A GUIDE

TO THE

OLD OBSERVATORIES

AT

DELHI ; JAIPUR ; UJJAIN ; BENARES

BY

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THREE years ago I examined, on behalf of the Archæological Department, the old astronomical observatories that were founded by Maharaja Jai Singh of Jaipur early in the eighteenth century. The results of my investigations were embodied in Volume XL of the new Imperial series of the Archæological Survey of India. The present small volume is based upon that larger work, to which reference should be made by those anxious for further details than are now presented.

G. R. KAYE.

Simla, 13th May 1919.

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CHAPTER I.

Jai Singh of Jaipur.

Mahārāja Sawāī Jai Singh II of Jaipur was born in A.D. 1686[1] and succeeded to the Amber territory at the age of thirteen in A.D. 1699, a few years before the death of Aurangzeb. He had difficulties in establishing himself, but in 1708 obtained complete possession of the province. In 1719 he was appointed by Muhammad Shāh governor of the province of Agra and soon after to Malwā. In 1734 he was again governor of Malwā and in that year, apparently with the cognizance of the Emperor, he resigned the province to the Peshwā. He died in 1743, two hundred years after Copernicus, and "his wives, concubines, and *science* expired with him on his funeral pyre."[2]

[1] The year in which Newton's *Principia* was completed.
[2] *Annals and Antiquities of Rajast'han.* By Lieutenant-Colonel James Tod, 1829, Vol. ii, p. 368.

Jai Singh mixed in most of the trouble and warfare of the long period of anarchy that coincided with his reign; but he distinguished himself more as a statesman than a soldier and has been termed the Machiavelli of his day. He was the founder of a new capital, named after him Jainagar or Jaipur, which in his time became a centre of learning; he erected caravansarais in many of the provinces; and he built astronomical observatories at five of the principal cities of Hindustan. He conceived and carried out a scheme of scientific research that is still a notable example; and his influence is still a living one. The observatories he erected are, in the words of his historian, "monuments that irradiate a dark period of Indian History."[1]

At an early age Jai Singh showed a predilection for astronomical work and, according to his own account, by constant study he obtained a thorough knowledge of its principles and rules. He found the astronomical tables in use defective and set himself the task of preparing new ones. With this purpose in view Jai Singh took every means to ensure success. He attached himself to no particular school but studied Hindu, Muslim and European methods impartially. He collected astronomical books and had certain of them translated; he organised a regular staff of workers and sent some of them to foreign countries to collect information; he invited certain Europeans and others interested in astronomy to Jaipur; he built a large observatory at Delhi and made careful observations there for seven

[1] Tod, ii, p. 360.

years with a view to the preparation of a new star catalogue; and afterwards he built other observatories at Jaipur, Ujjain, Benares and Mathurā. Such in brief were his astronomical activities which we now proceed to describe in some detail.

Sources of Jai Singh's astronomical knowledge.

Of the works of his predecessors and contemporaries there is evidence that Jai Singh was acquainted with the following: Ptolemy's *Almagest;* the astronomical tables of Ulugh Beg; some treatises on the Astrolabe; La Hire's *Tabulae Astronomicae;* and Flamsteed's *Historia Coelestis Britannica;* also certain western mathematical works such as Euclid's *Elements,* a treatise on plane and spherical trigonometry and on the construction of logarithms. This, of course, cannot be an exhaustive list: his valuable library no longer exists entire,[1] and it would be fairly safe to assume that Jai Singh collected and studied all the available astronomical works; indeed it is recorded specifically that he procured from Europe, besides the tables of La Hire, those of earlier dates.

The book that held sway in Europe for a thousand years after its publication, and among the Arabs for a thousand years after its translation, was Ptolemy's *Syntaxis*, commonly known as the *Almagest.* No other text-book that has ever been written has had such a

[1] It is said that Jaggat Singh gave Jai Singh's unrivalled library to a courtesan: it was thus despoiled and its treasures distributed among her "base relatives." This would account for the meagreness of the information now available; but the tale does not altogether bear the impress of truth;

reputation. Jai Singh himself speaks of Ptolemy as one of the greatest astronomers, and one of his most important acts was to order a translation from the Arabic of Ptolemy's great work. This was undertaken by Jai Singh's chief astronomer Jagannāth who, in an introduction to the translation entitled *Samrāṭ Siddhānta*,[1] records some interesting details.

Jai Singh, Jagannāth says, was clever in exhibiting new methods with globes and other instruments; and that, with the help of certain learned mathematicians and astronomers, he had made observations of the stars. The instruments proper to an observatory are said to be (1) Naḍi Yantra (sun-dial), (2) Gola Yantra (sphere), (3) Digaṁśa Yantra (azimuth instrument), (4) Dakhshiṇo Digbhitt (mural quadrant), (5) Vṛitta Shashtāṁśaka (an arc of sixty degrees placed in the meridian) which, he says, "the Yavanas call *shudsufkuri*," (6) Samrāṭ Yantra (an equinoctial dial), 'the best among the instruments,' and (7) Jaya Prakāś 'the crest jewel of all instruments.'

Then we are told that Jagannāth prepared this excellent *Siddhānta Samrāj* for the delight of Jai Singh; and that it is a rendering into Sanskrit for the benefit of mathematicians of a work in the Arabic language entitled *Mijāstī*.[2] He also tells us that "in the Yavana country, the Yavana masters of astronomy, Abarkhas, etc., found the maximum declination to be 23 degrees 51 minutes 19 seconds; and that in Yunan, 36 degrees north, it was found to be 23 degrees 51 minutes 15

[1] Another title is *Siddhānta Sāra Kaustubha*. See AUFRECHT, *Cat. Sans. Man. Trin. Coll., Dublin*, p. 75.

[2] *i.e.*, Ptolemy's *Almagest*.

seconds by the observations of Vitlamayus. Ulugh Beg found it to be 23 degrees 30 minutes 17 seconds at Samarqand, 39 degrees 17 minutes north. By observation with this instrument we found it to be 23 degrees at Indraprastha in 1651 Sāliṿāhana."[1]

Ulugh Beg's astronomical tables were completed in A.D. 1436 and became almost as famous as those of Ptolemy, and they formed the basis of most subsequent catalogues. Flamsteed used them and so did Jai Singh, who brought them up to date.[2]

Jai Singh himself refers to La Hire's tables and to other European tables, and in the palace library at Jaipur is still a copy of Flamsteed's great work.

P. de la Hire was a French scholar of repute who lived from A.D. 1640 to 1718. He wrote many mathematical works and in 1702 published his *Tabulae Astronomicae* of which the first part had appeared in 1687. This work contained, besides the usual tables, a refraction table (which, it is said, Jai Singh copied) and a description of a machine invented by la Hire to show the theory of eclipses. Another of la Hire's works was 'La Gnomonique, ou l'art de tracer des cadrans ou horologes solaires sur toutes sortes de surfaces, par differentes pratiques, avec les démonstrations géometriques de toutes les operations.' This

[1] Calcutta MS. The names are somewhat puzzling, but Abarkhas is for Hipparchus, Vitlamayus is for Ptolemaeus. By Yunan possibly Rhodes is meant. The date 1651 Sālivāhana is equivalent to A.D. 1729. Indraprastha is Delhi.

[2] Jai Singh's version is given in my larger volume (pp. 98-115). See also Mr. E. B. Knobel's recent edition of *Ulugh Beg's Catalogue of Stars*, published by the Carnegie Institution of Washington (1917).

was published in 1682 and would have been useful to Jai Singh.

John Flamsteed lived from 1646 to 1720. His *Historia Coelestis Britannica* appeared in 1712, in one folio volume, made up of two books, the first containing the catalogue of stars and sextant observations; the second, observations with Sharp's mural arc. The complete work, consisting of three folio volumes, was published in 1725. Flamsteed himself lived only long enough to finish the second of the three volumes. The third was edited by his assistants Crossthwaite and Sharp. It contains descriptions of the instruments used by Tycho Brahe, Hevelius, Flamsteed himself, etc.; the star catalogues of Ptolemy, Ulugh Beg, Tycho Brahe, the Landgrave of Hesse and Hevelius, and, finally, the British catalogue of 2,935 stars.

Undoubtedly Jai Singh possessed other astronomical works, for in the preface to his own catalogue he mentions several other astronomers by name. For example, he not only mentions Naṣīr-al-Dīn al-Ṭūsī (born A.D. 1201) but also his commentator (Ali b. M.) al-Gurgānī. Naṣīr-al-Dīn was one of the greatest Muslim astronomers. He made observations at the Marāgha observatory and published the famous 'Ilkhāṇic Tables.' He wrote numerous works on astronomy and mathematics, including commentaries on the works of Archimedes, Euclid, Ptolemy, etc.

Coupled with Naṣīr-al-Dīn, Jai Singh mentions also Jamshid Kāshi (Jamshid b. Mas'ūd b. M. G͟hyāth al-Dīn al-Kāshī), one of Ulugh Beg's assistants, who wrote several works on astronomy and particularly on the Khāqānī tables. Jai Singh also mentions al-Ṣūfī.

Hunter[1] tells us that he met at Ujjain a grandson of Jai Singh's principal assistant (? Jagannāth). "In his possession," he writes, "I saw the translation into Sanskrit of several European works, executed under the orders of Jaisingha, particularly Euclid's *Elements* with a treatise on plane and spherical trigonometry, and on the construction and use of logarithms which was attached to Cum's and Commandine's edition. In this translation the inventor is called Don Juan Napier[2] . . . . . Besides these the Pandit had a table of logarithms and of logarithmic sines and tangents to seven places of figures, and a treatise on conic sections."

We are also told that "maps and globes of the Feringhees were obtained from Surat."[3]

Jai Singh did not rely altogether upon information contained in books. He sent to Europe "several skilful persons along with Padre Manuel"; Muhammad Sharīf[4] was sent to some place where "the southern pole was overhead"; and Muhammad Mahdī was sent to the "further islands."[5]

[1] *Some account of the Astronomical Labours of Jaya Sinha, Raja of Ambhere, or Jayanagar.* By W. HUNTER. Asiatic Researches, Vol. V., 1799, p. 209.

[2] This seems to be the source of Tod's statement that Jai Singh caused "Don Juan Napier on the construction and use of logarithms to be translated into Sanskrit." (ii 358.)

[3] A. ff. GARRETT and C. GULERI. *The Jaipur Observatory and its Builder*, p. 20. In the Jaipur museum there is a terrestrial globe attributed to Jai Singh; and for the transference of Ulugh Beg's co-ordinates into declination and right ascension a large and fairly accurate celestial globe was used by Jai Singh's assistants.

[4] There is a treatise on the astrolabe (British Museum Adit. manuscripts No. 7489) by 'Abdu'l Rahīm b. Muhammad Sharīf al-Sharīf. The date of the manuscript is A. H. 1165 (=A.D. 1751). See Morley p. 2.

[5] GARRETT p. 20.

Confirmation of the expedition to Europe is found in the records of the Jesuit missionaries in India. In 1728 or 1729, we are told,[1] Jai Singh sent Father Figueredo, a Portuguese Jesuit, to Portugal. Also the same records relate that on January 6th, 1734, two priests set out from Chandernagore to Jaipur,[2] at Jai Singh's request. The account[3] of the astronomical work done by these two priests at Jaipur and on their journey was written, according to M. D'Anville,[4] by Father Boudier, one of the priests who made the journey. Observations were made at most of the important places through which they passed. The observatories at Delhi and Jaipur are mentioned but not those at Benares and Mathurā, at both of which places they made astronomical observations; and this seems to imply that the observatories at Benares and Mathurā were built after their visit, which took place in the early part of 1734.

Tieffenthaler, a French Jesuit, who landed in India in 1743, the year in which Jai Singh died, writes:[5] "I have made three or four journeys to Agra and Delhi in order to visit R. P. André Strobel, whom

[1] *Lettres édifiantes et curieuses, écrites des Missions étrangères Nouvelle édition. Mémoires des Indes. Tome quinzième.* Toulouse, 1810, pp. 260 f.

[2] A journey of over a thousand miles.

[3] *Observations géographiques faites en 1734 par des Pères Jesuites, pendant leur voyage de Chandernagor à Delhi et à Jaëpour*, p. 269.

[4] *Eclaircissemens géographiques sur la Carte de l'Inde.* Paris 1753, p. 46. Father Boudier's account was not published till later, but M. D'Anville obtained the manuscript from M. Despréménil.

[5] *Description historique et géographique de l'Inde.* Ed. by J. Bernouilli, 1786, Preface p. 5. This work contains descriptions of the observatories, which are quoted below.

Jessing, Raja of Djepour, interested in astronomy, had, with a companion, brought from Germany."

The only other European connected with Jai Singh, that we have information about, is a Don Pedro de Sylva, who, according to Hunter,[1] was a physician and an astronomer and resided at Jaipur with Jai Singh. De Sylva, it appears, died about A.D. 1792.

Jai Singh's astronomical tables.

The *Zīj Muhammad Shāhī* is a set of astronomical tables prepared under the direction of Jai Singh and named after the Emperor, Muhammad Shāh. Of this work there is an incomplete Devanāgarī manuscript at Jaipur, and at the British museum is a complete Persian manuscript.[2] Also Hunter had access to a Persian manuscript and gave in his paper in the Asiatic Researches (1799) the Persian version of the preface together with an English translation. The latter is reproduced below. The tables in both the Jaipur and British Museum manuscripts are identical, and the catalogue of stars is not an original one but is Ulugh Beg's brought up to date.

The Jaipur manuscript begins as follows :—

" Homage to holy Ganesh. Catalogue of 48 constellations. From the time of Ulugh Beg's table, A.H. 841, to the present date A.H. 1138, or 297 years, the mean motion is 4 degrees 8 minutes. In the *Zīj Muhammad Shāhī* the estimates of declination, etc., are taken from

[1] Asiatic Researches V. 1799, p. 210.
[2] C. RIEU *Catalogue of Oriental MSS.* " Add. 14373, Foll. 222."

the globe. Right ascension divided by six is apparent time."

The preface to the *Zīj Muhammad Shāhī* is, from an historical point of view, perhaps the most interesting part of that work, and is here given in full.[1]

"Praise be to God, such that the minutely discerning genius of the profoundest geometers in uttering the smallest particle of it, may open the mouth in confession of inability; and such adoration, that the study and accuracy of astronomers who measure the heavens, on the first step towards expressing it may acknowledge their astonishment and utter insufficiency. Let us devote ourselves at the altar of the King of Kings—
H? hallowed be his name—in the book of the register of whose power the lofty orbs of heaven are only a few leaves; and the stars and that heavenly courser the sun, a small piece of money in the treasury of the empire of the Most High.

"If He had not adorned the pages of the table of the climates of the earth with the lines of rivers, and the characters of grasses and trees, no calculator could have constructed the almanac of the various kinds of seeds and of fruit which it contains. And if He had not enlightened the dark path of the elements with the torches of the fixed stars, the planets and the resplendent sun and moon, how could it have been possible to arrive at the end of our wishes, or to escape from the labyrinth and the precipices of ignorance?

"From inability to comprehend the all encompassing beneficence of His power, Hipparchus is an ignorant

[1] Hunter, *As. Res. V.* p. 178 f.

clown, who wrings the hands of vexation; and in the contemplation of His Exalted Majesty, Ptolemy is a bat, who can never arrive at the sun of truth: the demonstrations of Euclid are an imperfect sketch of the forms of his contrivance; and thousands of Jamshīd Kāshī,[1] or Naṣīr Ṭūsī,[2] in this attempt would labour in vain.

"But since the well-wisher of the works of creation and the admiring spectator of the theatre of infinite wisdom and providence, Sawāī Jai Singh,[3] from the first dawning of reason in his mind and during its progress towards maturity, was entirely devoted to the study of mathematical science, and the bent of his mind was constantly directed to the solution of its most difficult problems; by the aid of the Supreme Artificer he obtained a thorough knowledge of its principle and rules.

"He found that the calculation of the places of the stars as obtained from the tables in common use, such as the new tables of S'aid Gurgānī[4] and Khāqani, and

[1] Jamshīd b. Mes'ud Ghyāth al-Dīn al-Kāshī was one of Ulugh Beg's astronomers.

[2] Naṣīr al-Dīn al-Ṭūsī was born A.D. 1201. He worked at the Marāgha observatory and published the famous 'Īlkhānic Tables.' He translated Euclid's *Elements* and Ptolemy's *Almagest*, and wrote many works on astronomy.

[3] Jai Singh writes in the third person.

[4] Possibly 'Alī b. M. al-Saijid al-Sarif al-Gurgānī, who lived from A.D. 1339 to 1414 in Shirāz, and wrote a commentary on Naṣīr al-Ṭūsī's *Tadkira* (See H. Suter's *Die Mathematiker und Astronomen der Araber und Ihre Werke*, p. 172); but Gurgānī was a designation of Ulugh Beg's family, and Ulugh Beg's tables were sometimes termed the Gurgānī cannon [See L.P.E.A. Sédillot's *Prolégomènes des Tables astronomiques d'Oloug Beg*. p.c. xix; also *Āin-i-Akbari*, (iii) 20 and 41 (Jarrett's edition); *Akbarnāma*, (i), 204 (Beveridge's edition).]

the *Tasahīlāt-Mula Chānd*[1] *Akbar Shāhī*[2] and the Hindu books, and the European tables,[3] in very many cases give them widely different from those determined by observation: especially in the appearance of the new moons, the computation does not agree with observation."

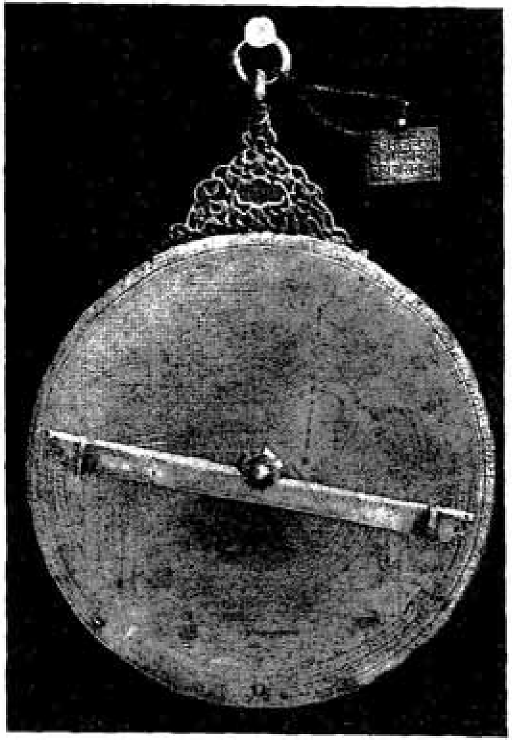
"Seeing that very important affairs both regarding religion and the administration of empire depend upon these; and that in the time of the rising and setting of the planets, and the seasons of eclipses of the sun and moon, many considerable disagreements of a similar nature were found—he represented it to his Majesty of dignity and power, the sun of the firmament of felicity and dominion, the splendour of the forehead of imperial magnificence, the unrivalled pearl of the sea of sovereignty, the incomparably brightest star of the heaven of empire, whose standard is the sun, whose retinue the moon, whose lance is Mars and whose pen is

[1] Suter (p. 95) mentions one al-Khāqānī, an astronomer and astrologer, who died in A.D. 1038 and who worked at improving the astronomical tables. The Khāqānī tables were supplementary to the Īlkhānic tables of Naṣīr al-Ṭūsī and were prepared and edited by Jamshīd al-Kāshī.

[2] "Maulānā Chānd, the astrologer, who was possessed of great acuteness and thorough dexterity in the science of the astrolabe, in the scrutinising of astronomical tables, the construction of almanacs and the interpretation of the stars, was deputed to be in attendance at the portals of the cupola of chastity in order that he might observe the happy time and ascertain exactly the period of birth (of Akbar). He reported in writing to the exalted camp that according to altitudes taken by the Greek Astrolabe and by calculations based on the Gurgānī tables etc." (*Akbarnāma*, Vol. I, 69-70. Ed. Beveridge). He also cast the horoscope of Jahāngir in A.D. 1570 according to the Greek cannon (*ib.* ii, 506-7. See also i, 56 and 374).

[3] He is possibly referring to La Hire's *Tabulae Astronomicae* and Flamsteed's *Historia Coelestis Britannica*.

a



b

ASTROLABE.

Photo-engraved & printed at the Offices of the Survey of India, Calcutta, 1915

Mercury, with attendants like Venus, whose threshold is the sky, whose signet is Jupiter, whose sentinel is Saturn—the Emperor descended from a long race of kings, an Alexander in dignity, the shadow of God, the victorious king Muhammād Shah[1]: May he ever be triumphant in battle.[2]

"He was pleased to reply, since you, who are learned in the mysteries of science, have a perfect knowledge of this matter, having assembled the astronomers and geometricians of the faith of Islām, and the Brahmans and Pandits, and the astronomers of Europe and having prepared all the apparatus of an observatory, do you so labour for the ascertaining of the point in question, that the disagreement between the calculated times of those phenomena, and the times which they are observed to happen, may be rectified.

"Although this was a mighty task, which during a long period of time none of the powerful Rajas had prosecuted; nor among the tribes of Islām, since the time of the martyr prince, whose sins are forgiven, Mirza Ulugh Beg, to the present, which comprehends a period of more than three hundred years,[3] had any one of the kings possessed of power and dignity turned his attention to this object. Yet to accomplish the exalted command he had received, he bound the girdle of resolution about the loins of his soul and constructed

[1] Muhammad Shāh reigned from 1719-1748.

[2] This must have been written before 1739 when Nadir Shāh sacked Delhi.

[3] Ulugh Beg was assassinated in A.D. 1449 while the *Zīj Muhammad Shāhī* is supposed to have been published in 1728, approximately 297 Muslim years after.

here[1] several of the instruments of an observatory, such as had been erected at Samarqand,[2] agreeable to the Mussalman books, such as *Zāt al-Halqa*[3] of brass, in diameter three gaz[4] of the measure now in use, and Zat al-Sha'batain,[5] and Zat al-Zaqatain, and Sads[6] Fakhri and Shāmalah.[7]

"But finding that brass instruments did not come up to the ideas which he had formed of accuracy, because of the smallness of their size,[8] the want of division

[1] At Delhi.

[2] We have very little information about the observatory at Samarqand. Greaves stated that the quadrant used by Ulugh Beg was as high as the summit of St. Sophia at Constantinople, or about 180 feet. The earlier Muslim astronomers had also devised huge instruments. In A.D. 995 Abul Wafa used a quadrant of radius 21 feet 8 inches; al-Khojendi used a sextant with radius 57 feet 9 inches. Nasir al-Dīn set himself the task of perfecting instruments, etc. See Sédillot's *Prolégomènes des Tables astronomiques d'Oulong-Beg*, p. cxxix.

[3] A ring instrument, armilla, sphæra armillaris—(Nallino ii. 329).

[4] 3 *gaz*=9 feet ordinarily, but perhaps here a *gaz*=1 *danda*=6 feet approximately.

[5] An astrolabe with two rings or parts. It is the *triquetrum* or *regulae parallacticae*. Al-Battānī calls it the 'long alhidade' (Nallino i. 321). In Leiden is a MS *De ratione qua ope instrumenti Zat al-Sho'batain, etc.*, by the celebrated *al-Kindi*. Muhammad bin 'Isāo b. Abī 'Abbād, Abu'l Hasan also wrote on the same instrument (Suter, pp. 25 and 48).

[6] This must be the same as the *Shashtāmśa Yantra*, which, according to Jagannāth, "the Yavanas called *shudasfkari*." See pages 4 and 31.

[7] The Jai Prakās is called *shāmlah* by Hunter.

[8] *Cf.* Albīrūnī *Chronology of Ancient Nations* (p. 11), who writes "It is impossible to fix the parts of the greatest circle by means of the parts of the smallest circle. I refer to the smallness of the instruments of observation in comparison with the vastness of the bodies which are to be observed. On this subject I have enlarged in my book called *Kitāb-al-istishhād bikhtilāf-al 'arsād.*' L.P.E.A Sédillot [p. cxxix] gives the following interesting quotations: "Si

into minutes, the shaking and wearing of their axes, the displacement of the centres of the circles, and the shifting of the planes of the instruments, he concluded that the reason why the determinations of the ancients, such as Hipparchus and Ptolemy, proved inaccurate, must have been of this kind.

"Therefore he constructed in Dār al-Khalafat Shāh Jahānābād,[1] which is the seat of empire and prosperity, instruments of his own invention, such as *Jai Prakāś* and *Rām Yantra* and *Samrāṭ Yantra*, the semi-diameter of which is of eighteen cubits and one minute on it is a barley corn and a half[2]—of stone and lime of perfect stability, with attention to the rules of geometry and adjustment to the meridian and to the latitude of the place, and with care in the measuring and fixing of them, so that the inaccuracies from the shaking of the circles and the wearing of their axes and displacement of their centres and the inequality of the minutes might be corrected. Thus an accurate method of constructing an observatory was established and the difference which had existed between the computed and observed places of the fixed stars and planets by means of observing their mean motions and observations was removed.

"And, in order to confirm the truth of these observations, he constructed instruments of the same kind in

j'avais pu, disait Ebn-Carfa, faire un cercle qui s'appuyat d'un coté sur les Pyramides et de l'autre sur le mont Mocattam, je l'aurais, fait ; car plus l'intrument est grand, plus les operations sont justes."

[1] *i.e.*, Delhi.

[2] To make the measurements fit, the cubit used must have been a large cubit=36 añgulas.

Sawāī Jaipur, Muttra and Benares and Ujjain.[1] When he compared these observatories, after allowing for the difference of longitude between the places where they stood, the observations agreed.[2]

"Hence he determined to erect similar observatories in other large cities so that every person who is devoted to these studies, whenever he wished to ascertain the place of a star or the relative situation of one star to another, might by these instruments observe the phenomena.[3]

"But seeing that in many cases it is necessary to determine past or future phenomena; and also that in the instant of their occurrence cloud or rain may prevent the observation—or the power and opportunity of access to an observatory may be wanting—he deemed it necessary that a table be constructed by means of which the daily places of the stars being calculated every year and disposed in a calendar may always be in readiness.

"In the same manner as the geometers and astronomers of antiquity bestowed many years on the practices of observation—thus, for the establishment of a certain method, after having constructed these instruments, the places of the stars were daily observed.

[1] This implies that the Delhi Observatory was completed before the others were started; and that all of them were built before the preface was written. This dates the preface after 1734 and perhaps after 1737.

[2] We must accept the statements about perfect agreement with some caution. We have very few records of Jai Singh's actual calculations or observations: his value for *precession* was 51·6″ a year and for the *obliquity* 23° 28′ 0.

[3] The project of building observatories at other places was never carried out.

"After seven years had been spent in this employment information was received that about this time observatories had been constructed in Europe[1] and that the learned of that country were employed in the prosecution of this important work: that the business of the observatory was still carrying on there and that they were constantly labouring to determine with accuracy the subtleties of this science.

"For this reason, having sent to that country several skilful persons along with Padre Manuel,[2] and having procured the new tables which had been constructed there thirty years before and published under the name Lir,[3] as well as the Europe tables anterior to those;[4] on examining and comparing the calculations of these tables with actual observations it appeared that there was an error in the former in assigning the moon's place of half a degree. Although the error in the other planets was not so great, yet the times of solar and

[1] Uraniborg (Tycho Brahe's observatory) in 1576; Leiden 1632; Paris 1667; Greenwich 1675; Berlin 1705; St. Petersburg 1725; Upsala 1730, etc.

[2] In 1728 or 1729 the Reverend Father Figueredo, a Portuguese Jesuit, went to Europe by the order of Jai Singh. Possibly this is the same man. See *Lettres édifiantes et curieuses*, xv. 269.

[3] La Hire's *Tabulae Astronomicae* was published in 1702. Father Boudier, who went to Delhi and Jaipur in 1734, actually refers to this edition. He writes: "En se servant de la méthode de M. de la Hire, édition de ses tables 1702, page 53, on a trouvé que le commencement de l'éclipse à Delhi lorsqu'il était à Rome 11 heures 40 minutes 55 seconds du matin, etc." *Lettres*, etc. xv. 288.

[4] We know that, besides La Hire's tables, Jai Singh possessed those of Ulugh Beg and Flamsteed. The latter's work contains also the tables of Tycho Brahe, the Landgrave Hesse, and Hevelius. Other possible tables are the *Toletan Table* of 1080; the *Alfonsine Tables*, 1252; Reinhold's *Prussian Tables*, 1551; Kepler's *Rudolphine Tables* 1627; Cassini's tables, 1668 and 1693; Halley's tables, 1719; etc.

lunar eclipses he found to come out later or earlier than the truth by the fourth part of a *ghaṭi* or fifteen *palas*.[1] Hence he concluded that, since in Europe astronomical instruments have not been constructed of such a size and so large diameters, the motions which have been observed with them may have deviated a little from the truth.[2]

"Since in this place by the aid of the unerring Artificer astronomical instruments have been constructed with all the exactness that the heart can desire and the motions of the stars have for a long period been constantly observed with them, agreeable to observations mean motions and equations were established; he found the calculation to agree perfectly with the observation. And although to this day the business of the observatory is carried on, a table under the name of His Majesty, the shadow of God, comprehending the most accurate rules, and most perfect methods of computation was constructed—so that, when the places of the stars and the appearance of the new moons and the eclipses of the sun and moon and the conjunction of the heavenly bodies are computed by it, they may arrive as near as possible at the truth, which, in fact, is every day seen and confirmed at the observatory.

"It therefore behoveth those who excel in this art, in return for so great a benefit, to offer up their prayers for the long continuance of the power and the pros-

[1] 60 *palas*=1 *ghaṭi*=24 minutes, and 15 *palas*=6 minutes.

[2] The instruments used by Flamsteed (1646-1719) were an iron sextant of 6 feet radius; a three-foot quadrant; a mural arc of 140 degrees and radius 7 feet, 'divided with hitherto unapproached accuracy,' and with which all his most valuable work was executed; two clocks and two telescopes.

perity of so good a King,[1] the safeguard of the earth, and thus obtain for themselves a blessing in both worlds.[2]"

[1] Muhammad Shāh died in A.D. 1748 five years after the death of Jai Singh.

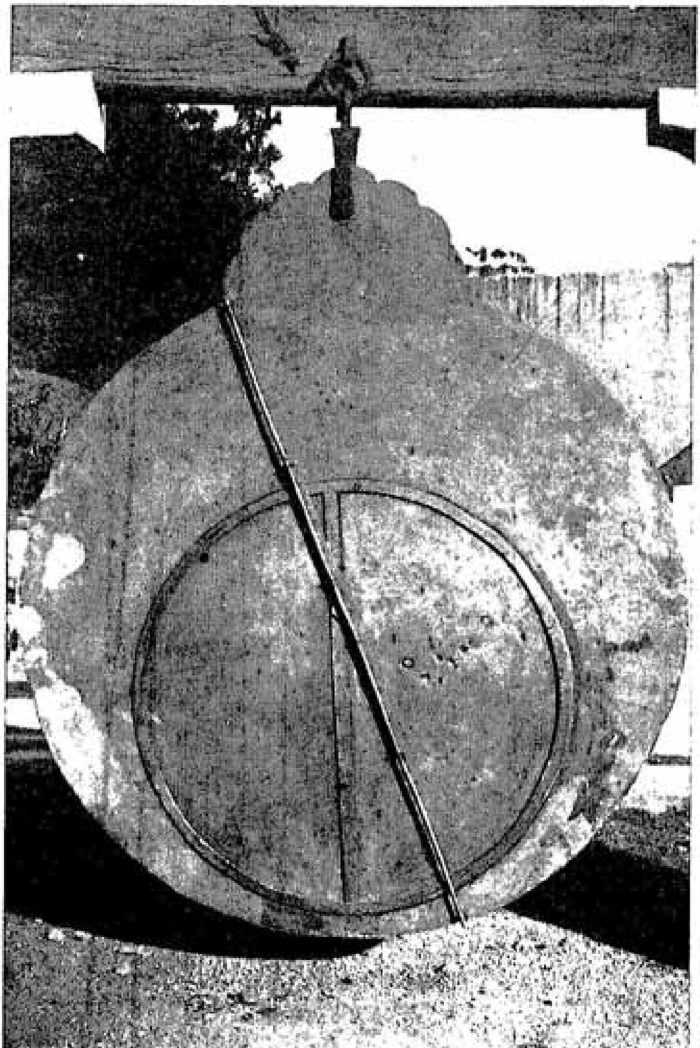
[2] There are some points about the preface that are not quite consistent with each other and known facts. The tradition is that the *Zīj Muhammad Shāhī* was completed in A.D. 1728 and this is, to some extent, confirmed by the Jaipur MS.; the preface was written some time after all the observatories had been built, that is after 1734, and "more than 300 years" after (the death of) Ulugh Beg [Ulugh Beg died in A.H. 853, and 853+300=1153 A.H.=A.D. 1740-1]. A legitimate conclusion is that the preface was written some considerable time after the tables had been completed.

CHAPTER II.

The Instruments.

1. Metal instruments.

Jai Singh himself relates that he first constructed ertain metal instruments 'agreeable to the Mussalman books,' and at Jaipur there is even now a fine collection of such instruments. The metal instruments originally at Delhi were possibly removed to Jaipur, but it is also possible that, when Delhi was sacked by Nādir Shāh in 1739, some of the portable instruments were either destroyed or carried off. There is, indeed, evidence that appears to indicate that the present collection at Jaipur does not preserve all Jai Singh's metal instruments. In 1790 R. Burrow examined an astrolabe "in the Nagri character, brought by Dr. Mackinon from Jaynagur"; and recently at Delhi I was shown a small brass sphere made in A.D. 1677 by the designer of the Jaipur Zarqālī instrument noted below, and with it three astrolabes. Tod tells us of a dial "on the terrace of the palace at Oodipoor, and various instruments at Kotah and Boondi, especially an armillary sphere at the former, of about five feet in diameter, all in brass, got up under the scholars of Jey Singh."



YANTRA RAJ.

At the Lahore exhibition of 1864 certain brass astronomical instruments from Kapūrthala and other places were shown; and these included "two fine astrolabes," one spherical and one plane, and several dials. In the Lahore museum is a small astrolabe of unknown history, and in the Indian Museum at Calcutta is one that was brought from Herāt, but long after Jai Singh's time.[1]

The more important of the metal instruments at Jaipur include (*a*) the astrolabe shown in plate I, (*b*) an astrolabe dated the 31st year of the reign of Shāh Jāhān and A.H. 1067 (=A.D. 1657), (*c*) a Zarqālī astrolabe dated the 23rd year of the reign of Aurangzeb and A.H. 1091 (=A.D. 1680), and made for Nawāb Iftikhār Khān of Jaunpur by Ziā al-Dīn b. Mullā Qāsim, astrolabe maker of Lahore, (*d*) two very large astrolabes now in the Jaipur observatory, one of which is shown in plate II, (*e*) a graduated brass circle, 17½ feet in diameter, now in the Jaipur observatory, and which is partly visible in plate VIII, (*f*) two equatorial circles, shown in plate X[a], (*g*) the Krāntivṛitti Yantra shown in plate X[b].

The astrolabe.

Of these metal instruments the astrolabe appears to have played a very important part in Jai Singh's work. The Arabs perfected it at a very early date and it remained one of the principal astronomical instruments until about the 17th century, and is still used in the east for astrological purposes. It was usually

[1] Journal of the Asiatic Society of Bengal, 1841, X, p. 761.

of brass[1] and varied in diameter from a couple of inches to several feet. The mariner's astrolabe (as used by Columbus) was adapted from that of the astronomers about A.D. 1480, but was superseded by Hadley's Quadrant of 1731. The famous scholar Gerbet, who afterwards became Pope Sylvester II, had such skill in making astrolabes, etc., that he was supposed to have sold his soul to the devil. There are many references in mediaeval literature to the astrolabe. More than three centuries before Jai Singh, Chaucer wrote his *Treatise on the Astrolabe.* "Trust well," he says "that alle the conclusions that have be founde, or else possibly might be founde in so noble an instrument as is an Astrolabe been unknowe parfitly to any mortal man in this regioun, as I suppose."

The type of astrolabe principally used by Jai Singh was the flat astrolabe, or *astrolabium planisphaerum*, in Arabic called *Ẕāt al-Ṣafā'iḥ* ('consisting of tablets'), an example of which is shown in Plate I. A brief description of an astrolabe is here given, and for further details the reader is referred to the larger work.

The *corpus astrolabii* is a circular disc with a raised edge into which fit the several parts of the instrument:

[1] Gower refers to one of gold: "With him his astrolabe he name, which was of fine gold precious, with points and circles marvellous."

The Granada astrolabe described by H. S. Cooper (*JRAS* 1904, 53f) has silver knobs on each pointer of the '*ankabūt*'; in the British Museum are several inlaid with silver; and others evidently had some sort of jewel fixed in the *kursi*. Gilt instruments are not uncommon.

(*i*) The containing disc is termed the *mater* (Ar. *umm*) and the inner part of this is the venter, which is often inscribed with latitudes and longitudes of important cities.

(*ii*) The ʿ*ankabūt* or *aranea* or *rete* is an open-work disc marked with the ecliptic, the signs of the zodiac and a number of stars. It fits in the venter and can be revolved. The branches on which the names of the stars are written and the points of which indicate the positions of the stars are termed *shaẓāya* or ʻ splinters.'

(*iii*) Several thin discs or tablets, marked with almucantarats, azimuth circles, hour circles, etc., for various latitudes, etc., fit into the body of the astrolabe.

(*iv*) The alhidade or sighter revolves round the centre on the back of the astrolabe. Each arm has a perforated *libna* or ʻ tile,' which is sometimes hinged on to the alhidade. European astrolabes sometimes have another marker or label without sights, for use on the front of the instrument.

(*v*) The tablets and alhidade, etc., are fixed together by a pin (Ar. *quṭb*) which is fastened by a wedge, termed by the Arabs *faras* or ʻ horse.' This wedge is often fashioned into some resemblance of a horse's head.

(*vi*) The whole is suspended by a ring (Ar. *ḥalqa*) joined to the ʿ*urwah* or handle, which in its turn is riveted to the projecting part, *kursi* or throne, of the instrument.

(*vii*) The back of the astrolabe generally has an outer scale of degrees, and certain other scales. It is often inscribed with tables of use to the astrologer and geographer : the details vary greatly.

The sighter and graduated circle on the back of the astrolabe form the part of the instrument used in actual observation; while the 'tablets' and the '*ankabūt* (which rotates) and the graduated circle on the raised edge form a very efficient calculating machine.

Most of the Indian astrolabes are engraved in Persian characters, and astrolabes of any antiquity in Hindu characters are not common. At Jaipur there are at least two such instruments engraved in Devanāgarī characters, but they are comparatively modern. As already mentioned, in 1790 R. Burrow [1] "compared an astrolabe in the Nagri character (brought by Dr. Mackinon from Jaynagur) with Chaucer's descriptions," and goes on to relate that "Even the centre pin, which Chaucer calls 'the horse,' has a horse's head upon it in the instrument." Morley[2] describes two Hindu astrolabes; and one of the Delhi astrolabes referred to above is engraved in Hindu characters, but it also is of very crude workmanship as compared with the Muslim instruments.

2. *Masonry instruments.*

The masonry instruments, which vary in size from a few feet to 90 feet in height, are Jai Singh's chief work. It has already been related how Jai Singh discarded brass instruments, and built massive masonry ones in their place. His reasons appeared to be, but were not altogether, sound. The brass instruments were, he said, faulty, because of their mobility and

[1] *Asiatic Researches*, 1790, Vol. ii, p. 489.

[2] W. H. Morley—*Description of a planispheric astrolabe ...... in the British Museum.*

size.[1] The axes became worn and the instruments untrue; the graduations were too small for fine measurements, etc. His remedy was to make large, immovable instruments: but he thus stereotyped his designs, for the larger and more immobile an instrument is the greater is the difficulty in making alterations and improvements. Jai Singh sacrificed facility for supposed accuracy.

Jai Singh claims to have devised the Samrāṭ Yantra, the Jai Prakāś, and the Rām Yantra. These three instruments are indeed peculiar to Jai Singh's observatories, and must be to some extent attributed to his personal ingenuity.[2] He used other stone instruments, such as the mural quadrant and cylindrical dial; but these were not mentioned specially in the preface, because they were common to many observatories. They are, however, mentioned in Jagannāth's introduction to the *Samrāṭ Siddhānta*.

The masonry instruments include (*a*) the huge dials (Samrāṭ Yantra) at Delhi and Jaipur, and smaller ones at Ujjain and Benares, (*b*) hemispherical dials (Jai Prakāś) at Delhi and Jaipur, (*c*) azimuth instruments at all the observatories, (*d*) Meridian circles (Dakshiṇovṛitti Yantra) at Jaipur, Ujjain and Benares, (*e*) cylindrical dials at Jaipur, Ujjain and Benares, (*f*) huge fixed sextants (Shashtāmśa Yantra) at Delhi and Jaipur

[1] The contrast with the procedure in Europe is interesting. The European scientist recognised the inevitability of error, and took measures to counteract it (*e.g.*, with the micrometer, vernier, telescopic sights, etc., etc.) Even a modern theodolite, as a useful astronomical instrument, is worth more than all Jai Singh's large buildings.

[2] See page 80 seq.

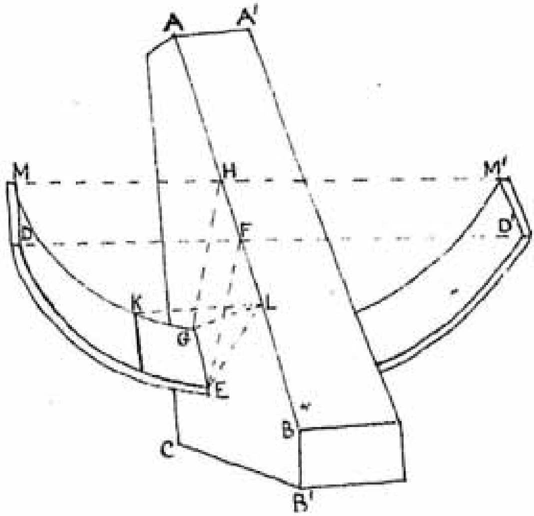
(*h*) the 'mixed instrument' (Miśra Yantra) at Delhi, and (*i*) the zodiac dials (Rāśi Yantra) at Jaipur.

The **Samrāṭ Yantra** is, as its name implies, the most important. It is an equinoctial dial, consisting of a triangular gnomon with the hypotenuse parallel to the earth's axis, and on either side of the gnomon is a quadrant of a circle parallel to the plane of the equator. It is, in principle, one of the simplest 'equal hour' sun-dials.

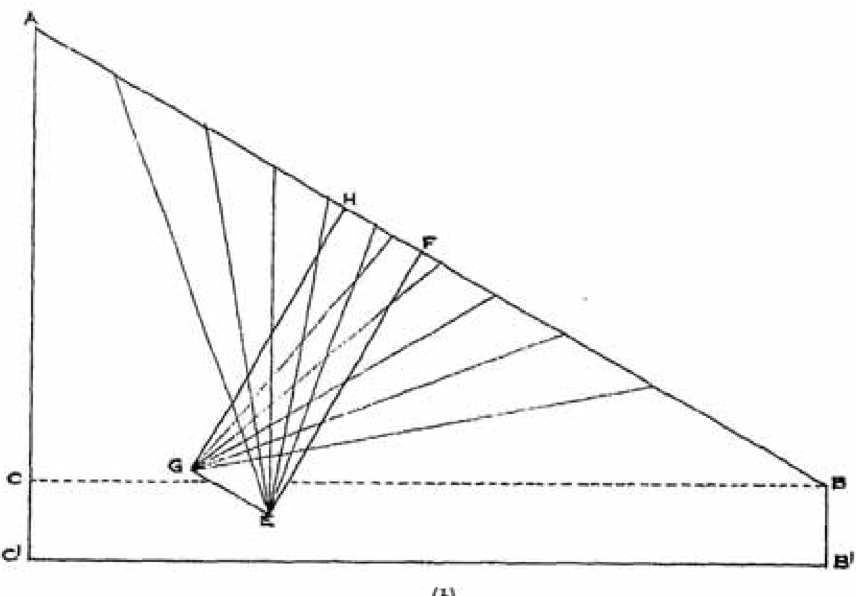
In plate III, AB is one edge of the gnomon, the angle ABC is equal to the latitude of the place, EF and GH are at right angles to AB, as also are DF and MH. If KL is the direction of the sun, then the arc KG indicates the time before noon, and the angle HGL the declination, or sun's angular distance from the equator. In the actual structure, the considerable width of AA' and GE (each being over 9 feet at Jaipur) practically duplicates the instruments. Each edge of the quadrants is graduated in hours and minutes, as well as in degrees, and each edge of the gnomon has two scales of tangents, one from H to B, and the other from F to A. In the figure $\tan HGL = HL/GH$, and GH is the radius of the quadrant MKG.

The shape of the gnomon is generally a parallel trapezium, as in plate III[b]. In the same figure GE represents the position of the quadrants as they enter the gnomon, $HG=FE$ is the radius, and the lines radiating from E and G show the construction of the scales of tangents on the edge AB.

These dials give apparent solar time, which varies from day to day, owing to (1) the eccentricity of the earth's orbit and its consequent more rapid angular



(a)



(b)

SAMRĀT YANTRA.

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HELIOZINCOGRAPHED AT THE SURVEY OF INDIA OFFICES, CALCUTTA.

motion in the winter (when it is nearer the sun) and its slower motion in summer; (2) the obliquity of the ecliptic.[1] Consequently a clock going regularly does not agree for long with solar time. In India there is another element of difference to consider, due to the standard time being fixed for the longitude of $82\frac{1}{2}°$ degree east of Greenwich, or $5\frac{1}{2}$ hours before Greenwich time. A table that will enable the observer to compare dial time with clock time is given in an appendix.

The **Jai Prakāś** is called by Jagannāth *sarva yantra śiromaṇi* 'the crest jewel of all instruments.' It is a hemisphere on the concave side of which are mapped out certain co-ordinates. Cross wires are stretched north to south and east to west, and the shadow of the intersection of the wires falling on the surface of the hemisphere indicates the position of the sun in the heavens: other heavenly bodies can be observed direct by 'placing the eye' at the proper graduated point, and observing the passage of the body across the point of intersection of the wires. For this purpose passages are cut into the hemisphere, and the instrument is duplicated.

The construction of the instrument is seen in plates IV and V. The upper edge of the hemisphere represents the horizon and is graduated in degrees. From the centre azimuth lines and altitude circles are drawn. The pole is at a point on the meridian line at a distance from the actual southern point[2] of the upper edge equal

[1] These are the two principal causes, but all other causes combined alter the equation of time by a few seconds only.

[2] The graduations are inverted.

to the latitude of the place. The equator cuts the meridian at a distance from the centre towards the north also equal to the latitude, and other diurnal circles cut the meridian at distances of $23\frac{1}{2}°$, $20° 12'$, and $11\frac{1}{2}°$ on either side of the equator. The circles of signs are such that when the sun's shadow falls on any one of them the corresponding sign is on the meridian. These circles of signs cut each of the seven diurnal circles on the meridian, and cut the neighbouring circles at the proper intervals. Through the pole hour circles are drawn. Theoretically the instrument is thus a very efficient dial, showing at any instant the local time, the sun's declination and the sign on the meridian.[1]

At Jaipur a similar instrument called *Kapāla* (' cup ' or ' hemisphere ') is so constructed as to show ' rising signs.' In this instrument the edge of the hemisphere corresponds, not to the horizon, but to the solstitial colure (*i.e.*, the circle passing through the poles and the solstitial points), and thus is the *Jai Prakāś* turned through a right angle.

The Jai Prakāś is found only at Delhi and Jaipur. The diameter of that at Delhi is 27 feet 5 inches and that at Jaipur 17 feet 10 inches.

The **Rām Yantra** is the third of the stone instruments mentioned in the preface to the *Zīj Muhammad Shāhī*. The Paṇḍits say it was named after Rām Singh, a predecessor of Jai Singh's. According to Hunter the instrument was also known as *Ustuwani*, which was the

[1] In the larger volume an explanatory diagram is given.—Plate XI, fig. 38.

name given by al-Bīrūnī to an astrolabe on a cylindrical (orthographic) projection he devised. The Rām Yantra is a cylindrical instrument open at the top and having at its centre a pillar. The floor and the inside of the circular wall are graduated for altitude and azimuth observations. The height of the wall from the graduated floor is equal to the distance from the circumference of the central pillar to the inside of the wall. To facilitate observation the floor is broken up into sectors and, consequently, as in the case of the Jai Prakāś, complementary buildings had to be constructed. The walls also are broken up, and one section of the wall corresponds to one sector. At Delhi there are 30 sectors, each of 6 degrees, in each building, but at Jaipur there are 12 sectors only, and their angle is 12 degrees in one instrument and 18 degrees in the other, the spaces between them being respectively 18 and 12 degrees. On each side of the wall sections are notches in which sighting bars can be placed horizontally. Plate V gives a good view of the instrument as a whole. Examples of the Rām Yantra exist at Delhi and Jaipur only: the Jaipur instrument is quite a modern one.[1]

The **Digamśa Yantra** ('azimuth instrument'), is a simple and useful instrument, and examples of it still exist at Jaipur, Ujjain and Benares. The instrument consists of a pillar surrounded by two circular walls. The central pillar is generally about 4 feet high, and the inner wall the same height, while the outer wall is

[1] It was built in 1891. There are also at Jaipur two small Rām Yantras which were constructed as models.

twice that height. Cross wires are stretched from the cardinal points on the outer wall, and both walls are graduated. The inner wall is a convenient height for a man to walk on and to look over the outer wall. By the aid of a movable string and an assistant, azimuth (horizontal angles) observations can be made with fair accuracy. The instrument may be described as a large circular protractor.

The **Narivalaya Yantra** ('circular dial') is mentioned by Jagannāth and it occurs at Jaipur, Ujjain and Benares. It may be described as a cylindrical dial—the axis of the cylinder being horizontal and pointing north and south, and the northern and southern faces being parallel to the plane of the equator. At the centre of each face, and at right angles to it, is an iron style surrounded by circles graduated into hours and minutes and *ghaṭis* and *palas* respectively. The shadow of the style marks the time of the day, and the instrument also shows, very effectively, the passage of the sun across the equator (the equinoxes). Jagannāth remarks that this instrument is not of much value, because it only gives readings for northerly observations. This applies to some extent to the Benares instrument but not to those at Ujjain and Jaipur.

The **Dakshiṇovṛitti Yantra** ('meridian circle') is like the mural quadrants found in most mediaeval observatories. It consists, essentially, of a wall lying in the meridian, and on the wall are two graduated quadrants which were used for observing the altitudes of heavenly bodies when passing the meridian. The instrument corresponds to the modern transit circle. Originally there was one at each observatory, but that at Delhi has been destroyed.

The **Shashtāṁśa Yantra** occurs at Delhi and Jaipur only and is really another form of meridian circle. It is a large graduated arc lying in the meridian and is built in a 'dark room' at the bottom of the masonry work that supports the huge quadrants of the Samrāṭ Yantra. A small orifice, some 30 or 40 feet above, admits the light of the sun at noon, and the image of the sun on the graduated arc marks with fair accuracy the sun's altitude. It is thus the aperture dial of the Muslims. At Jaipur there are two 'dark rooms,' one under each quadrant of the Samrāṭ, and in each room are two arcs, the radius of each being 28 feet 4 inches. The 'dark room' at Delhi is at present inaccessible.

Of other masonry instruments there are the Miśra Yantra ('mixed instrument') at Delhi and the Rāśi Valaya ('zodiac dials') at Jaipur. There are some indications that these two instruments, or rather sets of instruments, were not devised by Jai Singh. They will be described when the observatories at Delhi and Jaipur are dealt with. The most notable feature of the Miśra Yantra is the set of arcs for meridians at Greenwich and Zurich on the west, and two corresponding places on the east. The Rāśi Valaya consists of a set of twelve dials connected with the rising signs, which show the sun's latitude and longitude.

CHAPTER III.

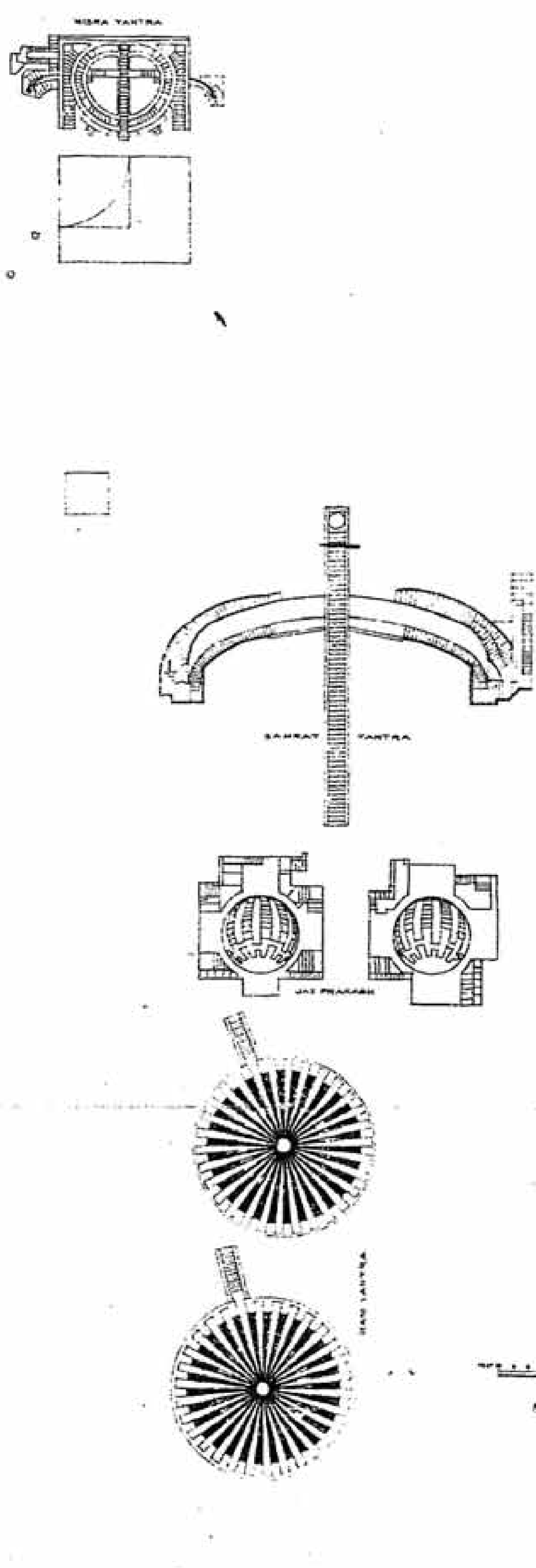
THE OBSERVATORIES.

1. Delhi.

For the Delhi observatory, known as the Jantar Mantar, we have the following approximately correct elements :—

Latitude 28° 37′ 35″ N.
Longitude 77° 13′ 5″ E. of Greenwich.
Height above the sea-level, 695 feet.
Magnetic declination E. 1° 45′, in 1919. Annual variation—3′.
Local time 21 minutes 7·7 seconds after standard time.

The observatory is 3 miles 3½ furlongs almost due south from the Pir Ghaib, the Trigonometrical Survey point on the Ridge, near to Hindu Rao's House. It is also 1 mile 7½ furlongs 32° west of south from the Jama Masjid. In the projected new city the observatory borders the road leading from the railway station to the Secretariat and Government House. It consequently will be a notable feature in the Imperial capital and, apart from its historical value, it is desirable that



DELHI
OBSERVATORY.

Latitude 28° [illegible] N. Longitude 77° [illegible] E.

Reg. No. 2600, E. 19

Heliozincographed at the Survey of India Offices, Calcutta.

it be made, by suitable surroundings and proper restoration, as dignified as possible.

The general plan of the observatory (Plate IV) shows the following structures: (*a*) the Samrāṭ Yantra, a large equinoctial dial, (*b*) the Jai Prakāś, consisting of two hemispherical structures just to the south of the Samrāṭ Yantra, (*c*) the Rām Yantra, two large circular buildings to the south of the Jai Prakāś, (*d*) the Miśra Yantra, north-west of the Samrāṭ Yantra.

The **Samrāṭ Yantra** is the central building of the observatory. It is the largest and most imposing, although a considerable portion of it is below the surface of the earth. It is, indeed, built into a quadrangular excavation some 15 feet deep, 125 feet from east to west and 120 feet from north to south. The structure is 68 feet high, of which 60·3 feet is above the earth's surface; 125 feet from east to west, and 113·5 feet from north to south. The essential parts are the inclined edges of the huge gnomon and the quadrants attached to it. The edges of the gnomon point to the celestial north pole, that is, they make an angle (28° 37′) with the horizon, equal approximately to the latitude of Delhi, and are parallel to the earth's axis. The quadrants (*M K G E D*, plate III) are at right angles to the gnomon and, therefore, the circles, of which they form part, are parallel to the plane of the equator. These quadrants have each a radius of 49·5 feet, and are graduated on each edge in hours, degrees and minutes, the scales on the northern edges being marked in English and those on the southern edges in Indian symbols. The edges of the gnomon are marked with scales of tangents, as already explained. The shadow of the edge of the gnomon on the quadrants gives the local time. The sun's declination is found by observing which part of the gnomon's edge casts its shadow on the edge of the corresponding quadrant.

In the mass of masonry work that supports the east quadrant is a chamber which contains the *Shashṭhāmśa Yantra*. This is a large graduated arc 60 degrees in length, built in the plane of the meridian; and through a small orifice, the sun, as it passes the meridian, shines on the arc and indicates its meridian altitude, from which its declination can be directly deduced. The chamber was closed up when the observatory was restored in 1910.

On the top of the gnomon is a circular pillar, which was probably used originally for rough azimuth observations, but which is now surmounted by a small sun dial of the European type. The latter was probably constructed in 1910: the pillar, but not the dial, appears in the Daniells' drawings.[1]

The lower part of the structure is sometimes below the water level of the locality. The height of the water varies but occasionally it covers the lower part of the quadrants and the steps and prevents access to the west quadrant altogether; and it makes the structure useless for astronomical purposes. If the instrument is to be saved, means must be taken to prevent the water percolating to the foundations.

According to Jai Singh, the Samrāṭ Yantra was built of stone and lime. Hunter and Thorn say that the edges of the gnomon and quadrants were of white

[1] Figures 43 and 44 of the larger volume.

marble, and von Orlich speaks of marble staircases. The quadrants are now faced with lime, but the time graduations are well marked with a soft black stone, neatly inlaid into the face of the quadrant. The graduations on the edges of the gnomon are scratched into the lime plaster surface and are becoming obliterated. See also page 26.

The **Jai Prakāś** consists of two complementary concave hemispheres, situated immediately south of the Samrāṭ Yantra. Their structure is best seen in plates IV and V. Theoretically only a single hemisphere is necessary, but, to facilitate observation, pathways are cut into the surface; and the second Jai Prakāś is so constructed that the two instruments together show the complete surface. Cross wires were originally stretched across the hemispheres north to south and east to west, and the shadow of the intersection of these wires on the concave surface of the hemisphere indicated the position of the sun. The surface of the hemisphere is marked with altitude and azimuth circles, the tropics and intermediate circles (declination parallels), etc., so that the position of the sun can be directly read off. Also there are 'circles of the signs of the zodiac,' by which the particular sign on the meridian is indicated by the position of the sun's shadow.[1] In the Delhi instruments the cross wires have been discarded, although the pins to which they should be fastened are still there; and iron rods (2 inch galvanized piping) have been fixed at the centre of each Jai Prakāś. See page 27.

[1] See page 28 above, and page 37 of the larger book.

The **Rām Yantra** consists of two large circular buildings, complementary to each other, situated south of the Jai Prakāś. Each consists of a circular wall and a pillar at the centre. The height of the walls and pillar, from the graduated floor, is equal to the inside radius of the building measured from the circumference of the pillar to the wall, *viz.*, 24 feet 6½ inches, and the diameter of the pillar is 5 feet 3½ inches. The walls and floor are graduated for reading azimuths and altitudes. To facilitate observation the floor is cut up into thirty sectors, with the spaces between of the same angular dimensions as the sectors, *viz.*, six degrees. The graduated sectors are supported on pillars three feet high, so that the observer can 'place his eye' at any point on the scale. The graduated walls are, similarly, broken up by openings, at the sides of each of which are notches for placing sighting bars. At Delhi there are no such bars in evidence but at Jaipur they are faced with brass and carefully graduated. At Jaipur the central pillar is replaced by an iron rod. At Delhi the pillar is graduated by vertical stripes, each six degrees in width, and these are necessary, as a point on the top of the edge (not the centre) of the pillar is the centre for which the altitude graduations on the corresponding sector and portion of the wall are made. The old descriptions and drawings show that no important structural alterations have been made during the last century.

To the north-west of the Samrāṭ Yantra, and some 140 feet away, is the **Miśra Yantra**, or 'mixed instrument,' so named because it combines in one building four separate instruments. Of these the Niyat Chakra

PLATE V.

DELHI OBSERVATORY.

occupies the middle of the building, and consists of a gnomon with two graduated semicircles on either side (plate VI[b]). These semicircles lie in planes inclined to the plane of the Delhi meridian at angles of approximately 77° and 68½° east and west. The semicircles may be said to correspond to meridians at places whose longitudes differ from Delhi by these angles, and tradition names Greenwich and Zurich, "Notkey a village in Japan where there is an observatory, latitude 43° 33′ N. and longitude 145′ 17″ E. of Greenwich," and "Serichew, a town in the Pic Island in the Pacific Ocean east of Russia, latitude 48° 6′ and longitude 153° 12′ E."

On either side of the **Niyat** Chakra, and joined to it, is half of an equinoctial dial, constructed on the same principle as the large Samrāṭ Yantra. On the west side of the building is a second quadrant, the face of which is horizontal instead of being parallel to the axis. Hunter makes no mention of this.

On the east wall of the building is a graduated semicircle called **Dakshiṇovṛitti Yantra**, used for obtaining meridian altitudes. The north wall of the Miśra Yantra is inclined to the vertical at an angle of 5 degrees and is marked with a large graduated circle. This is called the **Karkarāśivalaya,** or 'Circle of the sign of Cancer.' As the latitude of Delhi observatory is 28° 37′ 35″, and the obliquity of the ecliptic is 23° 27′ 5″ nearly, the zenith distance of the sun, when it enters Cancer, is 5° 10½′, approximately, and the sun then shines over the north wall for a short period, and the shadow of the centre pin falls on the graduated circle. This may be the northern dial referred to by Jagannāth.

In the front of the Miśra Yantra is a platform 47 feet by 43 feet, on which are traces of a quadrant of 20 feet radius. This platform was probably used for making measurements when the instruments were being constructed or repaired.

To the south-west of the Miśra Yantra are two pillars 17 feet apart, and the line joining their centres points 35° E. of north. These are mentioned in none of the accounts of the observatory. If they were part of the original observatory, they probably supported one of Jai Singh's metal instruments, such as are now found at Jaipur.

Hunter states that, to the west of the Miśra Yantra and close to it there was a wall in the meridian with double quadrants; and Jagannāth, Jai Singh's assistant, recorded that, in the year 1651 of the Sālivāhana era, "with this instrument, the latitude of Indraprastha was found to be 28° 39′ north, and the maximum declination 23° 28′."

History.

The observatory at Delhi was the first one built by Jai Singh, and it is here that the principal observations were made, which were to form the basis of his new tables. There is some uncertainty about the date of construction. Paṇḍit Gokal Chand gives A.D. 1710, and Syed Aḥmad Khān gives 1724. The latter states that the observatory was built "in accordance with the orders of the Emperor Muhammad Shāh, in the seventh year of his reign, corresponding to the year 1137 of the Hegira" (=A.D. 1724-25).

Jai Singh tells us that he himself represented the question of preparing new tables to the Emperor, who encouraged him to proceed. "To accomplish the exalted command he had received, he (Jai Singh) bound the girdle of resolution about the loins of his soul, and built here (at Delhi) several of the instruments of an observatory." This seems to indicate that the construction was started *after* Muhammad Shāh ascended the throne. In 1719 Jai Singh was appointed the Emperor's lieutenant at Agra. Jagannāth records observations made at Delhi in A.D. 1729. The facts seem to point to 1724 as about the date of the foundation of the Delhi Observatory.

We are told that Jai Singh first constructed at Delhi brass instruments of the astrolabe type in accordance with the Muslim books. These he found to be unsatisfactory, and, therefore, he constructed "instruments of his own invention, such as Jai Prakāś and Rām Yantra and Samrāṭ Yantra .... of stone and lime of perfect stability, etc." In Jai Singh's time, therefore, the observatory probably consisted of the Samrāṭ Yantra, the Jai Prakāś, the Rām Yantra, a mural quadrant, and some metal instruments. Of the present buildings, possibly, the Miśra Yantra was added by Madhu Singh, "who inherited no small portion of his father's love of science."[1]

Early descriptions.

There are fairly numerous references to the Delhi observatory in the accounts of travellers of the eighteenth

[1] Tod ii, 372.

and early part of the nineteenth century, and some of these are worth recording. Father Claude Boudier and another priest passed through Delhi in 1734 on their journey to Jaipur and took observations of latitude and longitude at the observatory at Delhi. Unfortunately they have left on record no description of the instruments.*

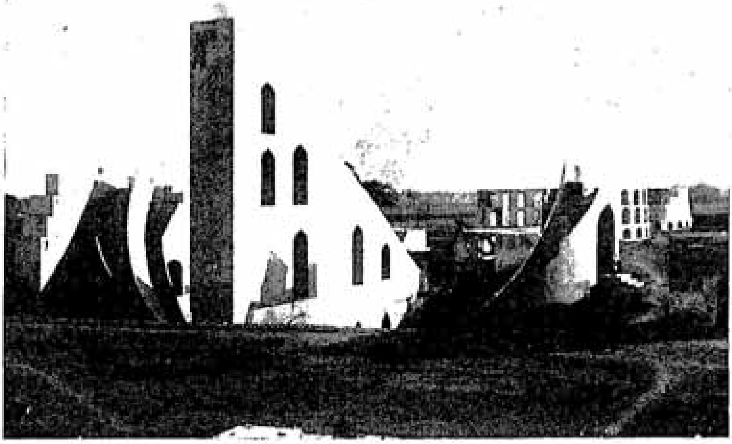
In 1795 Franklin, in his description of the city of Delhi,[1] wrote of the observatory: "It was built in the third year of the reign of Muhammad Shāh, by the Rajah Jeysing, who was assisted by many persons, celebrated for their science of astronomy, from Persia, India and Europe; but died before the work was completed, and it has since been plundered and almost destroyed by the Jeits, under *Juhwaher Singh*."

In 1799 W. Hunter published[2] a fairly complete account of the Delhi observatory. The list of buildings and the descriptions he gives show that, to the west of the Miśra Yantra and close to it was a wall in the plane of the meridian, on which was described "a double quadrant having for centres the two upper corners of the walls." Also, in describing the Miśra Yantra, he makes no mention of the third quadrant on the west side. Referring to the Samrāṭ Yantra he states "It is built of stone, but the edges of the gnomon and arches, where the graduation was, were of white marble, a few small portions of which only remain."

* See page 8.

[1] *An Account of the present State of Delhi.* By Lieut. Franklin. *Asiatic Researches*, vol. iv. 1795, p. 431. Muhammad Shāh's reign commenced in 1719, and Jai Singh died in 1743.

[2] *Asiatic Researches*, v. 1799, 177*f*.



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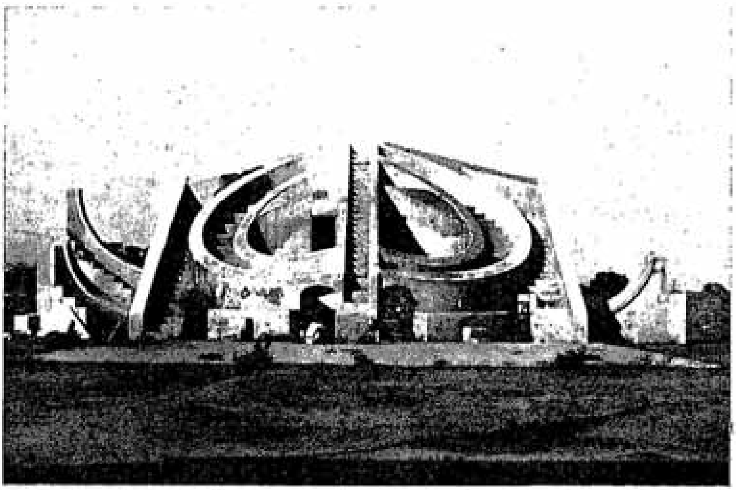


b

DELHI OBSERVATORY.

In 1803 Major William Thorn visited Delhi, and later wrote a description[1] of the observatory. His description, however, is simply a summary of Hunter's and he gives no additional information whatever, although he is sometimes quoted as an authority.

Soon afterwards, the Daniells gave two illustrations[2] of the chief features of the observatory. These are reproduced in the larger volume (figures 43 and 44) and they show that during the last hundred years very little alteration has really taken place.

In 1843 von Orlich visited Delhi and made the following notes about the observatory : "It lies in the midst of many ruins ; but it was never completed and has been, unhappily, so wantonly dilapidated by the Juts that the shattered ruins alone are to be seen. However, enough remains to show the plan of this fine building ; the colossal sun-dials and quadrants, which rest upon large arches, are formed of red sandstone and bricks, and the ascent to them is by handsome winding marble stair cases."[3]

Next comes Syed Aḥmad Khān's description,[4] which was translated by Garcin de Tassy.[5] This account is not very reliable, but the original work contains some rough but valuable drawings of the instruments. We read : "Now this observatory has fallen into

[1] *Memoir of the War in India conducted by General Lord Lake in 1818, p. 171.*

[2] *Oriental Scenery*, 1815, part v., plates XIX and XX. The original drawings for these plates must have been made about A.D. 1794.

[3] *Travels in India*, London, 1845, p. 49.

[4] *Āthār al-sanādīd* 1852. Reprinted 1876.

[5] *Journal Asiatique*, V. xv, 1860, 530*f*.

ruin; all the instruments are broken, and all traces of the lines of division have disappeared, etc."

Later writers on Delhi give brief notices of the observatory with, in two cases,[1] interesting photographs; and in the Delhi Museum is an interesting painting, of unknown date, which shows the observatory in a very dilapidated condition.

Restorations.

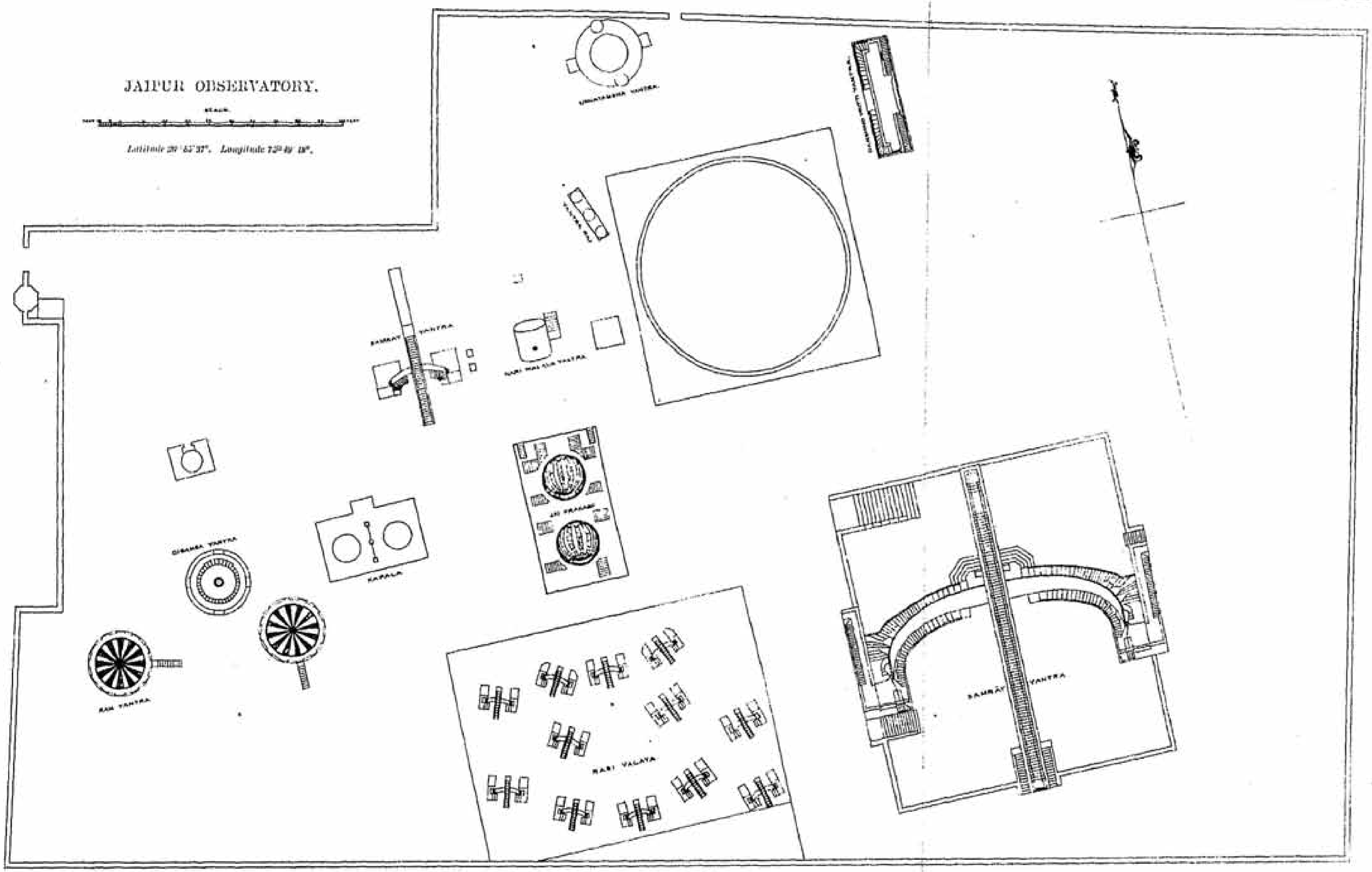
In 1852 the Raja of Jaipur, at the request of the Archæological Society of Delhi, partially restored the Samrāṭ Yantra. In 1910 His Highness the present Maharaja sanctioned the complete restoration of the observatory. This entailed the rebuilding of some of the instruments and the regraduation of all the scales. Most of the graduations were, unfortunately, done in lime plaster and are already becoming obliterated. The European dial on the top of the great gnomon appears to have been added on this occasion.

2. *Jaipur.*

The elements for Jaipur Observatory are approximately as follows :—

Latitude	26° 55′ 27·4″.
Longitude	75° 49′ 18·7″.
Height above sea-level . .	1,582 feet.
Magnetic declination . . .	E. 1° 35′ in 1919.
Local time[1]	is 26 minutes 43 seconds after standard time.

[1] Carr Stephen.—*The Archæological and Monumental Remains of Delhi*, 1876; and H. C. Fanshawe, *Delhi, Past and Present*, 1902.



GENERAL PLAN.

REG. No. 2600. E 19

HELIOZINCOGRAPHED AT THE SURVEY OF INDIA OFFICES, CALCUTTA.

The observatory is within the palace precincts, about 200 yards east of the minaret. It is in an excellent state of preservation and is one of the 'sights' of the city. Not only does the observatory contain masonry instruments such as those at Delhi, but also a number of metal instruments of very considerable interest: and in the Museum, outside the city walls, are other astronomical instruments that, no doubt, formed part of Jai Singh's astronomical equipment. The plan of the observatory (plate VII) shows the general arrangement of the instruments, the principal being the Samrāṭ Yantra, the Jai Prakāś, the Rāśi valaya, the large astrolabes, etc.

Samrāṭ Yantra.—The large Samrāṭ Yantra is situated at the south-east corner of the observatory enclosure. It is the largest of all of Jai Singh's instruments, being nearly 90 feet high and 147 feet long, the radius of each quadrant being 49 feet 10 inches. It is graduated to read to seconds, but this is impossible in practice, owing to the ill-defined shadow (due to the size of the penumbra). The tangent scales on the edge of the *gnomon* cannot now be used, owing to the instrument overlooking the palace zenana enclosure. The readings of the quadrants appear to be slightly inconsistent, the eastern quadrant giving readings that are about two minutes out, as compared with the time registered on the western quadrant.

The general structure is the same as that of the Delhi instrument, but it is of somewhat more elaborate construction and on a larger scale. Like the Delhi instrument, the foundations are below the ground level, but the floor is *pukka*, and proper arrangements are made for drainage.

Shashtāmśa Yantra.—The Shashthāmśa Yantra, or sextant instrument, is a huge convex arc of 60 degrees, and of 28 feet 4 inches radius, lying in the meridian. There are two pairs of such arcs built into the masonry that supports the east and west ends of the Samrāṭ quadrants. Small holes in the roof of each structure allows the sunlight to fall on the arc at noon. The instrument is capable of giving very accurate results, but the readings are said to be in error to about 4 minutes. See also page 31.

Rāśivalaya Yantra.—The Rāśīvalaya, or 'ecliptic instrument,' consists of a collection of dials on a platform to the west of the Samrāṭ Yantra. There are twelve such dials, one for each sign of the zodiac. Each instrument is exactly of the same type as the Samrāṭ Yantra, but the quadrants lie, not in the plane of the equator, but in the plane of the ecliptic when the particular sign is on the horizon, and the edge of the gnomon then points to the pole of the ecliptic; consequently, at the proper moment the instrument indicates the sun's latitude and (with appropriate graduations) longitude. The radius of the quadrant is 5 feet 6 inches in the case of four instruments, and 4 feet 1½ inches in the case of the other eight. The early lists do not mention the Rāśīvalaya.

Jai Prakāś.—The Jai Prakāś is constructed in the same manner as the Delhi instrument. The principle of the instrument has already been explained (page 27). It was completely restored in 1901, in white marble, and the various circles were then marked in different colours. It is 17 feet 10 inches in diameter. The instrument shows time and declination, and the signs on the meridian.

Kapāla.—The Kapāla is another hemispherical instrument, and is peculiar to Jaipur. There are two examples—one being a hemisphere with its upper edge representing, as in the Jai Prakāś, the plane of the horizon, while in the other it represents the solstitial colure. The latter indicates 'rising signs' instead of meridian signs. Each Kapāla has a diameter of $11\frac{1}{3}$ feet and is a complete hemisphere, that is, no pathways are cut, as in the Jai Prākāś. The graduated rims are in marble, but the remainder of the surfaces are in lime plaster.

Rām Yantra.—There are four instruments in white marble, but all of them are quite modern (? 1891), although made according to Jagannāth's instructions. In principle they are exactly the same as the instruments at Delhi, but are much smaller, the larger pair being 23 feet 11 inches in diameter. The sectors are twelve in number, occupying 12° each in one instrument, and 18° in the other. For an explanation of the construction see page 28.

Digaṁśa Yantra.—The Digaṁśa Yantra or azimuth instrument has already been described (page 29). There is no such instrument at Delhi, but there are examples at Ujjain and Benares.

Nari Valaya Yantra.—The instrument at Jaipur is a masonry cylinder some 10 feet in diameter.[1] The

[1] *In the general plan (plate VII) the supporting masonry work is not shown, but see plate IX*[b].

axis of the cylinder is horizontal and in the plane of the meridian, and the parallel faces, which form the dials, are in the plane of the equator. The dials are graduated into *ghaṭis* and *palas*, and also hours and minutes. According to Garrett, the southern face was added by Jai Singh's grandson, Mahārāja Purtāp Singh. There are similar instruments, but much smaller, at Ujjain and Benares.

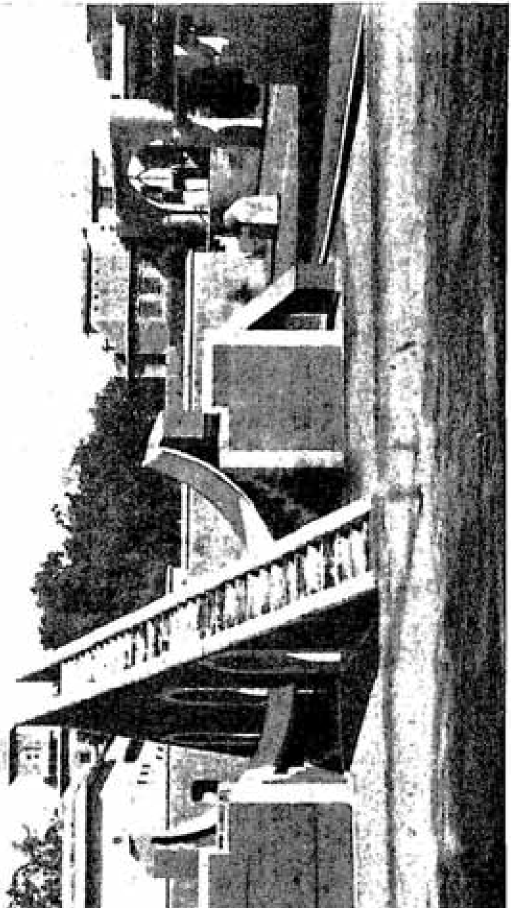
Dakshiṇovṛitti Yantra.—The construction of the Dakshiṇo Vṛitti Yantra, or mural quadrant, is seen in plates VII and IX. It is of the same principle as the similar instruments at Ujjain and Benares (that at Delhi has disappeared). On the east face are two quadrants of 20 feet radius, and on the west face is a semicircle of 19 feet 10 inches radius. It was used for taking meridian altitudes.

The following fixed metal instruments also form part of the observatory :—

(*a*) Two large single disc astrolabes 7 feet in diameter —one made of some sixty sheets of iron rivetted together, and the other (plate II) of brass, patched up with lead. From the iron instrument the graduations have disappeared. The brass instrument is designed for latitude 27°N. It has an ecliptic circle, and a tube sighter of modern workmanship. These two instruments may possibly be of the *original* metal instruments referred to by Jai Singh. If so they were probably brought from Delhi.

(*b*) The *Unnatāṁsa Yantra* is possibly another of Jai Singh's original instruments. It is a graduated brass circle, 17½ feet in diameter, suspended so as to revolve around a vertical axis. Jai Singh speaks of an

PLATE VIII.



JAIPUR OBSERVATORY.

instrument "*Ẓāt al-ḥalqa* (consisting of a ring) of brass in diameter three *gaz* of the measure now in use" ; but the *Ẓāt al-ḥalqa* is ordinarily an armillary sphere.

(*c*) The *Chakra Yantra* is an equatorial. There are two at Jaipur of 6 feet in diameter. Each is fixed so as to revolve about an axis parallel to the earth's axis. At the southern end of the axis of the instrument is a separate graduated circle, fixed on the supporting pillar. The axis carries a pointer, which indicates the hour angle on the fixed circle; and the main movable circle carries an index and sighter.

(*d*) The *Krāntivṛitti Yantra* (Torquetum), found at Jaipur only, is quite a modern instrument, but is said to have been made according to Jagannāth's instructions; and there still is at Jaipur the old masonry work for a much larger instrument of the same type. The Krānti Vṛitti Yantra is used for direct measurements of celestial latitude and longitude. It consists of two brass circles, pivoted so that one always moves in the plane of the equator and the other in the plane of the ecliptic. It is more suitable for demonstration purposes than for actual observation. This is the *Torquetum* of Regiomontanus (1434-1476), which was rejected by Tycho Brahe as a clumsy instrument.[1]

History.

Jaipur city was built about A.D. 1728, and the observatory was constructed about A.D. 1734. The earliest detailed description is that by Tieffenthaler,

[1] See R. WOLF *Geschichte der Astronomie*, p. 161, and J. L. E. DREYER *Tycho Brahe*, p. 317.

a Jesuit Missionary, who travelled in India from 1743, the date of Jai Singh's death, to 1786; but the earliest reference to the observatory is possibly that by Father Boudier, who, with another priest, visited Jaipur in 1834, and made astronomical observations there. Boudier makes no references to the instruments, and they were possibly only in the course of construction at the time of his visit. He, however, made observations for the determination of the latitude and longitude of the observatory itself.[1]

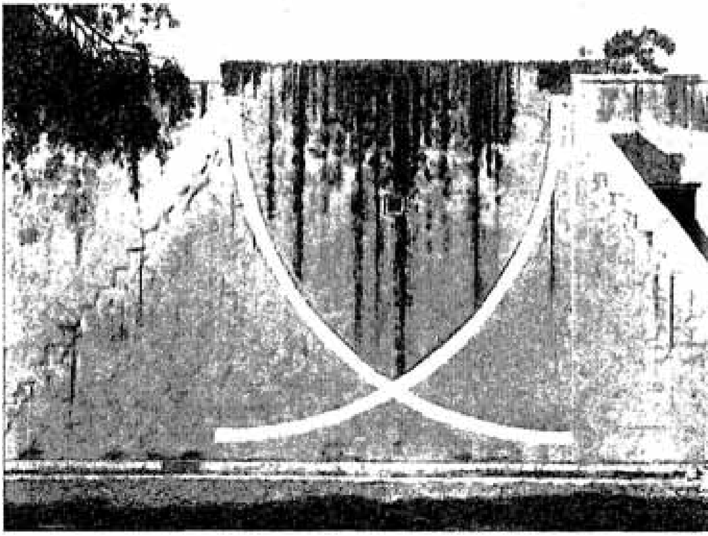
Tieffanthaler's description[2] of the observatory is as follows :—

"But a place that deserves detailed description is that where astronomical observations are made: it is such a work as is never seen in this part of the world, and, by the novelty and grandeur of the instruments, strikes one with astonishment. This large and spacious observatory is close to the King's palace. It is situated on a plain surrounded by walls and was constructed especially for the contemplation of the stars.

"On entering, one first sees the twelve figures of the Zodiac, all arranged in a large circle, and made of purest lime. Next are seen diverse sections of the astronomical sphere, fixed according to the height of the pole at the place—with diameters of 12 or more Paris feet, and besides these, some large and small equinoctial dials, and some astrolabes made in lime,

[1] *Lettres édifiantes*, etc., pp. 269-290.

[2] *Des Pater Joseph Tieffenthaler's historisch—geographische Beschreibung von Hindustan*, 1785, vol. 1, p. 244*f.* French edition p. 316*f.*



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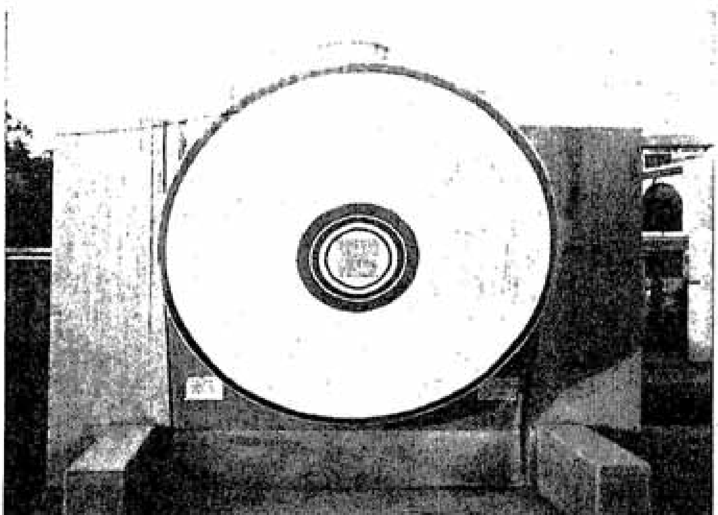


b

JAIPUR OBSERVATORY.

also a meridian line and a horizontal dial engraved on a very large stone.

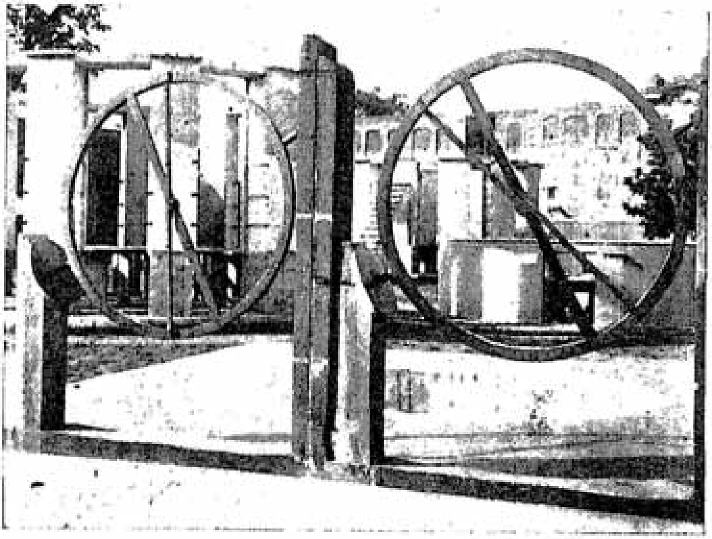
"But what attracts most attention is a gnomon (*axis mundi*), remarkable for its height of 70 Paris feet, and for its thickness—constructed in brick and lime, situated in the plane of the meridian, with an angle equal to the height of the pole. On the summit of this gnomon is a belvedere, which overlooks all the town and is so high that it makes one giddy. The shadow of this gigantic gnomon falls on a prodigiously large astronomical semicircle, of which the horns are turned towards the sky. It is artistically constructed in whitest lime or gypsum, and is graduated in degrees and minutes. In the morning the shadow falls on the western quadrant, and in the evening on that towards the east, and, as the gnomon lies between both the quadrants, the sun's altitude can be found at any moment. A double dial, constructed also in lime, is seen near these quadrants. It is enclosed in a kind of chamber, on either side of which it is raised. When the sun passes the meridian a ray of this star enters through each of two holes pierced in a sheet of copper, and when these rays fall exactly on the middle of the two quadrants, low in summer and higher in winter, the sun is in the meridian sign, and its meridian height is indicated.

"The instruments which follow have similar graduations: there are three very large astrolabes cast in copper, suspended by iron rings; a circle also of cast copper, fitted with a rule (or alhidade), and elevated at the height of the pole, suitable for determining the declination of the sun—for, when you turn this instrument towards the sun, it will indicate the declination on the ground.

"I pass over in silence other less important instruments, but a matter which detracts from the value of the observatory is that, in a low situation surrounded by walls, the observer cannot see the rising and setting of the stars; also the dial, gnomon and other parts being in lime plaster prevent one from making very exact observations."

Restorations.

The Jaipur observatory, being situated in the palace precincts, has been carefully preserved, and has been added to from time to time. Possibly the Rāśī Valaya was added after Jai Singh's reign, and possibly some of the brass instruments were brought from the Delhi observatory, but we have no direct information on these points. Some additions appear to have been made in 1891, and in 1901 His Highness the present Mahārāja decided to restore the observatory completely. The services of Lieutenant A. H. Garrett, R.E., were lent and the work was finished in 1902, in which year also Lieutenant Garrett, assisted by Pandit Chandradhar Guleri, prepared and published an account of the observatory. This account, as far as the descriptions of the instruments are concerned, is an excellent one, but the parts relating to the history of astronomy are not so reliable. It is difficult to judge of the work of restoration, as no reliable account of the observatory before the restoration took place is available. Colonel Hendley, in 1886, gave a rough plan of the observatory, and



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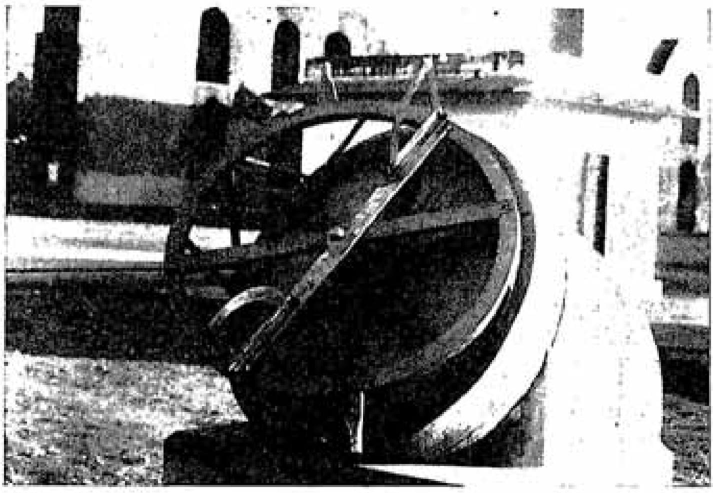


b

JAIPUR OBSERVATORY.

a list of the instruments,[1] but not in sufficient detail for purposes of comparison.[2]

3. *Ujjain.*

Latitude . . .	23° 10′ 16″ N
Longitude . . .	75° 46′ 3″ E of Greenwich
Height . . .	1,500 feet
Magnetic Declination .	0° 49′ E (1915) Variation 3′—3′

Local time is 26 minutes 52 seconds after standard time.

The observatory is situated to the south-west of the present city in the quarter called Jaisingpura, on the north bank of the river Sipra. From the Water Works it is half a mile west. The river bank is corroding away, and about a quarter of a mile to the east of the observatory is seen the remains of a well now standing in the river itself. The observatory is 125 feet north from the river, and is hardly in danger owing to this proximity ; but the drainage about the observatory is not under control. There is a small, and, apparently, fresh nullah quite close by, and the foundations of the Digaṁśa Yantra have already been partly worn away.

The observatory now consists of the remains of the following instruments :—the Samrāṭ Yantra (*A* in plate xi), the Narivalaya Yantra (*B*), the Digaṁśa Yantra (*EF*), and the Dakshiṇovṛitti Yantra (*CD*).

These are all in a state of ruin. The foundations of the Digaṁśa Yantra have evidently moved, and its walls are badly cracked. The Dakshiṇovṛitti Yantra

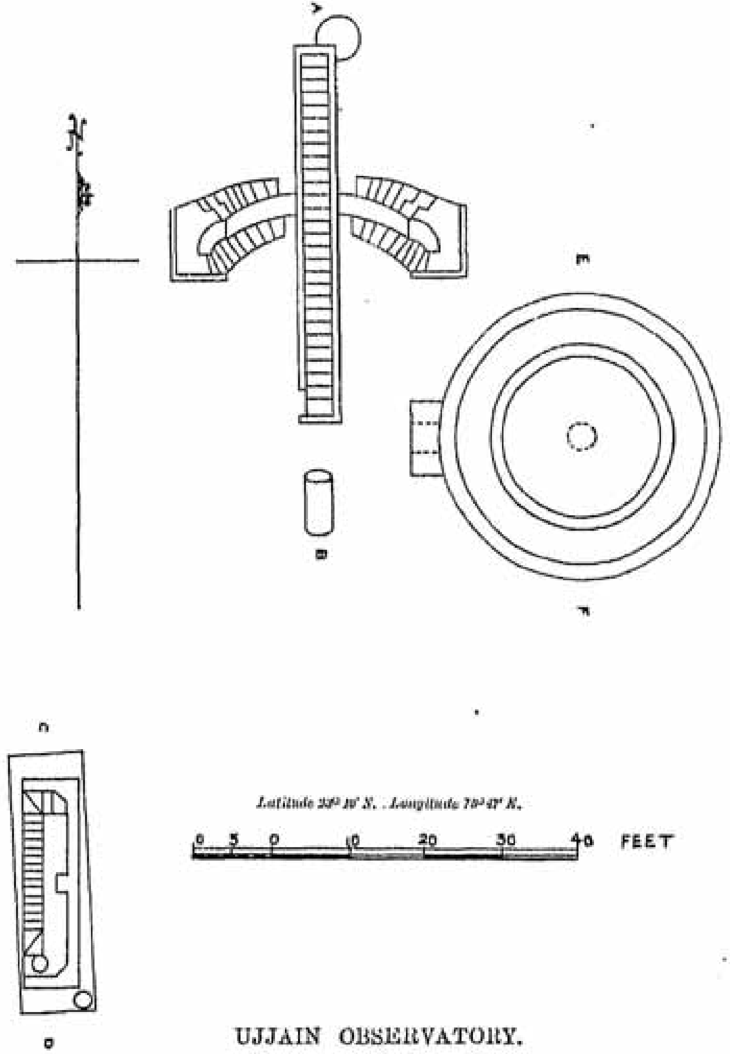
[1] London Indo-Colonial Exhibition in 1886. *Handbook of the Jeypore Courts*, pp. 59-62.

[2] *The Indian Antiquary* (XXXV, 1906, p. 34), criticises the method of restoration.

is inclined to the perpendicular at an angle of about 5 degrees. This is possibly due to the faulty structure, for the foundations for this heavy mass of masonry seem to be inadequate. The Samrāṭ Yantra is in a dilapidated state, and the styles and graduation have disappeared from the Narivalaya.

Of the **Samrāṭ Yantra** only a skeleton remains. In the general plan it is shown as though complete, but plate XII shows its actual present state. It is, practically, of the same size as the one at Benares, than the ? and the smaller one at Jaipur, namely, 22 feet high, the edge of the gnomon 47½ feet, and the radius of each quadrant 9 feet 1 inch. In 1796 or thereabouts, when Hunter visited Ujjain, the quadrants were divided into ghaṭis and subdivisions. From the edges of the quadrants, where they intersect the walls of the gnomon, lines at right angles (*GH*, *EF* in plate III) were drawn on the gnomon, perpendicular to its edge. From the points (*H*, *F*), where these lines meet the edge of the gnomon, scales of tangents were marked on the edges. All these graduations have disappeared.

Dakshiṇovṛitti Yantra ('meridian instrument') is shown in plate XII. The masonry work is fairly intact, but the graduations have disappeared. The instrument was originally something like that at Jaipur. It consists of a wall lying in the meridian, and on its east face was a double quadrant, the centres of which were at points near the top corners of the wall and 25 feet apart. A portion of one quadrant is still visible, engraved in the lime plaster with which the wall is faced, but this is probably not the original graduation. On the ledge below the quadrants there are traces of



UJJAIN OBSERVATORY.

Reg. No. 2600 E 19

Heliozincographed at the Survey of India Offices, Calcutta.

a scale of tangents. On the west side is a flight of steps leading to a narrow platform at the top. At the south-west end of this platform is a small pillar, 2 feet in diameter: according to Hunter this was "graduated for observing the amplitude of the heavenly bodies at their rising and setting." The graduations have now disappeared. At the middle of the platform, and on the east side, is a small projection of the parapet, 2 feet $4\frac{1}{2}$ inches long and deep. On this, Hunter tells us, was "constructed a horizontal dial." There is no sign of this dial now. As already pointed out this building is now out of the perpendicular and is in some danger of collapse.

The Narivalaya or 'circular dial' is constructed on the same principle as those at Benares and Jaipur. It is situated a few feet to the south of the Samrāṭ Yantra, and consists of a cylinder $7\frac{1}{2}$ feet long and 3 feet $7\frac{1}{2}$ inches in diameter, whose axis is fixed horizontally in the plane of the meridian, the faces of the cylinder being cut parallel to the plane of the equator. In the centre of each face, and at right angles to it, was an iron style, round which was a circle graduated into *ghaṭis* and subdivisions. The styles and graduations have disappeared.

The **Digaṁśa Yantra** is similar to those at Jaipur and Benares. It is situated quite close to the Samrāṭ Yantra on the east side and consists of an outer circular wall, 36 feet 10 inches in diameter and 8 feet 10 inches high. Concentric with this is another wall, 24 feet 4 inches in diameter and 4 feet 6 inches high. Originally there was a pillar at the centre, but it has been removed. Cross wires were stretched north to south and east to west on the outer wall. At the four points of the compass, in the outer and inner walls, were arched openings, but all of those in the outer wall, except that to the west, have been filled up. The outer walls are badly cracked, and a great part of the foundations is now exposed. This is due to the bad drainage of the slope to the river. The nullah that passes close by the Digaṁśa Yantra could easily be diverted. In Hunter's time the building was "roofed with tiles and converted into the abode of a Hindu deity," so that Hunter was unable to examine its construction. This is of interest, as showing that, even in the eighteenth century, the instrument was no longer used for astronomical purposes.

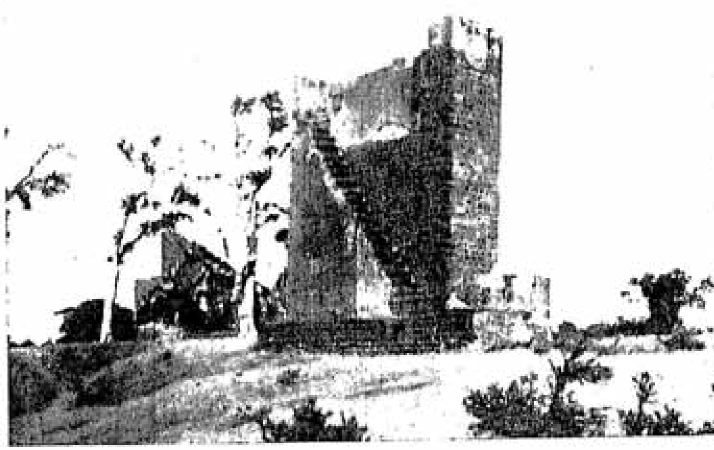
Early descriptions.

There appears to be no record of any astronomical instruments at Ujjain, earlier than those installed by Jai Singh. The date of the construction of his observatory is uncertain, but it was probably between A.D. 1728 and A.D. 1734. The earliest known description of the Ujjain observatory was by the Jesuit priest Tieffenthaler, who travelled in India from 1743 to 1786. His account[1] of the observatory is as follows :—

"Not far from there is a suburb built by Djésing, King of Djépour, a ci-devant governor of this province. (Mālwa). An astronomical observatory is to be seen there, with instruments, made of cement : namely two equinoctial dials, one large and one small ; a gnomon (*axis mundi*) elevated according to the height of the

[1] *Historische—geographische Beschreibung von Hindustan*, vol. i, 246.

a



b

UJJAIN OBSERVATORY.

pole at this place, and set in the meridian ; and on either side of this is a quadrant of a geometrical circle ; also a dial made in lime, and a meridian wall in stone."

The only other account of any value is that by Hunter (from which we have already quoted), who accompanied the Agra Resident's expedition to Ujjain in 1792-93. He briefly describes the instruments, and he states that Jai Singh determined the latitude of Ujjain to be 23° 10′ N., and Hunter himself took considerable trouble in verifying this result, which he considered correct to the minute.[1]

Ujjain, the Greenwich of India.

Ujjain (the Οζηνη of the Greeks), or Avanti as it was often called, is mentioned in early Hindu astronomical works as situated on the prime meridian, and tradition also makes it the centre of astronomical learning in India.

It is one of the most ancient astronomical centres in the world and even to the present day is regarded by the orthodox Hindu as the Greenwich of India. It would, therefore not be inappropriate if Ujjain once more became the centre of Hindu astronomical learning.

It is doubtful whether there ever was a fixed position in ancient Ujjain which was considered as of zero longitude. Rather vaguely, the old city of Ujjain—to the north of the present city—was meant ; or, it is just possible, that Jai Singh considered this point when he located his observatory to the south of the present city, and that the site of Jai Singh's observatory is the

[1] *Asiatic Researches* V, 1799, p. 194 f.

traditional place—but this is doubtful. If a new observatory is to be located at Ujjain the plan to follow is to fix upon a suitable position and then determine its longitude and latitude. The map of the city and its environs in the larger volume should be of help: it gives the position of Jai Singh's observatory as approximately 75° 46′ east of Greenwich, and 23° 10′ 16″ north of the equator.

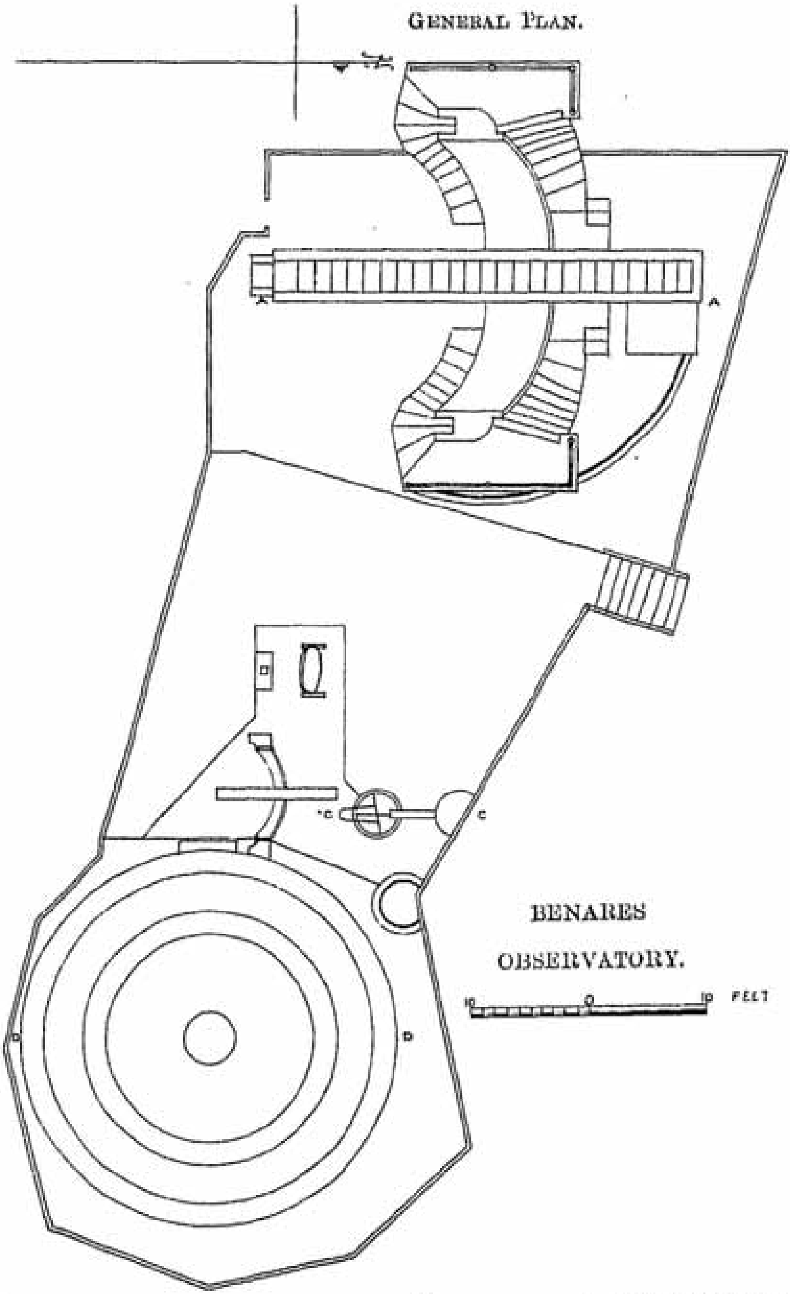
4. *Benares.*

Latitude . . .	25° 18′ 24·9″ N
Longitude . . .	83° 0′ 46·1″ E of Greenwich
Height above sea level .	350 feet
Magnetic declination .	E. 0° 45′ (1919)
Local time . .	2 minutes 3 seconds before standard time

The observatory is situated on the roof of the old part of the building known as the Mānmandira, which was built by Mān Singh, a Rājah of Amber who flourished at the beginning of the seventeenth century. (He died in A.D. 1614). This building is on the west bank of the Ganges, near the Maṇi Karṇikā ghat, and $1\frac{3}{4}$ miles south-east by south from Queen's College. The proper approach is from the river front, that from the city being through narrow, unsavoury alleys. "Though not very architectural in its general appearance," writes Fergusson,[1] "(it) has on the river face a balconied window, which is a fair and pleasing specimen of his (Mān Singh's) age."

[1] *A History of Indian and Eastern Architecture*, vol. ii, 178.

General Plan.



BENARES

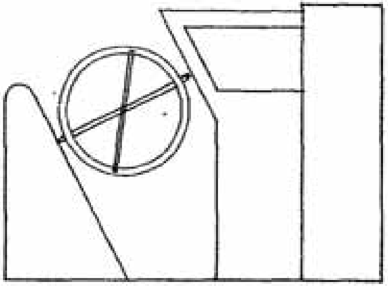
OBSERVATORY.

Reg. No. 2600 E 10

Heliozincographed at the Survey of India Offices, Calcutta.

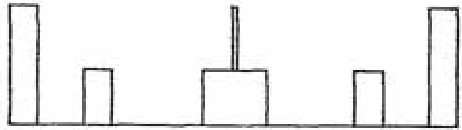
PLATE XIV.

SECTION ON C. C.



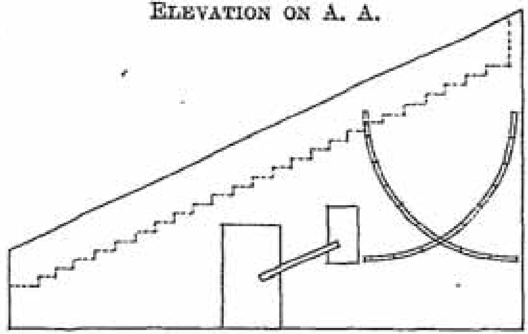
CHAKRA YANTRA.

SECTION ON D. D.



DIGAMSA YANTRA.

ELEVATION ON A. A.



SAMRAT YANTRA.

BENARES OBSERVATORY.

Latitude 25° 18' 24·9" N. Longitude 83° 0' 45·1" E.

Reg. No. 2500, E 19

Heliozincographed at the Survey of India Offices, Calcutta.

On the roof of the Mānmandira, as constructed by Mān Singh, and a little over a century after it was built, Sawāī Jai Singh of Jaipur placed the astronomical instruments that now form the observatory. Some time about the beginning of the nineteenth century the Mānmandira appears to have been enlarged,[1] and about the middle of the nineteenth century it was restored.

The general plan of the roof of this part of the building (plate XIII) shows the larger Samrāṭ Yantra (*AA*), the Narivalaya Yantra, the Chakra Yantra (*CC*), the Digaṁśa Yantra (*DD*), and the smaller Samrāṭ Yantra.

On the east wall of *AA* is a double quadrant or Dakshiṇovṛitti Yantra, and to the south of *AA* is another Dakshiṇovṛitti Yantra, not shown in the plan.

The Samrāṭ Yantra (*AA*) is of the same type as those at the other observatories, and is the same size as that at Ujjain and the smaller one at Jaipur. Its height is 22 feet 3½ inches, the edge of the gnomon is 39 feet 8½ inches long, and the radius of each quadrant is 9 feet 1½ inches. The edges of the gnomon and the quadrants are faced with sand-stone, and the graduations are carefully marked. On the quadrants every half-hour is marked by two inlaid metal discs, the one towards the north edge being inscribed in Indian characters, while the one on the south is in European figures. Each edge is also graduated into minutes

[1] Compare Campbell's drawing (figure 67 in the larger volume) and Prinsep's drawing. The latter is given in *Banares Illustrated by a series of Drawings*, by James Prinsep. There is also a large painting of the Mānmandira by Daniell, entitled *The Ghat*, at the Asiatic Society of Bengal, Calcutta.

and quarter minutes; and also into degrees and tenths of a degree. The edges of the gnomon are graduated with the usual tangent scales. A comparison between a drawing made about 140 years ago (figure 67 in the larger volume) and a recent photograph shows that very little alteration has been made.

On the east wall of the gnomon are two graduated quadrants, used as a Dakshiṇovṛitti Yantra or meridian instrument. Each quadrant has a radius of 10 feet 7 inches. The shadow of one of the pins (fixed at the top of each quadrant) gives the zenith distance at noon, and zenith distances of other heavenly bodies could be observed directly, by moving the eye along the appropriate quadrants. Under these quadrants is a platform (shown in the plan) for the observer. Apparently, in 1773, these quadrants were not in existence, but according to Paṇḍit Bapu Deva Śāstri they were there in 1865.

The other Dakshiṇovṛitti Yantra is a self-contained instrument, consisting of a wall lying in the meridian, on the east face of which are two quadrants, each of 7 feet 9½ inches radius. Sir Robert Barker in 1777 stated that the quadrants were of different radii, the larger of which he judged to be 20 feet. If his description be correct, the instrument must have been entirely rebuilt later on, possibly when the Mānmandira was added to.

The smaller Samrāṭ Yantra calls for little remark. It is 8 feet 3 inches high, and the radius of the quadrants is 3 feet 2 inches. If the early drawing is correct, the instrument has been moved from its original position.

The **Narivalaya** ('circular dial'), or Uttara-dakshiṇo Gola (north and south dial), is a cylindrical dial—the axis of the cylinder pointing north and south, and the northern and southern faces being parallel to, the plane of the equator. At the centre of each face, and at right angles to it, is a short iron style surrounded by two circles—the outer one (on the northern face) graduated in hours, etc., and the inner one in *ghaṭis*, etc. Besides serving as an ordinary dial the instrument marks the equinoxes, since the northern face can only be used for sun observations when the sun is north of the equator. The inscription on the instrument reads :—" Narivalaya Dakshin and Uttra Gola. The use of this instrument is to find whether the heavenly bodies are in the northern or southern hemisphere. It gives time also."

The Digaṁśa Yantra ('azimuth instrument'), marked *DD* in the plan, is the large circular building at the east of the terrace. The exterior diameter is 31½ feet, the outer wall is 8 feet 4 inches high and the inner wall and central pillar are each 4 feet 2 inches high, and an iron rod fixed to the central pillar is of the same height as the outer wall. The tops of both walls were originally graduated into degrees, etc. ; and cross wires were stretched north to south and east to west on the outer wall. The use of the instrument is to measure azimuths or horizontal angles, but it is now of little practical use, owing to its being surrounded on all sides but one by buildings.

To the south-east of the Digaṁśa Yantra there used to be another dial, whose diameter was 6 feet 2 inches. It was on a platform slightly higher than the terrace, and approached by steps. At the present time there is no space to accommodate such an instrument and Campbell's drawing of 1773 shows no such instrument. However, Williams mentioned that it had been excluded from Campbell's drawings,[1] and it was mentioned by Hunter in 1797 and by Paṇḍit Bapu Deva Sāstri in 1865.

The Chakra Yantra is shown in the plan at *CC*. It is an equatorial, and was common to most mediaeval observatories. It consists of an iron circle (declination circle) 3 feet 7 inches in diameter, one inch thick and two broad, faced with brass, on which degrees and minutes are marked. The circle is fixed so that it can revolve round an axis parallel to the earth's axis. At the southern extremity of this axis, and on the pillar which supports the instrument, is a graduated circle (hour circle) in the plane of the equator. There is no pointer for this hour circle, and, according to Hunter, there was none in 1797. Attached to the centre of the declination circle is a sighter, consisting of a hollow brass tube (figure 68), but this is comparatively new. Hunter wrote: "Observations with this instrument cannot have admitted of much accuracy, as the index is not furnished with sights; and the pin by which it is fixed to the centre of the circle is so prominent, that the eye cannot look along the index itself."

The sighting arrangement is fixed to the big circle by a pin, and this pin is fixed by a cotter or wedge, shaped roughly into some semblance of a horse's head. In the section on the astrolabe it was stated that the

[1] *Phil. Trans. Royal Soc.* 1793, i. 45.

Arabs called such a wedge *faras* ('horse'), and that in mediaeval Europe it was generally made into some semblance of a horse's head. "Thorw which Pyn," wrote Chaucer,* "ther goth a litel wegge which that is cleped the hors that streyneth alle these parties to hepe." There is evidence to show that the horse shaped design of the wedge was brought to India by the Muslims, and the example on the Chakra Yantra is interesting as evidence of the persistence of a traditional design, and in some degree as evidence of the ultimate source of the design of Jai Singh's instruments.

History.

The Mānmandira was built about the beginning of the seventeenth century. Campbell's drawing of 1773, the Asiatic Society painting (*circa* 1794), Prinsep's drawing of 1825, and recent photographs enable us, to some extent, to trace the additions and alterations made. The part of the façade that is directly under the observatory belongs to the oldest part of the building, and that part that has no balconied windows is comparatively new. The fine window on the extreme north of the building was given by Prinsep in his illustrations of Benares, and has been described by Fergusson and Havell.

The astronomical instruments were added by Jai Singh about A.D. 1737.[1] The date is not certain, and nearly every writer gives a different one. Sir Robert

* *A Treatise on the Astrolabe*, i, 14.

[1] This is the date given by Williams, who, on all points that can be verified, is extremely reliable.

Barker, who was almost a contemporary of Jai Singh,[1] said that the observatory was built by Akbar; Prinsep wrote: "The building was converted into an observatory by Jysing, A.D. 1680" and refers to a supposed description of it by Tavernier;[2] another writer gives A.D. 1693 and another 1700. Father Boudier who visited Benares in 1734 and made astronomical observations there makes no mention of the observatory. Jai Singh himself tells us that, in order to confirm the observations made at Delhi, he constructed instruments of the same kind at Jaipur, Mathurā, Benares and Ujjain; and the Delhi observatory was probably built about 1724; that at Jaipur was built in 1734, and Williams' date for the observatory at Benares, 1737, may be accepted.

Early Descriptions.

In A.D. 1777[3] Sir Robert Barker, who was for a short time Commander-in-Chief in Bengal, published a description of the instruments, together with a perspective drawing of the observatory as a whole, and detailed drawings of the Samrāṭ Yantra, done by Lieutenant-Colonel Campbell, Chief Engineer of the Company's service. This drawing shows that the main features of the observatory are the same to-day as they were nearly a century and a half ago. There are apparent differences, but some of them may be due to the nature of the drawing: *e.g.*, the Narivalaya and the

[1] Sir Robert Barker lived from 1729-1789, and went out to India in 1749, six years after Jai Singh's death.

[2] Tavernier died in 1689, three years after Jai Singh's birth.

[3] Sir Robert Barker left India in 1773. His notes and the drawings were probably made in 1772-73.

small Samrāṭ appear to have been displaced slightly; the wall that supports the east quadrant is different in detail; there are no graduated quadrants on the east wall of the gnomon; the edge of the plinth, on which the larger Samrāṭ stands, has changed its alignment; and, in the drawing, no plinth at all is shown for the other instruments. From the notes of Williams and Hunter it appears that the drawing is somewhat incorrect, or, at any rate, misleading for the south-east corner of the terrace, for it shows no trace of the second Narivalaya described by them.

Sir Robert Barker's account of the Benares observatory was of the nature of a communication to the Royal Society, London. Further information seems to have been asked for, and this was supplied by Mr. J. L. Williams of Benares in A.D. 1792, who recorded very careful measurements and added some interesting details as to the history of the place. He writes: "The area, or space comprising the whole of the buildings and instruments, is called in Hindoo, *Maun-mundel;* the cells and all the lower part of the area, were built many years ago, of which there remains no chronological account, by the Rajah Mansing, for the repose of holy men, and pilgrims, who came to perform their ablutions in the Ganges, on the bank of which the building stands. On the top of this the observatory was built, by the Rajah Jetsing, for observing the stars, and other heavenly bodies; it was begun in 1794[1] Sambat, and it is said was finished in two years. The Rajah died in 1800[2]

[1] A.D. 1737. [2] A.D. 1743.

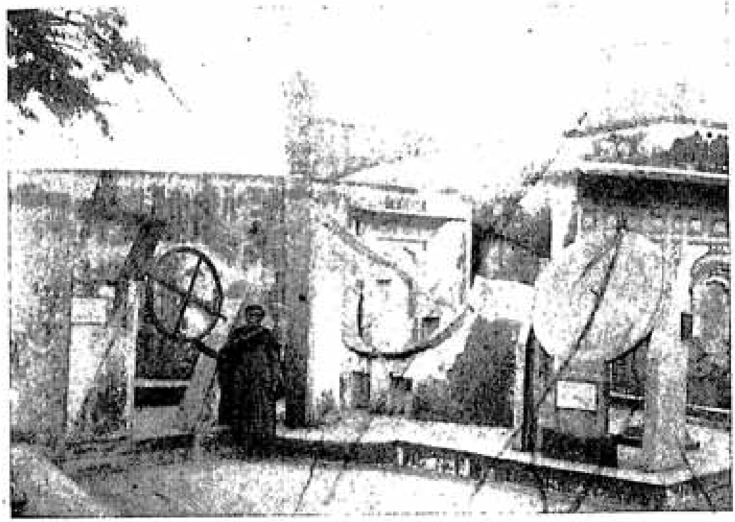
Sambat. The design was drawn by Jaggernaut and executed under the direction of Sadashu Makajin; but the head workman was Mahon, the son of Mahon, a pot maker of Jepoor."

In 1799 Hunter gave a brief description of the observatory, supplementary to the previous accounts. He speaks of the accuracy of Mr. Williams' measurements and explains some of the terms used; and clears up one or two other points. In 1848 Sir Joseph Hooker made excellent drawings of three of the instruments, and in his diary records[1] that "the observatory is still the most interesting object in Benares, although it is now dirty and ruinous, and the great stone instruments are rapidly crumbling away." The only other descriptions it is here necessary to mention are those by Paṇḍit Bapu Deva Sāstri and Lala Chiman Lal.[2]

Of previous restorations we know very little. Sherring states that the Brahmans "were utterly careless" about preserving the instruments. According to Havell, the Mānmandira was restored in the middle of the nineteenth century. In 1912 the present Mahārāja of Jaipur ordered the complete restoration of the instruments. This work was very thoroughly done under the direction of the court astronomer, Paṇḍit Gokal Chand.

The observatory at Benares has long since ceased to be used for practical purposes. The Brahmans consulted by Williams in 1792 all agreed that it "never was used for any nice observations." Its

[1] *Himalayan Journals*, 1854, pp. 74—77.
[2] See the bibliography on page 94.



a

b

BENARES OBSERVATORY.

present situation, surrounded on most sides by buildings, is not ideal for astronomical purposes; and the instruments are, of course, very crude compared with those in modern observatories. The value of the observatory is chiefly historical; it is a monument to one of the brightest intellects of India; and it illustrates a very interesting phase of the history of astronomy. It might have another value if advantage were taken, namely an educational one; for the demonstration of the elements of practical astronomy a better set of instruments could hardly be devised. But, apparently, astronomy is no longer studied at Benares, Ujjain and Jaipur.

CHAPTER XI.

Historical Perspective.

To enable us to place the material collected in its proper historical perspective it is necessary to survey briefly the development of astronomical science, as it affected Jai Singh's work.

Of Jai Singh's theories we have but little information: tradition has allotted to him the whole Ptolemaic theory, and possibly he accepted it without question, but he must have been acquainted with the teaching of Kepler, Galileo and Newton, for he possessed many European works. The topics he dealt with are outlined in the preface to the *Zīj Muḥammad Shāhī*. Principally he was concerned with the design of instruments and practical observation, with a view to the preparation of a catalogue of the stars, etc. His bent was practical, and he was particularly anxious to eliminate instrumental errors.

These points have been illustrated in the foregoing chapters, which also have indicated, incidentally, the sources from which Jai Singh obtained his astronomical notions and inspiration for his methods. There is not the slightest doubt as to the main influence that directed his activities—it was that of the Muslim astronomers of the type of Ulugh Beg; but it is still popularly supposed that Jai Singh's work was, principally, if not wholly, of Hindu origin, and previous writers have helped to strengthen the notion. Sir William Jones was one of the first to give this impression; Hunter was also misleading in a negative way, and more recently Garrett's (otherwise most excellent) book is also somewhat misleading on historical matters. It is necessary, therefore, not only to trace Jai Singh's theory and practice back to their proper sources, but to examine the possible connexions between his work and the traditional Hindu theory and practice.

For purposes of exposition it is convenient here to speak of the influence of three schools of astronomy: (i) Hindu, (ii) Muslim and (iii) European. Jai Singh was, to some extent, in contact with all three, and it is a matter of considerable interest to determine the quality and quantity of their influence on him. Although he actually lived in the seventeenth and eighteenth centuries of our era, the influences that directed his activities were mediaeval: little advance had been made by the Hindu and Muslim schools for centuries, and the advances in Europe were too recent to be fully appreciated.

Hindu Astronomy.[1]

There is a certain amount of very interesting mythological astronomy recorded in the Vedas, but the earliest

[1] The following notes attempt to give, very briefly, only a fair notion of Hindu astronomy. No attempt has been made at completeness. For further information reference should be made to my *History of Hindu Astronomy*.

formal Hindu astronomical works are the *Jyotisha Vedāṅga* and the *Sūrya Prajñapti*, the latter of which exhibits a strange cosmography (with two suns, two moons, etc.[1]), while both have the crude elements of a scientific astronomy. These works are of considerable historical interest: they show little, if any, Greek influence.

Soon after the beginning of the Christian era the traditional astronomical system in India was largely discarded, and the system in vogue in the Greek schools was imported and assimilated. In the *Pañcha Siddhāntikā* of Varāha Mihira we have, possibly, summaries of two western books—the *Pauliśa* and *Romaka Siddhāntas*, but, quite apart from this, there is abundant evidence to show, not only Greek influence, but, Greek domination. The representative Indian work, that exhibits the astronomy of this period, is the *Sūrya Siddhānta*. In its original form this work was probably composed about A.D. 400, and the recension now in use about A.D. 1000. Since then very little attempt at advance has been made. The orthodox still accept the *Sūrya Siddhānta* and similar works as authoritative.

Such are the facts, but there has been an extraordinary amount of misconception current. According to Hindu tradition the *Sūrya Siddhānta* was composed some millions of years ago.[2] Bailly, towards the end of the eighteenth century, considered that Indian astronomy had been founded on accurate observations made thousands of years before the Christian era.

[1] The astronomical notions of the early Christian writers were often far more absurd.

[2] *Sūrya Siddhānta*, i. 2-3.

Laplace, basing his arguments on figures given by Bailly, decided that some 3,000 years B.C. the Indian astronomers had recorded observations of the planets correct to one second; Playfair[1] supported Bailly's views; Sir William Jones argued that correct observations must have been made as early as 1181 B.C.; and so on; but, with the researches of Bentley, Colebrooke, Weber, Whitney, Thibaut and others, more correct views were introduced; and it has long been known that the figures used by Bailly are comparatively modern.

Vedic astronomy is more poetical than exact, and it is of interest, apart from its poetic value,[2] chiefly as a subject of controversy. Certain scholars, *e.g.*, Tilak, Jacobi, Dikshit and others, argue, from rather vague astronomical premises, partly based on the texts, an extreme antiquity for the Vedic writings; others do not accept their views.[3]

The Vedic year was 12 months of 30 days each, with an occasional intercalary month, "the thirteenth month fabricated of days and nights, having thirty members."[4] There is no indication of any definite cycle. The year was also divided into two equal courses or *ayanas*, a northern course or *Uttarāyana* beginning at the winter solstice, and a southern course or *Dakshiṇāyana* beginning at the summer solstice.

[1] Afterwards both Laplace and Playfair recanted. See my *History of Hindu Astronomy*, §3.

[2] Many of the 'astronomical' hymns of the Rig Veda are exceedingly beautiful. See my *Hindu Astronomical Deities*. JASB, 1919.

[3] See my *History of Hindu Astronomy* §§ 32 and 86, where the extremely interesting views of Jacobi and Tilak are discussed.

[4] *Atharva Veda*, XIII, 3⁸.

In the Rig Veda only two or three asterisms are mentioned but in later Vedic texts complete lists of the 27 or 28 *nakshatras* are given.[1] These early lists are headed by *Kṛittikā* which marked, it is believed, the vernal equinox of the Vedic year; and this is a foundation, although not a very secure one, for Vedic chronology. If the vernal equinox was marked by *Kṛittikā*, and, if by Kṛittikā the constellation of the Pleiades was meant, then the period of fixing this was about 2350 B.C., when the vernal equinox was approximately of the same longitude as Alcyone (η Tauri), the brightest of the Pleiades.

Other parts of the Vedic texts have also been used for the purpose of establishing their great antiquity: *e.g.*, Jacobi attempted to prove that the Vedic year commenced with the summer solstice. His arguments are based on the following somewhat doubtful rendering of a verse of the 'Frog Hymn':—

"Those leaders of rites observe the institutes of the gods, and disregard not the season of [the twelfth month]: as the year revolves and the rains return, then scorched and heated they obtain freedom."

Dikshit,[2] from a passage of the Brāhmaṇas (*ŚB* II, 1, 2 [2-4]), fixes the age of its composition at 3000 B.C. The words "They (the Kṛittikās) do not move from the eastern quarter while the other *nakshatras* do move from the eastern quarter" he takes to mean,

[1] Much has been written about the *nakshatras* or divisions of the ecliptic. They have been usually identified with certain constellations, but recent researches seem to show that they were rather conceived as divisions of the ecliptic and *not* connected with particular constellations. See my *History of Hindu Astronomy*, §20.

[2] *Indian Antiquary*, 1895, XXIV, p. 245.

definitely, that the Pleiades were always on the equator; and he writes "In my opinion the statement conclusively proves that the passage was composed not later than 3000 B.C." Many other similar interpretations have been striven after.

In Vedic texts no definite mention is made of the planets, although much ingenuity has been exercised in interpreting the texts otherwise. There are possible references to eclipses, which Ludwig, with some skill, has attempted to identify.

The *Jyotisha Vedāñga*[1] and the *Sūryaprajñapti* contain the earliest formal astronomical statements. The former introduces the five-year cycle of 1830 apparent solar days. The year was tropical in theory and contained 366 apparent solar days, and was, therefore, much too long. There were 27 *nakshatras*, each supposed to occupy $\frac{360^\circ}{27} = 13\frac{1}{3}$ degrees of the ecliptic, and each *nakshatra* was considered to be divided into 124 equal divisions, or *aṁśas*.

The five-year cycle appears to have commenced with the winter solstice, and Śravishṭha is said to have marked the beginning of this cycle, and also the beginning of the sun's progress, and also the winter solstice—all of which are in agreement. If Śravishtha is to be identified with β, α, γ and δ Delphini (as it usually is), then it marked the winter solstice about B.C. 1100. But a list of *nakshatras* given in the text begins with Aśvini, which is supposed to have marked the vernal equinox about the beginning of the Christian era. The

[1] *Vedāñga* is the name of certain works, or classes of works, regarded as auxiliary to the Veda. They are generally considered as of a later date.

Vedāṅga states that, during the northern progress of the sun, the days increase in length at an even rate of 1·57 minutes a day, or 4 hours 48 minutes in six months of 183 days[1]: the northern and southern progress are considered equal.

The *Sūryaprajñapti* is a Jain treatise on astronomy that is similar in many respects to the Jyotisha Vedānga. The Jainas held the old Indian idea of the heavenly bodies revolving round mount Meru, and, as a corollary to this, they conceived two suns, two moons and two sets of constellations. The five-year cycle began with the summer solstice, with the sun in Pushya, and Thibaut thought this was a correction, from actual observation, of the older Vedāṅga. Another point of difference was the employment of 28 *nakshatras* of unequal extent, and this altered, theoretically, the positions of the *nakshatras* — in some cases to a very considerable extent, and makes our estimations of the periods in which these works were composed very uncertain.

The characteristics of this period are :—

The five-year cycle, with a year of 366 days.
The division of the ecliptic into 27 or 28 *nakshatras*.
Equal daily change in the length of the day.
Omission of any explicit reference to the planets.

Varāha Mihira and others, about A.D. 550, made popular new ideas borrowed from the west: they remodelled the Hindu astronomical system on Greek

[1] An increase of 4½ hours corresponds to a latitude of about 36° 38′ N., the obliquity being taken as 23½ degrees. For a greater obliquity it would be further north.

lines. The Greek names of the signs of the zodiac were adopted, and the seven-day week introduced; many Greek astrological terms and some Greek mathematical terms were adopted without change. Practically all the Greek astronomical theories were taught and the Vedāṅga astronomy was largely discarded. Varāha Mihira's astrological works contain numerous Greek technical terms and show, unmistakably, Greek influence. His great astronomical work, the *Pañcha-siddhāntikā*, consists of summaries of the Paitāmaha, Vāsishṭha, Romaka, Pauliśa[1] and Saura Siddhāntas. "The Siddhānta made by Pauliśa is accurate, near to it is the Siddhānta proclaimed by Romaka, more accurate is Sāvitra and the two remaining ones are far from the truth." The summary of the *Paitāmaha Siddhānta* exhibits the teaching of the Vedāṅga stage but adds the epoch of 2 Śāka (=A.D. 80). The *Vāsishṭha Siddhānta* appears to represent the transition stage. It alters the longest day rule and introduces shadow calculations, and the *lagna* or 'rising sign' notion; while the other three introduce, unequivocally, the Greek teaching. The main characteristics of the *Romaka Siddhānta* are—

(*a*) A cycle of $2850=19\times 150$ years, perhaps based on the Metonic cycle.

(*b*) A year of $365^d\ 5^h\ 55^m\ 12^s$, which is exactly the tropical year of Hipparchus.

(*c*) The epoch of 427 Śāka (=A.D. 505).

(*d*) Omission of mention of epicycles.

[1] Albīrūnī writes (i, 153): "Pauliśa-Siddhānta, so called from Pauliśa the Greek, from the city of Samtra, which I suppose to be Alexandria."

F

The *Pauliśa Siddhānta* gives the elements of mathematical astronomy and in particular introduces trigonometrical functions and a table of sines agreeing with Ptolemy's table of chords.

The *Sūrya Siddhānta* is probably the best known astronomical work of the Hindus. The several sections of the accepted text[1] relate to—

1. The mean motions of the planets. 2. The true places of the planets. 3. The *gnomon*. 4. Eclipses. 5. Planetary conjunctions. 6. Asterisms. 7. Heliacal risings and settings. 8. Instruments. 9. Time, Cosmogony. 10. Astrology.

The topics dealt with in most of the later Hindu works are fundamentally the same as those of the *Sūrya Siddhānta*, and the following notes apply, fairly generally, to all these works. The earth is considered as a fixed unsupported sphere, round which the other heavenly bodies revolve. Its diameter is given as 1,600 yojanas, and the distance of the moon as 51,570 yojanas, or roughly the same relative distance as Ptolemy gives ($61\frac{1}{6}$ radii of the earth). The distances of the other planets are calculated on the assumption that they move with equal velocities. The equation of the centre of a planet is calculated by assuming epicycles. A cycle of 4,320,000 years is employed. The precession of the equinoxes is explained as a sort of libration, within limits of 27 degrees east and

[1] Varāha Mihira's summary of this work differs in some details from the text now in use, *e.g.*, the length of the sidereal year in the two works is: Old Sūrya Siddhānta 365^{d} 6^{h} 12 36^{s} modern Sūrya Siddhānta 365^{d} 6^{h} 12^{m} $36{\cdot}56^{s}$. The text now accepted possibly dates from about A.D. 1000, while the earlier limit for the original Sūrya Siddhānta is about A.D. 400.

west of a fixed position at a rate of 54 seconds a year; and the obliquity is generally reckoned at 24 degrees.

A great many interesting topics must be omitted in this brief sketch of Hindu astronomical theory. Āryabhaṭa taught that the earth rotated upon its axis, and a proper explanation of eclipses, but was not approved. The works of Brahmagupta and Bhāskara have considerable interest in matters of detail, but do not differ fundamentally from the *Sūrya Siddhānta*. Indeed, since the time of composition of this work there has been practically no alteration of fundamental importance in the Hindu theory.

At the present time there are three schools of astronomers: (i) The Saura-paksha, (ii) the Arya-paksha, (iii) the Brahma-paksha; and these only differ[1] in matters of detail. For example, a distinctive feature is the length of the year[2] employed. These are—(i) *Saura-paksha* year $365^d\ 6^h\ 12^m\ 36{\cdot}56^s$. (ii) *Ārya paksha* year $365^d\ 6^h\ 12^m\ 30^s$. (*iii*) *Brahma-paksha* year $365^d\ 6^h\ 12^m\ 30{\cdot}915^s$.

The only instruments of practical utility for astronomical purposes described in ancient Hindu works are the sun-dial consisting of a vertical gnomon, and the clepsydra. An armillary sphere is also described as an instrument for purposes of demonstration. The

[1] Really the differentiation is a geographical one. The *Sūrya Siddhānta* is the standard authority in the greater part of India, but the first *Ārya-Siddhānta* is the authority in the Tamil and Malayāḷam countries of Southern India, while Brahmagupta is followed in Gujarāt, Rājputāna and North-West India.

[2] Theoretically, at least, the year is a sidereal one, but there is some vagueness, and there are no records of the methods by which the results were attained.

F 2

only Hindu instrument of any antiquity actually found is a clepsydra consisting of a metal bowl floating in a vessel filled with water. There is no trace of any early Hindu observatory.

Muslim Astronomy.

The Muslim astronomers frankly acknowledged their indebtedness to Greek writers. Indeed they were to some extent the direct successors of the Greeks in intellectual matters,[1] and the historical problems of their astronomy are much less complicated than is the case with the Hindus. In the middle ages they were the foremost astronomers of the world. They accepted the fundamental features of the Ptolemaic system of the universe. They were aware of the precession of the equinoxes, and discovered the slight movement of the apogee of the sun, and also they perceived the variation in the obliquity of the ecliptic. They discussed the possibility of the earth rotating on its own axis, but generally rejected the theory.

They fully realised the necessity for methodical observation, and in practical astronomy, they excelled the Hindus and Europeans of their time. The first series of regular observations, with the aid of fairly accurate instruments, appears to have been made at Gondeshāpūr, in the south-west of Persia, in the first years of the ninth century of our era. During the Califiate of al-Ma'mūn (A.D. 813—833), at the observatory at Baghdād, all the fundamental elements of the

[1] Possibly they owed something to India also. See my *History of Hindu Astronomy*, §46.

Almagest were verified—the obliquity of the ecliptic, the precession of the equinoxes, the length of the solar year, etc. A measurement of an arc of the meridian in the region of Palmyra was also carried out during the same period, and similar observations continued to be made throughout the Muslim world until the middle of the fifteenth century. The observatory at Cairo was founded in the tenth century, and the observations there were recorded in the 'Hākimid Tables.' In Persia an observatory was founded, in A.D. 1074, at Naisābūr, and there, in A.D. 1118, al-Khāzinī complied his 'Sanjaric Tables.' In 1259 a great observatory was founded at Marāgha in North-West Persia, and there Nasīr al-Dīn-Ṭūsī (mentioned by Jai Singh), prepared his famous 'Ilkhānic Tables.'

The practical view taken by the Muslim astronomers led to attempts to improve the instruments in use, and to the design of others.

With Ulugh Beg, the grandson of Tamerlane, the study of scientific astronomy throughout the Islāmic world ceased. He founded a large observatory at Samarqand, to which he summoned such renowned astronomers as Jamshīd al-Kāshi (mentioned by Jai Singh), Kādī Zāde, al-Rūmī, 'Alī al-Ḳūsji, and others. He undertook a complete revision of the catalogue of the stars—based upon direct observation—and himself wrote a preface to the tables, a few months before he perished by an assassin's hand. Jai Singh professedly followed Ulugh Beg in his astronomical work.

The names of many Muslim astronomers of the middle ages, such as Ibn Sīnā or Avicenna, al-Bīrūnī, Omar Khayyām and Averroës, are well known.

European Astronomy.

In Europe, after the death of Ptolemy in the second century of our era, very little advance was made for a thousand years. The Christian church often opposed scientific enlightenment, and sometimes persecuted those who sought it; and the patristic writings contain the grossest of astronomical absurdities.

But, about the thirteenth century, sounder opinions began to prevail, and in the early part of the sixteenth century Copernicus wrote his *De Revolutionibus Orbium Coelestium*. Tycho Brahe, Kepler, and Galileo preceded Jai Singh by about a century. Greenwich observatory was founded some forty years before that at Delhi. Newton's *Principia* was written at the time of Jai Singh's birth; Huygens died a few years later; Flamsteed's catalogue of stars was first printed in 1688; Halley, in 1705, predicted the return of the comet named after him; the aberration of light was discovered in 1727. Jai Singh succeeded to the Amber territory in 1699, and the Delhi observatory was built about 1724.

The European instruments, at the beginning of the seventeenth century, were, in principle, much the same as those used by the Greeks and Arabs. Tycho Brahe[1] (1546-1601) had several sextants and quadrants, a parallacticum and armillary circles; Hevelius (1611-1687) had a somewhat smaller battery of similar instruments; and Flamsteed (1646-1720) used a quadrant of 3 feet and a sextant of 6 feet radius.

[1] See DREYER's *Tycho Brahe*, xii, 315 ff.

The telescope was used for the general observation of heavenly bodies in 1609 by Galileo, and telescopic sights were first systematically used about A.D. 1667. Gascoigne was probably the first (*circa* A.D. 1640) to introduce these, and he also invented a micrometer. Hevelius introduced the vernier and tangent screw; Flamsteed used cross wires in the eye pieces of his sighters; Galileo had used a pendulum for short time measurements; Huygens devised a pendulum clock (1656), and Jean Picard (1620-1682) introduced regular time observations at the new observatory at Paris. J. D. Cassini (1625-1712), it is stated, devised schemes (never realised) for the construction of gigantic instruments.

The three schools compared.

The Hindus, Arabs and Europeans all derived the fundamentals of their astronomical science from the Greeks. It was the Hindus who first profited by Greek experience, then the Arabs and lastly the Europeans. The last, indeed, obtained their knowledge of Greek astronomy primarily through the Arabs.

When we examine carefully the methods of the several schools we find somewhat marked differences. Even among the Greek astronomers (*e.g.*, Ptolemy himself) there was a distinct tendency to work only on the observations recorded by their predecessors, and, in the later Greek schools, there was a consequent neglect of observational astronomy. With the Hindus this tendency was emphasised to a remarkable extent, and practical work was neglected almost completely. The instruments they describe are either for purposes of theoretical calculations, or for purposes of demonstration. They built no observatories and they made no systematic records of observations.

The Arabs and other Muslim astronomers took an entirely different line. They recognised the value of practical observation; they built observatories and devised improvements in the instruments, and set about verifying and correcting Ptolemy's elements; but they hardly suspected the need for a re-examination of the Greek theories.

The European astronomers were, perhaps, not quite so bound by tradition as were the Hindus and the Arabs. The death of the Ptolematic theory and the invention of the telescope gave a great impetus to research, and the European astronomers largely discarded the methods of their predecessors. They recognised the inevitability of observational error, and devised means to counteract it; they were forced to consider, as of great importance, facility of observation, and gradually they devised instruments of types unimaginable to their Arabic teachers.

The evolution of Jai Singh's instruments.

The history of the evolution of Jai Singh's astronomical instruments would, if it could be recorded step by step, be of great interest; but detailed descriptions of the larger Muslim instruments are not generally available, and we must, for the present, be content with general indications of the lines of development. Generally speaking, Jai Singh's instruments are copies of, or direct developments from, those used by Ulugh

Beg and his predecessors and successors. The flat astrolabe played an important part. Jai Singh's first attempt at improvement was apparently the construction of huge astrolabes, such as that shown in plate II, and the construction of large graduated circles. He had some excellent Arabic and Persian models but the metal instruments he had constructed do not appear to be of that fine workmanship that adds so much to the value of many of the mediæval astrolabes. As far as can be gathered Jai Singh did not use the ordinary sextant and quadrant instruments, such as were used by Nasīr al-Dīn Ṭūsī, Tycho Brahe, Flamsteed, and others.

It has been related how he discarded brass instruments and pinned his faith on large immovable masonry instruments; and some of these he claims to have devised himself. As has already been pointed out, the basic idea was not peculiar to Jai Singh. The Arab, Persian and Tartar astronomers had constructed huge instruments; and they had formulated the notion that the only bar to accuracy of observation was the limit imposed by circumstances on the size of the instruments. Jai Singh was prepared to carry out the idea on which this proposition is based, to, what he thought, a reasonable extent.

The bases of the designs of Jai Singh's instruments are always obvious, but he showed very considerable ingenuity in the actual constructions. The Jai Prakāś is practically the hemisphere of Berosus, somewhat elaborated, and the Samrāṭ Yantra may also be considered as evolved from that instrument. This only means, however, that the dial of Berosus was of a very general nature. It consisted of a hemispherical bowl, placed with its rim horizontal, and in the centre, and in the same plane as the horizontal edge, was fixed a bead, whose shadow on the concave surface of the hemisphere marked the trace of the sun's diurnal path. The resemblance to the Jai Prakāś is striking enough, but it is doubtful whether Jai Singh had any knowledge of the earlier instrument: he could only have learnt of it from the Muslim astronomers (*e.g.*, al-Battānī, who refers to the principle of the instrument). The Jai Prakāś, however, is something more than the bowl of Berosus, for it is fully graduated, and appears to have been based upon the Muslim instrument known as *al-Masātarah*, descriptions of which are found in the works of the Muslim astronomers.[1]

In the British Museum are many dials of the seventeenth and early eighteenth centuries constructed exactly on the same principle as the Samrāṭ Yantra. The direct origin of the tangential scales on the gnomon, for measuring the declination of the sun, is not known, although Ibn Yūnus, and other Muslim writers on astronomy, had worked out the theory.[2] Hindu astronomers did not employ the tangent function, and refer to no other dial than the vertical gnomon, and to no other dial measurements than the length of the shadow. They made no direct angular measurements, and an angular

[1] See L. A. Sédillot's *Memoire sur les instruments astronomiques des Arabes*, p. 151f.; also a description by al-Barjendī; also Blagrave's *Art of Dyalling*, 1609. One section of Blagrave's book is—"How to make a dyall on a concave hemisphere of a globe two severall waies," and the second way is that of the Jai Prakās.

[2] Indeed they worked out the complete theory of the horizontal, vertical, inclined, cylindrical and conical dials, etc.

dial would have been almost contrary to the spirit of their teaching.[1]

The other instruments that can be attributed to Jai Singh's genius are the Digaṁśa Yantra and Rām Yantra, but these are simply enlargements, in masonry-work, of the azimuth and combined azimuth and altitude instruments of the Muslims.

The predominating influence.

The actual points of contact between Jai Singh's astronomical work and that of his predecessors and contemporaries have been generally indicated. Jai Singh himself was a Hindu and had Hindu assistants, the most notable being Jagannāth, who, however, it seems, was employed, because of his knowledge of Arabic—a somewhat unusual qualification among the Pandits of the day.[2] Jai Singh refers to one Hindu astronomer by name, who was, however, renowned because of his knowledge of Greek methods. Jai Singh was, no doubt, well acquainted with the works of the Hindu astronomers, but he does not seem to have made much direct use of them.

Jai Singh had certain Muhammadan assistants, he was acquainted with the chief astronomical works

[1] This is a curious point in the history of science. The Hindus seemed to avoid direct angular measurements, and their mathematical works contain no theorems or rules relating to angles (see my *Indian Mathematics*, page 20).

[2] It is related that Jai Singh was reproached with the statement that the Pandits, who pretended to great learning, were entirely ignorant of Arabic scholarship. He thereupon produced Jagannāth, who translated, from the Arabic, Euclid's *Elements*, and Ptolemy's *Almagest*. See SUDHĀKARA DVIVEDI *Gaṇakataraṅgiṇī* p. 102 f.

of the Muslims, he brought one of their star catalogues up to date, and he copied the instruments of the observatory at Samarqand. His masonry instruments were designed after the notions taught by the Muslim astronomers, and had absolutely nothing in common with those described in Hindu works. He sent certain of his assistants to Europe to get books and information; he invited European priests to visit him, and he obtained European tables.

We may leave out for the moment the question of European influence, as Jai Singh was really only on the border line of that influence, and consider the Hindu and Arabic schools. The characteristic difference between these is connected with practical work. The Hindus were practical astronomers only in so far as they could calculate, from a given starting point with given rules, the positions of the planets, eclipses, etc., with some accuracy. This, of course, implies a very considerable amount of knowledge and skill; but the Hindus had no instruments of precision of their own before Jai Singh's time; neither were they interested in making practical obervations of the heavenly bodies. Their rules and the elements given in their approved works sufficed them. The standpoint of the Muslims was entirely different: they were particularly interested in the verification and correction of previously recorded results. They built what were then the finest observatories in the world, and they perfected the astrolabe to an extraordinary degree.

The difference between the two schools is too well known to need elaboration; and the category into which Jai Singh's work places itself is perfectly clearly indicated; and the hypothesis that he received his main astronomical inspiration from Hindu tradition is completely eliminated. He followed "the martyr prince, Mirza Ulugh Beg" of Samarqand. Since both the Hindus and Muslims obtained their astronomy from the Greeks, they have much in common, but the work of Jai Singh was exactly of that nature which differentiates between the two schools; and, what the Muslim astronomers had, and, what Hindus lacked, attracted Jai Singh. In his work there is no point of contact with Hindu astronomy that did not also touch the work of the Muslims, while, on the other hand, there are many points of contact between his work and Muslim astronomy that are remote from the teaching of the Hindu schools.

Jai Singh's apparent indifference to European achievements is rather remarkable; but, it must be borne in mind that, he, very probably, only became acquainted with their results after he had conceived, and partially carried out, his scheme of astronomical research. His tables, it is supposed, were completed about A.D. 1728, and the observatory at Delhi had been built a few years previously. It was in 1728 or 1729 that Jai Singh sent Padre Manuel and others to Europe, and in 1734 he was visited by Father Boudier and his companion. These dates might be considered sufficient to account for Jai Singh's neglect of the European discoveries, but there is possibly another explanation. Galileo died a prisoner of the Inquisition in 1642, and his books were not removed from the *Index* until A.D. 1835: More recent European discoveries might thus have been discredited in Jai Singh's eyes, and he would, at any rate, have found it difficult to reconcile the persecution by authority, on the one side with the claim to brilliant scientific discoveries, on the other.

Jai Singh began his work at a time when European astronomers had arrived at, what may be termed, the modern conception of the universe. The discoveries of Copernicus, Kepler, Galileo and Newton had been accepted, and scientists were settling down to work out, in detail, the results of these discoveries. Flamsteed's great catalogue was completed just as Jai Singh began his work. But in the special circumstances of his experience, it is not surprising that Jai Singh refused to follow the lines of research indicated by the European astronomers. Had he done so, his power and his wealth might have enabled him to alter the whole condition of Indian scientific scholarship, and, instead of his labours ending with his death, when "science expired on his funeral pyre," there might have been established a lasting school of research. The troubled condition of the country, and the general state of civilization in it, were antagonistic to the progress of science, and Jai Singh's work is now only a tradition, and his observatories are archæological remains.

That Jai Singh made no new astronomical discoveries is hardly a fair criterion of the value of his work; for, indeed, a great deal of the most valuable astronomical work is not concerned with new discoveries. His

[1] See also DE MORGAN'S *A Budget of Paradoxes*, in which numerous works opposing the 'Newtonian theory' are referred to.

avowed object was the rectification of the calendar, the prediction of eclipses, and so on—work which entails a great deal of labour, and generally shows no remarkable achievement. Considering the state of the country in which Jai Singh lived, the political anarchy of his time, the ignorance of his contemporaries, and the difficulties in the way of transmission of knowledge, his scheme of astronomical work was a notable one, and his observatories still form noble monuments of a remarkable personality.

APPENDIX.

TABLE I.

Place.	North latitude.	Longitude East of Greenwich.		Difference between mean local and standard time.	Magnetic Declination.	
					For 1919.	Annual variation.
	° ′ ″	° ′ ″	hr. min. sec.	min. sec.	° ′	′
Allahabad—Fort—main gate	25 25 53·9	81 52 32·6	5 27 30·1	—2 29·9	E 0 45	—4
Benares—Observatory	25 18 24·9	83 0 46·1	5 32 3·1	+2 3·1	E 0 45	—4
Bombay—Colaba Observatory	18 53 46·5	72 48 47·3	4 51 15·1	—38 44·9	W 0 20	+3
Calcutta—Fort William—Flag Staff	22 33 32·1	88 20 15·1	5 53 21·1	+23 21·1	E 0 5	—6
Delhi—Jama Masjid—Central domes	28 39 2·3	77 14 2·8	5 8 56·2	—21 3·8	E 1 45	—3
„ Pirghaib	28 40 35·1	77 12 52·0	5 8 51·5	—21 8·5	E 1 45	—3
Hyderabad (Sind)—Tower in Fort.	25 23 4·9	68 22 23·9	4 33 29·5	—56 30·5	E 1 40	—1
Hyderabad (Deccan)—N W. minaret of college.	17 21 38·9	78 28 33·0	5 13 54·2	—16 5·8	W 0 45	+4
Jaipur—Palace minaret	26 55 27·4	75 49 18·5	5 3 17·2	—26 42·8	E 1 35	—3
Lahore—Sonahri Mosque	31 35 0·2	74 19 13·5	4 57 16·9	—32 43·1	E 2 40	—2
Madras—Observatory	13 4 3·05	80 14 54·2	5 20 59·6	—9 0·4	...	...
Simla—Centre chimney of Government House.	31 6 25·1	77 10 9·3	5 8 40·6	—21 19·4	E 2 25	—3
Ujjain—Railway station	23 10 16	75 45 18	5 3 1·2	—26 58·8	E 0 40	—3
„ Telegraph office	23 10 25	75 47 3	5 3 8·2	—26 51·8	...	...
„ Hill 1679	23 11 6	75 46 45	5 3 7·0	—26 53·0	...	...
For standard time	...	82 30 0	5 30 0	...	...	...

The elements for this table were kindly supplied by the Superintendent of the Trigonometrical Survey of India.

Table II.—The Equation of Time.

[The difference between apparent solar time (dial time) and mean solar time (clock time.*)]

Month.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Day.	min. sec.	min. sec.	min. sec.	min. sec.	min. sec.	min. sec.	min. sec.	min. sec.	min. sec.	min. sec.	min. sec.	min. sec.
1	—3 19	—13 38	—12 39	—4 11	+2 53	+2 31	—3 27	—6 13	—0 13	+10 1	+16 18	+11 11
3	—4 16	—13 54	—12 15	—3 35	+3 7	+2 13	—3 50	—6 6	+0 24	+10 40	+16 21	+10 25
5	—5 11	—14 6	—11 50	—3 0	+3 20	+1 53	—4 12	—5 56	+1 3	+11 17	+16 20	+9 38
7	—6 5	—14 15	—11 22	—2 25	+3 30	+1 32	—4 33	—5 44	+1 43	+11 53	+16 16	+8 48
9	—6 56	—14 21	—10 53	—1 51	+3 38	+1 10	—4 52	—5 29	+2 24	+12 27	+16 9	+7 56
11	—7 45	—14 24	—10 22	—1 18	+3 44	+0 47	—5 9	—5 12	+3 6	+12 59	+15 59	+7 2
13	—8 32	—14 23	—9 50	—0 46	+3 48	+0 22	—5 25	—4 53	+3 48	+13 30	+15 45	+6 7
15	—9 17	—14 19	—9 17	—0 15	+3 49	—0 2	—5 39	—4 31	+4 30	+13 58	+15 28	+5 10
17	—9 59	—14 13	—8 43	+0 15	+3 48	—0 23	—5 51	—4 8	+5 12	+14 25	+15 7	+4 12
19	—10 38	—14 3	—8 7	+0 43	+3 45	—0 58	—6 1	—3 42	+5 55	+14 49	+14 43	+3 13
21	—11 14	—13 51	—7 32	+1 9	+3 39	—1 19	—6 9	—3 15	+6 37	+15 10	+14 15	+2 13
23	—11 47	—13 37	—6 55	+1 34	+3 31	—1 46	—6 15	—2 46	+7 19	+15 29	+13 44	+1 13
25	—12 17	—13 20	—6 19	+1 57	+3 21	—2 12	—6 19	—2 15	+8 1	+15 45	+13 10	+0 13
27	—12 44	—13 0	—5 42	+2 17	+3 9	—2 37	—6 20	—1 42	+8 42	+15 58	+12 33	—0 47
29	—13 8	..	—5 6	+2 36	+2 55	—3 2	6 19	—1 8	+9 22	+16 5	+11 53	—1 46
31	—13 29	..	—4 29	..	+2 40	..	—6 16	—0 32	..	+16 15	..	—2 44

* In India clock time is ordinarily 'standard' time, which is 5½ hours earlier than Greenwich mean time.

The equation of time is given to the nearest second for 0 hours Greenwich mean time of alternate days of the months (1919). For intermediate times proportionate parts will give approximately correct results. (The instruments give at their best readings correct only to, say, half a minute of time). The equation of time is to be applied to mean time in accordance with the signs as given in the table.

To obtain the difference between dial time and standard time add the quantities in the fourth column of table I to the equation of time. For example, to deduce dial time from standard time on October 13th at Delhi add to standard time —21 min. 8 sec. +13 min. 30 sec. or —7 min. 38 sec.

Table III.—Hindu Measures

Divisions of the day.

60 prativipalas	=	1 vipala	=	0·4 seconds.
10 vipalas	=	1 prāṇa	=	4·0 seconds.
60 vipalas	=	1 pala or vināḍikā	=	24·0 seconds.
60 palas	=	1 ghaṭi, nāḍikā, daṇḍa	=	24 minutes.
60 ghaṭikās	=	1 divasa, dina, vāsara	=	1 solar day.
Also 2 *ghaṭis*	=	1 *muhūrta*	=	48 minutes and 30 *muhūrtas* =1 day.

Length.

8 yavas	=	1 aṅgula	?=	$\frac{3}{4}$ inch.
24 aṅgulas	=	1 hasta	=	18 inches.
4 hastas	=	1 daṇḍa	=	6 feet.
2000 daṇḍa	=	1 krośa	=	4,000 yards
4 krośa	=	1 yojana	=	$9\frac{1}{11}$ miles.

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GLOSSARY.

Alhidade.—[Ar. *'iḍādah* 'door post'] The 'sighter' of an astrolabe.

Almagest.—[Ar. *al majisti*, the greatest]. Ptolemy's work—the *Syntaxis*.

Almucantarats [Ar. muqanṭarāt]. Circles of altitude, particularly on the astrolabe.

Aṁśa.—Division, degree.

Aṅgula.—A digit. A measure of length approximately =¾ inch.

'ankabūt.—['spider']. The open-work rotating tablet of an astrolabe.

Astrolabe.—[Ar. usṭurlāb Gk. 'astrolábos]. See page 22.

Azimuth.—[Ar. *al-sammūt*, pl. of *samt*, 'way']. Angle between the meridian and vertical circle passing through the body.

Chakra.—Circle.

Chakra yantra.—Circular dial.

Dakshiṇa.—On the right or south.

Dakshiṇovṛitti yantra.—A fixed meridian circle.

Declination.—The distance from the equator measured on a great circle passing through the poles.

Digaṁśa Yantra.—[*diś* quarter, direction; *aṁśa* division, degree of arc]. An instrument for measuring horizontal angles or azimuths.

Equation of time.—The correction to be added to the *apparent* solar time to obtain the *mean* solar time.

Equatorial.—A revolving astronomical instrument whose fixed axis is parallel to the earth's axis.

Faras.—['Horse']. The wedge which fastens the parts of an astrolabe together.

Ghaṭī.—A sixtieth part of a day, *i.e.*, 24 minutes.

Gola.—Sphere.

Jantar.—Yantra, q. v.

Jantar Mantra.—Name for the Delhi Observatory (Mantra has here no specific meaning).

Jai prakāś.—A hemispherical dial designed by Jai Singh.

Kapāla.—A bowl. A hemispherical dial.

Krānti vṛitta.—The ecliptic.

Krāntivṛitti yantra.—An instrument for measuring celestial latitude and longitude. The *Torquetum* of Regiomontanus.

Local time.—The true solar time at a particular locality. Dial time.

Miśra yantra.—Mixed instrument. See page 36.

Nakshatra.—A division of the ecliptic. A constellation.

Narā yantra.—Sun-dial.

Pala.—One sixtieth of a *ghaṭī*, or 24 seconds.

Prakāśa.—Manifestation, elucidation.

Rām yantra.—A circular instrument for measuring altitudes and azimuths.

Rāśi.—A sign of the zodiac.

Rāśi valaya.—A set of 12 dials of the same type as the Samrāṭ Yantra—one, for each sign of the zodiac.

Samrāṭ.—[*samrāj*, supreme ruler].

Samrāṭ Siddhānta.—Name of a Sanskrit translation of the Almagest.

Samrāṭ yantra.—Name of Jai Singh's chief instrument, an equinoctial dial.

Shashtāmśa.—Consisting of sixty degrees.

Siddhānta.—Any canonical text-book or scientific treatise; especially on astronomy.

Solar time.—The mean solar day is the average of all the solar days of the year. The difference between apparent solar time, and mean solar time is termed the 'equation of time.'

Standard time is the local time of a standard meridian. In India the standard meridian is 82° 30′ east of Greenwich and standard time is 5½ hours earlier than Greenwich mean time.

Torquetum.—An instrument for measuring celestial latitudes and longitudes.

Triquetrum.—An instrument consisting of two arms of equal length hinged together, with a third graduated arm opposite to the hinge.

Unnatāṁśa yantra.—[*unnata*, elevated]. A graduated circle with vertical axis, for measuring altitudes, etc.

Valaya.—A circle.

Vertical circle.—Any circle passing through the zenith and cutting the horizon at right angles.

Vṛitta.—Round, circular.

Yantra.—Instrument.

Yantra rāja.—Hindu name for the astrolabe.

Ẓāt al-ḥalqa.—'Consisting of a ring.'

Ẓāt al-Ṣafā'ih.—'Consisting of tablets.' The astrolabe.

Ẓāt al-Shu'batain.—An instrument consisting of two parts. The *triquetrum*.

Zīj.—Astronomical table.

Zīj Muḥammad Shāhī.—Astronomical tables named after the Emperor Muḥammad Shāh.

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