India's Contributions to Chinese Mathematics Through the Eighth Century C.E.*

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1 Buddhism: The Medium of Interaction

The rock edicts of King Aśoka (third century B.C.E.) show that he had already paved the way for the expansion of Buddhism outside India.[2] Subsequently, Buddhist missionaries took Buddhism to Central Asia, China, Korea, Japan, and Tibet in the north, and to Burma, Ceylon, Thailand, Cambodia, and other countries of the south. This helped in spreading Indian culture to these countries. It is aptly observed that "Buddhism was, in fact, a spring wind blowing from one end of the garden of Asia to the other end causing to bloom not only the lotus of India, but the rose of Persia, the temple flower of Ceylon, the zebina of Tibet, the chrysanthemum of China and the cherry of Japan. It is also said that Asian culture is, as a whole, Buddhist culture."[3] Moreover, some of these countries received with Buddhism not only their religion but practically the whole of their civilization and culture.

The generally accepted view is that China received Buddhism from the nomadic tribes of Eastern Turkestan toward the end of the first century B.C.E., although there is evidence to show that Indians had gone there earlier to propagate the faith.[4] The Chinese tradition narrates that the Han emperor, Ming-Ti (first century C.E.), had sent an embassy to India to

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[2] Bapat, P. V. (general editor): *2500 Years of Buddhism*. Publications Division, Delhi, p. 53 (1964).

[3] Ibid., p. 397.

[4] Ibid., pp. 59 and 110.

B.S. Yadav and M. Mohan (eds.), *Ancient Indian Leaps into Mathematics*,

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bring back Buddhist priests and scriptures.[5] Consequently, two Indian monks, Kia-yeh Mo-than (Kāśyapa Mātaṅga) and Chu-fa-lan (probably Dharmaratna or Gobharana), reached the Han capital, Loyang. They learned Chinese and translated Buddhist books, the first of which was *Foshuo-ssu-shih-erh-cheng-ching* (the Sūtra of 42 Sections Spoken by Buddha).[6] With the arrival of more monks, both from India and Central Asia, the Loyang monastery became a centre of Indian culture. A large number of Indian books were translated, and people began to adopt Buddhist monastic rituals. Buddhism prevailed so extensively that by the sixth century, the number of monasteries had rise to about 30,000, and the number of monks and nuns to two million.[7]

The tradition of the Buddhist educational system gave birth to large-scale monastic universities. Some of these famous universities were Nālandā, Valabhī, Vikramśilā, Jagaddala, and Odantapurī. They attracted students and scholars from all parts of Asia. Of these, the Nālandā university was most famous, with about ten thousand students and fifteen hundred teachers. The range of studies covered both sacred and secular subjects of Buddhist as well as Brahminical learning. The monks eagerly studied, besides Buddhist works (including *Abhidharma-kośa*), the Vedas, medicine, arithmetic, occult sciences, and other popular subjects.[8] There was special provision for the study of astronomy, and it is said that the university included an astronomical observatory.[9]

According to the findings of a modern Chinese historian (Liang Chi-Chao), more than 160 Chinese pilgrims and scholars came to India between the fifth and eighth centuries.[10] Of these, Fa-Hien (fifth century), Yuan Chwang (seventh century), and I-tsing (eighth century) are the most famous. Some of them stayed and studied in India for several years. They returned to their homeland with many Pali and Sanskrit works, hundreds of which were translated into Chinese.

2 Indian Astronomy and Mathematics in Ancient China

We have seen that Buddhism was the medium for cultural exchange between India and China, providing opportunities for the exchange of ideas. Buddhism exerted great influence in various fields in China and was the main vehicle for transmission of Indian scientific ideas to that land. The influence was so great

5 Mukherjee, P. K.: *Indian Literature Abroad* (*China*). Calcutta Oriental Press, Calcutta, p. 1 (1928).

6 Ibid., pp. 2–3.

7 Chou Hsiang-Kuang: *The History of Chinese Culture*. Central Book Depot, Allahabad, p. 106 (1958).

8 Bapat (ref. 2), p. 239, and Mukherjee (ref. 5), pp. 78–79.

9 See K. S. Shukla, *Āryabhaṭa* (booklet), New Delhi, p. 5 (1976).

10 Bapat (ref. 2), pp. 163–164.

that even scientists embraced the new faith. For instance, the astronomer Han Chai and the mathematician Wang Fan (about 200 C.E.) both became Buddhists (Mikami, p. 57). A great deal of Indian astronomy and mathematics became known in China through the translation of Indian works, and through the visits of Indian scholars. We shall briefly outline the broad facts in this section.

The *Mātaṅga-avadāna* was translated (or retranslated) into Chinese in about the third century C.E., although the original is believed to date earlier.[11] It gives the lengths of monthly shadows of a 12-inch gnomon, which is the standard parameter of Indian astronomy. The work also mentions the 28 Indian *nakṣatraṣ.*

Śārdūlakarṇāvadāna was translated into Chinese several times, beginning in the second century. This work contains the usual Sanskrit names of the 28 *nakṣatraṣ* starting with *kṛttikā*, but the number of *grahas* mentioned is only seven, excluding thereby Rāhu and Ketu, which were often added in the manuscripts and translations.[12] The measures of shadows for various parts of the day mentioned in the work (pp. 54–55) are the same as in the *Atharva Vedāṅga Jyotiṣa*, verses 6 to 11.

Lalitavistara is another work that was translated into Chinese several times from the first century onward. It is in this work that the famous Buddhist centesimal-scale counting occurs during the dialogue between Prince Gautamaand the mathematician Arjuna. The first series of counts ends with *tallakṣaṇa* ($= 10^{53}$), beyond which eight more *gaṇanā* series are mentioned.[13] Atomic-scale counting is also mentioned (there being 7^{10} *paramaṇus* in one aṅgulaparva) (p. 104).

Vasubandhu (fourth century) was so honoured for his work that he was known as the Second Buddha. His *Abhidharma-kośa*, in which he wrote his own commentary, is an encyclopedic work that played an important role in propagating Buddhist philosophy and thought in Asia. It was translated into Chinese and Tibetan. It contains early Buddhist ideas in cosmography (Jambūdvīpa being given the form of a *śakaṭa*) and astronomy (sun and moon revolving around the Meru).[14] It is through this work that we know that the Buddhist school used 60 decuple terms in decimal counting.[15]

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[11] Yabuuti, K.: *Indian and Arabian Astronomy in China.* In: The Silver Jubilee volume of the Zinbun-Kagaku-Kenkyusyo, Kyoto, pp. 585–603 (1954).

[12] Mukhopadhyay, S. K. (ed.): The *Śārdūlakarāvadāna.* Visvabharati, Santiniketan, pp. 46–53 and p. 104 (1954).

[13] Vaidya, P. L. (ed.): *Lalitavistara.* Darbhanga, p. 103 (1958). The last number in the final count will be equal to $10^{7+9\times 46} = 10^{421}$.

[14] *Abhidharmakośa* edited by Dvārikadas Sastri, 2 Volumes, Varanasi, III, 45–60 (1981) (Vol. I, pp. 506–518).

[15] Ibid., p. 544.

The *Mahāprajñā-pāramitā Śāstra* (of Nāgarjuna, second century) was translated into Chinese by Kumārajīva in the early fifth century.[16] The astronomical parameters mentioned in this translation are comparable to those given in the *Vedāṅga Jyotiṣa*.[17]

Bodhiruci I arrived in China (from central India) in 508 C.E., and is said to have translated several Indian astronomical books into Chinese.[18]

An Indian system of numeration appeared in the Chinese work *Ta Pao Chi Ching* (*Mahāratnakūta Sūtra*), translated by *Upaśūnya* (in 541 C.E.).[19] Paramārtha (Po-lo-mo-tho), a native of Ujjain, arrived in China in 548 C.E. and translated about 70 works including the *Abhidharmakośa* (*vyākhyā*)-*śāstra* and the *Lokasthiti-abhidharmaśāstra* (which has astronomical content).[20]

There was a brief setback to Indian activities in China when Wu-Ti came to power in 557 C.E., but they were resumed during the Sui Dynasty (581–618 C.E.). The Indian paṇḍita, Narendrayaśas, was recalled from exile in 582 C.E. Among the works he translated was the *Mahāvaipulya Mahāsannipāta Sūtra*, from Sanskrit. It contains *nakṣatras*, the zodiacal cycle, calendrical material, and other Indian astronomical theories.[21]

The Chinese translations of the following works are mentioned in the *Sui Shu*, or *Official History of the Sui Dynasty* (seventh century):[22]

1. *Po-lo-mên Thien Wên Ching* (Brahminical Astronomical Classic) in 21 books.
2. *Po-lo-mên Chieh-Chhieh Hsien-jen Thien Wên Shuo* (Astronomical Theories of Brāhmaṇa Chieh-Chhieh Hsienjen) in 30 books.
3. *Po-lo-mên Thien Ching* (Brahminical Heavenly Theory) in one book.
4. *Mo-têng-Chia Ching Huang-thu* (Map of Heaven in the Mātaṅgī Sūtra) in one book.
5. *Po-lo-mên Suan Ching* (Brahminical Arithmetical classic) in three books.
6. *Po-lo-mên Suan Fa* (Brahminical Arithmetical Rules) in one book.
7. *Po-lo-mên Ying Yang Suan Ching* (Brahminical Method of Calculating Time) in one book.

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[16] Bapat (ref. 2), p. 115.

[17] Chin Keh-mu, "India and China: Scientific Exchange" in D. Chattopadhyaya (ed.): *Studies in History of Science in India*. Vol. II, pp. 776–790, (1982) (Solar month $30\frac{1}{2}$ days (year = 366 d.), $P = 27\frac{21}{60}$ (cf. $27\frac{21}{67}$), and $S = 29\frac{30}{62}$ (cf. $29\frac{32}{62}$).

[18] Mukherjee (ref. 6), p. 38.

[19] Needham, J.: *Science and Civilization on China*. Vol. III, Cambridge, UK, p. 88 (1959).

[20] See Bapat (ref. 2), p. 214; Mukherjee (ref. 5), p. 34; and Needham (ref. 19), p. 707, where the Chinese title of the second work appears as *Li Shih A-Pi-Than Lun* (Philosophical Treatise on the Preservation of the World).

[21] Needham, J. (ref. 19), p. 716, and *Chin Keh-mu* (ref. 17), p. 784.

[22] Gupta, R. C.: *Indian Astronomy in China During Ancient Times*. Vishveshvaranand Indological Journal, XIX, 266–276, p. 270 (1981).

Although these translations are lost, they were also mentioned in other sources.

More vigorous contacts and activities took place during the glorious period of the Tang Dynasty (618–907 C.E.). In response to an envoy sent by the Indian king Harṣavardhana in 641 C.E. to China, two missions came from there to India. Hiuen Tsang (or Yuan Chwang) needed 22 horses to carry the works that he took from India to China in 645. He translated 75 of these, including *Abhidharmakośa*.

The great influence of Indian astronomy at that time can be seen by the presence of a number of Indian astronomers in the Chinese capital Chang-Nan, where there was a school in which Indian *sidhāntas* were taught.[23] In fact, there were three clans of Indian astronomers, namely Kāśyapa, Gotama, and Kumāra. These Indians were employed in the Chinese National Astronomical Bureau and helped in improving the local calendar.

The greatest of these was Gotama Siddha (or Gautama Siddhārtha). He became the president of the Chinese Astronomical Board and director of the royal observatory. Under imperial order (from Hsuan-tsung) he translated the famous *Chiu Chih Li* ("Navagraha Karaṇa") from Indian astronomical material in 718 C.E. A few years later, he compiled the *Khai-Yuan Chan Ching* (the Khai Yuan Treatise on Astronomy and Astrology) in 120 volumes, of which the 104th is the *Chiu Chih Li*. It includes the Indian sine table ($R = 3, 438, h = 225\,\text{min}$) and Indian methods of calculation with nine numerals and zero (denoted by a thick dot $\bullet$). The astronomy was based on nine planets, including *Lo-hou* and *Chi-tu* (which are Chinese forms of the Sanskrit names Rāhu and Ketu).[24]

3 Earlier Chinese Parallels of Indian Mathematical Pieces

Before addressing the question of mutual transmissions further, we shall first mention the close resemblances that exist between some mathematical problems, rules, and formulas as found in China and India.

(I) The Broken Bamboo Problem (वंशभङ्गोद्देशकः)

In China this is found in the famous *Chiu Chang Suan Shu* (Nine Chapters on the Mathematical Art), whose present text is placed in the first century C.E. Its ninth chapter, entitled "kou ku" (Right Triangles), contains the following problem:[25]

[23] Ibid., pp. 271–273.

[24] The work has been fully translated with notes by Kiyori Yabuuti in his paper "Researches on the *Chiu-Chih Li* Indian Astronomy under the Thang Dynasty" Acta Asiatica, Vol. 36, pp. 7–48 (1979).

[25] Waerden, B. L. van der: *Geometry and Algebra in Ancient Civilization*. Springer–Verlag, Berlin, p. 53 (1983).

Problem 13: A bamboo is 1 chang (= 10 *Chhih*) tall. It is broken, and the top touches the ground 3 *chhih* from the root. What is the height of the break?

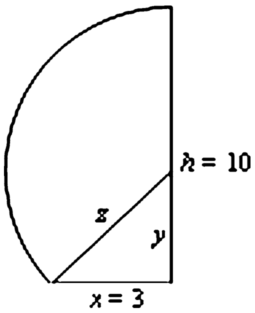

Fig. 1. The bamboo problem

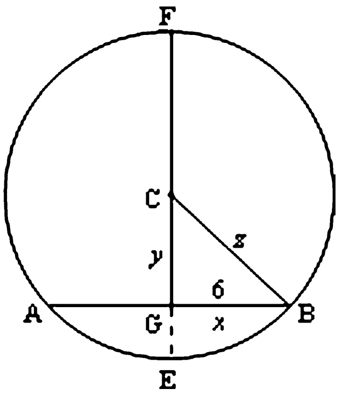

Fig. 2. Solution to the bamboo problem

The solution to the problem is (see Fig. 1)

$$y = (h - x^2/h)/2 = 4\frac{11}{20} \textit{ chhih}.$$

It is understood that the solution is based on the Pythagorean property, so that

$$y + z = h \text{ and } z^2 - y^2 = x^2.$$

One of the two similar examples given by Bhāskara I (629 C.E.) reads[26]

अष्टादशकोच्छायो वंशो वातेन पातितो मूलात् ।
षड्गत्वाऽसौ पतितस्त्रिभुजं कृत्वाक्व भग्नःस्यात् ॥

aṣṭādaśakocchāyo vaṁśo vātena pātito mūlāt
ṣaḍgatvāạsau patitastribhujaṁ kṛtvākv bhagnaḥsyāt

A bamboo of height 18 is felled by the wind. It falls at (a distance of) 6 from the root (thus) forming a triangle. Where is the break?

26 Shukla, K. S. (ed.); *Āryabhatīya* with the commentary of Bhāskara I and *Someśvara*, INSA, New Delhi, India, pp. 99–100 (1976).

Bhāskara's solution is based on applying the relation (see Fig. 2)

$$GF \cdot GE = GB^2,$$

which is given in *Āryabhaṭīya* II, 17 (second half), on which he is commenting. He gets

$$GE = x^2/h = 2 = z - y.$$

Then doing *saṁkramaṇa* with $z + y = 18$, he found z and y to be 10 and 8.

(II) Problem of a Reed in a Pond (कमलोद्देशक:)

This is problem no. 6 in the ninth chapter of the *Chiu Chang Suan Shu*:[27]

> There is a pond whose section is a square of side 1 *chang* (= 10 *chhih*). A reed grows at its centre and extends 1 *chhih* above the water. If the reed is pulled to the side (of the pond), it reaches the back precisely. What are the depth of the water and the length of the reed?

The solution given[28] is $x = (z^2 - e^2)/2e$, where z is half the side of the pond, and $y = x + e$ (see Fig. 3).

Bhāskara I's first similar example (out of two) reads[29]

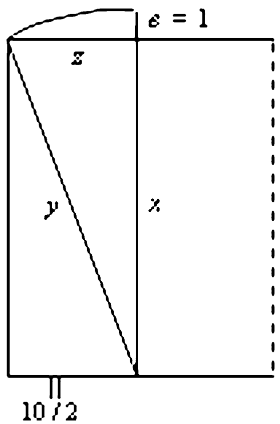

Fig. 3. The reed problem

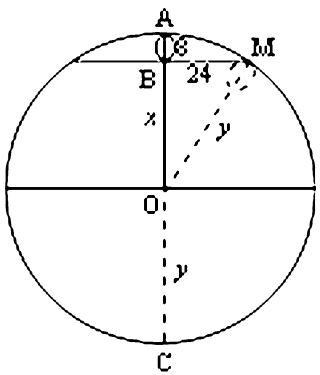

Fig. 4. Solution to the reed problem

[27] Waerden, B. L. van der (ref. 25), pp. 50–51.

[28] Swetz, Frank: The Amazing *Chiu Chang Suan Shu*. Math. Teacher, 65, 423–430, p. 429. Translation kindly supplied by D. B. Wagner.

[29] Shukla (ed.), op. cit. (ref. 26), pp. 100–102. Shukla's remark (p. 299) that the Chinese and Hindu solutions are "quite different" is not justified, since both are ultimately based on the Pythagorean property. The relation $BC = y + x = z^2/e$

कमलं जलात्प्रदृश्यं विकसितमष्टाङ्गुलं निवातेन।
नीतं मज्जति हस्ते, शीघ्रं कमलाम्भसीवाच्ये॥

kamalṁ jalātpradṛśyaṁ vikasitamaṣṭāṅggulaṁ nivāten
nītaṁ majjati haste, śīghraṁ kamalāmbhasī vācye

A lotus in full bloom of 8 *aṇgulas* is visible (just) above the water. When carried away by the wind, it submerges just at the distance of 1 *hasta* (= 24 aṇgulas). Tell quickly (the height of) the lotus plant and (the depth of) the water.

His solution is again based on the same property of chords, namely (Fig. 4)

$$BC \;=\; BM^2/AB \;=\; z^2/e.$$

And then applying *saṁkramaṇa* to $y+x \;=\; z^2/e$ and $y-x \;=\; e$, he gets the height of the lotus y and the depth of the water x as 40 and 32 (aṇgulas). On simplification, *Bhāskara's* solution

$$x \;=\; \frac{1}{2}\left(\frac{z^2}{e} - e\right)$$

becomes the same as the Chinese solution

(III) Approximate Volumes of a Sphere

The *Chiu Chang Suan Shu* (first century C.E.) used the approximate rule:

$$V \;=\; \frac{9}{2}r^3 \tag{11}$$

for calculating the diameter of a sphere when its volume V is known.[30] In India, Bhāskara I quotes a rule that gives (11) directly:[31]

व्यासार्धधनं भित्वा नवगुणितमयो गुडस्य घनगणितम्।

vyāsārdhadhanaṁ bhitvā navaguṇitamayo guḍasya ghanagaṇitam

The product of 9 and half the cube of the radius is the ball's volume.

follows from the property of chords (which itself is based on the Pythagorean property) or from $y^2 - x^2 = z^2$ and $y - x = e$. The slight difference in methods is not significant.

30 Mikami, Y.: *The Development of Mathematics in China and Japan*, reprinted by Chelsea, New York, p. 14 (1961).

31 Shukla (ref. 26), p. 61.

Two centuries later, *Mahāvīra* (about 850 C.E.) gave the same rule and regarded it, like Bhāskara, as only a *vyāvahārika*, or practical (not exact), rule.[32] The same is also found in other Jaina works such as *Tiloyasāra* (*gāthā* 19) of Nemicandra (about 975 C.E.) and the *Gaṇitasāra* (V. 25) of Ṭhakkura Pheru (about 1300 C.E.). This shows a Jaina tradition for (11).

Another item of interest is that in China, *Liu Hui* (third century) interpreted (11) wrongly as equivalent to[33]

$$V = \frac{\pi^2}{2} r^3. \tag{12}$$

In India also, Mahāvīra seems to have thought that (11) was based on (12) with the practical value $\pi = 3$. He further derived a better formula by taking $\pi = \sqrt{10}$, which he considered to be sūkṣma.[34]

(IV) The Problem of 100 Chickens

In China, the earliest statement of the problem of a hundred chickens is found in the *Chang Chhiu-Chien Suan Ching* (Arithmetical Classic of Chang Chhiu-Chien), which is generally placed in the second half of the fifth century. It runs as follows:[35]

> A cock costs 5 pieces (*wên*) of money, a hen 3 pieces, and 3 chickens 1 piece. If we buy, with 100 pieces, 100 birds, what will be their respective numbers?
> (Answers: 4 + 18 + 78; 8 + 11 + 81; 12 + 4 + 84.)

A century later, Chen Luan gave two similar problems with cost 5, 4, 1/4, (Answer: 15 + 1 + 84), and 4, 3, 1/3 (Answer: 8 + 14 + 78)[36].

In India such problems appear in the *Bakshāli Manuscript* (whose exact date is uncertain or controversial). One problem relates to buying a total of 20 animals (monkeys, horses, and deer) for a total of 20 *paṇas* at costs 1/4 (say), 4 and 1/2. (Answer: 2 + 5 + 15.)[37]

[32] Jain, L. C. (ed.): *Gaṇitasārasaṅgraha* (with Hindi translation), Sholapur, III, 28, p. 259 (1963).

[33] Wagner, D. B.: "*Liu Hui and Tsu Keng-chih* on the Volume of a Sphere," Chinese Science, No. 3, 59–79, p. 60 (1978).

[34] Gupta, R. C.: "Volume of a Sphere in Ancient India," paper presented at the Seminar on Astronomy and Mathematics in Ancient India, Calcutta, May 19–21, 1987, has details.

[35] Mikami (ref. 30), p. 43. On p. 39 he says that the work "probably belongs to latter half of the sixth century."

[36] Ibid., p. 44.

[37] Hayashi, Takao: The Bakshali Manuscript, Ph.D. thesis, Brown University, p. 649 (1985). He places the work in the seventh century, which is somewhere in the middle of the early (fourth century) and late (tenth century) dates assigned to it.

Another similar example relates to prices or earnings of men, women, and *śūdras* or children at rates 3, 3/2, and 1/2. (Answer: 2 + 5 + 13.)[38]

An example of buying 100 birds (pigeons, cranes, swans, and peacocks) with 100 *rūpas* (or *paṇas*) with rates 3/5, 5/7, 7/9, 9/3 occurs in *Śrīdhara's Pātīgaṇita* (Ex. 78–79) (eighth century) as well as in *Mahāvīra's Gaṇitasārasaṅgraha* (VI, 152–153) (ninth century).[39] This problem was quite popular in India, and one of the many solutions is 15 pigeons, 28 cranes, 45 swans, 12 peacocks.[40] Similar problems were also popular in other parts of the world, as shown by works, of various authors starting with *Alcuin* (ninth century).[41]

In simple matters, like the use of $\pi = 3$, we may accept independent discoveries or inventions by different cultural groups. But when specific characteristic rules and problems, such as (I)–(IV) considered above, are found to occur in different cultural areas, we have to favor a theory of diffusion. Of course, there may have been an older common source from which material was possibly transmitted to the various cultural areas. B.L. van der Waerden (p. 66) considers a pre-Babylonian common source for Chinese and Babylonian algebra. In fact, he has formulated the thesis of a common Indo-European origin of mathematics that flowed to China, India, Babylonia, Greece, and Egypt (pp. 67–69). We have evidence that some peculiar rules such as the "surveyor's rule" for the area of a quadrilateral[42] and the use of $h(c+h)/2$ (or its other derived forms) for the area of a segment of a circle were widely diffused.

Regarding pieces of (I)–(IV) discussed above, we have not come across specific earlier instances in which these are found as such. It is therefore to be presumed that there was some interaction that ultimately led to transmission between China and India. We have already noted above that even Chinese mathematicians, such as Wag Fan (about 200 C.E.), became Buddhists (Mikami, ref. 28, 57). Needham[43] mentions the monk Than Ying (about 440 C.E.), who could have been a teacher of *Chiu Chang Suan Shu* and commentary by *Liu Hui*.

References to Buddhism and Buddhist works are found even in the mathematical treatises of China such as the *Sun Tzu Suan Ching* or Arithmetical Manual of Master Sun, which is placed[44] between 280 and 473 C.E. Master

38 Ibid., p. 650; and David Singmaster, *Sources in Recreational Mathematics*, 3rd Preliminary Edition, p. 139, June 1988.

39 Shukla, K. S. (ed.): The Patiganita of Sridharacarya, Lucknow, pp. 80–83 (1959)(text) and 50–51 (transl.), Jain (ref. 30), p. 131.

40 Shukla (ref. 39) has given all the 16 solutions. Also see Hayashi (ref. 37), p. 650, for more references.

41 Singmaster, op. cit. (ref. 38), pp. 139–144.

42 Gupta, R. C.: The Process of Averaging in Ancient and Medieval Mathematics. *Gaṇita Bhāratī*, III, 32–42 (1981).

43 Needham (ref. 19), p. 149.

44 Mikami (ref. 30), p. 26.

Sun's work is important for early indeterminate analysis in China. *Chen Luan* (sixth century), who was also interested in indeterminate analysis, was an ardent believer of Buddhism. He read Buddhist works profoundly and mentioned them in his writings.

At least some of the Indian scholars who visited China must have become familiar to some extent with the local mathematical traditions, especially the more popular common and recreational types of problems. Some of these Indians frequently returned to India (if only temporarily). In addition, Chinese pilgrims, scholars, and envoys (including diplomats) who visited India may have taken some Chinese mathematical classics, such as the famous *Chiu Chang Suan Shu*, with them. Books may have been part of gifts that may have been presented to the kings or universities. All such things indicate a strong possibility of mathematical interaction between China and India. But while these were documented in Chinese sources, there is no similar positive literary or other documentary evidence known from Indian sources that specifies clearly the arrival of any Chinese mathematical material in India.[45]

4 I-Hsing (683–727 C.E.): The Great Chinese Astronomer–Mathematician

By the end of the seventh century C.E., much Indian mathematics and mathematical astronomy was known in China. The compilation of *Chiu Chih Li* in Chinese by Gautama Siddha from Sanskrit sources represents the culmination of such transmissions in 718 C.E. Through this work, Indian methods of computation based on the decimal place-value system (with a zero symbol) and Indian trigonometry (based on sines) were formally introduced in China. The analysis of the contents of *Chiu Chih Li* by Yabuuti (ref. 22 at the end) shows that mathematical astronomy as found in *Sūryasidhānta* and in the works of *Varaḥmihira* (sixth century C.E.) and *Brahmagupta* (seventh century) was known in China at the beginning of the eighth century.

At this time I-Hsing appeared on the Chinese scene. He was an able mathematician, deeply learned in astronomy, and was well-versed in Sanskrit (Mikami, ref. 28, p. 60). He combined in himself the traditions of Chinese and Indian mathematical sciences. He became a Buddhist monk, attended convocations of monks and *śramaṇas*, and traveled widely to acquire knowledge (Needham, ref. 17, p. 38).

[45] There are similarities in many other mathematical works that we have not discussed here. Some of these are treated by B. Datta in his paper "On the Supposed Indebtedness of Brahmagupta to *Chiu Chang Suan Shu*," *Bulletin of the Calcutta Math. Soc.*, Vol. XXII, pp. 39–51 (1930). Datta does not mention Bhāskara I. Also see van der Waerden (ref. 23), pp. 196–208, for $\pi = 3.1416$, and L.C. Jain, "Jaina School of Mathematics (A Study in Chinese Influences and Transmissions)," *in Contribution of Jainism to Indian Culture* (ed. by R.C. Dwivedi), Delhi, India, 206–220 (1975).

I-Hsing won a great reputation for his combinatorial calculations. Due to his Buddhist training, he could easily handle large numbers such as 3^{361} or 10^{172}. His methods were capable of enumerating all possible changes and transformations occurring on a go or chess board (Needham, ibid., p. 139). He could also handle indeterminate problems involving large numbers (ibid. pp. 119–120). In India, similar problems had already been solved by Bhāskara I (early seventh century). Some scholars have confused him with I-Hsing, the pilgrim.[46]

Between 721 and 727 C.E., I-Hsing prepared, by imperial order, a calendar known as *Ta Yen Li* (Needham, ref. 17, p. 37), in which he applied higher mathematics. Out of the 23 different systems of calendars known by that time, I-Hsing's was found to be accurate and has stood the test of time (Mikami, ref. 28, p. 60).

Gautama Chuan (of the Kumāra clan) probably knew that one of his Indian collegues had taught I-Hsing the method (say as given in the *Sūrya-Siddhānta*) for relating gnomon shadows and solar zenith distance (or altitude) by means of *Chiu Chih Li's* sine table.[47] I-Hsing fully used this knowledge.

Greatly influenced by Indian astronomy, I-Hsing made measurements in ecliptic coordinates, which had previously played a minor role (Needham, ref. 17, p. 202). He was associated in training officials and observers for the great meridian survey of 724 C.E.[48] The observed data were also analyzed by him. He developed a tangent table that is the earliest of its kind in the world. This development was based on Indian information about the use and values of sines, from which his tangent table was derived.[49] He used methods of finite differences, fitting of polynomials, and interpolation.[50]

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[46] Shukla (ref. 26), p. 311.

[47] Cullen, C.: "An Eighth Century Chinese Table of Tangents," *Chinese Science*, No. 5, 1–33, p. 32 (1982).

[48] Beer, A., et al.: An Eighth Century Meridian Line: I-Hsing's Chain of Gnomons. Vistas in Astronomy, Vol. 4, 3–28, p. 14 (1961).

[49] Cullen (ref. 47), p. 32.

[50] See Cullen's paper (ref. 47) and *Historia Mathematica*, Vol. 11, pp. 45–46 (1984), where it is stated that *Liu Ch′uo* (about 600 C.E.) knew the formula for interpolation for equal intervals and *Li Ch′un-feng* (665 C.E.) had studied finite differences up to the second order, and interpolation for equal as well as for unequal intervals. See R. C. Gupta.: Second Order Interpolation in Indian Mathematics, etc. *Indian J. Hist. Sci.,* IV, 86–98 (1969).

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