PATHANI SAMANTA'S

INSTRUMENT KITS

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Contents

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-P.C. Naik

INTRODUCTION:

Mahamahopadhayaya Chandra Sekhar Simha Samanta Harichandan Mahapatra (1835-1904) popularly known as Samanta Chandra Sekhar and more fondly by the nick name Pathani Samanta, happens to be one of the great Indian astronomers of the traditional school in the rank of Aryabhata, Varahamihira, Brahmagupta and Bhaskaracharya. He was possibly the last great naked eye astronomer of the world. Astronomy being the oldest of sciences, it developed in a number of civilizations, quite independently. It is basically an observational science supported by necessary calculations. Therefore, all ancient astronomers used a number of instruments in their work, based on earlier knowledge and partly on their own innovations.

Most of the well-known siddhantas like the Surya Sidhanta, Aryabhata Siddhanta, Pancha Siddhantika, Brahmasphuta Siddhanta, Siddhanta Siromani and Siddhanta Sekhara invariably devote a separate section/chapter to the description of instruments. A research paper by Yokio Ohashi, titled "Astronomical Instruments in Classical Siddhantas" has appeared in the Indian Journal of History of Science (April-June, 1994). But it is disappointing to note that Samanta's name does not figure out in this extensive review ; of course, for the obvious reason that Siddhanta Darpana, the work of Samanta Chandra Sekhar is unknown even to the modern workers in the classical field.

Ohashi's paper lists about twenty various instruments as described by different siddhantas. Samanta has also devoted a full chapter (20^{th}) of his Siddhanta Darpana to exhaustive description of more than ten different instruments. It is remarkable that the astronomer used cheaply available materials like wood and bamboo chips for fabrication of these devices and used them to attain results, which almost tally with the modern measurements. It will not be out of place to mention here that Savai Jai Singh of Rajasthan in the 16th century built a number if observatories in the northern India in the name of Jantar Mantar where he erected massive masonry structures as instruments. In comparison to that, Samanta's devices are simpler and handy, but accurate.

Besides, Samanta is a legendary figure in Orissa and lores go that he measured the height of distant mountains in a number if challenging situations with satisfactory accuracy with a pair of sticks only. Therefore, it is a general curiosity to ask, "If so, can we repeat his feats even today?" The answer is definitely "Yes", provided we go through sufficient practice.

Further, exposure of our teachers and student to such simple ways for observation in the grandest open laboratory, i.e. the sky, may arouse in them true spirit for quest, which may culminate in creation of more of Raman, Bose and Chandra Sekhars. We are presenting in this manual only five of the traditional instruments which have immediate relevance. These instruments are 1. Dhanuryantra, 2. Shanku & Sundial, 3. Chapayantra, 4. Gola Yantra and 5. Mana Yantra. We present their construction, principle of working and uses in the following pages.

1. DHANURYANTRA :

In modern literature it is called "sky cross". In fact, this simple legendary instrument made of coconut leaf sticks and a genuineness of Samanta as a practical astronomer to Jogesh Chandra Ray in an evening in 1890's at Cuttack.

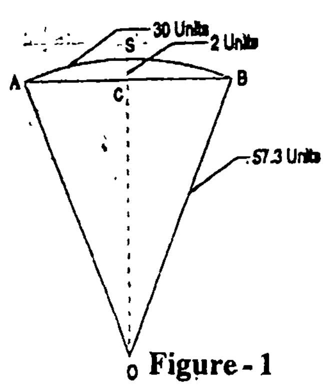


Figure - 1

Theory:

Let us look at the geometry of the figure by the side. (Fig-1). Let s be the length of the arc ASB of a circle of which O is the centre and AO = SO = BO are radii. C is the midpoint of the chord AB. It is well known in geometry that $s = r\theta$; where *s* is the arc length, r the radius and θ is the angle subtended at the centre of the circle by s given in radian. It isfurther known that $180° = \pi$ radian. In other words, an angle of $\theta° = \theta \times \pi/180$ radian $= \theta/57.3$ radian. Therefore, the arc length $s = r\theta°/57.3$. If the radius is made 57.3 units, then $s = \theta$, i.e. the units of length on s will read angular separation of degrees on the arc. This is so nice!

Construction and working

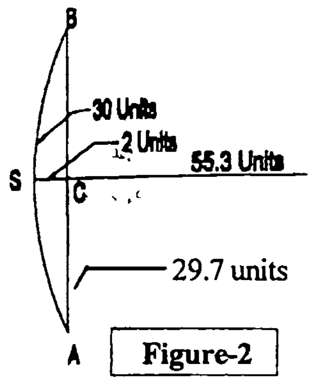


Figure-2

Bend the strip ASB (bamboo or iron wire) of 30cm length into a uniform arc tied by a string of 29.7cm length. Attach another stick 57.3cm from the mid point S of ASB such that it is perpendicular to AB and intersects the string at C. Check that SC = 2cm. Let O be the free end of the handle stick SCO. Now looking from the free end, separation between the celestial objects can be read in degrees from their cm separation on the arc. Subdivisions of mm will read 6′ each.

Experiment

With the dhanuryantra the separation between the stars in the Ursa Major and the distance of α-UrsaMajoris from the pole star may be checked with reference to Fig - 3.

Materials Required

1. 31cm wire or strip with ½ cm margin at both ends and graduated all through in cm and mm.
2. A 31cm string with margin for tieing and with graduation marks.
3. A 59cm handle stick (thicker) with marking at 57.3cm distance from initial margin and with holes for insertion of arc rod and chord strings at measured positions i.e. at 0 cm and 2cm from the initial margin.

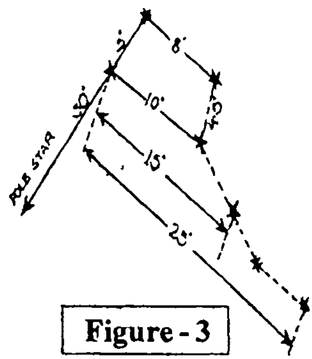


Figure - 3

An Historic Episode

It was February 1891. Sri J.C. Ray, a young professor of Physical Science of Cuttack College (Later on Ravenshaw College) and his companions met Chandra Sekhar at a place in Cuttack in the evening as scheduled previous day. Planets Mars and Venus were quite close in the western sky by that time. Prof. Ray had noticed them the previous evening and measured their separation as 6°20′ with a sextant.He had decided to set the event as a task for Samanta.So, pointing towards the western sky, he asked Chandra

Sekhar to tell the separation between theplanets. To this Samanta replied that they were 6° apart. But the scientist groups were not convinced by the mere statement .

They wanted to know the measurement. Here, Chandra Sekhar asked for two strands of coconut leaf sticks and a piece of string. With that he made this simple instrument and demonstrated the separation as stated. The group of modern scientists were awestruck by the effectiveness of the raw device and cheerfully began to believe Samanta's genuineness as an astronomer.

2.SHANKU AND HORIZONTAL SUNDIAL :

A. Shanku (Gnomon)

Gnomon is a vertical stick usually 12 units in length when affixed on a label ground under the open sky. Its shadow will measure a number of astronomical parameters.

(i) Location of directions using the Gnomon

On any day let the sun rise at a point E and set at W. let OA be the length of the shadow of gnomon OX at an instant before noon corresponding to the sun's position S and let S′ be the sun's position for a shadow length OA′ = OA an instant after- noon.

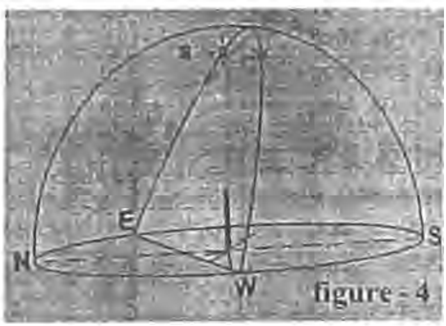


figure - 4

Bisect the angle AOA′ to get the line ON, which indicates north and its extension NOS south. If $\delta > \phi$, ON would point south, δ = declination of sun ; ϕ = latitude of place.

(ii) Latitude drom the equinoctical shadow

Let the shadow of OX on the noon of equinotical day be OA. Let z be the zenith and ZXS be the angle of latitude ϕ.

$$\therefore \tan\phi = \frac{OA}{12}$$

When OA is measured accurately, ϕ can be computed.

(iii) Declination of the sun

On any non-equinoctial day, $\tan(\phi-\delta) = \frac{OA}{12}$. So $(\phi-\delta)$ and δ can be computed. If ϕ is known.

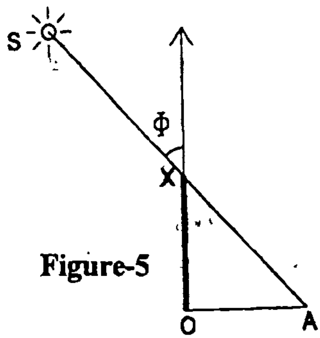


Figure-5

(iv) Longitude of the Sun

If ω is the inclination of liptic to the equator which is $23^1/_2°$; Sin δ = Sin λ Sin ω (from spherical trigonometry) So λ can be computed, if δ is known.

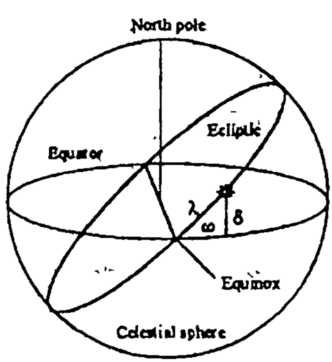


Figure-6

B. Horizontal Sun-dial

ONM is a right-angled chip to be inserted in the slot, such that ON points to the pole star. The hour marks on the dial are not equally spaced. The marks are determined by the formulae, $\tan \psi = \sin \phi . \tan H$; where ψ is the angle on the horizontal dial and H is the equidistant hour angles of equatorial dial, ϕ is the latitude.

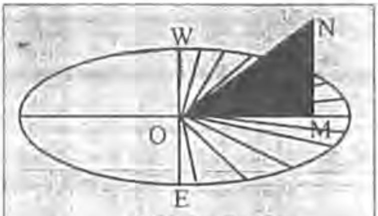


Figure-7

3. Equatorial sun-dial (Chapa Yantra) :

The plane of the dial is made to incline with the vertical by the angle of latitude of the place tilted towards the equator. The hour markings are equally spaced. The dial is to be set EW with the index rod pointing to the pole star. Both the dials will read local times.

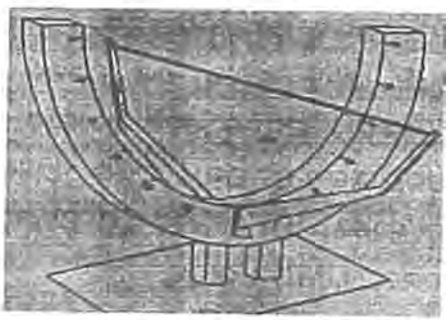


figure - 8

Seasonal correction tables are to be used to arrive at correct standard time. Appended herewith is a correction table for Bhubaneswar. However, each school or individual have to prepare their local correction tables.

Table-1Corrections in Local Time (Courtesy Sri R.N. Swain)

Month	*Date & Correction in minutes*			
	1	8	15	22
January	+ 3	+ 6	+ 8	+10
February	+12	+ 13	+14	+13
March	+ 12	+ 11	+ 9	+ 7
April	+ 4	+2	0	– 2
May	–3	– 4	– 4	– 3
June	– 2	–1	0	+ 3
July	+ 4	+ 5	+ 6	+ 7
August	+ 6	+ 5	+ 4	+ 3
September	0	-3	-5	-8
October	-11	-12	-14	-12
November	-17	-16	-14	-12
December	-9	-6	-3	0

4. GOLA YANTRA (ARMILLARY SPHERE) :

It is an instrument used invariably by all ancient astronomers. Basically it is a model of the terrestrial and celestial speheres. Set properly, it can be used to demonstrate the various astronomical reference circles imagined in the sky and also to measure the angular positions of celestial bodies. Even motion of planets can be demonstrated with this device.

(a) Description : Azimuth-altitude measurement

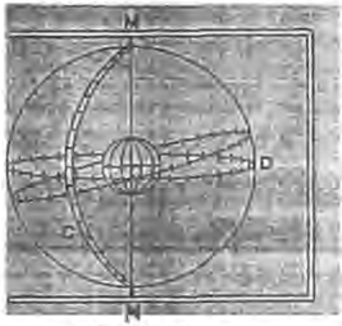


figure- 9

The diagram explains most of the components. The small central sphere, which is the replica of Earth, can be made to slide at will between the slip-holders. The object is to be viewed through the hole through the central sphere and its position be marked by sliding the movable scale C. The instrument can be set vertically or at desired inclination to the vertical by moving the end M on a graduated groove scale while the end N is fixed ; but rotatable. When vertically fixed, the graduations on C and D give respectively the altitude and azimuth when read with reference to zero positions. The local north point on horizon is taken as zero point for the azimuth and horizon again as zero point for the altitude. Conversion to geocentric equatorial coordinates can be made with standard formulae.

Definitions

1. Altitude of a celestial body is its angular distance from the horizon measured along a vertical circle.
2. Azimuth is the angle between meridian of the star and the observer's prime meridian.

(b) Measurement in equatorial co-ordinates

figure - 10

By moving the end M on the graduated scale the instrument can be made to point to the pole-star, so that the axis MN becomes parallel to the axis of earth. So now the instrument becomes parallel with the terrestrial sphere. The co-ordinate systems become parallel with only a change of origin by a distance of the radius of the earth and by the angles of local position.

In this setting, the angle of the object on the horizontal circular scale is to be read with zero at the east point of the equinoctical day and reading on the vertical scale be taken with respect to the equator. Let this angle be θ. So the declination of the object is $\delta = \phi \pm \theta$; where ϕ is the latitude of the place.

A positive sign is for both ϕ and θ north or south and negative for opposite locations. A δ negative will mean location in the opposite hemisphere.

The next reading is the angle α on the horizontal circular scale read with the east point of the equinoctical day as zero point. This angle is almost the right ascension. In stead of that one measures the hour angle in the equatorial system. It is the angle between the meridian of the observer and meridian of the object. Rather it is the analogue of longitude difference on earth. This can straight be measured with the instrument in this setting.

(C) Conversion of azimuth altitude to equatorial co-ordinates and vice-versa.

Standard formulae are available. Let the position of a celestial object have azimuth A and altitude a. let δ be the declination and H, the hour angle; also let ϕ be the local latitude. Now the standard formulae give,

$$\text{Sin } \delta = \text{Sin } \phi . \text{ Sin a} + \text{Cos } \phi . \text{ Cos a} . \text{ Cos A} \qquad (1)$$

$$\text{Cos H} = (\text{Sin a} - \text{Sin } \phi . \text{ Sin } \delta) / (\text{Cos } \phi . \text{ Cos } \delta) \qquad (2)$$

One can also get conversely,

$$\text{Sin a} = \text{Sin } \phi . \text{ Sin } \delta + \text{Cos } \phi . \text{ Cos } \delta . \text{ Cos H} \qquad (3)$$

$$\text{Cos A} = (\text{Sin } \delta - \text{Sin } \phi . \text{ Sin a}) / (\text{Cos } \phi . \text{ Cos a}) \qquad (4)$$

Example-1. *A star of declination 12° is observed with hour angle 3 hrs. If the observation is taken at Bhubaneswar with latitude 20°, calculate the azimuth and altitude at the time of observation.*

Solution : Given $\delta = 12^o$, $H = 3hrs = 3 \times 15^o = 45^o$,

$\phi = 20^o$

It is asked to find a and A

Now from the data,

$Sin\ \delta = 0.2079$, $Cos\ \delta = 0.9178$, $Cos\ H = 0.7071$.

$Sin\ \phi = 0.3420$ and $Cos\ \phi = 0.9397$

Using equation (3)

$$Sin\ a = 0.3420 \times 0.2079 + 0.9397 \times 0.9178 \times 0.7071$$

$$= 0.6809 \Rightarrow a = 37^o.57 = 37^o34'41''.$$

So the altitude is $37^o34'41''$.

Using equation (4),

$$Cos\ A = (0.2079 - 0.3420 \times 0.6809) / (0.9397 \times 0.7926)$$

$$= (0.2079 - 0.2328) / 0.7448$$

$$= -0.0249/0.7498 = -0.0334]$$

$\therefore A = 91^o54'57''$, *which is the azimuth.*

A within 0^o *to* 180^o *is West and within* 180^o *to* 360^o *is East.*

Example – 2. *Calculate the declination and hour angle of he sun at Puri with latitude 19^o when its altitude is 50^o and azimuth 65^o east.*

Solution: *Given,* $\phi = 19^o$; $a = 50^o$ *and* $A = 65^o$.
Required to find δ *and* H.

$\cos\phi = 0.9455$, $\sin\phi = 0.32556$, $\cos a = 0.6427$,
$\sin a = 0.766$ and $\cos A = 0.4226$.

Using equation (1),

$$\sin\delta = 0.32556 \times 0.766 + 0.9455 \times 0.6427 \times 0.4226 = 0.50618$$

$\Rightarrow \delta = 30^o 24' 35''$.
So $\cos\delta = 0.8624$.
And $\cos H = (0.766 - 0.32556 \times 0.50618)/(0.9455 \times 0.8624) = 0.1512/0.8154 = 0.18544$
$\Rightarrow H = 79.31^o = 5.2875$

(d) Variations of Rising and Setting points of the sun over a year.

Due to variation in declination, the rising and setting points of the sun varies throughout the year.
See equation (4) for rising and setting;

$a = 0$,

$\Rightarrow \cos A$ (Rising Setting) $= \sin\delta/\cos\phi$
or $A = \cos^{-1}(\sin\delta/\cos\phi)$ (5)

Example 3 : *Calculate the positions of sun-rise and sun-set for Bhubaneswar with latitude 20^o. Given declination of the sun for the following days.*

April 21	$\delta = 11°30'$ N
May22	$\delta = 20°12'$ N
October23	$\delta = 11°30'$ S
November	$\delta = 20°12'$ S

Solution: $\phi = 20°$ $\Rightarrow$ $\cos\phi = 0.93969$

Dates	21/4	22/5	23/10	22/11
δ	$11.5°$	$20.2°$	$-11.5°$	$-20.2°$
$\sin\delta$	0.199367	0.3453	-0.199367	-0.3453
Cos A	0.212162	0.3674	-0.212162	-.3674
A	$77°.75$	$68°.44$	$102.24°$	$111.55°$

(e) Sun Rise, Sun-Set and Day Duration

Sun rise and sun-set times can be computed by using the Chara correction, (ascensional difference) given by $\sin\psi = \tan\phi \,.\, \tan\delta$*, and the day-time duration is found from there.*

Example - 4: *Calculate the time of sun-rise and sun set at Bhubaneswar on Jan 1, April 1, July 1, October 1. Corresponding declinations of the sun are* $-23°7'$, $+4°17'$, $+23°18'$ *and* $-2°.55'$ *respectively. Hence compute the day and night duration on these dates.*

Solution.: Given the station to be Bhubaneswar with latitude $\varphi = 20°.15$. *So* $\tan\varphi = 0.3669$

Dates	1/1	4/1	7/1	10/1
δ	$-23°.7'$	$4°7'$	$+23°18'$	$-2°55'$

tanδ	*-0.4278*	*0.0748*	*0.430*	*-0.050*
sinψ	*-0.15695*	*0.0274*	*0.1577*	*-0.01834*
ψ	*-9°.029*	*1°.5°7*	*9°.07*	*-1°.050*
In Hr etc.	*0 36'7"*	*06'17"*	*036'17"*	*04'12"*

In case of negative declination this amount of time is to be added with 6AM and subtracted from 6PM to give the sun rise and sun set and in positive declination, these times are to be subtracted from 6AM and added with 6PM to give the corresponding values.

So following are the sun rise and sun set timings.

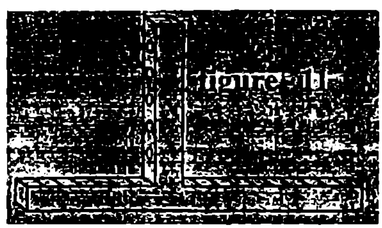
Sunrise in AM	*6 36'7"*	*5 53'3"*	*5 23'17"*	*6 4'12"*
Sunset in PM	*5 23'53"*	*6 6'17"*	*6 36'17"*	*5 55'48"*

From these, day and night durations can be calculated.

So, simple measurement with the Gola Yantra can lead to many interesting applications.

5. THE MANA-YANTRA (MEASURING INSTRUMENT) :

This is the instrument which has made Samanta a myth in Orissa. He correctly estimated the heights of distant mountains with this T-shaped device. In this simplified version of the actual instrument, the horizontal arms AO and BO are unequal. The vertical rod OC is pierced with small holes facing the horizontal arms at equal intervals or in a more modern set, a rider can be moved on the vertical groove making one single hole at desired position.



Mode of measurement.

In order to measure the height of distant objects, one has to hold the arm AOB (as in the figure on the cover) parallel to the ground and look through the hole on the vertical arm keeping one end of the horizontal bar, the hole and tip of the object in a straight line. Positionofthe hole on the vertical arm is noted. Such coincidence may come often in between two holes. In that case, the vertical reading with a paper strip is noted. For another reading one has to move backward in a straight line some 20, 50, 100, or 500 feet, as the need may be. One has to move longer distance for farther objects. Then with the instrument again a similar reading is taken and position of coincidence on the vertical scale is noted. From these observations both height and distance can be computed.

Theory

Let b_1 be the length of the horizontal arm from the fixed position O to an end. Let p_1 and p_2 be the heights on vertical arm marking coincidences in the first lrt d be the distance moved and second reading. So from similar triangles we will have,

$z / p_1 = (x + b_1)/b_1$ and $z/p_2 = (x + d + b_1)/b_1$ (6)

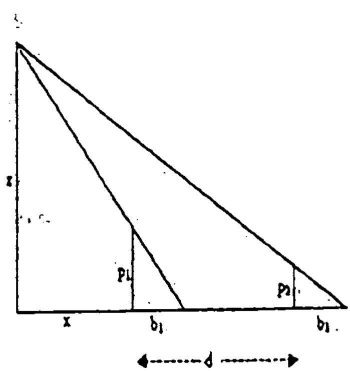


Figure - 12

where z and x are respectively the height and distance of the object. Neglecting b_1 compared to x and (x+d) one gets,

$z / p_1 = x / b_1$ and $z / p_2 = (x + d) / b_1$ (7)

These equations when solved give

$$x = d / [(p_1 / p_2)-1] \text{ and } z = (p_1 / b_1) \cdot d / [(p_1 / p_2)-1] \quad (8)$$

Two other episodes

It was around the year 1866. Samanta Chandra Sekhar had become somewhat well known in about a score of Gadajat states and British ruled regions of Orissa as a skilled astronomer. Around this time, Chandra Sekhar's nephew, King Natabara Simha of Khandapada got married in the royal family of Parikuda islands inside the Chilika lake. Chandra Sekahar went with the bridal party. He was introduced to King Jagannath Rajamani Dev of Manjusha, an invitee of the bride's side. The king was curious in nature. He invited the astronomer to his state. There he asked Chandra Sekhar to measure the height of mount Mahendra Giri. The astronomer, at the earliest convenience during the stay there estimated the height and gave the result to the king. The king was highly pleased and informed the Madras Government of Samanta's skills, so that he became famous in South India. Here, Samanta hade made use of his most favourite Mana Yantra for the measurement.

A second memorable instance was in 1893. Samanta was proceeding to participate in a Darbar in which the title of Mahamahopadhyaya was to be conferred upon him. In a curious turn of events, he had to meet the then British Commissioner, Mr. Cook at Cuttack, in latter's residence. In spite of the Government's recognition, the British officer wanted to test the astronomer. So he pointed to mount Sapta Sajya at Dhenkanal visible from Cuttack and wanted Samanta to give its height. Samanta, with his Mana Yantra took the measurement and stated the correct height. The Saheb congratulated the astronomer; and saluted him and to his Mana Yantra.

6. CONCLUSION

These are a few simple instruments which may be supplemented with a sextant and an astronomical telescope for making our schools active centres of astronomical observations. For calculations, an average scientific calculator is adequate.

EXERCISE

On Dhanuryantra

1. measure the separations between the stars in Ursa-Major and that of α-Ursa Majoris from the Pole star. Check them with standard data.
2. Measure the angular distance of Betelgeuse (Ardra) and Rigel (Bana Raja) from the middle star in Orion's belt.
3. Measure the local laatitude from elevation of the Pole star.
4. Compare the angular diameters of the full moon at horizon and zenith.

On gnomon

5. Using a gnomon, find the declination of sun on any day using local value of latitude. (Refer a standard geographical atlas)
6. Can you measure the declination of moon using the gnomon? Use an alternative of the shadow method. (Casting the moon's image through a pipe fitted with lens).
7. Estimate the inclination of ecliptic to the equator and if possible, inclination of moon's orbit to the ecliptic.
8. Using results of Q. No. 5,6 and 7, compute the longitude of the sun and approximate longitude of moon.

On Gola Yantra

9. A star of declination 23° is observed with hour angle 5 hrs.if the observation is taken at latitude 30°, calculate the altitude and azimuth at the local station.
10. Calculate the declination and hour angle of sun at your local latitude, when its altitude is 15° and azimuth 105° west.
11. Calculate the positions of sunrise and sunset at your latitude on December 1, March 1,June 1 & September 1 corresponding to sun's declinations −21°41′,−7°50′,+21°58′ and +8°31′ respectively on these dates.
12. Calculate the durations of day and night on the above dates for your latitude.

On Sundial

13. Take observations with horizontal and equatorial sundials and prepare a local time correction table in each 10 day interval for a year at your latitude.
14. Make a table of angular separations of time lines for each 15′ interval for a horizontal sundial with the formula from the text.

On Mana Yantra

15.(i) Estimate the heights of local tall buildings or hill, atleast for five cases. Check your estimate with standard values and find the % of error in each case.

(ii). Estimate the altitude of sun and from there get the local time. Compare with standard watch.

(iii) Estimate the spans of constellations Leo and Scorpion with Mana Yantra.

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SAMANTA CHANDRA SEKHAR
(1835 - 1904)