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ASTRONOMICAL INSTRUMENTS AT KOTA

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The paper describes a unique armillary sphere, a *ghaṭī-yantra,* and two sundials preserved at the Rao Madho Singh Museum of Kota, Rajasthan.

Keywords: armillary sphere, *ghaṭī-yantra,* Kota, sundials

ARMILLARY SPHERE

The armillary sphere is a very old instrument.[1] Hipparchus and Ptolemy are said to have used it. Al-Kāshī, in his treatise on astronomical instruments, describes a seven ring armillary.[2] In Hindu astronomy this instrument is called *Gola-yantra.* Lalla, writing in the eighth century, describes a fairly elaborate *Gola-yantra* for telling time.[3]

The *Gola-yantra* of Rao Madho Singh Museum of Kota, Rajasthan, is, however, much different from the instruments described in literature. It was first reported by Lancelot Wilkinson 1834.[4] Wilkinson wrote:

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[1] For a description of armillary sphere in literature, see Virendra Nath Sharma, *Sawai Jai Singh and His Astronomy,* Delhi, 1995, pp. 30-36.

[2] E. S. Kennedy, "Al Kāshī 's Treatise on Astronomical Observational Instruments," *Journal of Near Eastern Studies,* 20(1961) 98-107.

[3] *Śiṣyadhīvṛddhida Tantra of Lalla,* Part II, tr., Bina Chatterjee, Indian National Science Academy, New Delhi, 1981, pp. 280-281.

[4] Lancelot Wilkinson, "On the Use of the Siddhāntas in the Work of National Education," *Journal of the Asiatic Society of Bengal,* 3 (1834) 504-519; esp. 515.

> I take this opportunity of informing the public of the existence of a native observatory at Kotah, or rather of a valuable collecti of astronomical apparatus, made by the late Mahārāo UHMAID SINGH; and posited on one of the bastions of the citadel, fitted up for their reception. This apparatus consists of a very splendid and large armillary sphere; of the celestial and terrestrial globes, dials, gnomons, and also the Rāj Yantra. [sic! read,Yantrarāj] or astrolabe, borrowed from the Musalmāns about 250 or 300 years ago. The axes of the globes are fixed at an elevation of 24°30' the supposed latitude of the North Pole Star at Kotāh...

Basically, the Kota armillary sphere consists of three concentric shells or ring systems on a common shaft. The shaft is 17.5 cm long and has a diameter of 4.5 cm. The three shells are approximately 120 cm, 111 cm and 99.5 cm in diameter respectively. The outer shell rotates freely over the shaft but the inner two, as they exist today, do not. The rotation of the inner shells can be affected, however, by rotating the shaft. The instrument has been fabricated out of brass beams with square cross section of 0.75 cm to 1 cm on the side and bent into circles forming various rings. The rings are graduated in degrees and labeled in Devanāgarī. Before the museum was built in 1974, the instrument was mounted on the rampart of the fort known as the Jantar Burz. Now it is on display on a porch facing a courtyard of the musem. The construction of the instrument suggests that while at the Burz, its shaft must have been mounted parallel to the earth's axis, contrary to the conventional armillary spheres which are mounted vertically.[5] From the script engraved on the instrument, it appears that the instrument was fabricated in late eighteenth or in early nineteenth century.

The instrument as it exists today is not a perfect sphere, however. The deformity from spherical shape could have been caused by improper handling during its moving to the present location from the Burz. The instrument also has signs of recent repairs. Further, the observing ring of the innermost shell has come out loose and needs to be fixed.

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[5] For example see V. N. Sharma, op. cit.

OUTER SHELL

The shaft on which the three shells are mounted will hence forth be called the polar axis of the instrument. At the polar axis, two rings forming great circles of the outer shell cross one another. The planes of these rings are perpendicular to each other. A great circle intersects one of these rings at approximately 24.5^0 from the poles.[6] The ring intersected by the great circle is labeled with degree marks which increase 0^0 to 18^0 towards a pole from the point of intersection, and 0^0 to 90^0 in the direction opposite to

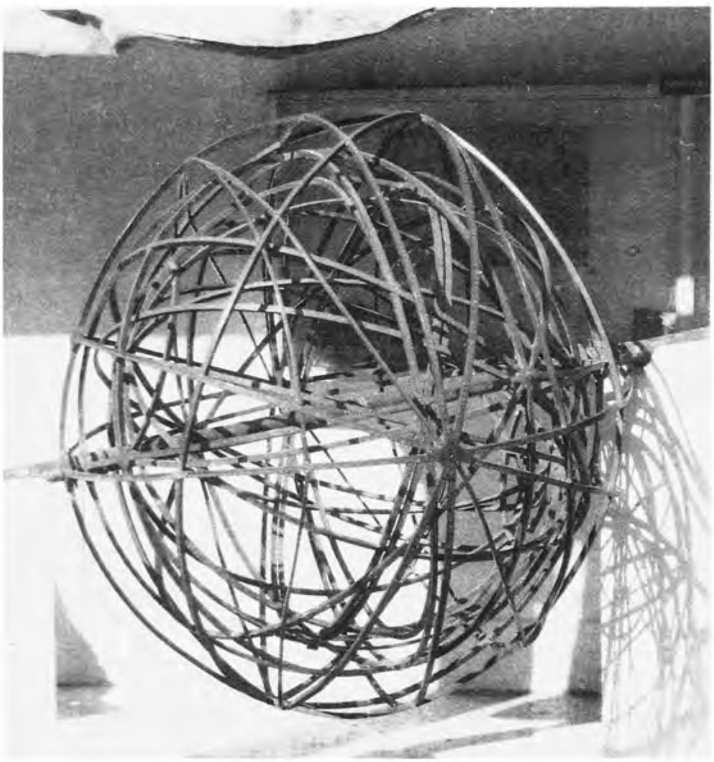

Fig. 1 : Armillary Sphere of Rao Madho Singh Museum, Kota, Rajasthan.

[6] The point of intersection is nearly 25^0 from the north pole and 24^0 from the south pole. According to Hindu canons of astronomy the pole of the ecliptic is 24^0 from the polar axis. The deviation from this value could be due to slackness of the bearings of the instrument at the poles.

the pole. The plane of the intersecting great circle is orthogonal to the plane of the ring. An extension of the diameter joining the two points of intersection on the ring can be made to point toward the pole of the ecliptic in the sky at any time of the day by rotating the outer shell. For the sake of convenience, therefore, we will designate the point of intersection of the great circle and the ring, near the north pole, as the "ecliptic pole" of the instrument.

At a distance of about 42° from the ecliptic pole on the ring, two circles, or rings, intresect the ring. The plane of one of these circles is perpendicular to the polar axis and thus it represents the tropic of Cancer. The other circle or ring has its plane inclined to the plane of the tropic of Cancer by about 24°. It thus represents the summer solstitial point. The ring, as it can be seen, is the solstitial coloure of the instrument. At a distance of apporximately 24° from the tropic of Cancer is the equator.

Further down on the solstitial colure at its 90° mark, or 90° from the ecliptic pole, four circles intersect it. One of these circles represents the tropic of Carpricorn and the other a different orientation of the ecliptic. In this orientation the ecliptic's winter solstitial point is in contact with the tropic of Carpricorn, and its pole coincides with the ecliptic pole, on the solstitial colure. The other two rings intersecting the solstitial colure at the "winter solstitial point" are great circles inclined at 45° with the plane of the colure. The role of these two rings is not clear.

As pointed out earlier, perpendicular to the solstitial colure there is another ring that passes through the polar axis. At the 90° mark of this ring four great circles intersect it. One of these circles or rings is the equator. Two other rings are great circles inclined with the equator at about 24°. These two circles, therefore, represent two orientations of the ecliptic as pointed out earlier. The point of their intersection with the equator then acts alternately both as the vernal and the autumnal equinoxes. The fourth ring is also a great circle inclined at approximately 66° with the equator, and it passes through the ecliptic pole. This ring, although divided into degrees, has only one-half labeled. The equator ring is divided into four quadrants which are further subdivided into degrees and labeled from 0°

to 90°. The 90° mark of one quadrant and the 0° mark of the adjacent quadrant are common. The two zero markings of the equator occur at the two equinoctial points. Although the outer shell rotates freely, there is no observing ring associated with it. However, the ecliptic pole and the corresponding other pole, 180° away, have circular holes of apporximately 1 cm diameter where an observing ring can be mounted if so desired.

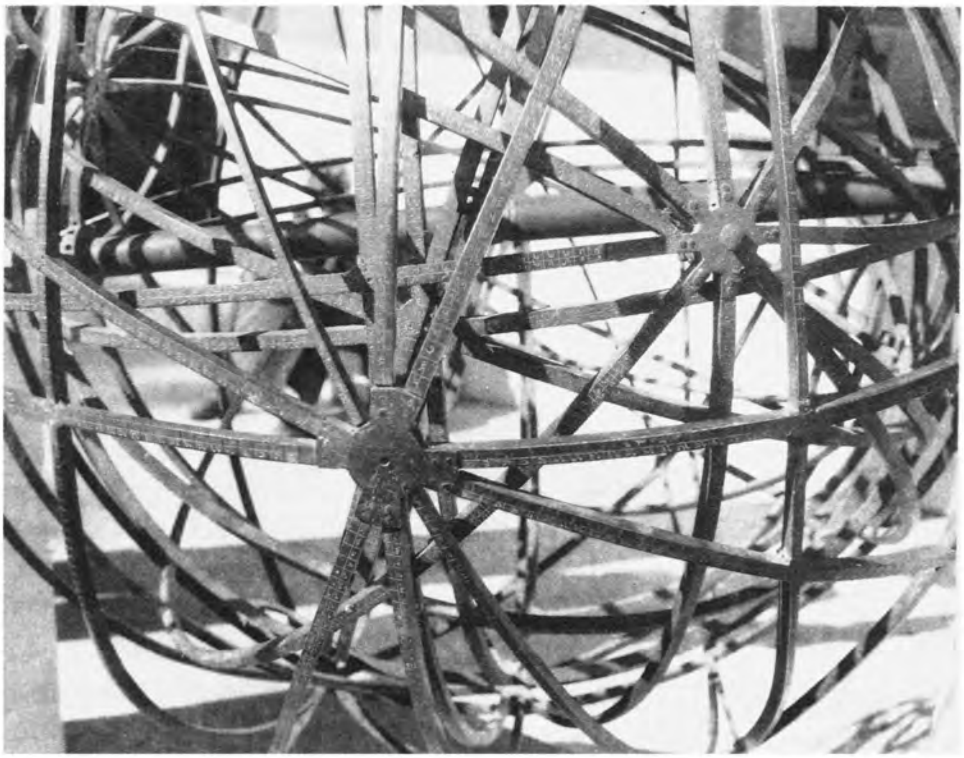

Fig. 2: Armillary Sphere: Detail

THE MID-SHELL

At a first glance, the mid-shell appears to be somewhat similar to the outer shell. It also has two equally spaced great circles, or rings passing through the polar axis of the instrument. On one of these rings, at a distance of nearly 24° from the north pole, is the ecliptic pole similar to the one in the outer shell. At the ecliptic pole a great circle, with its plane orthogonal to the ring, intersects it. Continuing along the ring, at a distance of nearly 66.5° from the ecliptic pole is the circle of equator. Further down, at its 90° mark, the ring is intersected by the ring of the ecliptic and two equally spaced great circles. These great circles or rings are inclined with the ecliptic at 45°. There are no rings or circles for the tropics on this shell. On the other ring passing through the polar axis, at a distance of 90° from a pole, are the equinoctial points where the ecliptic pole also intersects the equator at these two points. The mid-shell has a loosely fitted observing ring pivoted on the inside at the ecliptic poles.

THE THIRD SHELL

The third shell is inside the other two. It has two equally spaced great circles or rings passing through the instrument-poles, as in the other two shells. This shell also has an ecliptic pole at a distance of 24° from the north pole of the instrument, on one of the rings. Just as in the other two shells, this ring is crossed orthogonally at the ecliptic pole by a great circle. At a distance of 90° from the ecliptic pole, the shell has an ecliptic double-ring. The beams of the ecliptic double-ring have a one-half cm wide dove-tailed groove between them for attaching an observing sight. The observing sight consists of a small circular plate with a round hole that glides along the groove. Six equally spaced great circles divide the ecliptic into 12 sectors, or in 12 signs of the zodiac. The great circles meet at the pole of the ecliptic.

The signs have their degree divisions marked from 0° to 30° and labelled in Devanāgarī, such as *Mīna, Meṣa* etc. Around the two poles of the ecliptic, at a distance of about 24°, there is a circle each. These circles also pass through the axis of the instrument. The role of these circles is unclear.

The shell has an observing ring pivoted at the poles of the ecliptic, and it slides freely over the shell. The ring is divided into degrees, with its zero mark at the ecliptic and 90° at the ecliptic pole. The observing ring carries a loosely fitted one-half cm thick round plate with a hole in the middle which slides over one-half of the ring. The outer diameter of this plate is 11.5 cm and the inner approximately 8.5 cm.

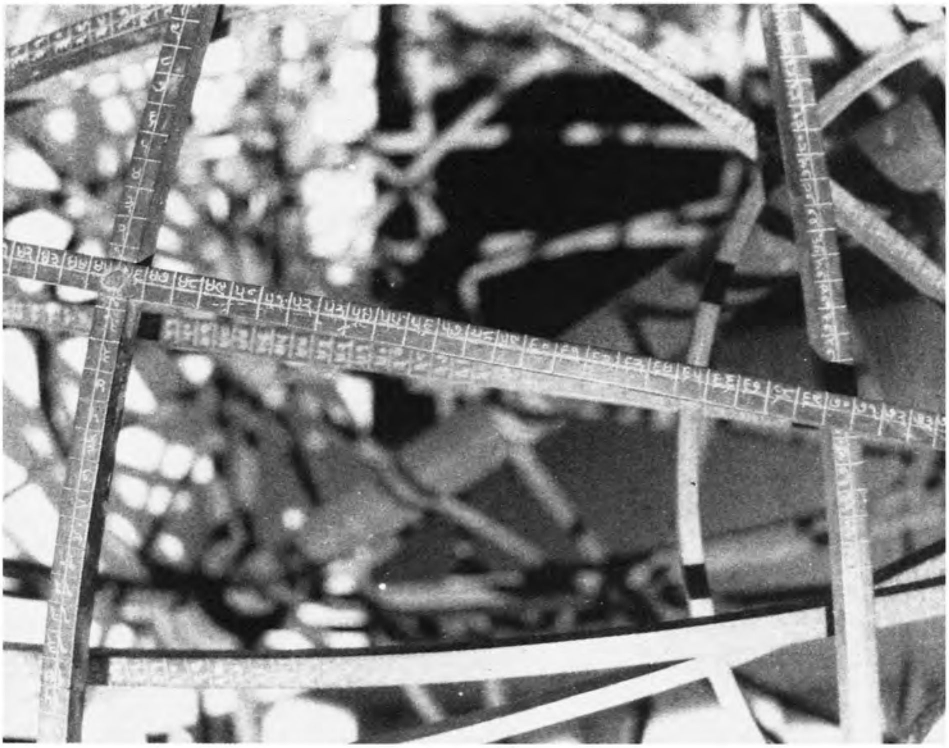

Fig. 3: Armillary Sphere: Scales on the Rings.

THE SHAFT

The section of the shaft, where the center of the shells of the instrument lies, has been given a somewhat spherical shape. On this spherical shape, two concentric circles have been engraved around the shaft. The planes of the circles appear to be inclined at about 24^0, and thus the circles may represent the equator and the ecliptic.

OBSERVING WITH THE INSTRUMENT

The instrument was apparently mounted with its axis pointing towards the north celestial pole while at the Burz of the fort, as pointed out earlier. The conventional armillary spheres are not mounted this way, as they are devoid of any shaft to support their ring system. Their rings support themselves freely. Besides they have pairs of sights mounted 180° apart over their observing rings. In contrast to conventional armillaries, the Kota instrument has only one observing sight each sliding over the observing ring and over the ecliptic of the third shell. It seems that the round section of the shaft played a role in observing with this instrument.[7] The first step of observing would have been to properly orient the ecliptic. This could have been done in conventional way with the knowledge of the latitude and longitude of a known star. Perhaps the mid-shell played some role in this exercise.[8] It has a movable ring pivoted at the ecliptic pole and an ecliptic circle.

The actual observing must have been done with the innermost shell, once the instrument has been properly oriented. Of this shell, the observing sight and the ring on which it is mounted were moved to and fro until the object in the sky as viewed through the opening in the sight was obscured by the round section of the shaft. The location of the sight on the ring then gave the latitude and that of the position of the ring on the ecliptic the longitude of the object in the sky. The observing of the sun must have been somewhat easier. It simply involved proper orientation of the ecliptic, which could be achieved by rotating the shaft until the rays of the sun would pass freely through the entire groove of the ecliptic double-ring of the innermost shell. Next move the observing sight of the ecliptic so that the rays of the sun passing through it fall on the round section of the shaft. The location of the observing sight on the ecliptic double-ring then gave the longitude of the sun at the time.

The design of an armillary sphere with a shaft in the middle clearly limits the precision of measurement with such an instrument. Beseides, a large array of rings in the Kota specimen must also be a hindrance to observing. As the outer shell does not have any observing sights etc., it is difficult to understand its role in observing. The instrument may be

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[7] The armillary sphere of the Jantar Mantar observatory of Sawai Jai Singh at Jaipur also has a shaft along one of its diameters. At the center of the instrument, on the shaft, there is a small sphere. See V. N. Sharma, op. cit., p. 35.

[8] This will require an observing sight over the movable ring of the shell; however, the author did not notice it.

described as a good tool for teaching principles of celestial astronomy.

GHAṬĪ-YANTRA

The *ghaṭī-yantra* of the museum of Kota is a bowl shaped clepsydra described in Hindu canons of astronomy and widely used in India for nearly fifteen hundred years.[9] The instrument is a hemispherical copper bowl of

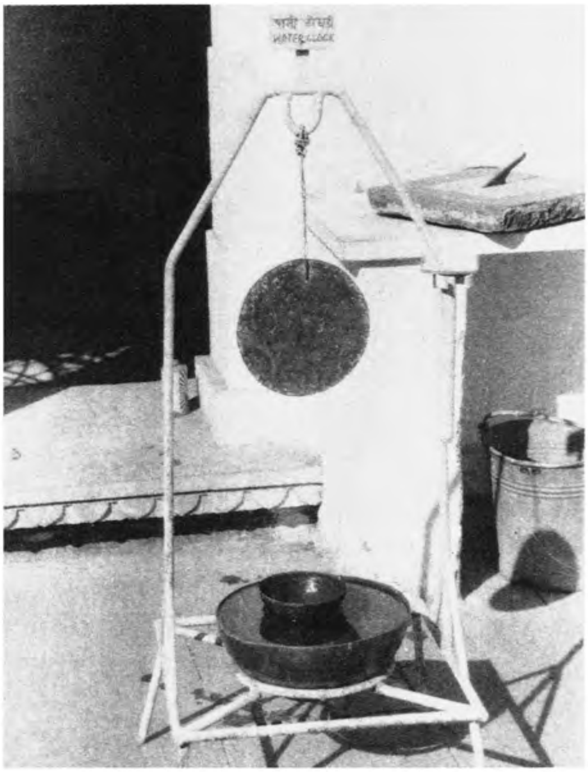

Fig. 4: *Ghaṭī -yantra.*

[9] For a description of clepsydra in Hindu canons of astronomy see R.N. Rai, "Astronomical Instruments" in : S.N. Sen, and K.S. Shukla (ed.), *History of Astronomy in India*, Indian National National Science Academy, New Delhi, 1985, pp. 316-317. Also S. R. Sarma, "Astronomical Instruments in Mughal Miniatures," *Studien zur Indologie und Iranistik*, 16-17 (1992) 235-276; "The Bowl that Sinks and Tells Time," *India Magazine, of her People and Culture*, 14.9 (September 1994) 31-36; "Indian Astronomical and Time-measuring Instruments : A Catalogue in preparation," IJHS, 29.4 (1994) 507-528.

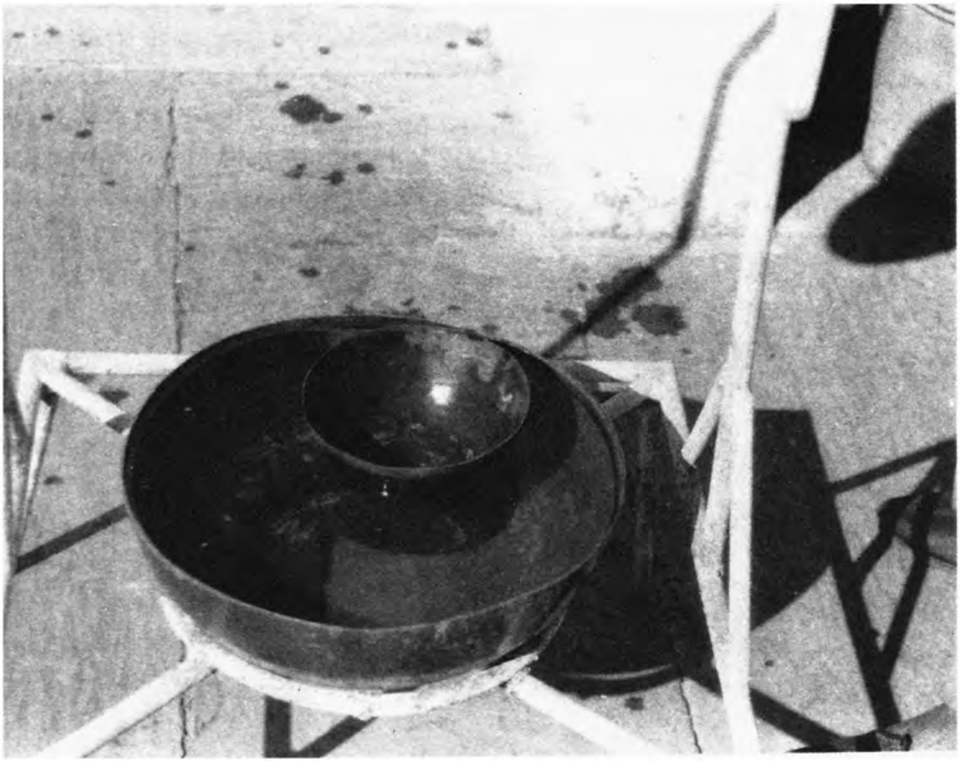

Fig. 5: *Ghaṭī Yantra* Bowl Floating in Water.

15 cm diameter with a pin-hole at the bottom.[10] The pin-hole is gold polished in order to prevent it from rusting. The bowl floats in water in a larger vessel of copper with a diameter of 31 cm. A *ghaṭī* bowl is supposed to sink in water every *ghaṭī*, or every 24 minutes. Over the large vessel filled with water, there hangs a gong to announce that a *ghaṭī* length of time has elapsed as indicated by the sinking of the little bowl in water.

In January 1993, the author took several readings with the *ghaṭī* instrument of Kota and found that its little bowl sank in water once every

[10] The author has seen a similar *ghaṭī* instrument displayed at the Golkonda fort near the modern city of Hyderabad.

24 min 17 sec ± 6 sec. However, when the author repeated his readings few years later, in January 2000, he found that the little bowl then sank at the rate of once every 22 min 38 sec ± 6 sec. Evidently, the hole at the bottom of the little bowl had become a bit wider by then. One of the readings of the author, which was discarded by him, was as high as 28 min 24 sec. The author noticed that at that moment, the little bowl was touching the side of the larger bowl, and thus took a longer time to sink. It seems that one has to constantly watch the little bowl as convection currents in water keep pushing it toward the side of the larger bowl causing an error. Further, surface tension of water can also cause a delay in sinking of the bowl.

SUNDIALS

There are two sundials with triangular gnomons on flat surfaces. The sundials are fabricated apparently for the latitude of Kota.[11]

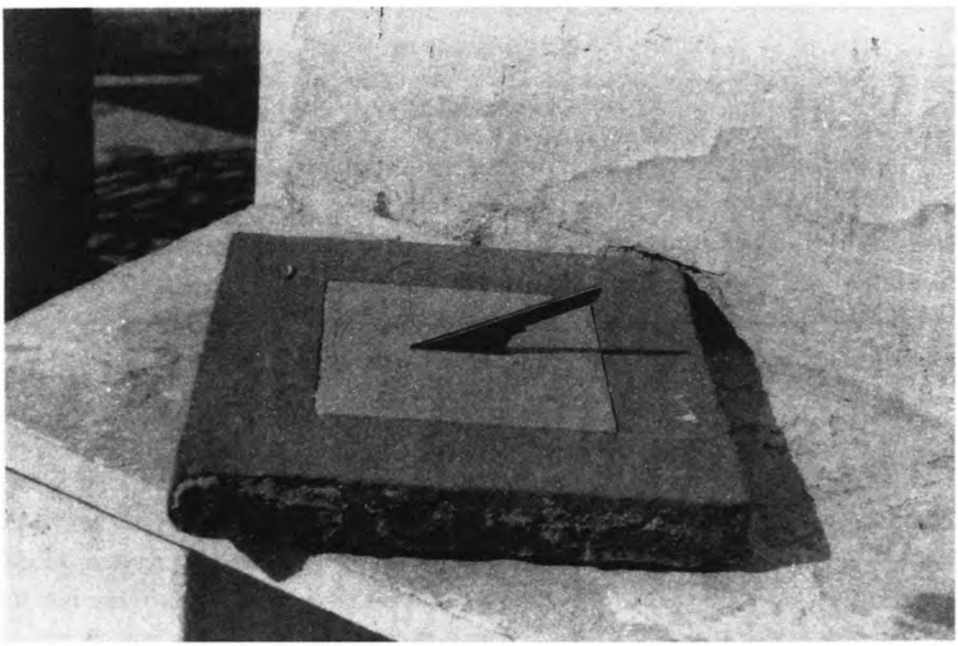

Fig. 6: Sundial 1.

11. The latitude of Kota is 25;11 N.

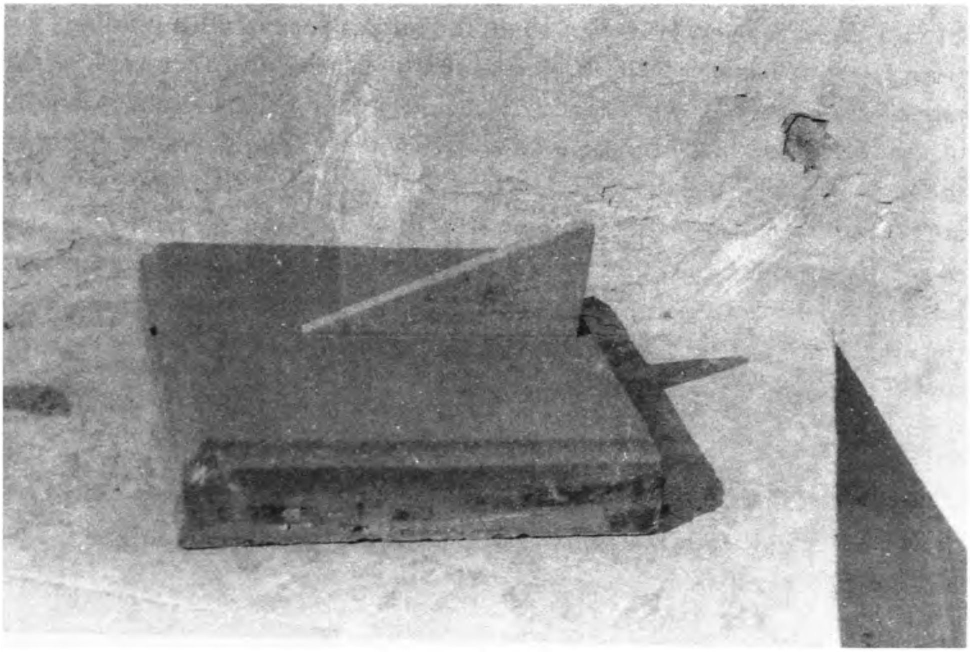

Fig. 7. Sundial 2.

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