11 ASTRONOMICAL OBSERVATORIES

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DEVELOPMENT OF ASTRONOMICAL OBSERVATORIES

In astronomical lore of ancients there were very few simple instruments. Naked eye observations were the earliest attempt to record astronomical events. The man observing his own shadow developed some empirical relations for knowing time lapsed after sunrise and also the time remaining of the day[1]. This way the use of gnomon (a vertical stick) started in a systematic fashion and the science of sciatherics (gnomonics) developed. At the same time or even earlier, water clock (clepsydra) might have been used in determining time. The rising and setting of Sun, Moon and stars, the waxing and waning of Moon's phases, lunar and solar eclipses and also the occultations of Moon and planets (like conjunction of Jupiter with δ-Cancri etc.) and other phenomena like heliocentric rising and setting of planets, etc. always fascinated the ancient man to have open air observatories.

We find a simple stick (or a *nalikā*, tube) and a thread being used for determining the diurnal rising and setting of Sun, Moon and planets, in the horizon of the locality[2]. This was the simplest instrument prepared by drawing a circle on ground and a stick was being used for pointing towards the disc of Sun, Moon or planet at the time of rising or setting. The thread (*davarikā* as sometimes it is called) was being used to draw geometrically the chords in the experiments as shown in fig. 11.1.

This is probably the first instrument in open-air observatory used for planetary observations. A simple stick and a tube too served the purpose to observe planets' conjunction etc. Along with it a gnomon [3] was being used for determining time. The gnomon might have been used for standardizing the amount of water in clepsydra on equinoctiol days.[4] These two instruments might have been used simultaneously for defining *muhūrtas*[5] during day and also during night from observations of Moon's shadow.[6] The observatories evolved from these open air collections having these simple instruments. We do not have any record of old observatories but there are scattered references like those of Emperor Babur mentioning the old observatory of Vikramāditya's time.[7] There is no doubt that the instruments were evolving gradually as evidenced from studies of astronomical texts in chronological fashion. When the spherical nature of shape of the Earth was established, a geometrical globe was developed as described in last chapter of *Sūrya-siddhānta*.[8] This instrument gave birth to a celestial globe when the astronomical circles like celestial equator, ecliptic etc. were defined. The *khagola*[9] (celestial sphere) was prepared by using wires or wooden splinters. The present recension of *Sūrya-siddhānta* mentions the setting of this instru-

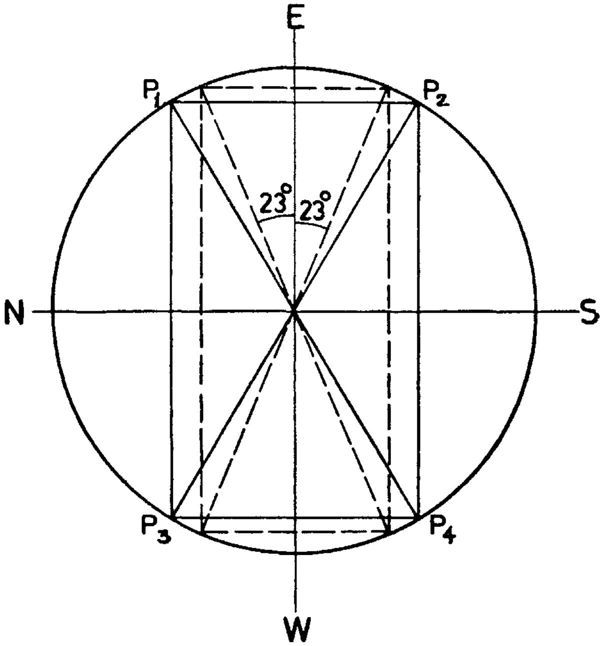


Fig. 11.1.

1. Cardinal coordinates used for celestial bodies at the time of rising due to diurnal motion in ancient astronomical tradition as in Vedaṅgajyotiṣa, Śulbasutras Sūryaprajñapti etc.

2. The height of planets etc. was defined w.r. to cardinal point S and was measured simply by geometrical construction. It was declinational height profected on the earth.

ment which in a bigger shape formed the armillary sphere used in observatories. It also gives some details of instruments like.

(1) Yaṣṭi the instrument already described, fig. 7.6..

(2) Dhanu (arc with chord) to be used for observing rising or setting celestial bodies, with the help of *śara* (the arrow) formed of a stick.

(3) Cakra, the wheel like instrument used for determining declination etc. or even for determining time by observing transits of stars.

(4) Watches being run with the help of sand, water, oil etc. Water clocks made in the shape of *mayūra* (peacock) and monkey-shaped Yantras.

(5) Kapāla-yantra (Bowl shaped water clock) with a thread in its hole.

(6) Gnomon or Nara-yantra,[9] [10] of 12 *aṅgulas*.

All these instruments constituted observatories in older times. Later in treatises like Brahmagupta's, Lalla's etc. and in *Siddhānta-śiromaṇi* of Bhāskarācārya, we find more detailed descriptions of astronomical instruments.[11] Bhāskarācārya discusses the following instruments :

(1) *Golayantra, the armillary sphere*—A sphere in which all movable and fixed circles are designed and the observer can perform observations sitting within the sphere itself. Āryabhaṭa-I has given little details of this instrument,[12] but Brahmagupta and Lalla have given similar elaborate details. This instrument although inconvenient to use, serves the purpose of an astrolabe. It may be remarked that Bhāskarācārya performed lunar observations with the help of this instrument and compiled his *Bījopanaya*[13] in which he discusses the variable corrections (sinusoidally varying corrections) to the moon.

(2) *Cakra-yantra*—A wooden or metallic wheel like structure with an axis fixed in a hole at its centre. It was fixed in the plane of ecliptic with the help of *yogatārās* of Puṣya, Maghā, Śatabhiṣaj and Revatī, which have almost zero latitude. It was used to determine longitudes and latitudes of planets.

(3) *Cāpa-yantra*—Just half the structure of Cakra-yantra.

(4) *Turīya-yantra*—Only one quadrant of the Cakra-yantra with a stick or *nalikā* (tube) for observing celestial bodies in order to determine their zenith distances and altitudes.

(5) *Nāḍīvalaya*—A Cakra in the plane of the equator used to determine directly timings of rising and setting of signs, horā, dreṣkāṇa, navāṃśa, etc.

(6) *Ghaṭī-yantra*—A *droṇa* (bowl-shaped) water-clock with a hole of standardized size at its bottom.[14]

(7) *Nara* or *Śaṅku* (the gnomon) made of ivory or a metal.

(8) *Phalaka-yantra*—A plank with a circle of radius 30 *aṅgulas* drawn on it. The circle is graduated in *ghaṭīs* and degrees. A *paṭṭī* of half *aṅgula* width and of length 60 *aṅgulas* (and some additional length of one *aṅgula* for fixing) is fixed in the axis through the centre of the circle. The axis forms a gnomon. The instrument is made to hang with the help of a chain. The *paṭṭī* is placed passing through the shadow on the circumference of the circle. When hanging in the plane of vertical circle, the instrument can read zenith distance directly through graduations on the circle. An additional attachment *yaṣṭi* is prepared by analytically computing its length using the latitude of the place of observation and the subsequent ascensional difference at the time of observation. This helps determining the hour angle of the Sun (and hence the time) just geometrically without going into the detailed computations.

(9) *Yaṣṭi-yantra*—consists of a circle with radius=the radius adopted for the chord sines in the text and east-west north-south points are marked on it. There is another concentric circle with radius=*dyujyā*=sin (codeclination)=R Sin (codeclination). The line joining the rising and setting points on the horizon is the *udyāsta-sūtra*. A *yaṣṭi* (rod) of length=radius R is used to point towards the Sun so that its shadow vanishes. This way the Sun is at the tip of the *yaṣṭi* (the *yaṣṭi* is to be rotated as the Sun moves along the *ahorātra-vṛtta* (diurnal circle) and consequently its hour angle changes). The distance between the tip of the *yaṣṭi* and the Sun's rising point is measured and a full chord *(jyā)* of this much length is drawn in the diurnal circle. The *ghaṭis* lying in the arc of this chord in the diurnal circle is the *unnatakāla* (i.e. lapsed time of the day after sunrise at the instant of observation). Bhaskarācārya has given various uses of this instrument.

(10) *Dhīyantra*—is the simple stick instrument (augmented by a plumbline like device to assign vertical direction). It was used to determine the heights and distances of objects by measuring the inclinations or angles of elevation (actually *bhuja* (x-coordinate) and *koṭi* (y-coordinate in Bhaskarācārya's treatment) at different points. The method is similar to the one depending upon parallaxes of terrestrial and celestial objects. This was used for determining heights, distances etc. by observing the objects also in water.[15] It may be remarked that in Bhāskarācāray's treatment geometry of refraction at an angle within water was not at all used. He used the facts like that the image of a vertically standing tree etc. within water is of the same size as the tree itself. In the solutions of problems by Bhaskarācārya the refraction does not occur, so his solutions are not affected by refraction. It may be remarked that laws of reflection were known to Indian astronomers of olden times,[16] but the laws of refraction were not discussed.

It may be remarked that in general these are the instruments described in standard treatises, but there are some variations or some additions by later astronomers. Gaṇeśa Daivajña (the author of *Grahalāghava*, śaka 1444) devised a whip like horizontal gnomon called the Pratodayantra (*Cābuka* instrument or the hunter sun-dial). A small booklet was written by him which was included by Munīśvara in his *Siddhānta-sārvabhauma*.[17] This is of cylindrical shape in which a gnomon of 1/6th of its size in holes (12 in number, one for each month) in the beginning of vertical columns. Thus there are 12 vertical columns graduated for observing shadows in all the 12 months throughout the year. There are other columns also to determine other parameters like *unnatāṃśas* (altitude) etc. too. The *Pratoda-yantra* was brought to light by Junnerkar of Pāṭana (Gujarat) in V. 1959,[18] and these are now found with some families too. This instrument was used to determine time during the day.

It is worthwhile to remark here that gnomonics in Indian tradition developed from ancient times to the time of Sawai Jai Singh. We find in Phalaka-yantra of Bhaskarācārya and in Pratoda-yantra of Gaṇeśa Daivajña the use of horizontal gnomons, while only vertical gnomons were being used in earlier works. In Sawai Jai Singh's instruments, we find the use of triangular gnomons and much more sophisticated uses of the vertical and horizontal gnomons as well, which will be discussed in details in the next sections.

It may be remarked that gnomons were also used to determine obliquity, latitude, hour angle (in terms of lapsed time of the day) etc. too. In the *Sūrya-siddhānta*[19] there is described a method for observing planets at the time of conjunction through a mirror with the help of two gnomons.[20] Also the gnomons were used to determine time during night too using shadow of the Moon, but this was an inadequate and erroneous method to define *muhūrtas* in terms of hour-angles of the Moon, (as 5° latitude of the lunar orbit will introduce much error in these findings) We also find nocturnal instruments[21] in Indian tradition, which were used to determine time during night using observations of *dhruvamatsya* (fish-shaped group of polar stars including Polaris) and during day using observations of the Sun. This could be used to determine *lagna* (ascendant) also. A book entitled *Dhruvabhramana-yantra* was written by Padmanābha S/o Nārmada (śaka 1320=A.D. 1398). In fact this forms the second chapter of this book *Yantra-ratnāvali*, or *Yantrakiranavali*. We also have a text on practical astronomy by Cintāmaṇi Dixit named '*Golānanda* which discusses an instrument designed to give equations of centre of planets, radii vectors *(śighrakarṇas)*, true velocities *(spaṣṭagati)*, declinations, latitudes, ascensional differences, ascendant (*lagna*), direction, altitude, parallaxes in longitude and latitude etc. A commentary on this text was written by Yajñeśvara. Another book on practical astronomy was written by Srī Viśrāma in 1537 śāka. We also find a small text on Koṇeri-yantra which is an instrument similar to the Dhī-yāntra of Bhāskarācārya. There might have been developed many other instruments and texts on practical Hindu Astronomy of which we have no records available now. All these instruments were designed either to find correct time or to determine planetary positions.

OBSERVATORIES OF SAWAI JAI SINGH

From previous section it is clear that astronomical instruments had been developing since early *Vedāṅga Jyotiṣa* period upto the medieval times in the hands of exponents of siddhāntic astronomy. There were open air observatories for daily observations of rising and setting of Sun (also of Moon and planets) for determination of solar year etc. as described in *Śulba-sūtras* and *Sūrya-prajñapti*. At the time of these observations time measuring devices, gnomon and clepsydra, too might have been placed nearby the place of the observation. The gnomon might have been used to standardize or calibrate clepsydras. The units of time, *muhūrtas* and *ghaṭīs* and the shadow length and equivalent waters were standardized by simultaneous use of these two instruments. These two portable instruments and the simple fixed circular device augmented with *dawarikā* (thread), as already shown in fig. 7.6, formed the earliest open air observatory. Later on more instruments were added as they developed. Gnomonic experiments were performed throughout the year to determine seasons etc. in terms of locus of shadow. Circular structures on levelled grounds for use of gnomons in order to determine position declination of Sun formed better structure instruments. On measurements using such devices cardinal points were used as coordinates and declinations as heights in diurnal paths. we do not have any records of those observatories now. But there are scattered references, for example, Emperor Bābur mentions of an observatcry of Vikramāditya's time. He writes in his memoire.

"Another observatory was made in Hindustan, in the time of Hindu Raja Vikramāditya, in Ujjain and Dhāra that is the Malwa country now known as Mandu. The Hindus of Hindustan use the tables of this observatory. They were put together 1584 years ago".[22]

These days we have only the observatories of Jai Singh preserved. Rajā Jai Singh Sawāi A.D. (1686—1743) constructed observatories at Delhi, Ujjain, Jaipur and Varanasi. There was an observatory in Mathura which is now no more. About the origin of these we have the evidence in document *Zīj Muḥammad Shāhi*. Lt. R. I. Gerrett worked on restoration of Jaipur observatory with the help of Chimman Lal Daroga, Pt. Chandradhara Guleri, Mistri Maliram and Shri Gokula Chandra Bhāvana.[23] Lt. Gerrett did not express his opinion about *Zīj Muḥammad Shāhi*.

In 1918 after discovery of Ulugh Beg's observatory,[24] Department of Archaeology of Government of India examined the tables and concluded that Jai Singh's star-tables were ordered the same way as Ulugh Beg's. Longitudes differed by 4°.8 due to precession but latitudes were the same. Also the astronomical tables were similar to those of De La Hire's.[25] But according to the preface, Jai Singh himself constructed these tables. There are many discrepancies and anomalies in this text and thus these deserve special study for any conclusive inference. According to Kaye, Padre Manuel and Mohammad Sharif were sent to Europe and other countries and in A.D. 1728. Father Figuereda, a Portuguese Jesuit, was sent to Portugal. In spite of all the informations, Jai Singh did not use the then available astronomical equipments in his observatories. Jai Singh renovated these and developed some instruments of his own. Māna Mandira observatory was two hundred years earlier than Jai Singh, as is evidenced from A. Campbell and T. D. Pearge's records who visited this observatory in 1770 and stated that the observatory was built two centuries earlier.[26] It makes no sense to construct a new observatory on the roof of an old building. It is logical to accept that an old one might have been restored by Jai Singh. William Hunter[27] and later Kaye summarised that Banaras observatory was one of the five Jantar Mantars erected by Jai Singh, the four others being built in Delhi, Ajmer, Ujjain and Mathura. Tavernier and Prinsep visited India in 17th century A.D. at the time of reign of another Rajā Jai Singh and took it for Jai Singh's work. The records of instruments in Bhāskarācārya's and others' works and the reports on Vikramāditya's observatory show that the traditions of astronomical techniques were in vogue in India throughout all centuries from Pre-christian era to the time of Jai Singh in different parts of the country in spite of many invasions and political upheavals.

Now let us turn our attention towards the equipments in these observatories. On seeing the big massive masonary instruments in Jantar Mantars, the first question, which occurs in one's mind is why Jai Singh constructed big stony structures leaving aside the metallic instruments which could easily be prepared during those daysö Here we try to view the problem faced by Jai Singh in the light of the back-ground of his astronomical achievements at that time.

The Reason why Jai Singh Resorted to Massive Masonary Instruments

Rajā Jai Singh was trained in his early years, in the field of Hindu astronomy but he was not satisfied with the use of old data on astronomical constants and wanted patterns advanced in comparison with those of earlier Indian astronomers. He interacted with scholars of Moslem world and got attracted to astrolabes and other metallic instruments. He got metallic instruments prepared with improvements and modifications which could give results in Indian astronomical tradition. According to *Ẓij Muāammad Shhāi.* (A.D. 1719—1748), he constructed Zat-al-Halqua (a spherical shape instrument *Golayantra*) with diameter = 3 gaz, Zat-al-Shabātain (an astrolabe with two parts *akṣs-patras* (discs for different latitudes) and *bhapatra* (disc with zodiac signs), Zat-al-Zaquātin and Sadas Fukhri (Shud-Sufkari in Arabic), (*SqsṭṭhFωsa yantra* according to Jagannatha) and *ShnmlFh* (the word used by W. Hunter for Jai Prakash Yantra) etc. A number of such instruments are still preserved in repositories in Jaipur and Varanasi,[28]

After using these instruments he realized that these instruments although being very handy suffered from serious limitations on account of their small size, wear and tear, loosening of axes, back-lash errors, displacements of centres, shifting of planes of instruments, inequality of divisions and effects of weathers etc, and took this to be the reason for inaccuracies in works of Hipparchus, Ptolemy, etc. In order to get more accurate results he thought of constructing big masonary instruments which could be best set once for all and being stable were not liable to change their azimuth. His approach was similar to the one adopted by Mirza Ulugh Beg (A.D. 1394-1449) in Samarqand observatory in Central Asia. Greaves states that it had a quadrant used by Ulugh Beg as high as summit of St. Sophia in Constantinople or about 180 ft. Earlier Moslems too devised big instruments. Abul-I-Wafa (A.D. 995) used a quaquadrant of radius 21 feet and 8 inches. Al-Khojendi used a sextant with radius = 57 feet 9 inches.[29]

He[30] (Jai Singh) constructed in Dar-al-Khilafat in Shāh-Jahānbād (i.e. in Delhi) an observatory in which he erected instruments of his own invention, such as Jai Prakāśa Yantra, Rāma Yantra, and Samrāṭ Yantra, which had semidiameters of eighteen cubits and one minute on it is a barley corn and a half, of lime and stone of perfect stability and in eracting these much care was taken for rules of geometry in adjustments to meridians and to latitudes of the place. This way all types of errors could be rectified. The Delhi observatory got completed by A.D. 1724. In order to confirm the reliability of the results obtained through observations, he constructed similar observatories in Jaipur, Ujjain, Benaras and Mathura. The observations at all these observatories were found to tally well. Later he sent Pedra Manuel to Portugal and some others to European countries who brought astronomical charts, tables and books. Jai Singh had also tables of Ulughbeg, Flamsteed, Tycho Brahe and Havelius, Said Gurgāni and Khāquāmi. On examining these tables and checking the computed results on the basis of European tables he found that the error in longitude of Moon was sometimes (near half-moon) as large as half a degree and at syzygies too there was some error resulting into error in predictions of eclipses. The times of solar and lunar eclipses were found to be in error to occur earlier or later by by 14th of a *ghaṭī* (=6 minutes). So Jai Singh's belief was confirmed that European instruments which were not of so big sizes suffered from errors. It may be pointed out that Flamsteed (1646-1719) used a sextant of just 6 feet radius, a 3 feet quadrant, a mural arc, (Yâm Yottars, Bhitti yantra) of radius 7 feet. Jai Singh's big instruments at least had better provisions of readings with better accuracies, but later developments of theories based on law of gravitation and advancements in theories of error like level correction, azimuthal correction etc. to be applied theoretically as remedies for errors in setting of transit instruments etc. using vernier calipers and pitch devices surpassed the old techniques. It may be remarked that the errors in the longitude of Moon etc. were not only due to experimental inaccuracies in determinations of equations of centres etc. but in fact were mainly due to the lack of development of lunar theories etc. in the light of law of gravitation at that time. These theories went on improving upto the middle of 19th century or so. There is no doubt that the European developments in these theories upto the 1st quarter of 18th century could not convince Rajā Jai Singh to be any of the better techniques and this was the real reason why he resorted to masonary structures in constructing his original devices. (See next chapter on Jai Singh's knowledge of telescopic observations and their limitations).

INSTRUMENTS IN THE OBSERVATORIES OF JAI SINGH

Now we would like to discuss in brief the instruments set by Jai Singh in his observatories. It may be pointed out that the instruments in all these observatories were the same but with some variations in dimensions etc. Here first we discuss some of the instruments which are described by Bāpu-deva Śāstrī in his exposition on Māna-mandira observatory in Kāśī (Varanasi) in the year 1788 vaka (A.D. 1866).

These days Kāśī Observatory (25° 18′ N, 83° 1′ E) is in a very bad condition. Earlier, it had very good instruments upto 18th century A.D. as reported by Robert Barker (Commander-in-Chief in Bengal in 2nd half of 18th century A.D.)[31], whose report is the earliest on this observatory after Jai Singh. This was prepared for Royal Society of London. Further information was supplied by J. C. Williams in 1792 A.D. He gives the information that the Māna-mandira was much older. It was built for repose of pilgrims and holymen. On the top of this, the observatory was built by Jai Singh. The construction was begun in the year 1794 Vikram (A.D. 1737) and it took two years for completion. Rajā died in 1800 Vikram (A.D. 1743). In 1799 Hunter gave a brief description and spoke of the accuracy of William's descriptions. Sir Joseph Hooker made excellent drawings of the three instruments invented by Jai Singh. He recorded in his diary that the Kāśī Observatory was even then the most interesting monument although it was fast getting in ruins. Paṇḍit Bāpudeva śāstrī,[32] Lālā Chiman Lal, Gokul Chandra Bhāvana,[33] G. R. Kaye[34] and others too have written about the instruments of this observatory.

Here we first describe the instruments of Kāśī observatory as described by Bāpudeva śāstrī in 1866 A.D.[35]

(1) *Yāmyottara-yantra (Mural quadrant)*

There is a Yāmyottara-yantra in the north-south direction in the form of a wall made up of lime brick-stones (hence the name *bhittiyantra*). It is 7½ hands (1 hand = 24 *aṅgulas* = 3/2 feet) in height, 6 hands, and 1½ *aṅgulas* in breadth and 16½ *aṅgulas* in thickness. One of its sides, facing east is whitewashed and smoothened. On this side at the points near top corners there are fixed two gnomons *(śankus)* made of iron, which are separated by 5 [8] hands from each other and are fixed at a height of 7 hands less 2 *aṅgulas* from the ground. With the gnomons as centres and radii equal to the distance between them, there are drawn two intersecting quadrants. Below these both quadrants there are concentric quadrants which are uniformly divided consecutively in 15 parts (6° each), 90 parts (1° each) and 900 parts (6′ each) (See fig. 11.2) This instrument can be seen by the visitors at first sight while entering the Mandira.

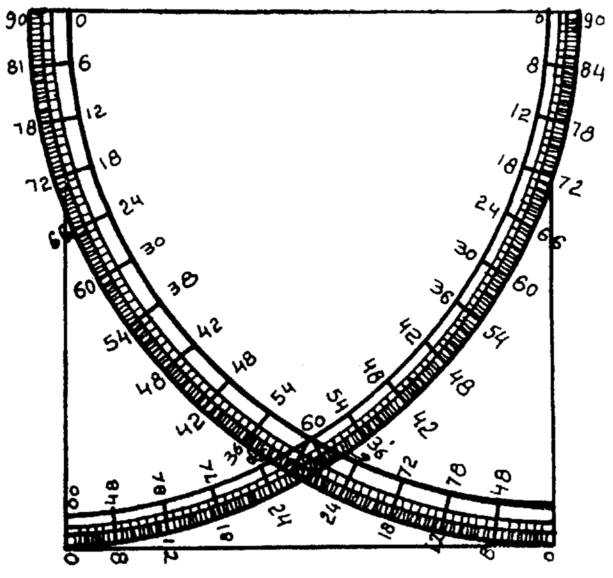


Fig. 11.2

In this instrument every day at midday time when the Sun is on the meridian, the shadow of gnomon falls on the quadrant, whose centre is the former. From the root of the other gnomon upto the shadow are the altitude degrees and from the bottom (upto the shadow) are the co-altitude degrees. But in Varanasi the latitude is more than the maximum declination (the obliquity) of the Sun. So it can not go higher (towards north) than the zenith there. Thus for the Sun, only the quadrant with centre towards south is useful. Here the graduations of both the north-south (gnomon)-centred quadrants are for the observations of all the stars north or south of zenith, when they are on the meridian.

With the help of this instrument one can easily know the latitude of place and the maximum declination of the Sun. Go on observing the zenith distances every day throughout the year. Note the maximum and minimum zenith distances (Z_{Eax} and Z_{mux} (Say)) then the obliquity of ecliptic ϵ (i.e. the maximum declination) is given by

$$\epsilon = \frac{Z\ Z_{max} - E_{min}}{2} \tag{1}$$

Jai Singh performed these observations and found the value $\epsilon = 23°28'$ a value very much accurate in comparison with the value 24° as accepted by all earlier siddhāntic texts. Even the value 23°35' as found by Mahendra Suri using astrolabe in 14th century was not accepted. Now the latitude of the place of observation θ can be found very easiy

$$\theta = Z_{max} - \epsilon = Z_{min} + \epsilon \tag{2}$$

Once the lątitude of the place and obliquity of the eclipıic are known, one can know the declination of the Sun on any desired day. One can directly note the zenith distance Z, at mid-day time; the declination of the Sun δ will be given by

$$\delta = Z \sim \phi$$

Knowing the declination, the longitude of the Sun can be computed.

It may be pointed out that this instrument can also give the zenith distance for Moon on the days when shadow of the gnomon is visible in moon-light. This way the declination of the Moon too could be determined easily. The maximum declination and hence the latitude too could be estimated by selecting proper days for the observations. For stars too this instrument was utilized to determine zenith distances at transit time and hence the declinations. In this case one had to view the star in line with edge of gnomon and see where the line cuts the graduation on the quadrant. In fact the naked eye sighting lacks precision. Still, the declinations of stars were determined and catalogues were prepared using this instrument.

2. *Some unknown instruments*

Towards east of this Yāmyottara yantra there is an adjacent plane with breadth equal to that of the wall and length equal to seven hands. Although it was initially levelled like water (surface) but now it is uneven. On this plane there were fixed two pegs of iron with holes at the top. These are fixed along eastern direction determined by the two gnomons in the wall. At present only one of them in the east exists there. Quite near this plane there is a levelled circular plane made up of lime bricks and with diameter equal to 1 hand and 9 *angulas*. There is also another levelled circular plane made up of stones and having diameter equal to 2 hands and 7 *angulas*.

Near this plane there is a levelled square with side equal to 1 hand and 11 *angulas*. The graduations on these two circular platforms and the square are erased now. But it seems that earlier these were made to determine the gnomonic shadow and the azimuth.

The use[36] of this construction was not clear to Shri Bapudeva śāstrī. It appears that this horizontal plane was used for determining time and zenith distances etc. during the day. Probably, there was only one gnomon and not two as con jectured by Bapudeva vāstrī. It is clear that the Bhitti-yantra is useful for determining the zenith distances at transits only. Before transiting the meridian, the vertical gnomon could be used to determine zenith distances, hour angles etc. The *Bhitti-yantra* has horizontal gnomons, while the horizontal plane had vertical gnomon(s). The plane could be used for all times during the day. The *Bhitti-yantra* with horizontal gnomon(s) could give only the zenith distances at transits, latitude of the place of observation and the declinations but not the time. On the other hand, the vertical gnomon on the horizontal plane could furnish additional information about time. Although latitude, zenith distance etc. can be determined with the vertical gnomon too, the *Bhitti-yantra* has its special merits in that it gives the zenith distance directly and, if used daily, can furnish quite accurate values of declination of the Sun and the latitude of the place of observation.

There were also two circles and a square. This construction too is quite confusing. It appears that circles were drawn for observing the planets or the stars at the time of their rising or setting, to know the azimuthal angle at that time. Circles could also be used to observe the Sun every day at the time of rising or setting and thus determine the declination and the length of the tropical solar year. A stick or a tube through the centre of the circle was used to record the position of the celestial body on the horizon. Such experiments are discussed in *Sūrya-prajñapti* (as also shown in Fig. 11.1) and also later by Bhāsdkarācārya and others. Probably, earlier, the circle had a smaller size, and so another bigger circle was drawn to get more accurate results. The square structure seems to be the result of drawing north-south and east-west lines as reference lines for the para llel directions. Probably, this square was circumscribed by a circle which was used for the observations on the horizon. We can not think of any other feasible explanation for all of them as a single unit or composite instrument but there is no doubt these were *Śulba-sūtra* like devices for observing achronical risings of stars etc.

3. *Yantra Samrāṭ*

Towards north of the Bhitti-yantra somewhat in the eastern part there is another big instrument called Yantra Samrāṭ. This has a gnomon wall which is set in the precisely determined north south direction and is made up of limebrick stones. This is 3 hands in thickness and 24 hands in length. Its upper part is slanting, made up of stones and points towards Polaris. In the south the root side is 4½ hands in height and on the front side in the north it is 15 hands less 3 *aṅgulas* in height. It has ladders in between. On the eastern and western sides there are two stony arcs with radii 6 hands and somewhat more than a quadrant each in size. These have breadth somewhat less than 4 hands and their thickness is $9\frac{1}{2}$ *aṅgulas*. Their centres lie on the *śankupālis* (the edges of the gnomon wall). On each arc there are quadrants which on edges have divisions in 15 equal *ghaṭis*. Each division is further graduated in uniform six subdivisions which are somewhat less than an *angula* in measure. On the *śankupālis* (on both edges of the gnomon wall) there are two small iron rings, whose centres coincide with the centres of the *cāpa-pālis* (the edges of the arcs). In this instrument, during day time, from the root of the gnomon upto the shadow on the *cāpa-pāli* (in units of *ghaṭi*-timings or the *nata-ghaṭis*). If the shadow of the gnomon falls on the western side then take these (*nata-ghaṭis)* to be the time left for midday and if the shadow falls on the eastern side then take these to be the time past midday. In order to see keenly the shadow from nearby positions there are made stony ridin passages on both the arcs. But now because of excecessive weights, the arcs are little inclined from the actual positions near the terminal edges. So in these parts the sha dow gives time which is somewhat erroneous.

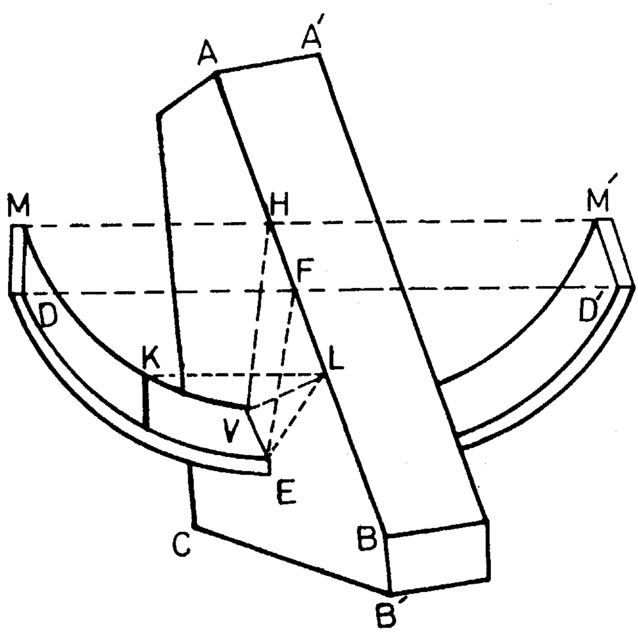


Fig. 11.3.

These shadow of the *śaākupnli* from the Moon is not so clear as it is from the Sun. Moreover the planets and stars do not produce shadow at all, so how the hour angles of the planets Mars etc. and those of stars can be determined with the help of this instrument ? For the here we give the method:

Construct a fine, narrow and exactly straight tube from a metal. Place one of its ends on the edge of the arc and the other end on the *śaṅkupāli* in such a way so that the planet or the star whose hour angle is to be determined is visible through the hole of the tube by placing the eye below a *cāpapāli*. This way from the point of contact of the tube on the *cāpapāli* the hour angle is evidently determined. From the point of contact of the tube with the *śanku-pāli* upto the centre of the *cāpa-pāli* is the tangent line of the declination of the planet or the star. In Fig. 11.3 the Samrāṭ Yantra is shown. Here L is the point where the tube touches the *śaṅku-pāli* and H is the centre of *śaṅkupāli* where there is the iron ring. The other end of the tube is at K. LH is the tangent line of declination (δ) of the star. VH is the radius of the circles V AB, L HLL$=\delta$. It is clear that the reading of the point K gives the hour angle. It is clear that the declination δ is given by

$$\delta = \tan^{1} \frac{LH}{VL}.$$

It may also be remarked that the author of this text[35] claims that Sawai Jai Singh using that big masonary *Bhitti yantra* determined the obliquity of ecliptic to be 23°28′ which is very much accurate a value in comparison with the values prevalent in the literature and accepted by astronomers at that time. It may be pointed out that Sawai's Bhitti yantra being a big scale instrument could yield so accurate a value, better than even the Bhitti yantra of Prof. Flamsteed (1st Royal astronomer of England) in Greenwich could furnish at that time.

In order to find the *viṣuvakāla* (right ascension expressed in units of time) of a star with the help of Samrāṭ Yantra proceed as follows :

1. At the time of sun-set note down the hour angle H'_s of the Sun and after sun-set note down the time t, the star X takes to be just visible. In the diagram (Fig. 11.4) S_2 and S_2 are the positions of Sun on its diurnal path at the time of setting and at the time of star being visible. (The diurnal path of the Sun is not shown here).

Here in fact t must include also the angle traversed by the Sun due to its apparent motion during this time. γ is the vernal equinox, P is the pole of celestial equator and PM is the meridian of the place of observation, D is the culminating point of ecliptic (intersection of ecliptic with the meridian towards zenith side). D is usually referred to as *daśama-lagna* in the traditional Indian astronomical terminology.

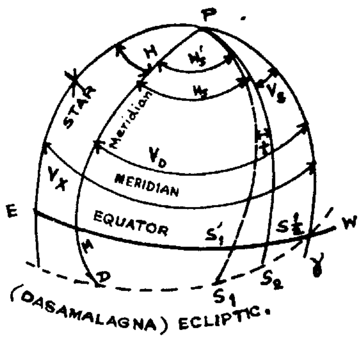


Fig. 11.4

At the time of observation of the star, the hour angle of the sun $H_s = H'_s + t$.

Also *viṣuvakāla* of the Sun $= V_s$.

Thus the *viṣuvakāla* of the *daśama-lagna* is $V_D = V_s + H_s$.

If the hour angle of the star X is measured to be H then it is evident that

The *viṣuvakāla* of the star $V_X = V_D \pm H$.

It is clear that if the star is towards west of *daśama-lagna* then H is to be subtracted from V_D. Thus knowning the *viśuvakāla,* one can convert it to degrees to get right ascension of the star.

4. *Nāḍi-maṇḍala (Equinoctial circle)*

There is set another stony instrument called Nāḍī-maṇḍala towards eastern direction. Its plane lies in the plane of equator. On northern side of it there is made a circle, whose diameter is 3 hands and 2 *aṅgulas*. It is divided in four parts by vertical and horizontal lines. In each quadrant there are graduated 90 degrees. At the centre of this circle there is an iron peg pointing towards the Polaris. From the shadow of this rod, when the Sun or the *nakṣatra* is in the northern hemisphere, its hour angle is known. Also the south-facing side of this instrument has a circle with diameter equal to 1 hand and 13 *aṅgulas*. This too like the north-facing side is divided into quadrants by vertical and horizontal lines and graduated in degrees. This circle is to know the hour angle of the *nakṣatra* or the Sun in the southern hemisphere.

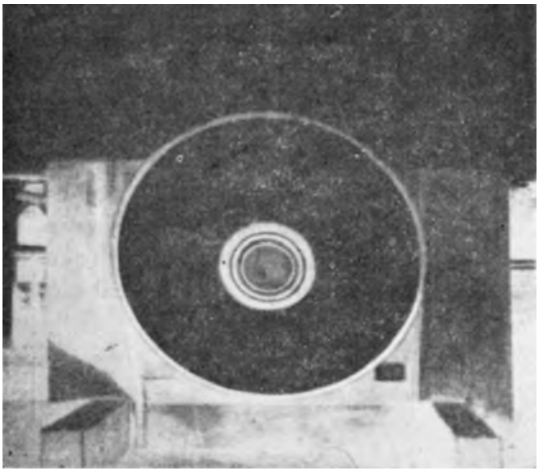


Fig. 11.5. *Nāḍ-maṇḍala*

5. *Cakra-yantra*

Near this very instrument there is Cakra yantra. It lies in between two walls. It is made of iron and is capable of rotating. On the outer periphery, there is covering with pittal-foil. Its diameter is towards Polaris. The periphery is 3 *aṅgulas* broad and

$\frac{1}{2}$ *aṅgula* in thickness. On edges it is graduated in degrees and each degree is further divided into four equal parts. There is a *paṭṭi* (tube device) made up of pittal. It is 3 *aṅgulas* broad and passes through the peg at the centre. The same has a thread with a mark (Index) in the middle.

To know the declination of a planet or star with the help of this, move the instrument and the *paṭṭi* in such a way that the celestial body, whose declination is to be determined is visible along the thread to the eye placed below the *paṭṭi*. From the diameter perpendicular to the one facing the pole, the degrees on the periphery upto the *paṭṭi* is the declination of the planet or the star.

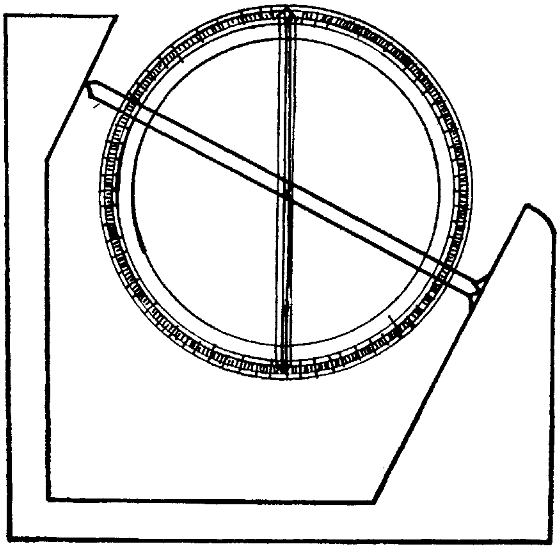


Fig. 11.6

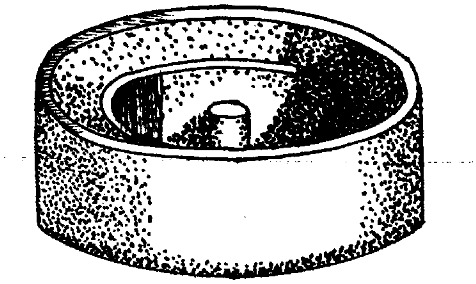
In this very instrument there were base circles etc. for determining hour angles of planets and stars, but these have been erased now. The *paṭṭi* is bent so with the help of this as described above, the declination can not be determined correctly. This instrument is somewhat similar to meridian circle or transit instrument of present times, which is fitted with a telescope instead of a Vedha *paṭṭi* and is set always in meridian for observations at transits only.

As has been already remarked, there exists an English version of the Kāśī Mānamandira Vedhālaya Varṇanam by Bāpudeva Śāstri. It has some more or somewhat different details.[37] In the discussion of Cakra-yantra more information is given in the English exposition indicating that the breadth of the circle was 2 feet and 1 inch thick, faced with a plate of brass 3/10 inches in thickness. Thus, there are more or somewhat different details in the English exposition. Probably, the English exposition was written later, having measured the dimensions more precisely, but the date of compilation of first edition of the English text is not known.

Now, let us come to those points which are not clarified by Bāpudeva śāstrī. In the discussion on Cakra-yantra he has mentioned that there were some base circle which were lost or broken. These circles were provided with this instrument in order to determine the hour angles etc. of planets and stars. Probably, they were the meridian and the equator with proper graduations. It is clear that the reading on the equator from its point of contact with the meridian upto the *paṭṭi* pointing towards the celestial body gives the hour angle. Another possibility is that there might have been the *kṣitija* (the horizontal circle of the place) and the equator. In this case the angle between the *paṭṭī* (index) and the horizontal circle is the complement of the hour angle.

6. *Digaṃśa yantra*

On the eastern side of this instrument there is a big Digaṃśa yantra (an instrument for knowing diagaṃśa or azimuthal angle). At its middle there is a pillar having diameter equal to two hands and 10 *aṅgulas* and height equal to $2\frac{3}{4}$ hands. At its centre there is fixed a gnomon with a hole at its bottom (see Fig. 11.7). From this pillar at a distance of five hands minus four *aṅgulas* there is an enclosing (circular) wall. Its height is equal to that of the pillar and thickness is one hand. From this wall too somewhat more than 2 hands away towards the outer side there is another enclosing wall. Its height is double that of the first one and the breadth is $1\frac{1}{3}$ hands. The upper sides of both the walls are graduated in directions and degrees. On the outer wall there are pivoted iron pegs in the four directions.



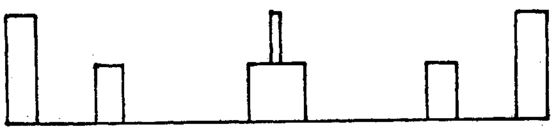


Fig. 11.7

The instrument of this type is used to find the azimuth. A thread is fastened to the eastern and western pegs and another one to the similar pegs fixed at the north and the south points. The two threads intersect at the centre of the pillar in the middle. Then a third thread is fastened tight to the centre at the pillar, the other end of this straightened thread is moved in such a way that the planet whose azimuth is to be determined and the intersection of the two threads are along the third thread as seep by placing eye on the outer edge of the middle wall. This way the azimuth of the planet is the angle measuring as many degrees as there are on the edge of the outer wall from the east or west point upto the third thread.

Besides these there is another small Bhitti yantra and a small Samrāṭ yantra.[38] There was another Nāḍī-maṇḍala which is not mentioned in the Sanskrit text but is described in the English exposition by Bapudeva Śāstrī. Also there was a big quadrant—Turīya yantra made up of massive stone with very precise fine graduations. Burrow witnessed and praised the workmanship in the 18th century.[39] This instrument is not at all mentioned by Bāpudeva Śāstrī. Where has it gone now? No one knows. These are the only instruments which we have come to know of in Māna mandira observatory of Kāsī.

Ujjain Observatory

In Ujjain observatory there are the following instruments of the above type: (a) Samrâṭ yantra; (b) Nāḍīvalaya yantra; (c) Digaṃśa yantra; and (d) Yāmyo-tittarabhittiya yantra.

Digaṃśa yantra is in ruined condition. In Nāḍīvalaya yantra the graduations are in bad condition. Samrāṭ yantra is also in skeleton. In Yāmyottara-bhitti yantra too, the graduations have disappeared. The *bhitti* is inclined at 5° to the vertical and is much dilapidated. There is a flight of steps leading to narrow platform at the top. The constructions of this yantra and other yantras are basically the same as in Varanasi, although the dimensions differ.

Delhi Observatory

In Delhi, there are mainly the following instruments:

(1) It is Samrāṭyantra similar to the one in Varanasi but has also a Saṣṭāṃśa yantra which is a large graduated arc of 60°, built in the plane of the meridian. Through an orifice, Sun while transiting the meridian, shines on the arc indicating its meidian altitude. At the top of the triangular gnomon there was a circular pillar which was used for rough azimuth observations but now there is a small Sundial. Before 1910 A.D. there was only a pillar as evidenced from Daniel's drawings.[40]

(2) *Jai Prakōśa yantra*

The observatory of Kaśī has no Jai Prakāśa yantra and Rāma yantra which too were the inventions by Mahārājā Jai Singh. Delhi observatory has these instruments. Here we give the details of Jai Prakāśa yantra[41] which was called Crest Jewel or Yantra śiromaṇi by Pandit Samrāṭ Jagannātha. This is an armillary sphere cut into two by planes of the horizon. Only the upper part being kept as it is the only portion visible to us. It consists of a concave hemisphere dug in the ground (See Fig. 11.8). The rim represents the horizon of the place of observation and is graduated in degrees and minutes. Here *EW* and *NS* are east-west and north-south lines. *NPS* is the meridian passing through the zenith of the place of observation and the north south points. Here *P* represents the south. With *P* as centre and radii $\pi/3 \pm \epsilon$ (ϵ being obliquity of the ecliptic) draw two circles. These will evidently represent the circles described by the ecliptic around the pole. Both these are marked in signs *(rāśis)* degrees minutes and second. On these circles mark points indicating position of 12 *rāśis* representing their rising from west to east. Taking these as centre draw 12 circles which will represent 12 positions of the Sun in *rāśis* on the ecliptic. With the lowest point of the hemisphere as centre and spherical radii 6°, 12°, 18°,.., 90° describe 15 circles, the lowest one being the horizon. Through *O* draw sixty circles of azimuth and a hole is made at the lowermost bottom point of the bowl. The rays of the Sun fall through this hole inside the hemisphere and revolve as the Sun describes diurnal motion. At all instants its position can be directly read from the graduations. In the hemisphere, the paths are dug out for observer to go inside the hemisphere for taking readings. Since the dug portions can not have graduations, there is made another complementary hemisphere in which the part dug in the 1st hemisphere is not dug, instead have graduations and whichever parts are graduated in 1st one, are dug in the second hemisphere. Thus with the help of two complementary hemispheres, position can be read for any instant. The duplicate Jai Prakāśa yantras in Delhi and Jaipur have five passagese each.

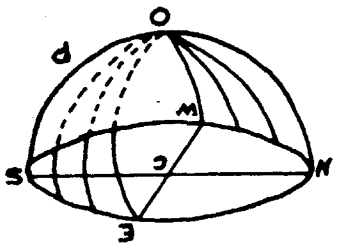


Fig. 11. 8.

G. R. Kaye[42] has speculated Berosus' Bowl to be the basis of Jai Prakāśa yantra. L. V. Gurjar[43] has contradicted his view and proved the same to be baseless arguing that Berosus (A priest at Bel in Babylon) is not accredited with any invention of Bowl-like device. He (Ka ye) himself accepts that the Berosus' Bowl was not fully graduated and may be Jai Singh never knew of it and developed Jai Prākāśa yantra independently. In fact Jai Prakāśa yantra originated from Armillary sphere described in *Sūrya-siddhānta, Siddhānta S'iromaṇi* and other texts of Indian Astronomical tradition.

3. *Rāma yantra*

This consists of a cylindrical vertical graduated wall of diameter 24 feet and 6 inches[44] and a vertical pillar at the centre. The wall and the floor are graduated. The wall is cut in between, for fixing rods in order to have observations of stars (see fig. 11.9). There is another complementary identical Rāma yantra which differs from the first one in graduated and cut passage portions of the wall. This instrument gives altitudes and azimuth of planets and stars.

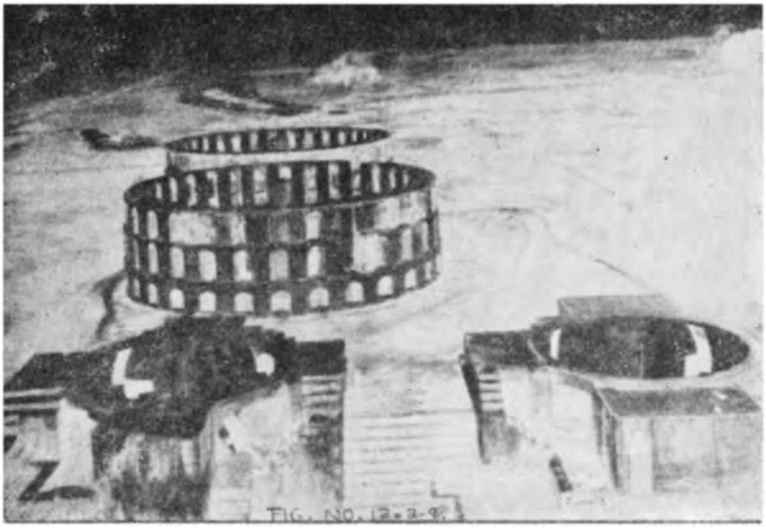


Fig. 11.9. Rāma Yantra

(4) *Miśra-yantra*

It consists of a Samrāṭ yantra-like structure, which has towards east and west side of triangular gnomon two or more non-horizontal half circles instead of quadrant arcs in horizontal plane. (Fig. 11.10.) These semicircles are inclined to the plane of the Delhi meridian at angles approximately 77° and 68½° east and west, one semicircle being in the meridian of Greenwhich and the other in the meridian of Zurich (Germany). Thus, even sitting in Delhi one can perform Samrāṭ yantra experiments for Greenwich and Zurich also.

Besides these, in Delhi Jantar Mantar there is a Bhitti yantra similar to the one in Kāśī Māna-mandira. The north wall of Miśra yantra is inclined to the vertical at ap angle of 5° and is marked with a large graduated circle. This is called Karka rāśi-valaya (i.e. circle of sign of Cancer). Latitude of Delhi is 28°28′. Since the obliquity is almost 5° less than this, so when Sun enters *sāyana* (tropical) Cancer, it will shine over the north wall for a short period and the shadow of the central pin fitted there falls on the graduated circle; which indicates *sāyana karka-saṃkrānti* (transit of Sun in tropical Cancer). There was one quadrant also, which is no more now.

Jaipur Observatory

In Jaipur, the collection has a Samrāṭ yantra, Saṣṭyaṃśa yantra, Rās'i-valaya yantra, Jai Prakāśa yantra, Kapāla yantra, Rāmayantra, Digaṃśa yantra, Nāḍīvalaya yantra, Yāmyottara-bhitti yantra, two big astrolabes, a Unnatāṃśa yantra, Cakra-yantra, Dhruvadarśaka yantra, and a Krānti-vṛtta-yantra of 17.5 feet diameter.

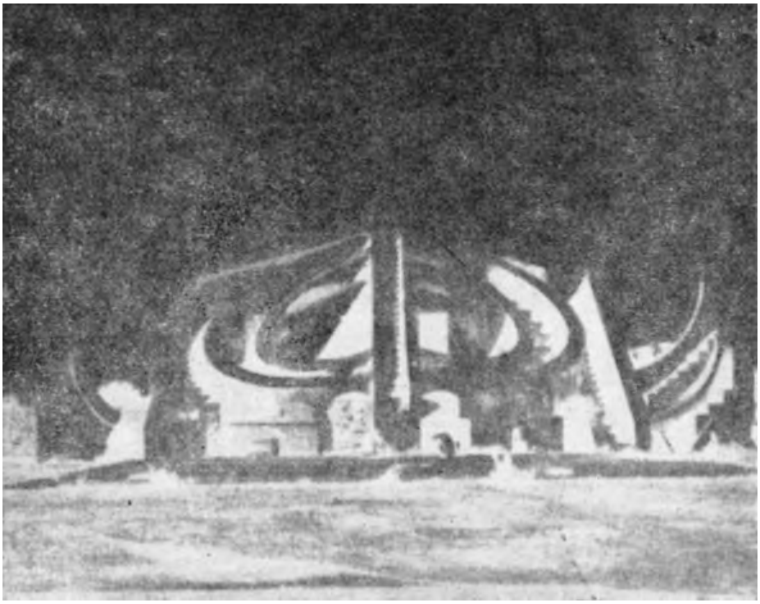


Fig. 11.10. Misra Yantra

Rāśi-valaya-yantra is a combination of 12 Samrāṭ-yantra-like structure one for each *rāśi* (sign). The cylindrical wall is not in the equatorial plane; instead it is in the plane of the respective *rāśi*. Kapāla yantra is a hemispherical bowl similar to the Jai Prakāśa yantra but it is used for studying rising *rāśis*, knowing time, azimuth, longitude, *lagna* etc.[45] Unnatāṃśa-yantra (altitude instrument) is made up of metal and is used to determine altitudes of heavenly bodies. In Jaipur observatory it is made up of circular metal of 18 ft diameter graduated to 1/10th parts of a degree. The circle can be rotated about its vertical diameter. A pointer was attached to a hole at its centre. The instrument is fixed at an elevation so that readings can be taken by standing at any point. Dhruva-darśaka yantra is a triangular gnomon of sand stone with elevation=27°. The north face is at right angles to the base. Such an instrument was a big help to astronomers, navigators in determining directions, in setting instruments and in knowing local mean time with the help of *dhruva-matsya* (polar fish). Garret et al.[46] described all instruments in Jaipur observatory with good drawings in details.

Krānti-vṛtta

This was an instrument which could give celestial longitudes and latitudes of heavenly bodies directly. It consists of a masonary pillar with north face fitted with a circular stone in the plane of equator (see fig. 11.11). There is a brass pin *P* at its centre to which a metal frame work is attached. The metal frame consists of two inclined brass circles *APB* and *BQA′* which represent equator and ecliptic which was taken to be 23°27′ at that time.[47] The metal frame work can be rotated around the pin *P* and the angle of rotation can be measured by a pointer moving over the circumference of the circular stone graduated in signs degrees and minutes. The ecliptic circle is fitted with two quadrants at right angles to the plane of *BQA′* with a bar whose centre passes through a pin at *Q*. The bar *AA*' can be rotated freely about *Q*. The two quadrants too can rotate about the bar *BA′*. These are graduated in degrees and minutes and fitted with sighting bars. Note that *AA′* points towards solstices. The quadrant at *A′*, when rotated to see the heavenly body with the help of the sighting rod makes a certain angle α with *AA′*. Then $90+\alpha$ or $90°-\alpha$ gives the longitude and the sighting bar gives the latitude. This instrument is found in dilapidated condition in Jaipur observatory.

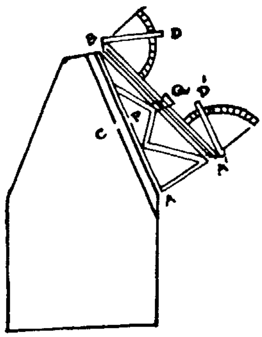


Fig. 11.11.

Astrolabes

In addition to the instruments discussed in the previous sections, we also find astrolabes of different sizes in repositories of Sawai Jai Singh's observatories. Earlier Mahendra Guru (A.D. 1370) wrote a text on the subject "Yantra-rāja"[48]. It is believed that Arabs developed astrolabes but there is no doubt that several excelleent astrolabes of improved designs were produced in India after the tradition of Central and West Asia.

(I) The principle of construction of this sophisticated instrument is based on stereographic projection of celestial circles on a plane. This is a conformal mapping in which angles are preserved. All circles on the sphere project into circles except those which pass through the point of projection, latter ones project into straight lines. Astrolabe is generally made up of a metal plate on which two perpendicular diameters are carved. In the figure given below (Fig. 11.12) there are *SN* and *EW* representing the south-north and east-west directions. The circle *NWSE* with centre *C* is taken to represent the circle of tropic of Capricorn. Take a point *P* such that $\angle SCP = \epsilon =$ the obliquity of ecliptic. Join *CP* and *EP* cutting *CS* in *X*. With *C* as centre and *CX* as radius, draw a circle, which will represent equator. If Υ is the point of intersection of this with *CP* and *A* with *WE*, join *A* and Υ cutting *CS* in *V*.

With C as centre and radius $=CV$ describe a circle. This circle will stand for tropic of Cancer.

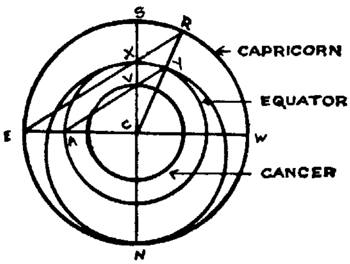


Fig. 11.12. (a)

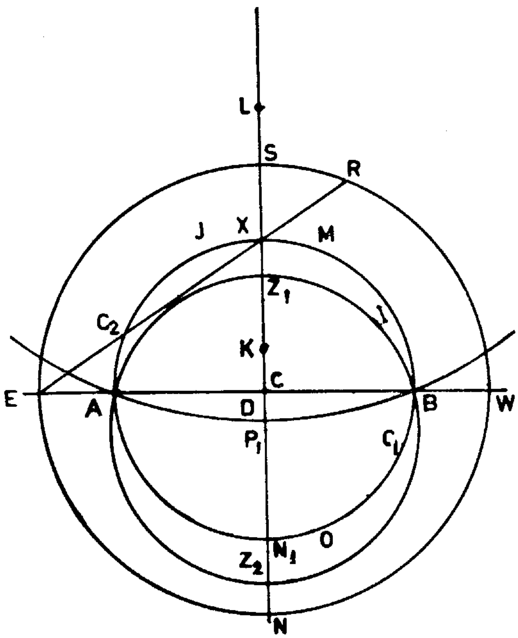


Fig. 11.12 (b)

Let us see how the other circles can be drawn using the basic three properties[49] of stereographic projection. Here all the drawings could not be plotted in the figure but one can understand the details of drawings from the following :

(II) Let B be the point of intersection of EW and equatorial circle.[50]. Let $BC=\theta$ the latitude of the place towards north. Join AC, cutting NS in P_1 (say the point P^1 is called first point). Take an arc $AC=\theta$, so that C_2 is diametrically opposite to C_2. Join AC_2 cutting NS in P_2 (Say). The point P_2 is called second point. On P_2P_2 as diameter, draw a circle which will represent the horizon of the place of observation.

(III) To draw parallel of altitude a, take $C_1I=a$, towards S, and point J so that $C_2J=C_1I$. Join AI and AJ cutting NS in K and L respectively. On LK as diameter draw a circle which will represent the parallel of altitude.

If $AC=r_a$ then it can be shown that the radius r of the parallel of altitude 'a' is given by :

(using the projection geometry)

$$r_a = \tfrac{1}{2}\, LK = \frac{r \cos a}{(\sin \theta + \sin a)}$$

The mid point of IK will be the zenith of the place of observa tion.

(IV) To draw prime vertical, take arc $XM=\theta$ towards W. Join AM cutting at Z_1. If N_1 is the point, where equator cuts NS, take arc $N_1C=\theta$. Join C_1C, produce it to meet NS in Z_1. The circle drawn with diameter Z_1Z_2 will be the prime vertical.

It can be shown that

$$Z_1Z_2=2\ r_e \text{ sed } \theta.$$

Thus the radius of the prime vertical is r_e sec θ Angle is θ the point is P_1 (Fig. 11.12(b)). Here P_1, is the centre of prime vertical, and $CP_1 = r_e \tan \theta$.

(V) Since the latitude of the place is equal to the declination of its zenith, the lines joining intersections of horizon and NS with he divisions of equator will give us graduations of the prime vertical.

(VI) To draw *digvalayas* (azimuth circles) draw circles through graduations of horizon, zenith and nādir. The centres of all such circles will lie on a line through P_1 and parallel to EW. If $Z_1\ RZ_2$ be one of the azimuth circles corresponding to the azimuth angle A and C' be its centre then $\angle OC\ Z_1 = A$. The distance of the centre C' from Z_1 is

$$C'Z_1 = r_e\ s_e \text{ c } \theta \text{ cosec } A.$$

(VII) In order to draw hour circles make equal divisions of tropics of capricorn and cancer and equator. Mark these (1), (2), (3)....(12) on each of these with (1) of equator as centre draw a circle (α_1) through (1) of Cancer and with (1) of Capricorn as centre and same radius draw another circle (β_1) to cut (α_1). Take (1) of cancer and same radius draw a circle (γ_1). The lines joining the points of intersection (α_1), (β_1) and (γ_1) will intersect at a point which is the centre of 1st hour circle. With this as centre draw a circle through (1) of the tropics and equator. This is the 1st hour circle. Similarly all the twelve circles can be drawn.

(VIII) The equator can be graduated in regular hours (=1/24th of a day) divisions by dividing the same in equal parts and drawing 24 radiating straight lines from pole to the points of divisions.

(IX) It can be shown that in this mapping diameter of ecliptic$= \dfrac{r_e^2}{r_c} + \gamma_c$

where r_e and r_c are radii of equator and tropic of capricorn. In the figure VN is the of the ecliptic. Within this the circles are to be drawn as discussed above. Such a diameter disc is to be taken and to be pivoted at the pole as the ecliptic. One thread passing through the pole of the ecliptic (ϵ=23°—27 from pole along the meridian) with its other end moving on the graduations, gives the divisions on the ecliptic wherever it cuts the ecliptic.

Knowing the ecliptic and equatorial coordinates of planets and stars, their positions can be fixed on the disc. From east point towards north-south of equator mark a point at angular distance equal to the declination of the celestial body. Join it to the south of equator. Mark its intersection with *EW* (produced if necessary) as '*I*'. Describe a circle with pole as centre and radius=distance between pole and the point *I*. This is the ecliptic, indicating its ecliptic distance from nearest equinox. Join pole and this point, wherever this line cuts the parallel of declination, is the position of the celestial body.

Alternatively one also uses horizon at 66°33′ *N* and digvalayas. This horizon is the ecliptic and the digvalayas are great circles passing through the pole of ecliptic. Mark the celestial latitude on the perpendicular circle which passes through graduation, representing the position of the body on the ecliptic. This point is the position of the body.

This instrument serves the purpose of solving problems involving relations between azimuth, altitude, latitude, longitude time and positions in a very handy way. At its back is fitted a sighting bar with which only the altitude is to be noted. Using only this single observation, the instrument serves as a calculator like a slide rule.

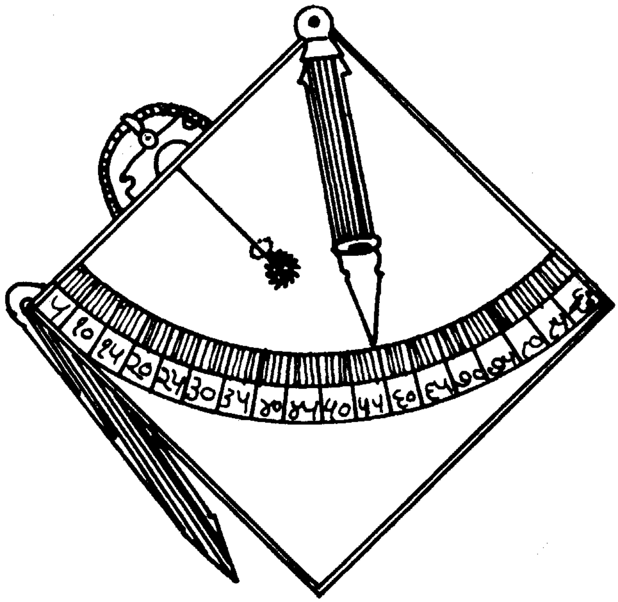
There is no doubt that such instruments are common in India and Arab countries, but the accuracy and ease in Jai Singh's designs of astrolabes was remarkable. Yantra rāja of Jai Singh is not found in any collection of astrolabes in foreign museums. One has to study the available literature on the topic, for any conclusive inferences regarding the originality of the Hindus in the field of astrolabe-making.[51]

It may be pointed out that there are available some astrolabes in Arabic and also in Devanāgari script. The astrolabes of Jai Singh Sawai are preserved in Jaipur observatory. Probably the astrolabes of Delhi observatory might have been removed to Jaipur or some other place at the time of invasion by Nadir in 1739 A.D. There is no doubt that the collection does not have all astrolabes of Jai Singh Sawai. The number of such astrolabes in Devanāgari was more than thirteen.I[52] R. Burrow in 1790 A.D. witnessed an astroiabe in Devanagari which is not avallable now.[53] Also G. R. Kaye was shown some brass astrolabes prepared under the scholarship of Sh. Jai Singh Sawai. In 1864 in Lahore exhibition there were some astrolabes from Kapurthaia.[54] The museum at Caicutta and Lahore had astrolabes in Devanāgari in eariy 20th century. Thus we believe, that there were quite many astrolabes in Devanāgarī script. Jaipur collection has astrolabe of Shah Jahan's time (dated A.D.) 1657 and astrolabe of the time of Aurangzeb (dated A.D.) 1680 This collection has two big astrolabes. In Red Fort museum at Delhi there are few astrolabes. One astrolabe is dated 16th A.D. the other one of 1637 A.D. made by Mr Muhammad Mukhim, grandson of Shekha Alla-Hadadi son of Mr Mulla Isa of Lahore. In Indian traditional astrolabes important parts referred to are :—(1) *Akṣapatra* which differs from latitude to latitude. (2) *Bhapatra* which is same for all places. In two of the astrolabes of Jai Singh, there are 7 akṣapatras on both sides for latitudes from Delhi to Kashmir. In one of the astrolabes there is no *bhapatra* and one has to rotate the *vedhapaṭṭī* conjoint with ecliptic. Thus this one is of inferior type as regards its operation. In the other ones, the pointer can directly tell *daśamalagna* etc. The astrolabes of Arabic origin too have in general both the plates. (See fig. 11.13).

Fig- 11.13,

In Devanâgari characters, there are *laṅkodayas* (intervals for rising of signs) engraved on *bhapatra* which are characteristics of Indian tradition. Also there are 27 asterisms in Sanskrit names. These markings are in Indian traditional style, and differ from Arabic or Persian engravings on astrolabes, preserved in American Institute of Researches on History of Science in Cairo and in Museum at Greenwich.

The 48 divisions of sky were used by Ptolemy but the astrolabes of Jai Singh use as many as 108 divisions like Arabic astrolabes. Sh. Sawai Jai Singh corrected the positions of 1029 stars which were quite accurate according to the standards of those times but not so accurate as in Nautical Almanac these daye. It may be remarked that Shri Jai Singh used Indian *ayanāṃśa* (angle of precession) of *Sūrya-siddhanta* unlike the Arabic traditions of Ptolemic origin. The value of *ayanāṃśa* used is 23° as it appeared but it could not be decided finally. In spite of all these deviations, the astrolabes of Sawai Jai Singh were flat astrolabes (Astrolabium planisphaerum or zat-al-safaih). These have thin discs (tablets) marked with *digaṃśas* (azimuths) *nata-vṛttas* (hour circles) etc. The *chunchu* (pointer) (See fig. 11.14) and the graduated circle form the important parts used in observatories while the tablets and rotating *aṅkabut* the graduated circle etc. form an efficient machine which differs much in details in Arabic and Indian astrolabes. The observational parts do not differ much. The markings on the circles in Hindu astrolabes are as in Muslim ones in general, but the large astrolabes of Jaipur have finer graduations.



gig. 11.14.

It is to be pointed out that Indian astrolabes do have their specialities in markings (like in *lankodayas* rising of signs etc.) and different styles in workmanship. For comparison all astrolabes of essentially Hindu tradition must be studied for final conclusions. It may be remarked that in India there are no astrolabes of much antiquity available anywhere. Even we do not find astrolabes of the times of Mahendra Suri or other authorities on astrolabe-making before the time of Jai Singh. The instruments might have been destroyed or taken off during invasions. We do not hope to find any old ones and under these circumstances, the only way is to study the works of Mahendra Suri etc. and compare with the features of astrolabes of Arabic and European origins. Also the comparison of existing instruments in a quantitative fashion will reveal the originality in the features of these instruments.

The observatory at Mathura[55] was located on the banks of Yamunā. Jai Singh Sawāi a staunch devotee of Lord Kṛṣṇa usually visited Mathura and built a temple of Lord Krisṇa. For observatory, he chose a fort built by his ancestor Rāja Māna Singh of Amber (end of 16th century A.D.). Due to attacks by religious fanatics there are not even debris of the Vedhaśālā (observatory) there. This observatory had Laghu-Samrāṭ-yantra, Dhūpa-ghaṭī (Sun dial), Yamyottara-bhitti-yantra (Meridian wall). Here yantras were of smaller size, in comparison with the similar ones in Jaipur. The last remains of the Vedhaśālā were put to oblivion in 1857 A.D. when Jyoti Prasad, a contractor bought the fort and demolished every bit of the Vedhaśālā.