ĀRYABHATA I, HIS LIFE AND HIS CONTRIBUTIONS

S. M. Razaullah Ansari

Physics Department, Aligarh Muslim University, Aligarh

Abstract :—After recalling a few historical facts concerning Aryabhata's life and time we ist his three known works out of which the only one extant presently is *Aryahbatiya*. The content of the various chapters of this treatise on mathematics and astronomy are described briefly. We present in particular the salient features of Aryabhata's astronomy and mention also the astronomical ideas of other cultures which bear some similarity to those of Aryabhata. Following this, we deal with the specific *yuga* system of Aryabhata, its roots in Indian tradition and its possible connection with Baby-lonian and pre-Islamic Iranian astrological ideas. We then discuss briefly the impact of Aryabhata's astronomy on the development of astronomy and mathematics in India and West Asia.

Finally we emphasize the importance of the study of History of Sciences in India and argue for its recognition as a full discipline.

> "When the methods of five Siddhāntas began to yield results conflicting with the observed phenomena such as the setting of the planets and the eclipses etc. there appeared in the *Kāli* age at Kusumapura *Sūrya* himself in the guise of Āryabhata, the *kulapa* well-versed in astronomy."
>
> **(Ancient Sanskrit saying)**

What a vivid and lucid description of Āryabhaṭa and his contribution to ancient Indian astronomy! If one reflects a while on this saying[1], one is able to draw a wealth of information about that great savant and father of a new period of Indian mathematics and astronomy. In the following we dilate it by drawing from the history of Indian sciences as worked out and reconstructed in the last several decades. To our knowledge, research on Aryabhata was first initiated as late as 1874 by H. Kern, who first edited the Sanskrit text of Aryabhata's only extant treatise: *Āryabhatīya* [2,*]

1. ARYABHATA'S LIFE :

Aryabhata was born in 476 A.D.[3], most probably in the region lying between the rivers Narmada and Godavri which was called in ancient Sanskrit literature *Ashmaka* country. Whereas one of the commentators of Kautiliya's *Arthashāstra* identifies it with the modern Maharashtra, according to the early Bhuddist sources *Ashmaka* or *Assaka* was situated in Daccan (*Dakkhinapath*). In any case *Ashmakians* were so brave a people that due to their gallant resistance to the Greek invasion under Alexander (4th century B.C.) they even earned a mention by the Greek chroniclers as *Aspasioi* and *Assakenoi* [5, 6].

The period of Aryabhata—he wrote his Aryabhatiya in 499 A.D. at Kusumapura, i.e. Patliputra or modern Patna—coincided with the Kingdom of Buddhagupta (477-497), the last great ruler of the Gupta dynasty. Buddhagupta "succeded in establishing a firm rule, restoring peace and order" [9], disrupted after the death of his grandfather Kumaragupta. We should note that the Gupta empire inspite of its internal strife and power struggle was quite a vast empire, extending from the Bay of Bengal to the Arabian Sea and in the South upto the river Narmada. The Gupta age is supposed to be the golden age of ancient Indian learning [10]. The capital of this Kingdom of Magadha (modern Bihar) Patliputra, was a great centre ot learning, the famous university of Nalinda was situated there and one can suppose that Aryabhata might have been the head (*Kulapati*) of the astronomical observatory of that university [11]. There is evidence that in his non-extant *Aryabhata Siddhanta* he described several astronomical instruments, see section 2 below. Unfortunately one does not know about Aryabhata's life more than what has been said here, except that he must have lived for some time at *Kusumapura*, where the science of astronomy was held in great esteem [12].

2. ARYABHATA'S WORK :

There are three works of Aryabhata known to us today, out of which only one is extant in several manuscripts. They are (i) *Arya-Siddhanta*, (ii) *Aryabhatiya* and (iii) on Al-ntf or Al-nanf. The latter seems to be a translation of some of his work (or part thereof) into Arabic, mentioned by the Iranian scholar Abū Reḥān al—Bīrūnī (973—1048) in his account of India. Al-Biruni quotes about *caturyuga* from this small book, which he must have possessed [13], but which has not been identified till to-date. On the other hand about all other excerpts from Arybhata's work Al-Biruni says quite clearly that "all I know of him I know through the quotations from him given by Brahmagupta" [14].

Aryabhata's *Siddhanta* is not extant either; we know it only through the writings of his contemporary Varahamihira (d. 587), further through Brahmagupta (b. 598), his commentator Bhaskara I (6-7th c.) and also other commentators. It is known today that the *Siddhanta* was based by Aryabhata on the old *Sūrya-Siddhānta* (see section 4 below), since some of the methods of calculation and astronomical constants employed in it (for instance, midnight day-reckoning) appear to differ from those used in his treatise *Aryabhatiya* [15]. The most significant aspect of Aryabhata's *Siddhanta*, as mentioned earlier, is that he described there in sufficient details several astronomical instruments in a special chapter named *Yantrādhyāya* : Gnomon (*śaṅku-yantra*), perfect circular shadow instrument (*chāya-yantra*), semi circle (*dhanur-yantra*) and circle (*chakra-yantra*), *yasti-yantra* (resembling a cylindrical stick), *chatra-yantra* (resembling an umbrella) and water clocks (cylindrical and bow shape) [17].

---

[*] Hereafter we shall employ the convention that every Sanskrit Word will be furnished with dicritrical marks once, when it is used for the first time.

Aryabhata's only extant treatise : *Aryabhatiya* is in fact a compendium of mathematics and astronomy, written in a style of extreme brevity. It consists of 123 verses (*sūtras*) divided into four chapters : *Daśagītaka, Gaṇita, Kālakriyā* and *Gola.*

Dasagitaka consists of a total of 13 verses. Two verses at the beginning and one verse at the end are not supposed to be counted (*dasa* = ten). The first verse (A) is an introductory verse in *āryā* metre as an invocation; the following one (B) is in *gitī* metre, giving representation of numbers by an alphabetical notation, which he invented probably for memorizing the large numbers employed in this chapter. The next 9 verses (again in *giti* metre) contain the basic definitions of great Indian periods : *yugas, manu* and *kalpa*, a distance measure *yojna* and astronomical parameters of his system. In the following section we discuss them briefly . The 10th verse of *Dasagitaka* gives a table of the sine function in steps of 225 minutes of arc with first differences. The last verse (C) of this chapter is a tail-piece in which the importance of astronomy is stressed by asserting that the knowledge of this section leads one beyond the planets to the absolute Brahaman [18a] .

The chapter on mathematics (*Ganita*) consists of 33 verses. The organisation of the chapter is as follows :

(i) 7 verses on artithemetic, viz., on extraction of square roots and cube roots, fractions and the rule of three.

(ii) 12 verses on mensuration and geometry, namely on the areas of triangle, trapezium, circle or of any plane figure; on the surface area of a sphere, volumes of pyramid and sphere, value of $\pi = 3.1416$; construction of circles, triangles and quadrilaterals, Pythagoras theorem, length of a chord and shadow problems.

(iii) 2 verses on trigonometry, viz. geometrical determination of values of the sine-function and calculation of tables of sine-differences.

(iv) 12 verses on algebra : arithmetical progression, sum of squares and cubes of natural numbers and the rule for the solution of the following equations [18b]:

a) $ax \pm b = cx + d$
b) $ax^2 + bx + c = 0$
c) $x - y = a, xy = by$
d) the indeterminate equations

$$x_2 + x_3 + x_4 = a_1$$
$$x_3 + x_4 + x_1 = a_2$$
$$x_4 + x_1 + x_2 = a_3$$
$$x_1 + x_2 + x_3 = a_4$$

In this paper we shall not go into the details of Aryabhata's mathematics which are amply given in recent works [1, 19-21] . It may be remarked, however, that his *Ganita*, inspite of being not a systematic and exhaustive exposition of the mathematics of his time, excercised a great influence not only on the development of mathematics in India but also, through the Arabs as intermediary, on early European mathematics [22] .

The third chapter, *Kālakriyā* i.e. the reckoning of time, consists of 25 verses. Aryabhata defines here first the various units of time : *yugas*, solar year, lunar month, sidereal day, civil day, the division of the day into *nadi* (*ghatis*) and *vinadika* (*vighatika*) : 1 *vighatika* or *pala* = 24 sec. = 6 *parana* [23a] . Further he presents in *sutra* form the eccentric and epicyclic theory of sun, moon and planetary motion.

The final chapter of 48 verses deals mainly with spherical astronomy and eclipses, the last two verses being colophon. It is controversial whether, like verse I-A, the 50th verse of this chapter is a later addition or not. It states : "He who disparages this universally true science of astronomy, which formerly was revealed by *Svayambhū* and is now described by me in this *Aryabhatiya*, loses his good deeds and his long life" [23b] . It is difficult to understand how Aryabhata could give a title like *Aryabhatiya* to his own work. In fact Bhaskara I in his commentary on *Aryabhatiya* (written in 629) named the treatise *Ashmakatantra*. It has also been referred to in the post-Aryabhata literature by just *Dasagitikasutra* and *Aryastasasta* (108 verses in Arya metre), the latter comprising all the last 3 chapters.

There are 5 editions of the Sanskrit text of *Aryabhatiya* and a number of complete translations : 4 in English, 3 in Hindi, one in Marathi and another in Telgu [24] . Besides, there are extant about a dozen Sanskrit commentaries written in the period 525 to 1854 [24] . A wealth of literature for historians of science indeed ! It may be mentioned that on the occasion of the 1500th Birth Anniversary clelebration of Aryabhata at New Delhi on 2nd Nov. 1976, four important publications were released [25] . Besides, an international Symposium was also held at which 25 papers were presented. The Indian National Science Academy, New Delhi, which sponsored the whole programme must be congratulated for it !

3. ARYABHATA'S ASTRONOMY :

The astronomical system of Aryabhata consists of the following : (i) Recognition of the terrestrial rotation, (ii) optical explanation of lunar and solar eclipses instead of the demonic *Rāhu-Ketu* mythology, (iii) a new *yuga* system and (iv) epicyclic-eccentric model of planetary motion. Below we would like to describe first these basic features of Aryabhata's contribution to Indian astronomy and in the following section critically examine it in the general context of astronomical ideas as developed in India before Aryabhata.

3.1 The Axial Rotation of the Earth :—

In the verse IV-9 of *Aryabhatiya*, Aryabhata clearly identifies the apparent motion of fixed stars (asterisms) with that of stationary objects for an observer in a moving boat. In another verse (I-4) he gives even the angular velocity of the earth as 1 minute of arc per *prana*, i.e. in 4 seconds. It must be stressed here that Aryabhata did not imply at all the orbital or heliocentric motion of the earth. This is evident from his other verses (III-15 and IV-6) according to which the earth is situated in the centre of space, surrounded by the orbits of the planets, his order of the celestial bodies being: the asterisms, Saturn, Jupiter, Mars, the Sun, Venus, Mercury, Moon and Earth. A clear geocentric view!

It may be noted that such ideas of relative motion are also found in other cultures : In a Chinese text it is said about the orbital motion of the earth : "The earth ... is always moving and is not still, as a man, who sits within a ship. The ship moves without the knowledge of the man (Shang-shu K'ao-ling-yao)"[26]. According to Neugebauer[27] Cleomedes, writing in 370 ± 50 B.C., compared the planetary motion "with the motion of a person on a moving ship or of ants on a potter's wheel". Neugebauer gives several references of ancient literature on such cinematic equivalence [28]. The similie of a potter's wheel is also used by Brahmagupta as quoted by Al-Birūni[29] "... But the planets move in a slow pace towards the east, like a dust-atom moving on a potter's wheel in a direction opposite to that in which the wheel is revolving. That motion of this atom which is visible is identical with the motion which drives the wheel round, whilst its individual motion is not perceived. In this view Lāta, Aryabhata and Vasishtha[30] agree, but some people think that the earth moves while the sun resting."

Whether Aryabhata borrowed the idea of the motion of the earth from his predecessors or not is not the point of discussion here. What we would like to say is that his clear concept of relative motion was not accepted by many Indian astronomers following Aryabhata. Some of them even tried to manoever his text so as to obtain just the contrary meaning[31] . And it is probable therefore that Aryabhata's idea of axial rotation of the earth could not be developed further in India so as to extend it to the orbital motion of the earth, as was done by Copernicus in 15/16th c. in Europe.

3.2 Eclipses :—

In pre-siddhantic astronomy *Rahu* and *Ketu*, identified as pseudo-planetary nodes of the lunar orbit, were supposed to cause solar and lunar eclipses. Aryabhata replaced this mythological explanation by a scientific one. In the first few verses of the fourth chapter of the *Aryabhatiya* he introduces the idea of shadows, cast by and falling on earth, moon and planets, and in verse IV-37 he states that the lunar eclipse is caused by the entering of the moon into the earth-shadow. In the following verses (38-48) he gives then formuals for the length and diameter of the earth shadow, the timing and duration of the eclipses and or the size of the eclipsed part of sun or moon[32].

The theory of eclipses must have been improved later by other Indian astronomers. The accuracy of the Indian method of eclipse calculation can be estimated by the report of Le Gentil[33] on the lunar eclipse of Aug. 30, 1765. Accoridng to him the duration of the eclipse as calculated by a Tamilian astromoner turned out to be only 41 sec. too short; the same calculated by the famous tables of Tobias Mayer (1752) was 68 sec. too long. However, for the duration of totality Mayer's table turned out to be superior to the Tamilian method[34].

3.3 Model of Planetary Motion :—

Chronologically the Aryabhatiya is the first *extant* primary Indian source in which a geometrical model of planetary motion is clearly prsented. The salient features of this model are [35-38] .

(a) Geocentric circular orbits for the mean planets, the true planets moving on epicycles or eccentres with equal linear velocities.

(b) Equivalence of the eccentric and epicyclic motions.

(c) Whereas for the sun or the moon only one epicycle is envisaged, for the planets two epicycles are to be used, the epicycles of apsis and of conjuction. In Sanskrit they are called *manda* and *shighra* epicycles. Note in particular that unlike the solar or the lunar epicycle these epicycles are of variable radii.

(d) To get the true longitude of a particular planet, the mean longitude is to be corrected (*mandaphala* and *sighraphala*) for the epicyclic motions [35a]

In order to appreciate Aryabhata's model we compare his astronomical parameters with corresponding modern values. In Table 1 we give his data for the sidereal period of various planets [39]. In Table 2 we list the reciprocal heliocentric distances in units of earth-sun distance as calculated from the data given in *Aryabhatiya* and other Indian sources [40].

A remark about a similar Greek planetary theory will certainly be of interest [41] . It is known today that the mathematical treatment of eccentric and epicyclic models was first introduced by Apollonius (240-170 B.C.), who also proved the equivalence of these models. Hipparchus (190-120 B.C.) then developed an especially *simple* epicycle model for both the sun's and the moon's motions, using Babylonian astronomical parameters. However, in order to fit his model with the observational data of two lunar eclipse triples (of 383/382 B.C. and 201/200 B.C., recorded in Babylon and Alexandria respectively) he had to take the radius of the lunar epicycle (r) as different from that of its eccentricity (e). This *epicyclic anomaly*, according to Neugebauer, might have convinced Hipparchus of the non-constancy of e and r. Much later, however, Ptolemy (100-170 A.D.) still tried to keep in his model a fixed r and attributed the disagreement to Hipparchus' wrong astronomical parameters [42]. An idea similar to the Hipparchian artifice is also to be found in the inscription of

Table 1

Mean Motion of the Planets

Planets	Revolutions per Mahayuga	Sidereal Period : No. of days per revol.		
		Aryabhata	Ptolemy	Modern
Sun	4 320 000	365.25858	365.24666	365.25636
Moon	57 753 336	27.32167	27.32167	27.32166
Lunar A	488 219	3 231.98718	3 231.61655	3 232.37543
Lunar N	232 226	6 794.74951	6 796.45587	6,793.39108
Mercury	17 937 020	87.96988	87.96935	87.9693
Venus	7 022 388	224.69814	224.69890	224.7008
Mars	2 296 824	686.99974	686.94462	686.9797
Jupiter	364 224	4 332.27217	4 330.96064	4 332.75637
Saturn	146 564	10 766.06465	10 749.94640	10 759.201

A = Apogee, N = Ascending node, 1 Mahayuga = 4320000 years

(Ref. K. S. Shukla : *Aryabhata*, Indian National Science Academy, New Delhi, 1976)

Keskinto (on the Island of Rhodes), dated around 100 B.C. The cinematic planetary model underlying the parameters of the text presupposes a knowledge of the "sidereal anomaly". To this finding Neugebauer comments: "...The Indian shigra anomaly appears to have a predecessor in the "sidereal anonmaly" of the Keskinto inscription. It is of course impossible to say whether this is purely accidental or not"[43]. In support of an independent origin of the epicyclic planetary model in India Kuppanashatri gives several reasons[38] which, though, for want of space we cannot discuss here in detail. The interested reader may see the original paper.

Table 2

Planetary heliocentric distance in units of Earth-Sun distance

Planets	Arya-bhatiya	Old S.S.	New S.S.	Modern
Earth	1.00	1.00	1.00	1.00
Mercury	0.38	0.37	0.37	0.39
Venus	0.73	0.72	0.73	0.72
Mars	1.54	1.54	1.54	1.52
Jupiter	5.16	5.00	5.07	5.20
Saturn	9.41	9.00	9.11	9.55

S. S. = Sūrya-Siddhānta

(Ref. T. K. Shastri, I.J.H.S. **9** (1974), esp. p. 40.)

3.4 The Yuga System :—

In ancient Indian literature a period of time comprising an integral number of years has been denoted by the term *yuga*[44]. This concept of *yuga* as a unit of time and endowed with an astronomical content (see below) had developed in India gradually, from the Vedic age to the period in which astronomical treatises, *siddhantas*, were compiled. One can find the word *yuga* at serveral places in the Vedas [45,46]. In pre-siddhantic astronomy, i.e. in *vedanga jyotisa*, a *yuga* consisted of 5 years. Not only was this period extended in the course of time, for instance in *Romaka siddhanta* it is of 2850 years, but a whole *yuga system* was also developed. One finds such a cosmogonic system already existing in *Manu smrti* and Mahābhārata[47]. We shall first summarize this system. Employing the following notation

Brahmā = B, Kalpa = K, day = d, Lifetime = L, Mahāyuga = Y, solar year = y, gods = g, Planet = P (or yuga)

we have

$$1\ L(B) = 100\ y(B) = 100\times 360\ d(B) = 36{,}000\ K,$$

that is $1\ d(B) = 1\ K = 1000\ Y(g)$

$$1\ Y(g) = 12{,}000\ y(g) = (4{,}800 + 3{,}600 + 2{,}400 + 1{,}200)\ y(g)$$

The *mahayuga* was partitioned into four smaller epochs which were called *kritayuga*, *tretayuga*, *dvapara-* and *kaliyuga*. These terms are found already in the Vedas[48]. Note that the four *yugas* are unequal; their durations are in the order of 4 : 3 : 2 : 1. We are presently supposed to be in the *Kali* epoch which began in the year 3102 B.C. (see below).

Some time in the first few centuries of the Christian era, this highly imaginative system was given an astronomical content by setting up the relation

$$1 \text{ y(g)} = 360 \text{ y}.$$

Then

1 Kaliyuga = 432,000 y, 1 Mahāyuga = 4.32×10^6 y and
1 Kalpa = 4.32×10^9 y.

In what way did Aryabhata contribute to this *yuga* tradition? To answer this question we attempt to show below on the basis of his verses that he not only modified and simplified this system but also converted it into a real measure of time.

Disregardingd the (irrelevant) age or lifetime of Brahmā, he equates: 1 K = 1 d(B) = 1,008 Y (verse I-3) The difference of 8 *yugas* is a deviation from the tradition for which Aryabhata was criticised by Brahmagupta[49], although 1,008 is a "better" number than 1,000, since it is divisible by 7 and therefore every d(B) begins then on the same week-day[50]. An aesthetic modification indeed! Besides, Aryabhata dispensed altogether with the aforementioned unequal partition of a *mahayuga*. He divided it instead into four equal parts, called *yugapadas*, namely

$$1 \text{ yugapāda} = \tfrac{1}{4} \times 4{,}320{,}000 = 1{,}080{,}000 \text{ y}.$$

His terminology for each of the quarter *yugas* was taken from Jaina canons[51].

However, the most noteworthy innovation carried out by Aryabhata was the identification of the *mahayuga* (Y) with the "yuga of planets" (verse III-8). He writes: "The time is measured by (the movements) of the planets and the asterisms on the [celestical] shphere "[52]. The beginning of the *mahayuga* as also those of the quarter *yugas*, e.g. *Kaliyuga*, was defined with respect to the conjunctions of Sun, Moon and all Planets[53]. The zero-point of the *Kali-yuga* thus turns out to be Thursday/Friday 17/18th February 3102 B.C. To have fixed this date of the *Kali*-beginning is the most significant contribution of Aryabhata since neither this date nor the use of the *Kali*-era are found in any of the Indian astronomical or other texts prior to Aryabhata. After him only in one inscription of 634/35 A.D.—the Aihole inscription of Pulakeshin—the *Kali*-era is mentioned [54].

It would be interesting to understand how Aryabhata could think out this date. Modern calculations have shown that on 17/18th Feb. 3102 B.C. there did not occur any such "grand conjunction" [55]. Therefore this date could have been found by a backward extrapolation, maybe from the values of the planetary positions in the year 499 A.D. Another possibility could be the identification of the beginning of the *Kaliyuga* with that of the *Mahabharata* battle as mentioned in *Mahabharata* itself and reiterated by Aryabhata in verse I-3. However, a contemporary of Aryabhata, Varahāmihira (d.587) in his *Brhatsamhita* dated the Mahābhārata battle in 2448/49 B.C. [57], [58]. Furthermore one could look for the origin of Aryabhata's date 17/18th Feb. 3102 B.C. in the writings of his predecessors in other cultures. To generalize the question: Has there at all been any such concept of recurrent cycles of great lengths elsewhere ? In the following we summarrize the results of the work done on this question :

(i) In the early Chinese astronomy the idea of planetary conjunctions and their cycles did occur, whence a "Great Year" was derived : 19 cycles of great planetary conjunctions [59], each of which was believed to be of 138,240 y, made the Great Year equal to 2,626,560 y [60] — a period completely unrelated to the Indian eras!

(ii) In ca. 280 B.C. a priest of Bel, called Berossos, who wrote "Babyloniaka" and founded an astrological school in Kos, gave the period of reign of the ten Babylonian Kingdoms before the Great Flood as 120 *sars*, each *sar* equal to 3600 y, i.e. 120 × 3 600 = 432 000 y. This coincides exactly with the length of the *Kaliyuga*.

(ii) In Zervanish works written in Pahlavi (old Persian) it is said: "Time was for 12 000 years." This period was then divided into four "states" of 3 000 years each [61]. Recall that 1Y = 12 000 y(g), divided by Aryabhata into four *yugapadas* of equal length :

(iv) As mentioned above, according to *Manusmrti* a *Kaliyuga* consists of

$$\begin{aligned} 1{,}200 \text{ y(g)} &= (100 + 1{,}000 + 100) \text{ y(g)}, \\ &= (36{,}000 + 360{,}000 + 36{,}000) \text{ y} \\ &= 432{,}000 \text{ y}. \end{aligned}$$

The first and the third term on the right side of this equation are the so-called "twilights", the second term being the middle period of the *Kaliyuga*, which lasts for 360,000 y. From *Visnupurana* one finds this number as the age of the *Kaliyuga*. Incidentally this period is exactly the World Year of the Persians according to a report of Al-Sijzī (10th centruy)[62] and Abū Ma'shar Al-Balkhi (787-886) dated the Great Flood (or Deluge) at the end of one half of this World Year [63], i.e. 180,000 y. This number is again to be found in Indian astronomy also : It is the period employed in the old *Suryasiddhanta* extant in Aryabhata's time and which was reported by Varahamihira in his *Pañcasiddhantika* (505 A.D.).

(v) According to van der Waerden[61] the Persians, influenced by the Babylonian astronomical tradition, had developed a theory of their own for determining the conjunctions of planets. This theory is reported by Abū Ma'shar in his Book of Conjunctions: Kitāb al-qirānāt. It has been shown that the occurrence of the Grand Conjunction of all planets according to the Persian system turns out to be Thursday Feb. 16/17, 3102 B.C. near midnight Babylonian time, just one day before the date given by Aryabhata ! [64]. According to E.S. Kennedy and van der Waerden[65] the Persian theory "could have been invented between 400—450 A.D."

> "...... Hence the Persian Astronomy existed before Aryabhata and may have influenced him ......It is... probable that Aryabhata who was an excellent theorist and who had rather accurate observations at his disposal, modified the Persian system, making it more flexible."

That Aryabhata had access to excellent observations has been recently proved conclusively by Billard, employing a novel method, viz. probability theory[32b]. It has also been suggested that perhaps an *old* version of the famous Persian astronomical tables, Zij-i-Shāh, complied between 400—450 A.D., could have played some role in the above-mentioned hypothetical transmission[66].

(vi) The idea of the astrological significance of the conjunctions of planets occurs already in *Mahabharata*[53], which was composed between 400 B.C.—400 A.D[67]. The author of "Babyloniaka", Berossos (280 B.C.), correlated the occurrence of fire catastrophe and Great Flood with the lining up of all planets in the constellation Crab and Aires respectively[68]. According to van der Waerden, the Persians—influenced by these Babylonian astrological ideas—also correlated the Deluge with the Grand Conjunction[69]. If a transmission of astronomical/astrological ideas from Persia to India did occur as indicated in paragraph (v) then, naturally the concept of Deluge had to be substituted by another catastrophe. The *Mahabharata* battle leading to the "worst era" was readily available in Indian tradition. Thus it is not out of question that a creative mind like that of Aryabhata could carry out a synthesis of Persian and Indian astronomical/astrological ideas.

4. IMPACT OF ARYABHATA'S WORK:

To appreciate the bearing of Aryabhata's work on the development of mathematics and astronomy in India as well as abroad, especially in West Asia, one should first be clear about the status of Indian exact sciences in the pre-Aryabahata period. So far as astronomy is concerned, in the first few centuries A.D. Indian Astronomy developed from the calendaric astronomy (*vedic* and *vedanga jyotish* period) to the stage of mathematical astronomy (*siddhantic* period) which culminated in the epicentric-epicyclic planetary model in the old *Suryasiddhanta*[70]. Varahamihira (d. 587) in his *Pancasiddhantika* (written in 505, i.e. 6 years after *Aryabhatiya*) gave a histrical review of *siddhantic* astronomy of several centuries.

In contradistinction to *Pancasiddhantika*, which soon after Varahamihira was almost completely foregotten[71], *Aryabhatiya* became the most significant astronomical work of the 6th c. This is due to its character as a compendium not only of the fundamentals of astronomy but also of mathematics relevant to astronomy. The chapters on mathematical tools must have made it easier for the followers of Aryabhata to learn quickly the art of astronomical calculations. The importanace of his treatise can also be gauged by the fact that apart from many works based on his astronomical system like those of Brahamagupta (598—628) and Bhaskara I (7th c.), about a dozen commentaries were written on *Aryabhatiya* from 7th c. to 18th c.[72]. No wonder that this treatise initated an era in India in which mathematics (especially algebra and trigonometry) was developed from being just a tool of astronomy to a full discipline in its own right, culminating in the algebraic treatise of Bhāskara II (1114—1185) and Nilakantha Somyajin (15/16th c.).

It is not known to-date whether *Aryabhatiya* was translated directly into Arabic or was known to the Arabs through some Pahlavi translation. In any case Aryabhata has been mentioned as Al-Arjabhar and Al-Arjabad by several West Asian mathematicians/astronomers, for instance, by Abul Hasan Al-Ahwazi (8/9th c.), Abū Mashar (786?—886), 'Āli bin Sulaimān al-Hāshmi (9th c.), Al-Sijzi (10th c.) and Al-Biruni (10/11th c.)[73]. The latter even equotes in his treatise on India the number of revolutions of the Sun, Moon and other planets as given by Al-Ahwāzi in "years of Arjabhar"[74], i.e. *mahayuga*. Except for Mars where there is a difference of +4, all the other numbers agree exactly with those of Aryabhata. It is also possible that the work of Aryabhata was known to the West Asisans through Arabic translations of *Brahamasphuta Siddhanta* (628) and *Khandakhadayaka* (665) of Brahmagupta, known as Sindhind and Al-Arkand respectively, especially Aryabhata's midnight system given in the latter. In fact on the basis of this midnight -system the Persian King Khosro Anushirvan (531—579) ordered the revison of the afore-mentioned famous tables: Zij-i-Shāh.

So far as the impact of Āryabhata's mathematics is concerned we may mention that Āryabhata's value of $\pi = \frac{62,832}{20,000} = 3.1416$ was reported by Al̄-Khwārizmī in his book on Algebra. Besides, Al-Khwarizmi also wrote a monograph on the so-called Indian mathematics, *Kitab al j-ama' w-al tafriq bi hisab al hind*, only the latin version of which as *algo-ritmi de numero indorum* is extant to-date. It is through this work that the Indian decimal place value system was introduced into Western Europe[76].

5. IMPORTANCE OF THE STUDY OF HISTORY OF SCIENCES IN INDIA:

Finally we would like to quote here an opinion of O. Neugebauer, one of the greatest historians of science of this century[77]:

> "Inspite of the pioneering work done by H.T. Colebrook (1765—1837), G. Thibaut (1848—1914) and others, the study of Hindu Astronomy is still at its beginning. The mass of univestigated manuscript material in India as well as in Western collections is enormous"[78].

Among the "others" I should like to include P.C. Sen Gupta, K.S. Shukla, K.V. Sarma, T.S. Kuppanashastri and Bina Chatterji. In fact, what Neugebauer says on Indian Astronomy is true in general for History of Sciences in India—as well for ancient as for medieval and modern period.

However, to work on a problem of history of science, one requires beside primary sources also secondary and reference literature, if one wishes to be abreast of international work. A cursory look through the bibliography of this very paper will convince everyone that even the secondary literature, let alone the primary, is out of the reach of an Indian historian of science working on his own [79]. It is the need of the hour that Indian universities and especially institutions of national importance recognise History of Science as a descipline so as to provide facilities for a directed programme of research and teaching in History of Scienecs in India.

ACKNOWLEDGEMENT :

I acknowledge gratefully the invitation by the Editors of the Bulletin to write this article, which provided me with an opportunity to deepen my insight into ancient Indian astronomy. I am indebted to Prof. R. Billard (Paris), Prof. Irfan Habib, Dr. S.R. Sarma and Dr. H. Mohsin at Aligarh for bibliographic hints and several fruitful discussions. I am also grateful to Dr. R. Mercier (Southampton) for putting at my disposal a xerox copy of Clark's translation of *Aryabhatiya* and to my wife Dr. Annemarie Ansari for going through this paper critically.

Notes and References :

1. K. S. Shukla, *Aryabhata, Indian Mathematician and Astronomer* (5th c. A.D.), Indian National Science Academy, New Delhi, 1976; for the Sanskrit text of the quotation see p. 1.

2. H. Kern (Ed.), *The Aryabhatiya* with the commentary Bhatadipika of Paramesvara, E. J. Brill, Leiden, 1874.

3. This date has been testified by Aryabhata himself. He gives it in *Kali-era*. Cf. ref. 4, chap. III, verse 10, p. 54. Hereafter we shall refer to Aryabhata's verses such as this by III-10.

4. W. E. Clark, *The Aryabhatiya of Aryabhata*, University of Chicago, Chicago, 1930. All references to Aryabhata's verses are to this translation. For other editions or translations of Aryabhatiya see ref. 24 and 25.

5. B. C. Law, *Historical Geography of Ancient India*, reprint, Delhi, 1976, esp. p. 51.

R. C. Majumdar (Ed.), *The Age of Imperial Unity*, vol. II of the History and Culture of Indian People, Bharat Vidya Bhavan, Bombay.

6. Here I donot mean to rouse the naive idea that such a direct contact with the early Greeks led the flow of Greek learning into India. This idea, although held up in the past, has been rejected completely even in the West, for instance by O. Neugebauer, see ref. 7 part 1, p. 6. The Greek influence, however, started spreading already in the *Saka* reign (1^{st}-2^{nd} c. A.D.) in Western India and the first *astrological* Greek text was translated into Sanskrit by Yavanesvara (150 A.D.), see ref. 8a.

7. O. Neugebauer, *A History of Ancient Mathematical Astronomy* in three parts, Springer Verlag, Berlin, 1975. A remarkable work in the best tradition of History of Science!

8. (a) D. Pingree, *Astronomy and Astrology in India and Iran*, Isis **54** (1963), 229–246.

(b) M. N. Saha (chairman), Report of the Calendar Reform Committee, CSIR, New Delhi, 1955, chap. V, p. 212.

9. R. C. Majumdar (Ed.), *The Classical Age*, vol. III of the History and Culture of Indian People, Bharat Vidya Bhavan, Bombay, 1970, esp. p. 30—32.

10. R. N. Saletore, *Life in the Gupta Age*, Popular Book Depot, Bombay, 1943.

11. Ref. 1, p. 5.

12. Ref. 4, verse II-1, p. 21.

13. E. C. Sachau (Ed.), *Al-Biruni's India*, London 1910, in two volumes. Cf. esp. vol. 1, p. 370—371. Born in Khwarizm (modern Kiev, USSR), Al-Biruni came to India some time between 1019 and 1029. He was a prolific writer and wrote 183 works dealing with mathematics, astronomy, physics, geography, history etc. Out of these "27 works are on India or relating to Indian sciences and philosophy, which also include translations from Sanskrit into Arabic and from Arabic into Sanskrit." Cf. Maqbul Ahmad et al., Ind. J. Hist. Sci. **10** (1975), 98—110, esp. 101—102.

14. Ref. 13, vol. I, p. 370.

15. Cf. Ref. 1, p. 36—37; for details see also ref. 16 and 17. In *Aryabhatiya* sun-rise day-reckoning is used.

16. K. S. Shukla, *Glimpses from the Aryabhata-Siddhanta*, Proceedings of the Seminar held on the occasion of the celebration of the 1500th Birth Anniversary of Aryabhata I, New Delhi, Nov. 2—4, 1976, to be published in Ind. J. Hist. Sci.

17. K. S. Shukla, Ganita **18** (1967), 83—105, esp. p. 92 ff.

18.(a) Here A, B and C are the numeration of the three additional verses of chap. I according to Clark (ref. 4).

(b) Ref. 1, p. 18

19 D. M. Bose, S. N. Sen and B. V. Subbarayappa, *A Concise History of Science in India*, Indian National Science Academy, New Delhi, 1971. For general survey on ancient Indian mathematics see chap. 3 by S. N. Sen.

20. S. N. Sen, *Aryabhata's Mathematics*, Bull. National Inst. Sci. India No. 21 (1963), p. 297—319.

21. Kurt Elfering, *Die Mathematik des Aryabhata I*, Wilhelm Fink Verlag, Munich, 1975. This is to our knowledge the best critical edition of the Sanskrit text of Ganita, with a German translation of the verses.

22. Ref. 21, p. 184.

23.(a) See also ref. 8b, p. 160.

(b) Ref. 4, p. 81.

24. For details see ref. 1, p. 34—36. Cf. also David Pingree, *Aryabhata I*, in Dictionary of Scientific Biography by C.C. Gillispie (Ed.), Charles Scribner, New York, 1970, Vol. I. In the latter an excellent bibliography on Aryabhata is given. For another one see R. C. Gupta, Maths. Education **10** (1976), 21—26.

25. K. S. Shukla, *Aryabhatiya*, cr, ed. with introduction, Engl. translation and notes (in collaboration with K. V. Sarma); K. S. Shukla, *Aryabhatiya* with the commentary of Bhāskara and Someśvara, cr. ed. with introduction and indexes K. V. Sarma, *Aryabhatiya* with the commentary of Sūryadev Yajvan, cr. ed. with introduction and indexes; R. N. Rai, *Aryabhatiya*, text in Sanskrit with Hindi translation, commentary, introduction etc., Indian National Science Academy, New Delhi, 1976.

26. This is my translation from the German one given in E. Eberhard, *Das Astronomische Weltbild im Alten China*, Die Naturwissenschaften **24** (1936), 517—519.

27. Ref. 7, pt. 2, p. 964.

28. Ibid., p. 695, footnote 13

29. Ref. 13, vol. I, p. 280, see also p. 276—277.

30. Lata's review of the old *Surya-Siddhanta* and Vasisths's *Siddhanta* were surveyed by Varahamihira in his *Pancasiddhanta*. See section 4 also.

31. Bina Chatterjee, *A Glimpse of Aryabhata's Theory of Rotation of Earth*, Ind. J. Hist. Sci. **9**, (1974), p. 51—55. See also ref. 1, p. 24—26, and ref. 2, p. 13—16.

32.(a) For details see S. N. Sen in ref. 19, p. 117—124. See also W. Petri, *Indische Astronomie*, Rete (Germany) **1**, (1972), 311—329.

(b) R. Billard, *L'Astronomie Indienne*, École Fran. caise D'Extreme-Orient, Paris 1971, p. 125—132, esp-for *Rahu* and *Ketu*.

33. Le Gentil was an assistant to the then newly founded Paris observatory. He was sent by the King of France to observe the transit of Venus occurring in 1971 at Pondicherry. However, he could not record it, neither in 1761 nor in 1769; for the latter he waited for 8 yrs. in Mauritius and Madagascar. See Ref. 7, pt. 2, p. 820 ff.

34. Ref. 7, pt. 2, p. 820. Neugebauer quotes (p. 821) another comparison of a lunar eclipse calculation by John Warren.

35.(a) Ref. 19, p. 111—118, also ref. 20, p. 302—305.

(b) S. N. Sen, Epicyclic, Eccentric Planetary Theories in Ancient and Medieval Indian Astronomy, Ind. J. Hist. Sci. **9** (1974), 107—121.

36. K. S. Shukla, *Astronomy in Ancient and Medieval India*, ibid. **4** (1969), 99—106.

37. T. S. Kuppanashastri, *The School of Aryabhata and the Peculiarities Thereof*, ibid. p. 126—134. See also the criticism of K. S. Shukla, ibid. **8** (1973), 43—57.

38. T. S. Kuppanashastri, *Main Characteristics of Hindu Astronomy* (Pre-Copernican Period), ibid. **9** (1974), 31—44.

39. Ref. 1, p. 27

40. Ref. 38, p. 40.

41. O. Neugebauer, ref. 7, pt. 1, p. 263, 275, 315—319.

42. For a comparative study of the Ptolemaic and Aryabhata's planetary model see B. Chatterjee, *The Khandakhadyaka of Brahmagupta*, World Press, Calcutta 1970, vol. I, appendix VII, quoted in ref. 1, p. 29.

43. O. Neugebauer, ref. 7, pt. 2, p. 698—705.

44. Ref. 8b, p. 217.

45. S. B. Dikshit, *Bharatiya Jyotish Sastra* (History of Indian Astronomy), translated from Marathi into English by R. V. Vaidya, Pt. 1 (Manager of Publications, Civil Lines, Delhi, 1969). The Marathi text was published in 1896 and reprinted in 1931 at Poona. There is also a Hindi translation, published by Prakashan Bureau, Suchana Vibhag, Lucknow, 1957. We shall refer here always to the English translation.

46. Ref. 45, p. 11—15; Dikshit quotes from Rk *Samhita*, *Taittriya Samhita* and *Vajasanyi Samhita*. He concludes that "the *yuga* must have been a unit of time smaller than the span of human life......100 years." But he does not reject the possibility of "a *yuga* representing a much longer period of time" (p. 12—13).

47. Ibid., p. 103—105, 109.

48. Ibid., p. 13—15. But the world *Kalpa*, according to Dikshit (p. 11), is not used in the Vedas in the sense of some unit of time.

49. For original and other references see Ref. 4, p. 53, footnote 2.

50. Ref. 1, p. 22

51. Ref. 4, p. 53—54; see also Ref. 1, p. 23.

52. Ref. 4, p. 55, verse III-11.

53. Cf. verse I-1 and I-2, Ref. 4, p. 9. It may be added here that the idea of conjunctions ("battles") of planets occurs also in *Mahabharata;* see ref. 45, p. 117 for quotations on the conjunction of Venus and Jupiter.

54. King Pulakeshin of Caluka dynasty of Badami was a contemporary of Harsha. This is mentioned in ref. 56 p. 253. see also R. N. Rai, *Al-Biruni and Indian Era*, Ind. J. Hist. Sci. **10**, 166—173 (1975). For the original see Epigraphica Indica, vol. VI, p. 1—12. I owe this information to Dr. S. R. Sarma (Sanskrit Dept., A.M.U. Aligarh).

55. For original reference on this work see ref. 56, p. 253, ref. 45, p. 142, and also ref. 61, p. 46.

56. *Report of the Calender Reform Committee*, Govt. of India (CSIR, New Delhi), 1955—Chairman: M. N. Saha. This is an excellent resume of calendaric astronomy in general and of the Indian calender in particular.

57. Ref. 45, p. 119, Sanskrit quotation given, see also ref. 56, p. 552.

58. According to R. N. Rai "there is internal evidence in the *Mahabharata* itself which shows that it was not composed earlier than 400 B.C."; see Ind. J. Hist. Sci. **10** (1975), esp. p. 169; M. Winternitz (ref. 67) dates it between 400 B.C. and 400 A.D.; quoted in ref. 19, p. 35.

59. For a similar cycle in Greece, called cycle of Meton, see Ref. 7, pt. 1, p. 4.

60. N. Sivin, *Cosmos and Computation in Early Chinese Mathematical Astronomy* (E. J. Brill, Leiden 1969), p. 17.

61. This is quoted in: B. L. van der Waerden: *Das heliozentrische System in der griechischen, persischen und indischen Astronomie*, Zuerich 1970, esp. p. 26. It may be added here that Zervan denoted the God of infinite time and Zervanism was a confession of the Persian religion before Zorashtrianism, i.e. in the first half of 6th c. B. C.

62. Ibid., p. 41—42. See also ref. 64 below.

63. The Persian calendaric system probably originated between Apollonios (201 B.C.) and Mani (250 A. D.) see ibid. p. 48.

64. E. S. Kennedy and B. L. van der Waerden, *The World Year of the Persians*, J. Am. Oriental Soc. **83** (1963), 315—327, esp. p. 324.

65. Ibid., p. 323.

66. Ibid., p. 6—7.

67. For this dating see ref. 19, p. 35, where is quoted M. Winternitz, A History of Indian Literature, Calcutta, 1959, Pt. I, p. 475.

68. Ref. 61, p. 21. V. d. Waerden gives an excerpt from "Babyloniaka".

69. Ibid., p. 50.

70. This periodisation was first conceived by Dikshit, ref. 45. For an excellent summary of these periods see also ref. 19, chap. 2 and ref. 56, chap. V. For a comparison between the old *Suryasiddahnta* and the new one which is extant today see the introduction of K.S. Shukla: *The Sūrya-Siddhanta*, with the commentary of Paramesvara, Lucknow University, 1957.

71. Actually Varahamihira attempted to deal in his treatise the astronomical methods of five *Siddhantas* instead of only one of them. This might be one of the reasons why it was completely forgotten soon after him. His astrological writings, on the other hand, became quite known throughout India; see G. Thibaut, *Astronomie, Astrologie und Mathematik* (Strassburg, 1899). esp. p. 57.

72. For a list of commentaries see ref. 1, p. 34—36

73. F. Sezgin, *Geschichte des Arabischen Schrifttum*, Bd. V (E. J. Brill, Leiden, 1974), esp. p. 197.

74. See ref. 13, vol. II, p. 19.

75. Ref. 61, p. 35—36.

76. For details see S. M. R. Ansari, *A Comparative Study of the Mathematics of Aryabhata and Al-Khwarizmi*, paper presented at the Symposium held on the occasion of the 1500 th Birth Anniversary of Aryabhata I, New Delhi, Nov. 2—4, 1976 (to be published).

77. Ref. 7, p. 6.

78. The Briton Colebrooke (1765-1837) and the German G. Thibaut were the first who published the Sanskrit mathematical and astronomical texts. Their most famous works are: H. Colebrooke: *Algebra, with Arithmetic and Mensuration from the Sanscrit of Brahmagupta and Bhascara*, London 1817, Calcutta 1927; G. Thibaut and S. Drivedi, *Panca-Siddhantika of Varahamihira*, Benares 1889, Second Edition Lahore 1930.

79. The enormity of secondary literature available at present can be imagined when one goes through any of the critical bibliographies of ISIS—the organ of the American History of Science Society. For instance, in the 96th bibliography, published in 1971, 323 periodicals have been surveyed for the purpose of documentation. Nearly 100 journals in the world are exclusively devoted to the discipline of History of Science.