

## Continuity of Indian Mathematics: From Ancient Times to Modern Era

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### Abstract:

Indian mathematics boasts a rich, unbroken tradition spanning over 3,000 years, evolving from the practical geometric needs of the Vedic period to the highly abstract<sup>1</sup>, analytical, and intuitive contributions of modern times. This paper explores the continuity of this intellectual journey, highlighting the foundational concepts of the decimal place-value system, zero, algebra, and calculus developed in ancient and medieval India (Aryabhata, Brahmagupta, Madhava) and their enduring legacy in modern mathematical research, exemplified by the genius of Srinivasa Ramanujan. The paper argues that an "algorithmic" and "intuitive" approach forms the thread connecting these periods.

**Keywords:** Indian mathematics, Aryabhata, Brahmagupta, Ramanujan, infinite series, zero, algorithmic. Sulbasutras, continuity, number theory. Kerala School, algebra, and calculus.

### Introduction:

Mathematics, known as *Ganita* in India, has been an integral part of its cultural and intellectual history. Unlike some traditions where mathematical, astronomical, and religious studies were separated, Indian mathematics was deeply intertwined with astronomical calculations and practical applications. The development of Indian mathematics was not sporadic; it was a continuous process that moved from the Indus Valley's precise measurements to the sophisticated infinite series of the Kerala School, eventually influencing global mathematics.

### 1. The Foundation:

#### Vedic & Ancient Period (c. 1500 BCE – 400 CE)

##### ➤ The Sulba Sutras:

Dating back to 800-500 BCE, these texts contain the earliest, albeit verbal, expressions of the "Pythagorean theorem" (Bhujā-Koti-Karṇa-Nyāya), used for constructing sacrificial altars.

##### ➤ Decimal System & Zero:

The concept of zero as a number and the decimal place-value system was developed in this period. The Bakhshali Manuscript (dated between 3rd and 4th century CE) is evidence of a sophisticated decimal system.

##### ➤ Large Numbers:

The Vedic literature shows the usage of powers of 10, up to a trillion, enabling complex calculations.

### 2. The Golden Age:

#### Classical Period (400 CE – 1200 CE)

This period saw the rise of iconic mathematicians who refined the foundational concepts:

#### 2.1 Aryabhata (476–550 CE):

Aryabhata (476–550 CE) was a pioneering Indian mathematician and astronomer of the Gupta period, famous for composing the *Aryabhatiya* at age 23. Born in Kusumapura (Patna), he calculated an accurate value of  $\pi$  (3.1416), introduced trigonometric sine (*jya*), and proposed that Earth rotates daily and revolves around the sun.

##### 2.1.1 Key Contributions and Achievements:

- **Mathematics:** Developed foundational concepts in algebra, including quadratic equations and the *kuttaka* (pulverizer) method for indeterminate equations. He provided accurate approximations for square/cube roots and areas of geometric shapes.
- **Works:** His primary surviving work, the *Aryabhatiya* (499 CE), covers arithmetic, geometry, trigonometry, and astronomy. He also authored *Arya-siddhanta*.
- **Influence:** His work on trigonometry (sine tables) and the decimal place-value system significantly influenced both Indian and Islamic mathematics.

#### 2.2 Brahmagupta (7th Century):

Brahmagupta (598–668 CE) was a pioneering Indian mathematician and astronomer from the 7th century who formulated

the first comprehensive rules for arithmetic operations with zero and negative numbers in his masterpiece, Brāhmasphuṭasiddhānta (628 CE). He developed methods for quadratic equations, trigonometry, and cyclic quadrilateral area formulas.

### 2.2.1 Key contributions and facts about Brahmagupta:

- **Mathematics with Zero:** He was the first to treat zero as a number in its own right, rather than just a placeholder, defining rules for its use.
- **Algebraic Advances:** Provided solutions to quadratic equations, linear equations, and Pell's equation ( $x^2 - ny^2 = 1$ ).
- **Brahmagupta's Formula:** Discovered the formula for the area of a cyclic quadrilateral:  $\text{Area} = \sqrt{(s-a)(s-b)(s-c)(s-d)}$  where  $s$  is the semi-perimeter.
- **Astronomy:** As head of the astronomical observatory at Ujjain, he authored Brāhmasphuṭasiddhānta and Khandakhadyaka, which covered longitudes, eclipses, and the Earth's circumference.
- **Gravity:** Described gravity as an attractive force, using the term *gurutvākaraṣaṇam*

### 2.3 Bhaskara II (1114–1185 CE):

also known as Bhaskaracharya ("Bhaskara the Teacher"), was a preeminent 12th-century Indian mathematician and astronomer from Karnataka. He was the head of the astronomical observatory at Ujjain, the leading mathematical center of ancient India. His major work, Siddhanta Shiromani, includes groundbreaking contributions to arithmetic (Lilavati), algebra (Bijaganita), and calculus.

#### 2.3.1 Key Contributions and Achievements

- **Calculus Pioneer:** Bhaskara II is credited with developing early concepts of differential calculus, including infinitesimals and the derivative, centuries before European mathematicians.
- **Number System & Zero:** He provided a full, systematic use of the decimal system and defined that dividing by zero yields infinity.
- **Algebraic Solutions:** He developed methods to solve quadratic, cubic, and quartic equations, including handling negative and irrational solutions.
- **Astronomy:** He calculated the Earth's revolution around the Sun as 365.2588 days.

### 3. Continuity in Medieval India: The Kerala School (14th–16th Century)

The Kerala School of Astronomy and Mathematics, flourishing between the 14th and 16th centuries, represents a significant period of continuity in Indian intellectual history. Rather than a break with the past, this school bridged ancient Indian mathematical traditions with pioneering developments in calculus, infinite series, and trigonometry, while simultaneously navigating a changing medieval socio-political landscape.

#### 3.1 Key Contributions and Innovations:

While honoring tradition, Madhava of Sangamagrama (c. 1340–1425) and his successors introduced revolutionary concepts that pre-dated European developments by two centuries.

- **Infinite Series:** Madhava discovered the infinite series for the sine, cosine, and inverse tangent functions (power series).
- **Calculus Foundations:** They developed concepts essential to calculus, such as the Taylor series for trigonometric functions.
- **Approximation of  $\pi$ :** Madhava calculated the value of  $\pi$  accurate to 11 decimal places, and later, some members achieved 17 decimal places.
- **Yuktibhasa:** Jyesthadeva (c. 1500–1610) authored the Yuktibhasa in Malayalam, which is considered the world's first comprehensive treatise on calculus, providing rational proofs for previous, unproven theorems.

#### 3.2 Key Figures (14th–16th Century)

The school was not a physical building but a lineage of scholar-disciples:

- **Madhava of Sangamagrama (Founder):** Initiated the study of infinite series.
- **Paramesvara:** Known for astronomical observations and the Drgganita system.
- **Nilakantha Somayaji:** Author of Tantrasangraha (c. 1500), a crucial text detailing the school's results.
- **Jyesthadeva:** Author of Yuktibhasa, providing geometric proofs for calculus concepts.
- **Melpathur Narayana Bhattathiri:** A 16th-century scholar whose work marked the end of the school's most creative period.

### 3.3 Decline and Legacy

The school's original creative output began to decline by the late 16th and early 17th centuries, partly due to the turbulent political climate caused by the colonial interventions of the Portuguese and later the Dutch. However, the school's work represents a vital, independent, and indigenous development of mathematical thought in pre-modern India.

### 4. Modern Mathematics and the Ramanujan Legacy (18th Century – Present):

Srinivasan Ramanujan (1887–1920) profoundly impacted 20th-century mathematics by producing ~3,900 results—including mock theta functions, partition congruence's, and modular forms—derived through deep intuition rather than formal proof. His legacy thrives in modern number theory, string theory, computer algorithms for  $\pi$ , and in navigating cryptographic, network, and AI-driven mathematical research.

#### 4.1 Key Aspects of the Ramanujan Legacy:

**Fundamental Contributions:** He pioneered revolutionary insights in analytic number theory, infinite series (specifically, new formulas for calculating  $\pi$ ), continued fractions, and highly composite numbers.

- **The "Lost Notebook":** Rediscovered in 1976, this collection of his last year's work contained groundbreaking theorems on mock theta functions, which are now crucial in studying black hole physics and string theory.
- **Mathematical Impact:** His work on partitions and modular forms is now foundational for modern fields, including representation theory, statistical mechanics, and k-not theory.
- **Modern Applications:** Ramanujan's methods are used in high-precision computing to calculate  $\pi$  to millions of digits and in AI-driven mathematical discovery, such as the Ramanujan Machine.
- **Enduring Influence:** The Ramanujan Journal was established to publish work influenced by his research, and he is celebrated on India's National Mathematics Day (December 22).

### 5. The Thread of Continuity: Algorithmic Approach

A significant theme connecting ancient to modern Indian mathematics is the algorithmic and computational nature of the work.

- **Sutra System:** The ancient method of using condensed verses (Sutras) to represent complex procedures for easy memorization.
- **Computational Efficiency:** Focus on methods that allow quick and efficient calculations, which are still reflected in modern "Vedic Mathematics" techniques.
- **Numerical Focus:** A persistent, deep interest in number theory, from the large numbers in the Vedas to the partition functions of Ramanujan.

### 6. Global Influence and Conclusion

Indian mathematics was not isolated. Through the Arab world, the Indian decimal system and zero ("Indo-Arabic numerals") revolutionized global mathematics. The journey from *Shunya* (void) to modern binary computing systems, and from the *Sulba Sutras* to modern topology, demonstrates an unbroken, evolving legacy. The continuity of Indian mathematics lies not just in the persistence of its scholars, but in the enduring, practical, and intuitive nature of the methods they developed.

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