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Research Article

The Silent Zero in Aryabhatiya: Aryabhata's Mathematical Vision in Gupta India

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ABSTRACT

Background: Aryabhata, the renowned mathematician and astronomer of the Gupta Golden Age, composed the Aryabhatiya in 499 CE at the age of 23. The text, consisting of 121 stanzas in four chapters: Gitika-pada, Ganita-pada, Kalakriya-pada, and Gola-pada presents a synthesis of mathematics, astronomy, and calendrical science. **Methodology:** It includes definitions of time units, astronomical tables, planetary positions, and rules of calculation, introducing innovative methods such as trigonometric functions, approximation of π, and indeterminate equations. Aryabhata's mathematical originality lies in the positional number system with an implied zero, expressed through alphabetical notation, which operated as a "silent zero" shaping later mathematical traditions. **Results:** His precise value of π, trigonometric sine tables, and kuttaka method for indeterminate equations stand as pioneering contributions. In astronomy, Aryabhata explained the rotation of the Earth, the fixed position of stars, the concept of continuous time (anadi, ananta), cyclical yugas and kalpas, planetary motions, epicycles, and eclipses. His calculation of the sidereal rotation of the Earth (23 hr 56 min 4.1 sec) closely matches modern values. Comparisons with the Surya-siddhanta highlight both differences and continuities, particularly regarding planetary cycles, time divisions, and eclipse phenomena. **Conclusion:** The study emphasizes Aryabhata's intellectual vision within the Gupta period, where mathematical abstraction and astronomical precision were integrated into a coherent system. His legacy influenced subsequent scholars like Bhāskara I and extended through Arabic and European traditions, marking the Aryabhatiya as a milestone in the global history of mathematics and astronomy.

Keywords: Aryabhata, Aryabhatiya, Gupta period, Silent zero, π, Trigonometry, Kuttaka, Astronomy, Surya-siddhanta.

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INTRODUCTION

Aryabhata (476-550 CE), the renowned mathematician, and astronomer of the Gupta period often described as the Golden Age of India is credited with composing the Aryabhatiya in 499 CE at the age of 23 (Shukla, 1976). The text, consisting of 121 stanzas in four chapters (Gitika-pada, Ganita-pada, Kalakriya-pada, and Gola-pada), presents fundamental concepts of mathematics, astronomy, and calendrical science. It includes definitions of time units, astronomical tables, planetary positions, and rules of calculation, supported by innovative methods such as trigonometric functions, approximation of π, and solutions for indeterminate equations. His disciples and commentators, including Bhāskara I (Ansari, 1977) and later scholars, ensured its lasting influence.

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Aryabhata's originality lies in his implied use of zero in the positional system, his correct explanation of eclipses, and his assertion of the earth's rotation while stars remain fixed. His ideas of continuous time (anadi and ananta), cyclical yuga and kalpa, and the treatment of planetary motions, epicycles, and eclipse phenomena mark a significant departure from earlier traditions. Comparative references with the Surya-siddhanta highlight both differences and continuities, while his astronomical determinations such as the sidereal rotation of the earth (Gupta, 1997), nearly identical to modern values-demonstrate remarkable precision. Thus, the Aryabhatiya stands as a landmark in the history of Indian mathematics and astronomy, representing the thematic foundation of this study.

This study has been chosen to emphasize Aryabhata's originality in employing the positional number system without an explicit symbol for zero. The term "silent zero" reflects how the concept operated implicitly in his calculations, shaping later developments in Indian mathematics. The study focuses on this thematic core while also examining the structure of the Aryabhatiya, his mathematical and astronomical innovations, and the historical continuity seen through comparisons with texts like the Surya-siddhanta and the Bakhshali Manuscript. The concept was selected to highlight Aryabhata's intellectual vision within the Gupta Golden Age, where mathematical abstraction and astronomical precision achieved lasting significance.

RELATED WORKS

Biographical and Historical Context of Aryabhata

Ansari (1977) described Aryabhata's life based on historical facts in Aryabhatiya. He briefly discussed the astronomy and mathematical portions and examined the yuga system with connections to Babylonian and pre-Islamic Iranian astrological ideas. Similarly, the Wikipedia entry on Aryabhata (n.d.) briefly discussed Aryabhata's biography, works, mathematical contribution, astronomical contributions, and legacy. Sarma (2001) discussed the name traditions of Aryabhata from his composing works and attempted to draw a correct position to address this matter. Shukla and Sarma (1976) critically edited about Aryabhata and his time, place, pupils, works, etc., and analysed the commentaries on the Aryabhatiya in different languages such as Sanskrit, Telugu, Malayalam, and Marathi. They also discussed the Aryabhata Siddhanta. Gupta (1997) provided an encyclopaedic entry on Āryabhaṭa, situating him within the history of science, technology, and medicine in non-Western cultures. Hayashi (2008) offered a scholarly overview of Aryabhata I in the Dictionary of Scientific Biography, discussing his works and contributions. O'Connor and Robertson (2012) presented a biographical sketch of Aryabhata the Elder in the MacTutor History of Mathematics Archive, highlighting his mathematical and astronomical achievements.

Mathematical Contributions and Traditions

Boyer (1991) in The Mathematics of the Hindus and Cooke (1997) in The History of Mathematics: A Brief Course divided their books into multiple chapters according to historical ages such as Egypt, Mesopotamia, Ionia, the heroic age, the age of Plato and Aristotle, Greece, China, India, and the Renaissance through to aspects of the twentieth century. These works provide contextual placement of Indian mathematics within global mathematical traditions. Yadav (2010) in Ancient Indian Leaps into Mathematics divided his book into different chapters including Indian calendrical calculations, Indian trigonometry on the Chinese calendar, Pingala binary numbers, the golden mean and the physics of aesthetics, ancient Indian mathematics, and mathematical traditions with Kerala. Eves (1990) introduced Aryabhata's mathematical contributions in An Introduction to the History of Mathematics, referencing him in the broader context of global mathematical history. George (1998) examined Aryabhata's role in the historical development of numbers within A Universal History of Numbers. Ifrah (1998) also presented Aryabhata's contributions in A Universal History of Numbers, linking them to the global evolution of numerical systems. Jacobs (2003) discussed aspects of Aryabhata's geometry in Geometry: Seeing, Doing, Understanding, placing him in the tradition of early mathematical thinkers. Dutta (2002) examined Aryabhata's treatment of Diophantine equations, particularly the Kuttaka, in Resonance. Rao (1994/1998) explored significant landmarks of Indian mathematics and astronomy, including Aryabhata's contributions. Rao (2000) offered a broader introduction to Indian astronomy, situating Aryabhata within its traditions.

Astronomy and Philosophical Dimensions

Ansari (1977) briefly discussed astronomy in the Aryabhatiya alongside mathematics and the yuga system. Shukla and Sarma (1976) provided further analysis of Aryabhata's astronomical works and the associated Aryabhata Siddhanta. Pingree (1996) discussed Aryabhata's astronomical ideas in Astronomy in India, situating his work within the larger framework of pre-telescopic astronomy.

OBJECTIVES OF THE STUDY

The study is undertaken to explore Aryabhata's mathematical vision and astronomical insights as presented in the Aryabhatiya within the Gupta period. The main objectives are:

- To present the biography of Aryabhata within the Gupta period and examine the structure and features of the Aryabhatiya.
- To study Aryabhata's mathematical innovations, including the positional number system with implied zero, approximation of π, trigonometry, and indeterminate equations.
- To analyze his astronomical contributions such as the rotation of the earth, concept of time, yugas, kalpas, planetary motion, eclipses, and related phenomena.
- To compare Aryabhata's views with the Surya-siddhanta, highlighting differences, adjustments, originality, and the accuracy of his calculations.

METHODOLOGY

The methodology of the study is based on textual analysis of primary and secondary sources. The core text is the Aryabhatiya, which consists of 121 stanzas divided into four chapters: Gitika-pada, Ganita-pada, Kalakriya-pada, and Gola-pada. The study includes examination of Aryabhata's verses, astronomical tables, algebraic equations, and numerical notations, along with supporting interpretations by Bhāskara I, Al-Biruni, Nilakantha, and later scholars. A descriptive and analytical approach is followed to interpret Aryabhata's mathematical vision, the implied role of zero in his positional system, and the precision of his astronomical determinations.

Biography Of Aryabhata

Aryabhata (Aryabhata I) (O'Connor and Robertson, 2012), the celebrated mathematician and astronomer of ancient India, is widely acknowledged to have lived during the 5th-6th century under the Gupta period, often referred to as the Golden Age of India. Despite debates over the existence of Aryabhata I and II, history distinguishes the former as the author of the Aryabhatiya and the latter as the composer of the Maha Siddhanta (Shukla, 1976). Aryabhata explicitly states in the Aryabhatiya, "when sixty times sixty years and three quarter-yugas had elapsed, twenty-three years had then passed since my birth," which situates his birth around 476 CE and the composition of the Aryabhatiya in 499 CE, when he was 23 years old. To be more precise, "3600 years of the Kali era came to an end on Sunday, March 21, AD 499 at mean noon at Lanka or Ujjayini, at the time of the mean sun's entrance into the sign Aries" (Yadav, 2010) (see Figure 1).

Aryabhata is traditionally known as "Aryabhata of Kusumapura," a title used by the Persian scholar Al-Biruni (AD 973-1048). Bhāskara I (AD 629) identified Kusumapura with Pataliputra, the ancient capital of Magadha, which is present-day Patna in Bihar. According to Raghunātha-rāja (1957), Aryabhata "while living at Kusumpura, sets forth the knowledge honoured at Kusumpura (Cooke, 1997)." Kusumapura at that time was a renowned center of learning, and D.G. Gupta suggested that Aryabhata may have been the kulapa or kulpati (head) of a university there- likely Nalanda, which flourished as a seat of astronomical studies during the Gupta period (Sarma, 2001).

Aryabhata's name is also associated with Asmaka. In the Asmakatantra, he is referred to as an Asmaka, and his followers are mentioned as Asmakiyah in various sources (Sarma, 2001). Nilakantha (AD 1500) also describes Aryabhata as an Asmaka citizen, implying his association with the Asmaka janapada. According to Bhāskara I (AD 629), Aryabhata had several notable disciples, including Latadeva, Panduranga-svami, and Nisanku, who later became distinguished for their contributions to astronomy. Aryabhata I is credited with two significant works: the Aryabhatiya and the Aryabhata-Siddhanta. While the former survives and forms the core of his legacy, the latter is known only through later references and translations into Arabic (Ansari, 1977).

The Aryabhatiya: Structure And Features

The Aryabhatiya contains 121 stanzas and is divided into four chapters, known as pada, covering the two principal subjects of mathematics and astronomy. Although Aryabhata himself did not name the text, the title Aryabhatiya was later assigned by commentators. The work is said to consist of 108 verses along with 13 introductory verses (Aryabhata, n.d.).

The following Table 1 presents a detailed breakdown of each pada, including stanza count, focus area, conceptual highlights, and special features, all based on authentic textual sources.

MATHEMATICAL INNOVATIONS IN ARYABHATIYA

Positional Number System and the Implied Zero

As a feature of Aryabhatiya, numeral notation of the alphabetical systems is used to express the number briefly in verse. Aryabhata did not use Brahmi numerals; he used letters of the alphabet to denote numbers and express quantities, such as the table of sines in a mnemonic form (see Figure 2).

Table 1: Chapter-Wise Overview of the Aryabhatiya.

Pada No.	Name of Chapter (Pada)	No. of Stanzas	Subject Area	Key Concepts	Special Features
1	Gitika-pada	13	Astronomy (Basic)	Definitions of time units: kalpa, manu, yuga; circular units: sign, degree, minute; linear units: yojana, nr, hasta, angula.	States number of rotations of Earth, revolutions of Sun, Moon, planets over 4,320,000 years; includes astronomical tables.
2	Ganita-pada	33	Mathematics	Geometrical figures, mensuration, series, interest, square and cube root extraction, indeterminate equations (kuttaka).	Provides mathematical rules, including quadratic and linear equations; introduces shadow problems, simulations; methods for problem-solving.
3	Kalakriya-pada	25	Astronomy (Calendrical)	Time divisions: month, day, year; motions of Sun, Moon, planets; lords of hours, circle of the sky.	Describes different types of year and month, planetary positions, and celestial time cycles.
4	Gola-pada	50	Astronomy (Spherical)	Celestial motion, Earth's rotation, planetary paths on celestial sphere.	Describes spherical astronomy, eclipse diagrams, daily celestial motion, and visibility rules for planets (Gujrati, 2024).

Mean positions of the Planets[2]
at Kali 3600 elapsed, *i.e.*, on Sunday, March 21, A.D. 499, mean noon at Ujjayinī.

Planet	*Āryabhaṭīya*	*Āryabhaṭa-siddhānta*	Ptolemy	Moderns
Sun	0° 0′ 0″	0° 0′ 0″	357° 8′ 16″	359° 42′ 5″
Moon	280° 48′ 0″	280° 48′ 0″	278° 24′ 58″	280° 24′ 52″
Moon's apogee	35° 42′ 0″	35° 42′ 0″	32° 43′ 42″	35° 24′ 38″
Moon's asc. node	352° 12′ 0″	352° 12′ 0″	349° 25′ 33″	352° 2′ 26″
Mars	7° 12′ 0″	7° 12′ 0″	4° 20′ 12″	6° 52′ 45″
Mercury	186° 00′ 0″	180° 0′ 0″	178° 0′ 27″	183° 9′ 51″
Jupiter	187° 12′ 0″	186° 0′ 0″	185° 20′ 55″	187° 10′ 47″
Venus	356° 24′ 0″	356° 24′ 0″	351° 4′ 15″	356° 7′ 51″
Saturn	49° 12′ 0″	49° 12′ 0″	45° 55′ 39″	48° 21′ 13″

Figure 1: Mean Positions of the Planets (Source: Siddhanta-sekhara of Sripati, part ii).

ख्युघृ	denotes the number		43,20,000
चयगियिङुशुछ्लृ	,,	,,	5,77,53,336
ङिशिबुण्लृष्खृ	,,	,,	1,58,22,37,500

Figure 2: Alphabetical Notation (Source: Gitika-pada).

There is a difference between the Katapayadi system and the alphabetical system by Aryabhata. In the Bakhshali Manuscript, the place-value system was first seen as early as the 3rd century. Georges Ifrah says that the knowledge of zero was implicit in Aryabhata's place-value system as a placeholder for the powers of ten with null coefficients. This implies that even though Aryabhata did not use an explicit symbol for zero, his positional system inherently required the concept of zero to represent null values in numerical expressions (George, 1998).

Approximation of π

In Ganitapada 10, Aryabhata worked on π (pi) for approximation. He shows that if a circle has a diameter of 20,000, then the circumference will be 62,832 by applying the formula:

$100 + 4\times8 + 62{,}000$, resulting in the value of π as $62{,}832 \div 20{,}000 = 3.1416$

Aryabhata stated that this value of π (pi) is correct to four decimal places and better than 3.141666 given by Ptolemy (Jacobs, 2003). However, he has called this value only approximate. Aryabhata meant that π is irrational, a fact that was proved in Europe only in 1761 by Lambert. His work was translated into Arabic, and this approximation was mentioned in Al-Khwarizmi's book on algebra (Rao, 1998).

Trigonometry

Aryabhata probably was the earliest astronomer who had given a sine-differences table, along with geometrical and theoretical methods. In Ganitapada 6, Aryabhata says, "tribhujasya phalaśarīraṃ samadalakoṭī bhujārdhasaṃvargaḥ" which means "for a triangle, the result of a perpendicular with the half-side is the area" (Cooke, 1997).

He used ardha-jya as the concept of 'sine' in his work. The term ardha-jya later underwent several transliterations: it was translated from Sanskrit into Arabic as jiba, which became jb, then jaib, and ultimately was translated into Latin as sinus, and into English as sine (Eves, 1990).

$$1^2 + 2^2 + \cdots + n^2 = \frac{n(n+1)(2n+1)}{6}$$

and

$$1^3 + 2^3 + \cdots + n^3 = (1 + 2 + \cdots + n)^2$$

Figure 3: Algebra equations by Aryabhata (Boyer, 1991).

Indeterminate Equations and Algebra

In Indian mathematics, such recursive algorithms became the standard method for solving first-order Diophantine equations. In 621, Bhaskara elaborated Aryabhata's method for solving problems as 'kuttaka' (breaking into small pieces) or 'kuttaka-ganita' (Dutta, 2002).

An example of such a problem is: find a number which gives 5 as the remainder when divided by 8, 4 as the remainder when divided by 9, and 1 as the remainder when divided by 7. That is, find N such that:

$N = 8x + 5 = 9y + 4 = 7z + 1$

It turns out that the smallest value for N is 85. Aryabhata also provided elegant results for the summation of series of squares and cubes (Figure 3).

ASTRONOMY IN ARYABHATIYA

Rotation of the Earth and Fixed Stars

Aryabhata revealed that the earth rotates and the stars are fixed in space. But at that time, it was generally believed that all the bodies revolved round the earth (Hayashi, 2008). As described in the Gola-pada, the observations of Aryabhata himself were a remarkable determination from the previous astronomers. In the first chapter of Aryabhatiya, Aryabhata mentioned the number of earth rotations in a yuga. In 47 AD he discussed the shape (round) of the earth and its rotation (daily) (Rao, 2002). He identified the movement of the stars in relative motion, which happened due to the rotation of the earth. In the Gola chapter, he made further explanation of this.

Concept of Time and Astronomical Periods

In the accuracy aspects, Aryabhata was cent percentage right about his opinions. He said that time is a continuous process which has no anadi (start) and ananta (end). Based on the positions of the sky, according to him, periods (yuga and kalpa) are astronomical phenomena (Shukla, 1976). Aryabhata described the epicycles in the geocentric model of the solar system in the concept of the sun and the moon. In the Paitamahasiddhanta, it was found that the planets are governed by mainly two epicycles, which are slow (manda) and fast (sighra) (Pingree, 1996). It is also found that the serials of planets from the earth are moon > mercury > sun > mars > jupiter > saturn > and asterisms (Ansari, 1977).

Yugas and Kalpas

As per Surya-siddhanta, Brahma is also used to define kalpa. The beginning of the current kalpa was 50 years. A yuga was composed of four smaller yugas like krta, treta, dvapara and kali. According to Aryabhata, one day of Brahma or kalpa is 14 Manus or 1008 years, one Manu is 72 years, and one yuga is 4,320,000 years. Aryabhata also divided the yugas into two divisions: (i) Utsarpini and (ii) Apasarpini (Shukla, 1976).

Adjustments with Surya-siddhanta

There is a simple difference between Aryabhata and the Surya-siddhanta, but it is also adjusted that the beginning of the current Kaliyuga falls on the same day. Aryabhata stated the misconception about rahu and ketu, where he explained the reflection of the sunlight on the moon and planets (Ansari, 1977). From the core methods of Aryabhata, further research improved the calculations of the computations and the size of the eclipses. His accuracy in calculation was remarkable, as he calculated the time of the earth referencing the fixed stars (sidereal rotation). He stated the time for the sidereal rotation as 23 hours, 56 minutes, and 4.1 seconds (Gupta, 1997), where the modern value is 23:56:4.091.

CONCLUSION

The study highlights Aryabhata's mathematical vision as expressed in the Aryabhatiya, where his implied use of the positional number system and innovative treatment of astronomy laid the foundation for scientific traditions in India and beyond. His precise astronomical determinations, along with trigonometric concepts like sine, cosine, versine, and inverse sine, were transmitted into Arabic and later into European scholarship, becoming integral to global mathematical development. These findings demonstrate that Aryabhata's contributions were not isolated achievements but milestones that shaped knowledge systems across centuries.

Aryabhata's legacy extends beyond his texts, as seen in the adoption of his solar transit in the Hindu panchangam and the Islamic Jalali calendar, and in the recognition, he continues to receive through institutions, space research, and commemorations. From the idea of Earth's axial rotation noted by Al-Biruni, to the establishment of Aryabhata Knowledge University, ARIES, India's first satellite Aryabhata, and the lunar crater named in his honor, his influence bridges ancient scholarship and modern science. Thus, the findings confirm that Aryabhata's innovations created a tradition that endures as both a historical milestone and a continuing inspiration for scientific progress.

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ABBREVIATIONS

AD: Anno Domini; **CE:** Common Era.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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AUTHOR CONTRIBUTION

The article is a single-author work. Kishore Dey solely conceived the research idea, conducted the literature review, analyzed the sources, and prepared the manuscript.

SUMMARY

This study examines the mathematical and astronomical vision of Aryabhata through his seminal work, the Aryabhatiya (499 CE), emphasizing the concept of the "silent zero" in his positional number system. It highlights his key contributions, including the approximation of π (3.1416), development of sine tables, the kuttaka method for indeterminate equations, and his assertion of Earth's rotation with highly accurate sidereal calculations. By comparing his ideas with the Surya-siddhanta, the study demonstrates Aryabhata's originality within the Gupta scientific tradition and his lasting influence on later Indian, Arabic, and European mathematics and astronomy.

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