (card no. 10). On this image the sunspots are clearly visible.

- The big Sun spots are also visible with ball-mirror projector alone.

This image of the Sun was obtained in the amphitheater of Fergusson College Pune with the help of ball-mirror. It showed 3 sun spots.

You can study how the sunspots move by taping the white paper screen to the wall and tracking the outline of the Sun's disc. Mark the position of the sunspots and write the date next to it. Keep the screen fixed. Next day again form the image of the Sun so that it exactly fits the circular outline using your ball mirror projector. Again mark the date and position of the sunspots, which will have moved. Do this experiment every day for several weeks.

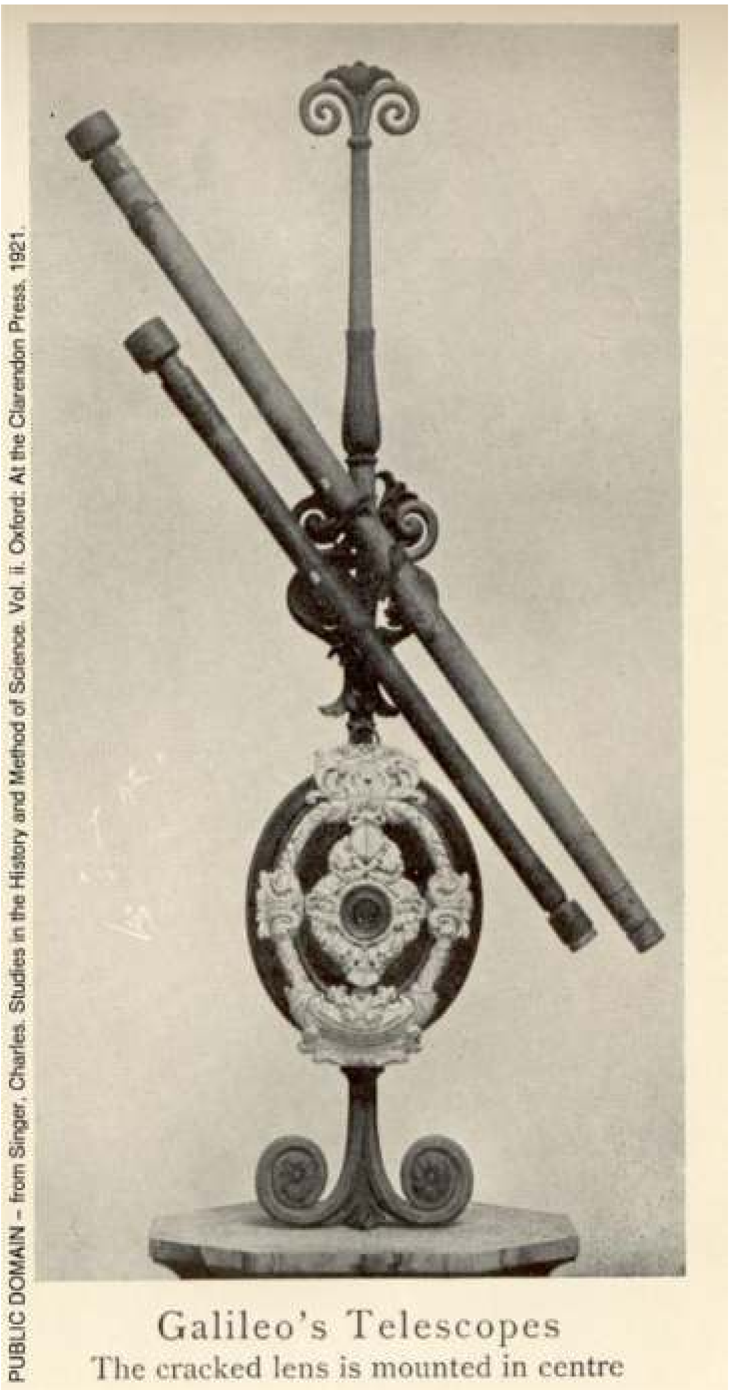
You will discover that after about 4 weeks the large Sun-spots return to their original locations. (Most of the smaller Sun Spots however will not last for four weeks).

You will discover the rotation of the Sun, that the Sun has a tilted axis of rotation, an equator and poles just like the earth.

Discuss with your teacher/parents/scientist in your city or refer to books to find out what are SUN-SPOTS.

THE GALILEOSCOPE

29.1
Galileo was not the first person to build a telescope. Before him others like Lippershey from Holland had built telescopes. But Galileo was the first person to turn the telescope to the skies and use it for astronomy.



Galileo's Telescopes
The cracked lens is mounted in centre

This is a photograph of Galileo's telescopes. The most important part of the telescope is the optics- the lenses. Galileo's telescopes had two lenses. The front lens, called the objective, and the rear lens, called the eyepiece.
The front lens has a long focal length. The eyepiece has a small focal length.

29.2
You too can build your own telescope, with two lenses, and mountboard, like the one shown in the photograph below*.

29.3
With this telescope, you will be able to see the moons craters.

29.4
You can use your ball mount to mount the telescope. Use thick rubber bands, or thick string to tie your telescope to the mount :

*For obtaining lenses and more details, you can contact :
Gunavatta at Navnirmiti Pune, Discover It Centre : Navnirmiti Mumbai.

HOW ANAXAGORUS MEASURED THE SUN'S DISTANCE

We know from historical records that Anaxagorus was one of the first human beings in the history of humankind to state that the moon and the sun are rocks. He stated that the sun is a burning rock “larger than the Peloponessus”.

If you look at the map of what is today Greece, you will see that the Peloponessus is a peninsula in the South of Greece, about 80 km across.

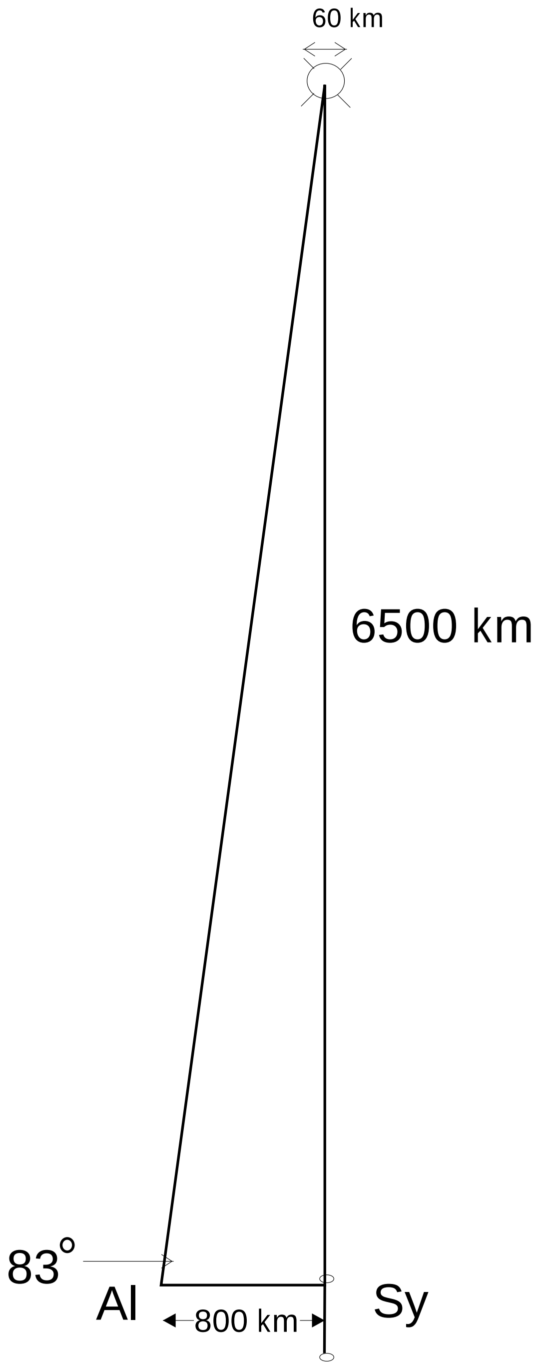
Based on this historical fact, the physicist George Gamow has reconstructed in his book “A Star Called the Sun”, an account of how Anaxagorus may have arrived at this conclusion.

According to Gamow, Anaxagorus knew, 200 years before Eratosthenes, that on summer solstice day, at Syene, the sun is exactly overhead at noon, and can be seen in reflection in a deep well.

He also knew that on the same day, it made an angle of 83 degrees at Alexandria, at noon.

He also knew that the distance between Syene and Alexandria is around 5000 stadia (approximately 800 km).

On the basis of this information, he drew the diagram, and calculated the distance of the sun as 6500 km away from the earth.



30.1

Draw a right triangle with one angle as 83^{o} on a graph paper. Note that the height of this triangle is about 8 1/4 times the base.

Therefore if the base is 800 km, calculate the height.

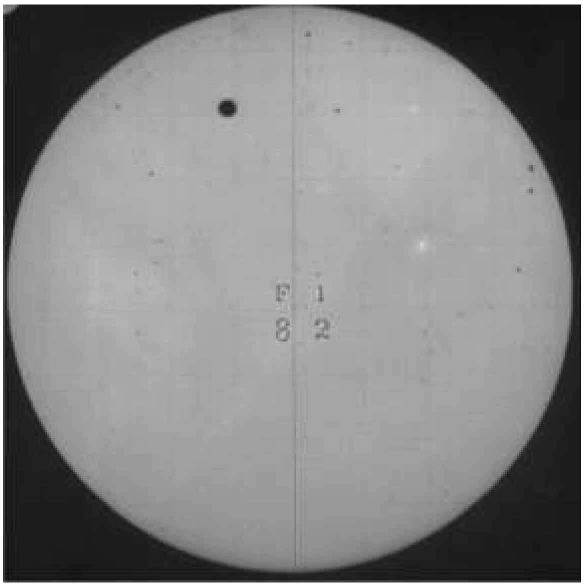
Anaxagorus got an answer for the distance of the sun as 6400 km. This was not the correct answer to the question “How far is the sun”. Why ? Because Anaxagorus assumed that the earth was flat.

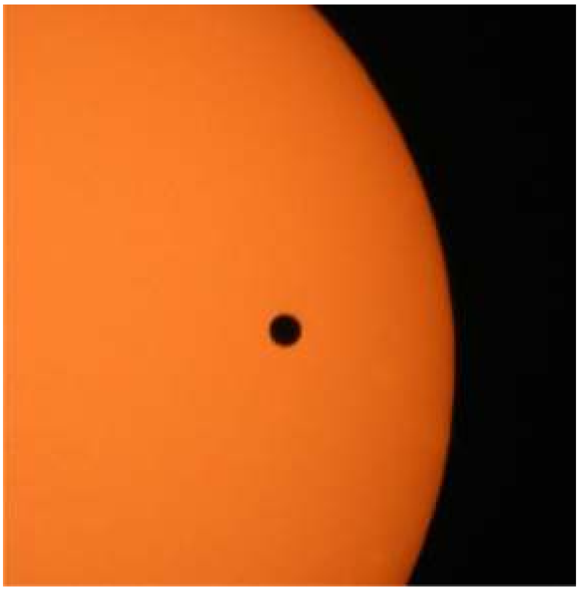
However,this answer was the correct answer to a different question.
This question was : "What is the radius of the earth?".

Actually, 200 years before Eratosthenes, Anaxagorus had calculated the earth's radius, but he did not know this, because he did not know that the earth was round.

31. THE TRANSIT OF VENUS

Below is a photograph of the 1882 Transit of Venus (TOV). (Left photograph)





On the right is a photograph of the TOV which took place on the 8^{th} of June 2004, taken by Shri Kedar Bhatt.

When Venus comes in front of the Sun, so that we can see Venus as a black dot against the bright sun, we call this a Transit of Venus(TOV). The TOV is a very rare event. It happens once in 121 years, then again after 8 years, and then again after 121 years and so on. The TOV is important in the history of science because it allows us to measure how far the Sun is from us. This distance- the distance between the Earth and the Sun is called the Astronomical Unit.

In the year 2004, when the TOV occurred after 121 years, thousands of students were able to observe it in different ways;

(card no 4, 10, 29)

At Shaniwarwada, Pune, using a ball mirror projector, Very Long Focal Lens, and Portable Darkroom.

Directly looking at the sun using solar filters to protect the eyes

Projecting the sun with a solar telescope made with two lens.

On the 8th of June 2012, the TOV will again take place. Thereafter, it will not happen in your lifetime. The 2012 TOV will be a once-in-a-lifetime experience.

31.1

This rare and unique scientific event can be observed in the following ways :

- By projecting the sun's image with a ball mirror projector
- Using a Very Long Focal lens
- Projection with a telescope
- Through a telescope, using appropriate optical filters.

31.2

If you learn to get a sharp image of the Sun, you might be able to see the atmosphere of Venus as a thin halo of light around the dark circle of Venus, as Venus Transits the sun.

31.3

In the year 1639 Horrocks and his friend Crabtree were the first to observe the TOV using a telescopic projection method. Horrocks also tried to calculate the distance of the sun by measuring the relative sizes of Venus and the Sun during the TOV, (just as you will do in 31.1. To calculate the distance of the Sun Horrocks had to make an assumption about the relative sizes of venus and the earth. He made the wrong assumption: He assumed that the sizes of the planets increased as their distance from the sun increases, such that the diameter of each planet is proportional to its distance from the sun. Because of this wrong assumption, Horrocks got a wrong answer for the Astronomical Unit. He would have got the right answer if he had made a different, simpler, assumption. Had he assumed that Venus and Earth are the same size, he would have calculated the sun's distance accurate to about 5 % and earned a place in history next to Eratosthenes.

The next TOV took place in 1761. The great astronomer Edmund Halley showed how the TOV could be used to measure the Astronomical Unit. But he himself could not use his own method ! Because no TOV occurred during his lifetime. Even the great Newton did not know the Astronomical unit. No TOV occurred during Newton's lifetime. Newton died without knowing the answer to the missing link in his theory of the Solar system- the answer to the question “How far is the Sun from us?”

31.4

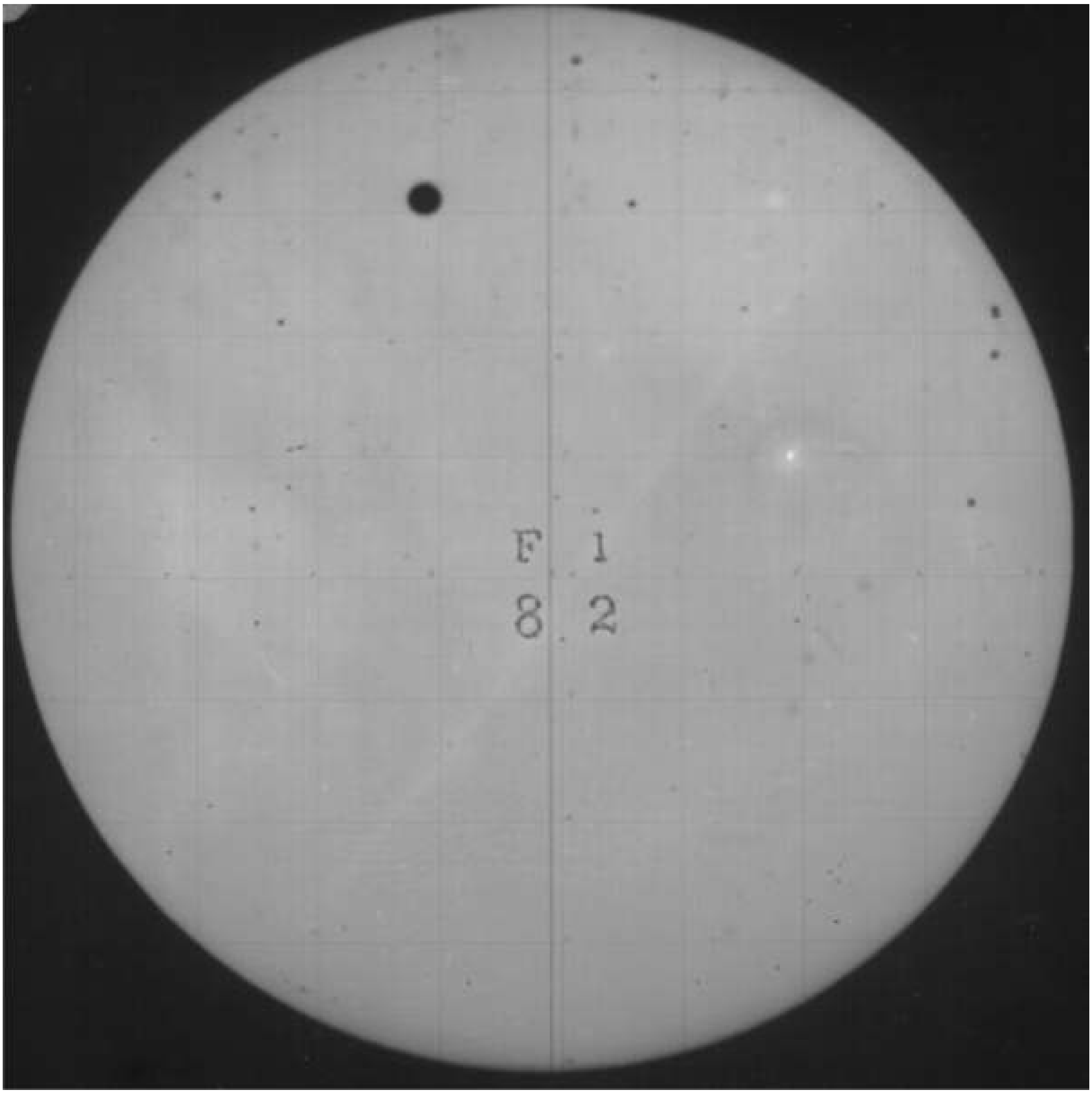
Do the activities given in card 32 and 33.

For full details of how you can yourself measure the Earth-Sun distance, refer to the Navnirmiti booklet “Measuring the Universe with a String and a Stone”, by Dr. Vivek Monteiro.

32. USING VENUS TO MEASURE THE SUN

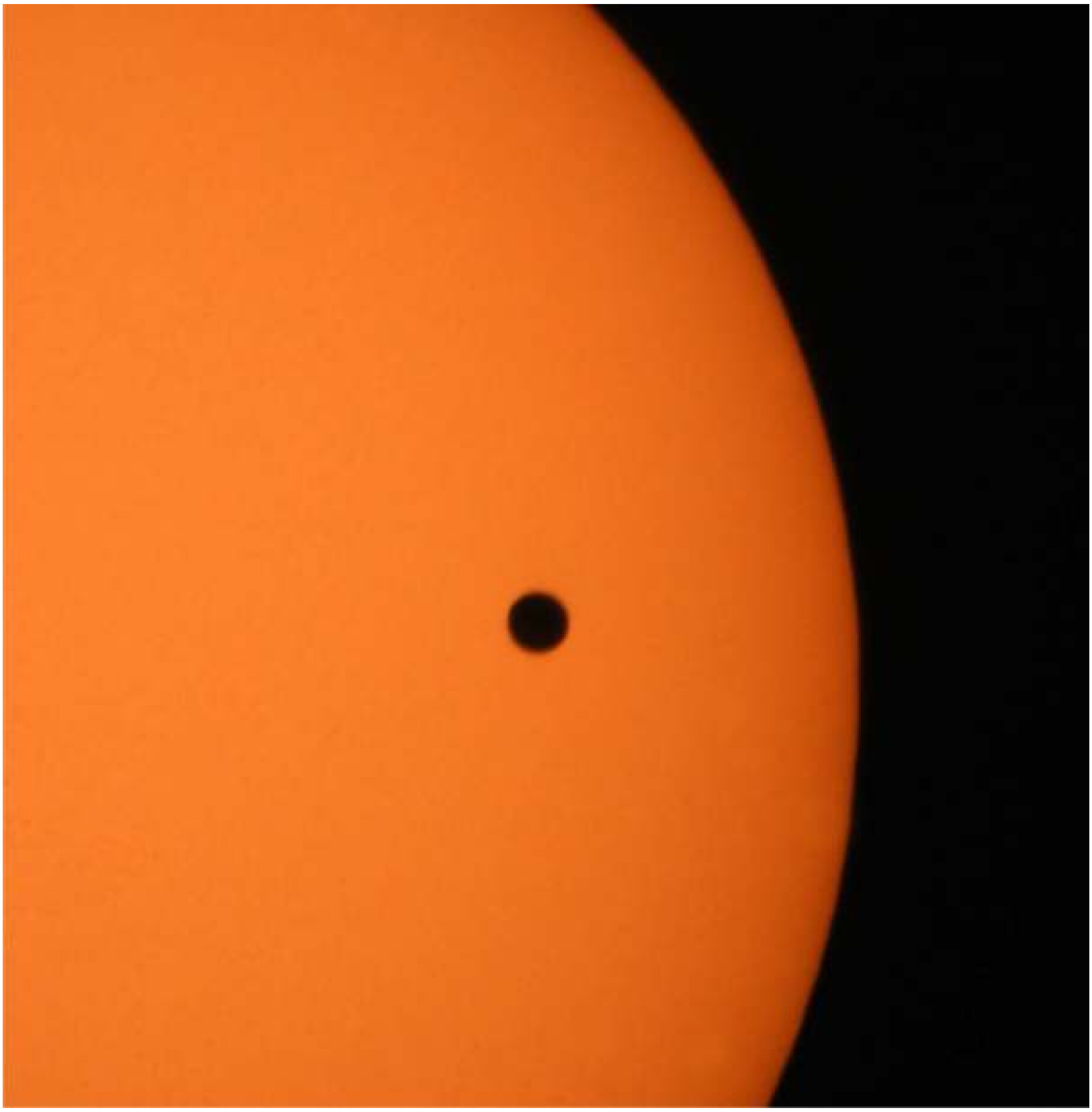
32.1

The two photographs given in this card were taken when Venus was transitting the sun. The first photograph in the year 1882. The second on June 8, 2004, by Shri Kedar Bhatt. In each photograph, measure the diameter of Venus, and then measure the diameter of the Sun. How will you measure the diameter of the Sun in the 2004 photograph ?



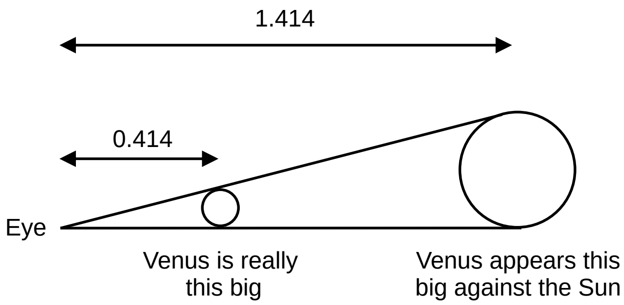
32.2

From your measurements, you can calculate that the diameter of the Sun is a little more than 30 times the diameter of the black dot which is Venus. Accurate measurement will give you a factor of 33.



32.3

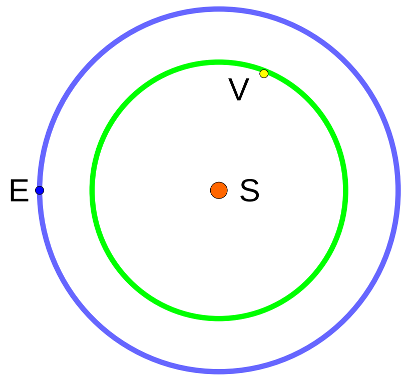
Does this mean that the Sun is about 33 times as wide as Venus ? No. The Sun is much bigger, but during the transit, it is further away, and Venus is nearer the earth (see figure below). So Venus appears bigger than it really is. How much bigger ? This we will calculate in the next activity card.



HOW FAR AWAY IS VENUS?

33.1

Look at the following figure. At the centre of the two concentric circles is the sun. The inner circle represents the orbit of Venus. The outer circle is the orbit of the earth. Venus is the point V. Earth is E. The sun is S. Draw two concentric circles yourself and take different positions for V and E. Note that the angle VES is always acute, because V is inside and E is outside.

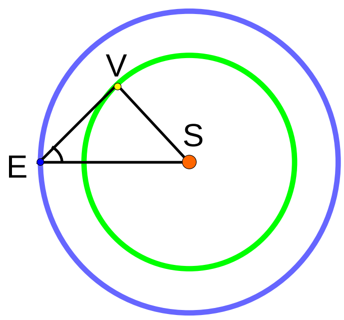


33.2

When is angle VES maximum ? When angle VES is maximum, what is the angle angle EVS ?

33.3

You will have discovered in 33.2 that angle VES is maximum when the line EV is tangent to the inner circle. At the tangent point the radius SV is perpendicular to the tangent EV. So at maximum angle VES, the angle EVS is 90^{o}.



33.4

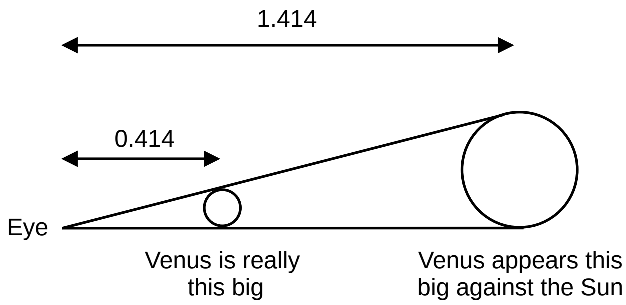
Look at Venus just as the sun sets. At the time of sunset ES is a horizontal line. Now E is your eye, or also the earth. (It does not matter much, because the distance EV and ES is so large, Earth and Venus are like pencil points, in relation.) You can measure the angle VES with your angle meter (card no. 12) . Measure it every evening for a few weeks.

33.5

Venus appears to go further and further from the sun, then stops and starts getting closer and closer to the sun. On January 14th 2009, Venus will appear to be most distant from the sun, and highest in the sky, when the sun is just setting on the horizon. If we measure the angle VES on January 14th, we will find that it is around 45^{o}. This means that on Jan 14th VES forms a right angle isosceles triangle. This also means that the radius of earth around the sun is v2 times the radius of Venus around the sun.

33.6

On the day of transit, Venus is closest to earth. If the distance of earth from sun is v2 , then Venus is one unit away from the Sun. Venus is (v2 - 1) away from earth. The sun is at a distance of 1.414, and Venus at a distance of 0.414 from earth. The Sun is 3.4 times further, and appears 3.4 times smaller than it really is compared to Venus.

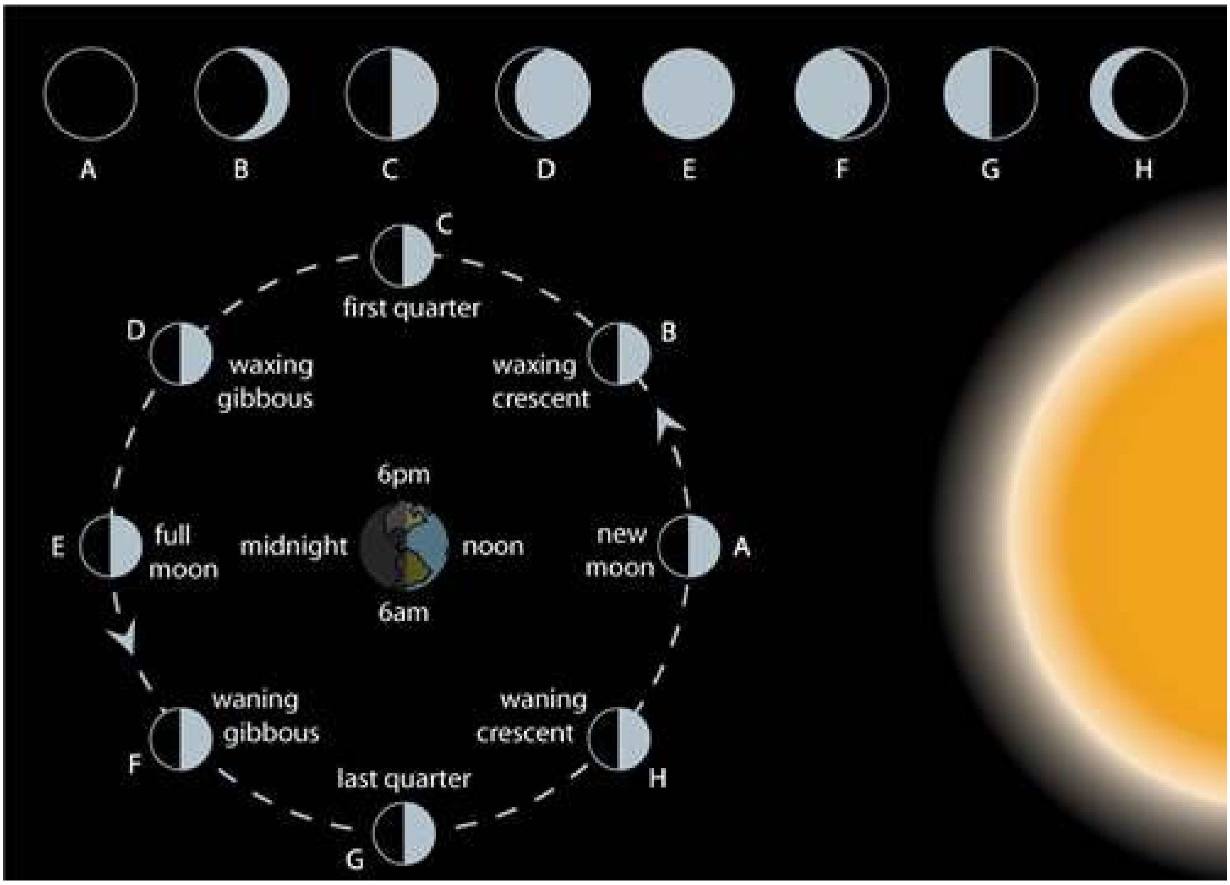


33.7

So the sun is actually 33 x 3.4 times as wide as Venus.

34. Phases of the Moon

Ancient scholars watched the moon, night after night and noticed that it changed its position as well as shape in respect to the sun.



When the moon and sun were on opposite side of the earth, the moon was always a full circle of light. The sun shone past the earth onto the moon. It lit up the whole side of the moon.
When the moon and sun were on the same side of the earth, they couldn't see the moon at all. The sun shone on the other side of the moon, the side they couldn't see. The side they could see received no sunlight and it was dark.

So, they concluded that the sun has light of its own and the moon doesn't. Moonlight is "reflected light." The different shapes of the lighted part of the moon are named as half- moon, crescent-moons etc.

You can see these different shapes (also called Phases of Moon) by doing a simple experiment:

34.1

- Take a white ball or an orange or any other round shaped object.
- On the day when you can see both the sun and the moon in the daytime, hold the ball in the same line of sight as that of the moon. The ball almost hides the moon behind it.

Can you now see the phase of the moon on your white ball? Is the phase seen on the ball the same as the phase of the moon?

Moon in the sky

Repeat the experiment on other days whenever possible. Does the phase of the ball exactly match with the phase of the moon?

Shadow on sweet lemon

35. PHASES OF THE MOON AND SUNSET-MOONSET TIME DIFFERENCE

By studying the moon phase, we can know where the sun is in space. To understand this we create an artificial moon and study how phases are related to the triangle made by the sun, moon and eye.

35.1

Cover the inside of your portable darkroom (card no. 5) with black paper. Make small slits on all sides of the box. Keep a white tennis ball or an orange (artificial moon) suspended at the centre of the portable darkroom. Project the sun on the tennis ball from a close distance (less than 2 m) with a ball and mirror projector. Use a larger mirror. Now look at the artificial moon from different angles and study the appearance of the phases as you change the angle∠ MES, where M is the artificial moon , E is your eye, and S is the ball and mirror sun.

photograph of illuminated sweet lime taken from above with cover of the darkroom box opened

Note that when the angle MES is acute you see a phase like this:

When the angle MES is a right angle, we see a half moon.

When the angle MES is 180, we see a full moon.

Note that the curve of the crescent shows you where is the sun.

35.2

Look at the moon, and from the curve of the crescent guess where the sun is.

35.3

The angle MES is also related to the time between sunset and moon set.

When MES is 90, What is the phase of the moon ?

What is the time between sunset and moonset, when the moon is a half moon?

35.4

When MES is 180, what is the time between sunset and moonset ?
Do you see why the full moon rises, just when the sun sets ?
Do you understand why the full moon is directly overhead at midnight ? When the full moon is directly overhead where is the Sun? (Answer : Under our feet!)

36. PHASES OF VENUS

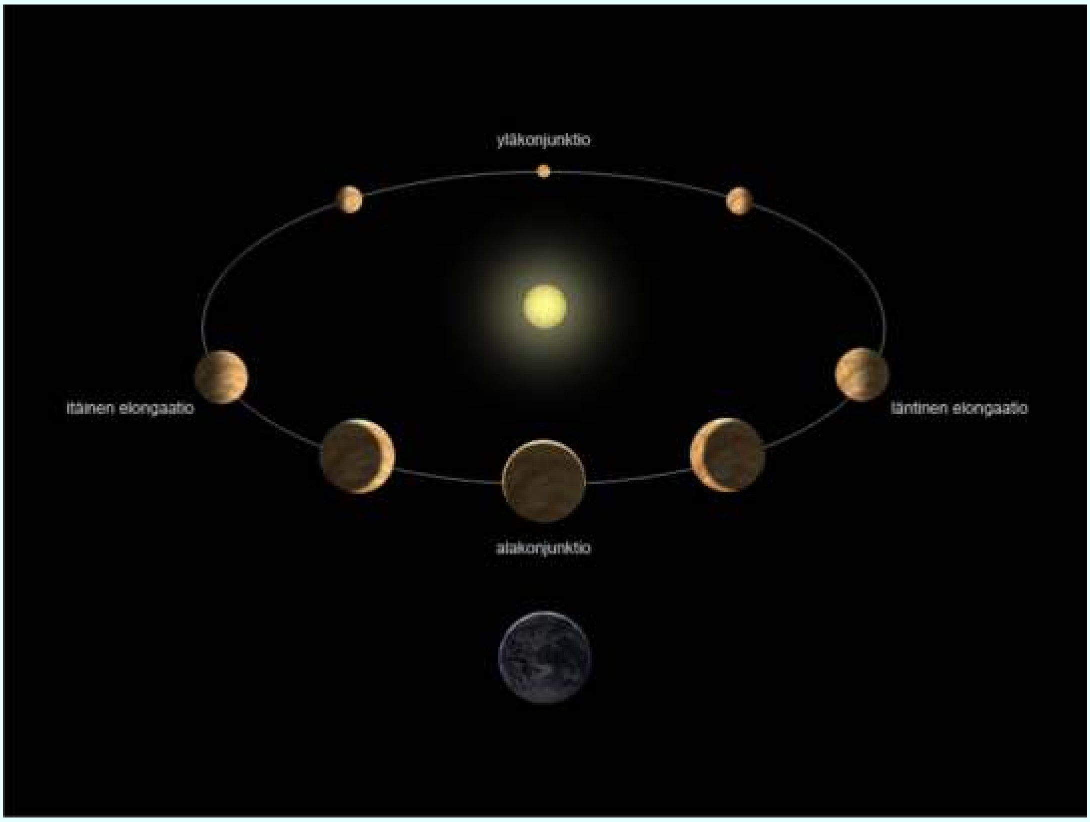
36.1

Look at Venus through your telescope towards the end of 2008, and in early 2009.

Can you observe that the shape of Venus is not circular?

Like the moon-eye-sun angle, ∠MES, gives us the phases of the moon, similarly the Venus-eye-sun angle∠ VES, gives us phases of Venus, which we can see through the telescope.

The phases of venus



Galileo was the first person who observed the phases of Venus. The phases of Venus were a powerful piece of evidence in favour of Kepler's 'heliocentric' universe : that earth goes round the sun and Venus goes round the Sun in an orbit inside the earth's orbit.

36.2

Observe the phase of Venus on the night of January 14th or 15th 2009, when Venus is highest in the sky at sunset. As we saw in Activity card 33, at this point, $\angle$ EVS is 90^o .
When $\angle$ EMS is 90^o, we saw in the activity card 35, that the phase of the moon is a halfmoon. Note that Venus is also in the same phase when $\angle$ EVS is 90^o.