

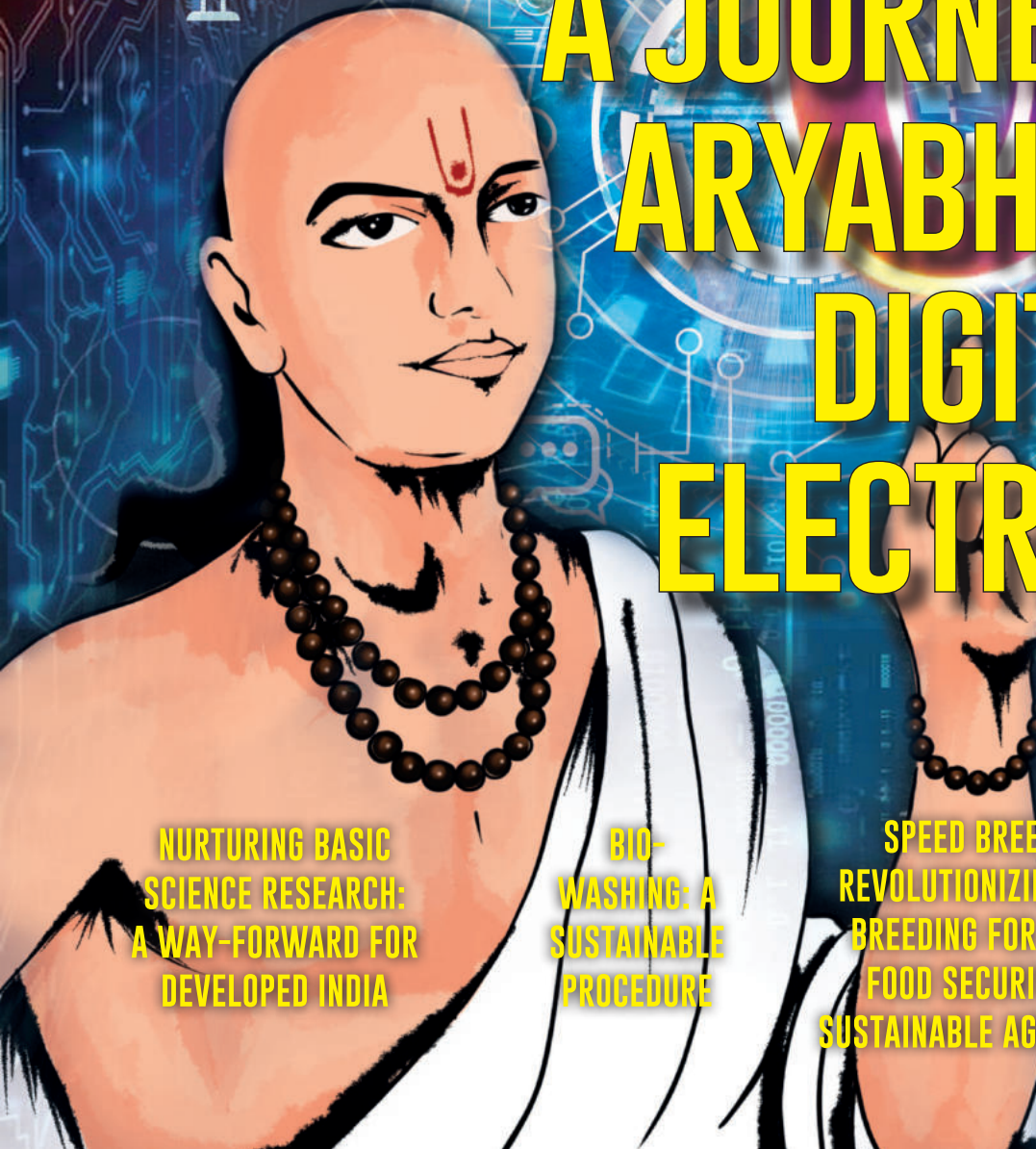
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ZERO: A JOURNEY FROM ARYABHATA TO DIGITAL ELECTRONICS



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SCIENCE RESEARCH:
A WAY-FORWARD FOR
DEVELOPED INDIA**

**BIO-
WASHING: A
SUSTAINABLE
PROCEDURE**

**SPEED BREEDING:
REVOLUTIONIZING PLANT
BREEDING FOR GLOBAL
FOOD SECURITY AND
SUSTAINABLE AGRICULTURE**

**PLASMA-
IT'S VARIOUS
USE IN
HUMAN LIFE**

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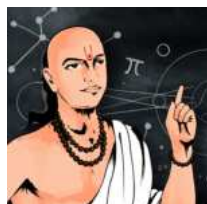
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The Renaissance of Science and Technology in India

India, a nation with a rich tapestry of history and culture, is undergoing a remarkable transformation in the realms of science and technology. From ancient times, when scholars like Aryabhata and Sushruta made groundbreaking contributions to mathematics and medicine, to the contemporary era where Indian scientists and technologists are at the forefront of global innovation, India's journey is a testament to its enduring spirit of inquiry and innovation.

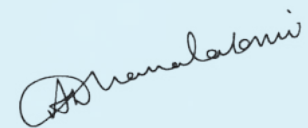
The foundation of India's scientific and technological progress was laid in the post-independence era. The establishment of institutions like the Indian Institutes of Technology (IITs) and the Indian Space Research Organisation (ISRO) signified the nation's commitment to fostering a robust scientific community. In recent decades, India has emerged as a global powerhouse in various scientific and technological domains. The IT boom in the late 20th century positioned India as a hub for software development and IT services, with cities like Bangalore earning the moniker "Silicon Valley of India." This growth was propelled by a highly skilled workforce and a conducive policy environment that attracted multinational corporations and fostered homegrown tech giants. In the field of space exploration, ISRO has become a symbol of India's technological prowess. The successful Chandrayaan-3 mission in 2023, which made India the first country to achieve soft landing near the South pole, is a landmark achievement. ISRO's focus on cost-effective missions has garnered international acclaim, demonstrating that innovation is not solely the purview of wealthy nations.

India's advancements are not confined to IT and space exploration. The biotechnology sector is burgeoning, with significant contributions to healthcare and agriculture. Indian pharmaceutical companies have become global players, providing affordable medications worldwide. The rapid development and mass production of COVID-19 vaccines underscored India's capacity for biotechnological innovation and its role in addressing global health crises.

Despite these achievements, India faces several challenges that could impede its scientific and technological progress. Issues such as inadequate funding for research and development (R&D), departure of educated and professional people from India, and bureaucratic hurdles continue to pose significant obstacles. Moreover, the disparity in educational quality and access across different regions of the country needs addressing to harness the full potential of its young population.

The future of India's scientific and technological landscape looks promising, however, with a renewed focus on innovation and digital transformation. The government's "Digital India" initiative aims to bridge the digital divide and empower millions through improved internet connectivity and e-governance. Additionally, programs like "Startup India" and "Make in India" are fostering an entrepreneurial ecosystem that encourages innovation and self-reliance.

India's journey in science and technology is a narrative of resilience, ingenuity, and vision. From ancient scholarly pursuits to modern-day innovations, the nation continues to push boundaries and set new benchmarks. As India navigates the complexities of the 21st century, its commitment to fostering a culture of scientific inquiry and technological innovation will be crucial in shaping a future that is not only prosperous but also inclusive and sustainable. The renaissance of science and technology in India is not merely a chapter in its history but a continuous, evolving saga of progress and potential.



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ZERO: A JOURNEY FROM ARYABHATA TO DIGITAL ELECTRONICS

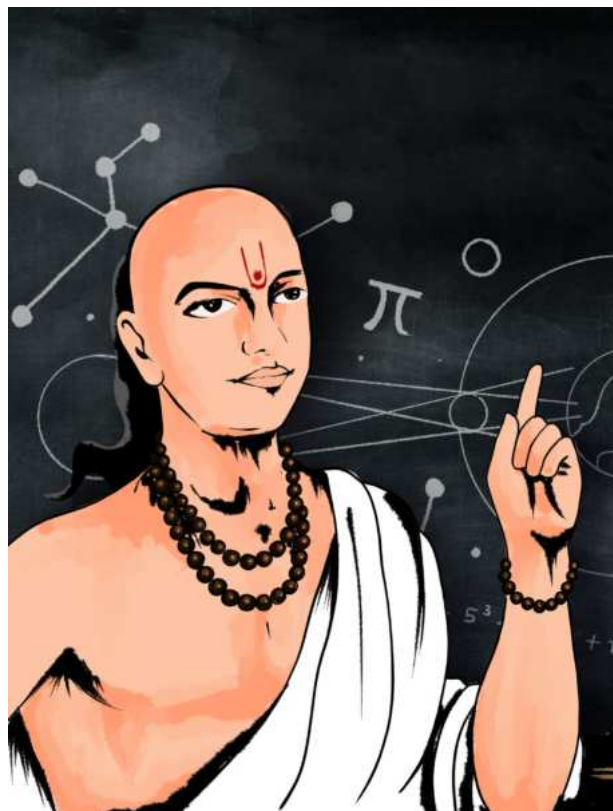
Zero, a seemingly simple digit, holds immense historical and scientific significance. Originating in ancient India, it revolutionized mathematics by providing a placeholder for nothingness. Initially depicted as a dot or a circle, zero transformed numerical systems, enabling complex calculations and laying the foundation for modern mathematics and science. Its introduction marked a paradigm shift, shaping our understanding of the universe and leading to advancements in astronomy, engineering, and technology. Zero's profound impact continues to resonate today, serving as a symbol of both emptiness and infinite possibility in the realms of mathematics, philosophy, and beyond.

The journey of zero from ancient India to digital electronics is a testament to its profound impact on human civilization. Originating in the mathematical treatises of ancient Indian scholars around the 5th century, zero was initially depicted as a dot or a placeholder, signifying the absence of a quantity. Its revolutionary concept transformed numerical systems, enabling more efficient calculations and paving the way for advancements in mathematics, astronomy, and science. As Indian mathematical ideas spread

to the Arab world and Europe, zero became integrated into various cultures and civilizations. Its inclusion in the Arabic numeral system facilitated the development of Algebra and Calculus, shaping the foundations of modern mathematics. In the Renaissance era, zero's significance was further recognized, leading to its widespread adoption across Europe.

Fast forward to the digital age, zero plays a central role in the binary numeral system, fundamental to digital electronics and computing. In binary code, zeros and ones represent the absence or presence of electrical signals, forming the basis of all digital communication and computation. From ancient India to the modern era, zero's journey underscores its enduring importance as a symbol of nothingness and infinity, transcending time and culture to become a cornerstone of human knowledge and technological innovation.

Aryabhata, an ancient Indian mathematician and astronomer, played a pivotal role in the introduction of zero as a numerical placeholder. In his seminal work, the *Aryabhatiya*, composed around the 5th century, Aryabhata utilized a dot to represent zero, signifying the absence of a quantity. This revolutionary concept transformed mathematical notation, enabling more sophisticated calculations and laying the groundwork for modern mathematics. Aryabhata's innovative use of zero as a placeholder revolutionized numerical systems, facilitating the development of algebra, calculus, and other branches of mathematics. His contributions to the field not only shaped the mathematical landscape of ancient India but also influenced mathematical thought across



Aryabhata (476–550 CE)

cultures and civilizations, ultimately contributing to the advancement of human knowledge and understanding.

Later, Brahmagupta further elaborated on zero's properties in his seminal work, the *Brahmasphutasiddhanta*, around the 7th century, discussing arithmetic operations involving zero and its role in quadratic equations. Later, Bhaskara II expanded on these concepts in his treatise, the *Lilavati*. These contributions laid the foundation for zero's integration into the decimal numeral system, facilitating advanced mathematical calculations and the development of algebra and calculus. Indian mathematicians' pioneering insights into zero's significance revolutionized mathematical notation and paved the way for its widespread adoption across cultures, shaping the course of mathematical thought and contributing to the advancement of human knowledge.

Zero holds profound philosophical implications in Indian thought and spirituality. In Indian philosophy, zero represents *shunya*, or emptiness, symbolizing the infinite potential and boundless possibilities inherent in the universe. It embodies the concept of non-duality, where the distinction between existence and non-existence dissolves, leading to a state of unity and interconnectedness. Zero's philosophical significance is reflected in spiritual practices such as meditation and self-inquiry, where practitioners seek to transcend the limitations of the ego and realize the underlying unity of all existence. Additionally, zero serves as a symbol of liberation (*moksha*) from the cycle of birth and death (*samsara*), representing the ultimate goal of spiritual enlightenment and union with the divine. Thus, zero transcends its mathematical significance to become a profound symbol of cosmic unity, spiritual awakening, and the inherent interconnectedness of all beings in the universe. Its inclusion in ancient texts such as the Vedas and

Upanishads underscored its cultural significance, highlighting its association with concepts of infinity, eternity, and the interconnectedness of all existence. Thus, zero became deeply woven into the fabric of ancient Indian society, permeating various aspects of life, thought, and spirituality.

The integration of zero into Arabic numerals and algebraic notation marked a pivotal moment in the history of mathematics, profoundly impacting the development of algebra and the transmission of mathematical knowledge across cultures. Initially introduced by



Leonardo Pisano Fibonacci (1170 – 1240 CE)

Indian mathematicians, zero, along with other numeral symbols, was adopted by Arab scholars during the Islamic Golden Age.

Zero's introduction into algebraic notation transformed the field of algebra. Al-Khwarizmi's influential work "*Al-Kitab al-Mukhtasar fi Hisab al-Jabr wal-Muqabala*" (*The Compendious Book on Calculation by Completion and Balancing*) introduced systematic methods for solving linear and quadratic equations, utilizing zero as a placeholder and variable. This treatise laid the foundation for algebra as a

distinct branch of mathematics, providing a framework for solving mathematical problems symbolically. The integration of zero into Arabic numerals and algebraic notation facilitated the development of algebraic algorithms, paving the way for advancements in various fields such as astronomy, engineering, and commerce.

The diffusion of zero from the Islamic world to medieval Europe played a crucial role in the development of Western mathematics. During the Middle Ages, European scholars encountered Arabic texts containing Indian mathematical concepts, including zero. Translations of works by Arab mathematicians like Al-Khwarizmi and Al-Kindi introduced zero as a numerical placeholder into European mathematical discourse. This exchange of knowledge catalyzed the adoption of Arabic numerals, including zero, in Europe, eventually supplanting the Roman numeral system. Zero's integration into European mathematics revolutionized numerical notation, facilitating more efficient calculations and laying the groundwork for the scientific and mathematical advancements of the Renaissance and beyond.

Zero encountered initial skepticism and resistance in European mathematical circles during its introduction from the Islamic world. European scholars were accustomed to using the Roman numeral system, which lacked a symbol for zero and made complex calculations cumbersome. Additionally, the concept of a number representing nothingness challenged traditional philosophical and religious beliefs. Some mathematicians viewed zero as a void or a concept with no tangible value, leading to reluctance in accepting its validity. However, as Arabic mathematical texts gained prominence and European scholars recognized the practical utility of zero in mathematical notation, skepticism gradually gave way to acceptance, paving the way for its integration into European mathematics and the eventual adoption of

the decimal numeral system.

European mathematicians played a vital role in the acceptance and integration of zero into mathematical discourse. Influential figures such as Fibonacci and Leonardo of Pisa popularized the Hindu - Arabic numeral system, which included zero, through their writings and translations of Arabic mathematical texts. Fibonacci's 'Liber Abaci' introduced zero to European audiences, demonstrating its practical applications in arithmetic and algebraic calculations. Moreover, the emergence of algebraic notation, pioneered by mathematicians like

for understanding functions' behaviour near critical points and for studying convergence and divergence in series and sequences.

Zero finds extensive applications in Physics, engineering, and computer science, serving as a foundational concept in various fields. In Physics, zero represents absolute zero temperature, a critical point in thermodynamics, and serves as a reference point in measurements and calculations. In engineering, zero denotes null states or equilibrium conditions in systems, such as zero velocity or zero force. Additionally, zero is integral to

spaces, such as the zero-dimensional point or the null space. Understanding the properties and relationships associated with zero in these contexts is essential for developing foundational concepts and theories in mathematics.

The introduction of zero as a binary digit, or bit, in digital computing revolutionized the field, paving the way for modern information technology. In binary code, zero represents the absence of an electrical signal, while one represents its presence. This binary system, based on the concept of zero and one, forms the foundation of digital electronics and



The introduction of zero as a binary digit, or bit, in digital computing revolutionized the field

François Viète and René Descartes, further solidified zero's status as a fundamental numerical concept. Through their efforts, European mathematicians contributed to the widespread adoption of zero, laying the foundation for modern mathematics.

Today, zero plays a foundational role in calculus, algebra, and mathematical analysis as a fundamental numerical concept. In calculus, zero serves as a critical point for defining limits, derivatives, and integrals, enabling the study of rates of change and accumulation. In algebra, zero functions as both a numerical placeholder and a key element in equations and polynomial expressions, facilitating the solution of equations and the manipulation of algebraic expressions. In mathematical analysis, zero serves as a reference point

computer science, where it is used in programming languages to represent null values, termination conditions, and starting points for indexing arrays and lists. Further, zero plays a crucial role in digital electronics, where it signifies absence or presence of electrical signals, serving as the basis for binary code and data representation in computers and electronic devices.

In fields like set theory and topology, zero holds theoretical significance as a fundamental concept with diverse implications. In set theory, zero represents the empty set, the set with no elements, which serves as a building block for defining other sets and operations. Additionally, zero plays a role in topology as the origin or base point for constructing topological

computing. Zero's inclusion as a binary digit enables the representation and manipulation of data using electronic devices such as computers, smartphones, and digital circuits. Through Boolean logic and binary arithmetic, zero facilitates complex calculations, data storage, and communication in digital systems. Its introduction marked a paradigm shift in computing, enabling the development of advanced technologies and applications that have transformed nearly every aspect of modern life.

Zero plays a crucial role in Boolean logic and digital circuit design, particularly within computers and smartphones as it represents the absence or low state of an electrical signal. They operate on the binary system, utilizing

zeros and ones where each digit denotes a power of 2, with 0 representing absence and 1 indicating presence, forming the cornerstone of digital data representation. In numerical representations, zero functions as a placeholder across various scales, akin to its role in the decimal system. It signifies absence in digital storage, such as in RAM or hard drives, where a bit set to zero denotes the lack of electrical charge or magnetic polarization. In digital circuit design, zero is used to implement logic gates, such as AND, OR, and NOT gates, which process binary inputs and produce binary outputs based on Boolean functions. Zero's presence or absence in digital signals determines the behaviour of electronic devices, enabling them to perform logical operations, store information, and execute instructions, thus forming the basis of modern computing and communication technologies.

Zero enables the representation and manipulation of data, facilitates logical operations, and underpins the architecture of computers, smartphones, and other digital devices. Additionally, zero's role in algorithms, data structures, and programming languages has revolutionized software development, enabling the creation of complex applications and systems. Without zero, modern computing as we know it would not exist, highlighting its indispensable role in shaping the technological landscape of the 21st century.

In digital communication and networking protocols, zero assumes diverse roles, like in IP addressing where 0.0.0.0 denotes an unspecified or wildcard address on a local machine. Moreover, in computer and smartphone user interfaces, zero is employed to denote the lowest setting in controls or as the starting point in numerical scales, exemplified by progress bars or sliders. Overall, zero is a pivotal concept in the digital domain, playing indispensable roles in representation, computation, storage, communication, and user interaction.

Zero's ubiquitous presence permeates everyday life and digital technologies. In numerical representations, zero serves as a placeholder, enabling the expression of absence or nullity. In digital technologies, zero is fundamental to binary code, where

it represents the absence of an electrical signal. This binary system underpins all digital communication and computation, from smartphones and computers to internet networks and electronic devices. Additionally, zero plays a crucial role in algorithms, data processing, and software applications, shaping the way we interact with technology on a daily basis. Its pervasive influence underscores its indispensable role in modern life and digital innovation.

Ethical and philosophical considerations surrounding zero in digital culture encompass notions of presence and absence, representation and reality. Zero's role in digital technologies raises questions about privacy, identity, and power dynamics in an increasingly interconnected world. Philosophically, zero prompts reflections on the nature of existence and nothingness, challenging perceptions of value and meaning in a digital age. Ethical dilemmas arise regarding the consequences of zero's manipulation, such as data erasure or algorithmic bias. Moreover, zero's symbolic significance in digital culture underscores broader philosophical inquiries into the boundaries between the virtual and the real, shaping perceptions of truth, authenticity, and human experience in the digital realm.

In the continued evolution of zero, future prospects and challenges abound. Technological advancements, particularly in quantum computing and artificial intelligence, may redefine the role of zero in computational paradigms, unlocking unprecedented capabilities and applications. However, challenges such as data privacy, security vulnerabilities, and ethical implications will necessitate careful consideration and regulation. Additionally, the philosophical implications of zero's expanding role in digital culture may prompt deeper inquiries into the nature of consciousness, existence, and reality. Furthermore, ongoing research in mathematics and theoretical physics may uncover novel interpretations and applications of zero, shaping our understanding of the universe and its fundamental principles. As zero continues to evolve, interdisciplinary collaboration and ethical foresight will be

essential in navigating the opportunities and challenges that lie ahead in its journey of discovery and innovation.

Zero's historical journey traces back to ancient India, where it emerged as a revolutionary concept in mathematics. Initially depicted as a dot or circle, zero served as a numerical placeholder, enabling more sophisticated calculations and laying the foundation for modern mathematics. Its integration into various numeral systems, including Arabic and decimal, facilitated advancements in algebra, calculus, and scientific inquiry.

Today, zero's contemporary significance is pervasive across diverse fields, from physics and engineering to computer science and digital culture. As a binary digit, zero forms the backbone of digital communication and computation, underpinning the architecture of modern computing systems and technologies. Moreover, zero's philosophical and symbolic resonance transcends its mathematical utility, prompting reflections on existence, nothingness, and the nature of reality in philosophical discourse.

The enduring legacy of zero as a symbol of human ingenuity and mathematical abstraction underscores its timeless relevance in shaping human knowledge and technological progress. From its humble origins in ancient India to its ubiquitous presence in digital culture, zero stands as a testament to humanity's capacity for innovation and intellectual exploration. As we reflect on zero's journey, we are reminded of its profound impact on the way we perceive and interact with the world, embodying the spirit of curiosity and discovery that defines human civilization.

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NURTURING BASIC SCIENCE RESEARCH: A WAY-FORWARD FOR DEVELOPED INDIA

Science and Technology are bound to play key roles in attainment of the goal of emergence of India as a developed country by the year 2047 (Viksit Bharat, 2047).

In tune with the vision, the investment in Science and Research has observed a consistent growth with around 150 universities and 1500 research units already operational in the country and the State University Research Excellence (SERB-SURE) propelled by Science and Engineering Research Board aiming to create an active, productive, and robust research ecosystem in the universities and colleges. Under the Union Budget 2024, the Government allocated Rs. 16,361 crore to the Department of Science and Technology (DST). Additionally, between April to December 2022, an unparalleled expansion of Rs. 1,000 crore was observed in Space Startups. Besides the public funded programs, private investments are also pouring in the thrust areas of scientific research from industry and philanthropy. Recently, an uptrend has also been realised in the investments made by Multinational Companies (MNCs) who are keen on setting up their Research and Development centres in India. National Science Technology and Innovation Policy 2022 (STIP, 2022), seeks to position India amongst the top 5 countries in the world in terms of research quality and outcomes by the year 2030. It also envisions to enhance the participation of women in STEM (Science, Technology, Engineering and Mathematics) by 2030 so that they are represented in the various domains and for this many initiatives such as GATI (Gender Advancement for Transforming Institutions), "SWATI" (Science for Women: A Technology and Innovation) Portal and many such initiatives have been rolled. Indian Space Policy-2023, approved by the Cabinet Committee, have granted permits to non-government entities (NGEs) to not only offer national and international space-based communication services, but also establish and operate ground facilities for space object operations, encouraging a more proactive participation of the private sector along with public sector



enterprises in the scientific activities. India's space research has witnessed significant strides over the past years. Chandrayaan-2 and Chandrayaan-3, launched in July 2019 and July 2023, respectively, by the Indian Space Research Organisation (ISRO) aimed at exploring the lunar surface of the Moon, while the Mangalyaan mission in 2013 made India the fourth country to successfully reach the orbit of Mars. Currently, preparations for the Gaganyaan mission, set to send Indian astronauts to space, mark a significant milestone. The ISRO's Polar Satellite Launch Vehicle (PSLV) has also been instrumental in launching satellites for various purposes since its inception. With plans for future planetary exploration and applications in sectors like agriculture and disaster management, India's space endeavours are advancing rapidly and creating ripples across the world. Though the facts and figures look highly convincing and point in the direction of eventual transformation of India as a knowledge hub, it is far behind in a variety of aspects from its contemporaries. As against India's 0.7 %, China not only invests 2% of GDP in research and development, but also produces graduates twice in number in STEM (Science Technology, Engineering and Mathematic). Japan and South

Korea are also far ahead in research in both basic and applied sciences with the state of art infrastructure and labs. It, therefore, is imperative to understand that for becoming Viksit Bharat, the gaps must be identified and plugged. Research in basic science is starved of funds and some frontier areas are the focus of the funding agencies. However, understanding and appreciating the nuances of science, scientific theories and principles is like



taking a dip into an ocean of knowledge to search for the unknown, that unknown which can have huge potential. The advancement in any field of study firmly stands on its ability to attract young and passionate brains and involve them in steering the nation to the top.

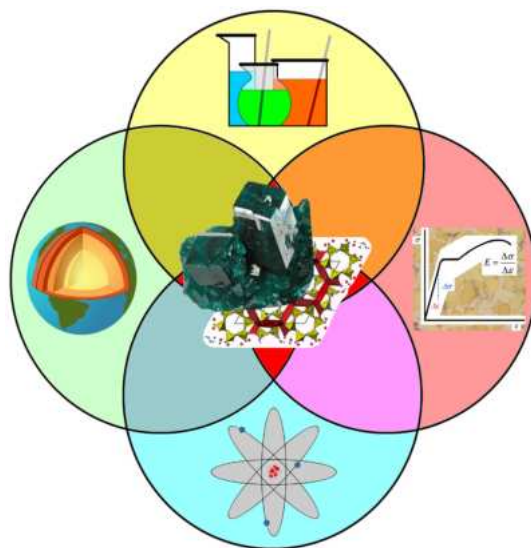
Viksit Bharat 2047 will materialize only when there is a harmonization of basics with applied. The Department of Biotechnology (DBT), Ministry of Environment, Forests and Climate Change (MoEFCC), Department of Science and Technology (DST), Defence Research and Development Organization (DRDO), Department of Atomic Energy (DAE) and Council for Scientific and Industrial Research (CSIR) are some notable funding agencies in the country. However, a strong bias towards the applied research such as genomics, proteomics, molecular biology, biotechnology, medicine, pharmaceuticals in comparison to subjects such as botany, zoology, biochemistry, microbiology, and diversity studies has been observed, knowing that these subjects lay the foundation for progress in the former. It is unconvincing to believe that techniques such as gene editing (e.g., CRISPR-Cas9), gene therapy for treating genetic disorders and the development of vaccines would

have even surfaced if it weren't for the knowledge of structure of DNA, the principle of central dogma and gene expression. Production of genetically engineered crops would have remained a distant dream if it weren't for the understanding of basic plant development and processes through experimentation on locally found plants. Furthermore, the discovery and understanding of principles of basic physics like Ohm's Law, Faraday's Law of Electromagnetic Induction, and Maxwell's Equations underpins the designing of electrical circuits, semiconductors, and electronic devices like computers, smartphones, and communication systems. In the same line, conceptual understanding of chemical bonding, molecular structures and reactions, synthesis of novel materials with tailored

properties such as superconductors, polymers, and nanomaterials would have only remained a distant endeavour if basic properties of materials, transistors, circuits, electricity, and magnetism were not understood. Additionally, the agenda of sustainability, meeting of sustainable development goals (SDGs) through employment of renewable energy, mentioned in Governments Policy Documents in the public domain, can only be envisioned by understanding and conceptualizing the underlying mechanisms of heat transfer, entropy, and energy conservation. Study of periodic classification of elements, vectors, colloidal chemistry will always stay relevant as these are the foundation of the science. However, it is demotivating for curious, inquisitive researchers when there are few opportunities available to them and the funding agencies are conveniently shunting funds from basic sciences to translational research centred on commercial gains. Translational research is important and for public good, but so is fundamental knowledge that tolls for years to derive applications. The recent rationalization of syllabus to facilitate students and reduce the examination related stress has also affected the basic science component as committees.

For Viksit Bharat 2047, it therefore remains undisputable that basic sciences (Botany, Physics, Chemistry, Geology, Mathematics) need to be taught with rigour and should precede applied science for it is more likely to push the country to move ahead in many fields while simultaneously inducing knowledge-spillover effects. Besides, it also cultivates critical thinking skills, promotes curiosity and creativity, and inspires young minds to pursue careers in science, technology, engineering, and mathematics (STEM). India as Viksit Bharat is a movement and not a short-term program, it has goals and aims, aspirations, and ambitions and seeks the cooperation and support and development in all areas, including human health and wellbeing. Capacity building of young leaders can create a fertile ground for emergence of new ideas

and innovation that is needed by the country to make it a Developed Nation. Furthermore, basic research imparts global competitiveness to a country by fostering a culture of innovation, attracting top scientific talents and establishing a strong scientific infrastructure. Investments in biology have also played a crucial role in fostering vaccine research and development in India in recent years, especially during the Pandemic. India emerged as a Global Leader and helped many countries by providing Covid



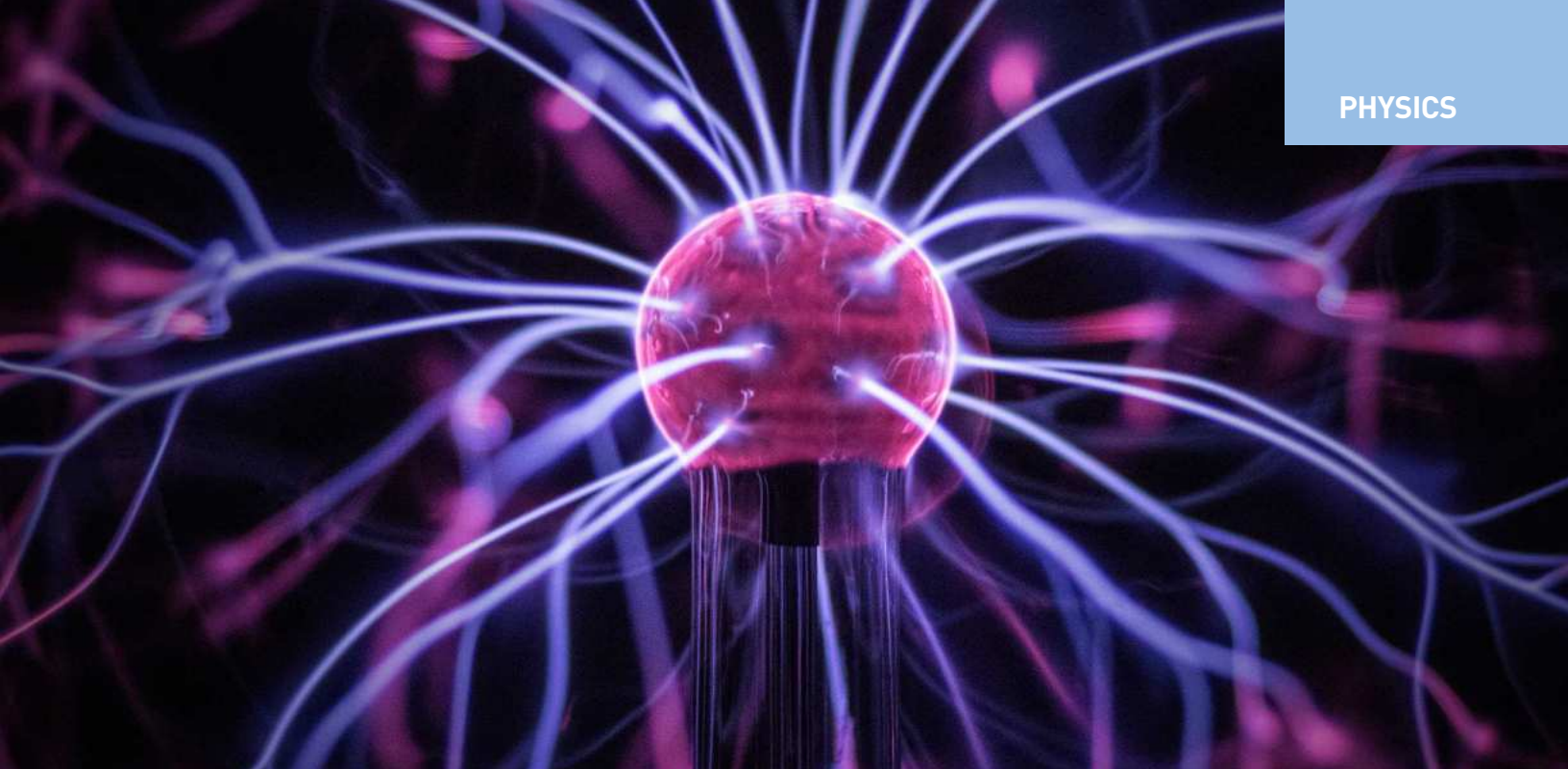
Vaccines, justifying that Science in India is working in its own way to take the wheel of progress forward. Research in virology, immunology, molecular biology, and bioinformatics has not only built a strong foundation of scientific knowledge and expertise but the country has also leveraged this knowledge to develop novel vaccine candidates, improve existing vaccines, and streamline vaccine production processes against a wide range of infectious diseases. Recent civil engineering marvels in India highlight the critical relationship between investment in basic science and infrastructure development. By leveraging principles from various scientific disciplines such as geology, materials science and urban planning, projects like Chenani-Nashri Tunnel (2017), Mumbai Coastal Road Project (2019) and Signature Bridge, Delhi (2018) amongst others have successfully addressed complex challenges in construction, transportation,

and environmental sustainability. Lastly, it plays a crucial role in realising the envisioned goals of Viksit Bharat, 2047, which encompass economic growth that is likely to be materialised by the rippled positive effects that investments in basic sciences brings about. The enhancement of global collaborations in diversified research projects in different disciplines of sciences will boast the ease of doing business in India, alongside also ensuring infrastructural development. It will also aid in addressing the grand challenges such as climate change, disease prevention, sustainable energy, and food security which form pivotal parts of the vision.

Reforms are thus indispensable to be implemented in the way resources are distributed in the country. Instead of orienting all the resources in one direction, it is logical to seed the money equally in different fields of sciences. Moreover, it would be prudent to identify capable and talented people harbouring genuine passion and scientific temperament and provide them the resources and facilities to carry out 'good science', irrespective of their age and field of study. Even if the usefulness of a study cannot be reckoned with in the present, it might prove to be transformational in years to come. It may also drive interdisciplinary innovations which may solve still unfathomed problems and revolutionize science holistically. Thus, no study or project should be dismissed as insignificant, and every enthusiast should be given an opportunity to pursue the envisioned. The whole and sole way to achieve the target of a developed nation till 2047 is to promote hand in hand progress in both basic and applied fields, without abandoning either.

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PLASMA – IT'S VARIOUS USES IN HUMAN LIFE

The fourth state of matter is Plasma. The British physicist Sir William Crookes first identified it in 1879, but in 1928, the name “plasma” was applied by American physicists Tonks and Langmuir. Plasma is of Greek origin meaning anything formed or molded. Plasma comprises charged particles. As these charges move around, they generate local concentration of positive or negative charges, which give rise to electric fields. Motions of charge also generate electric currents and hence, magnetic fields that affect the motion of other charged particles far away. Elements of plasma exert a force among them even at a large distance. Thus, by collective behavior we mean motions that depend not only on local condition but on the plasma in remote regions as well. Plasmas are grouped as “thermal” or “non-thermal” grounded on the corresponding temperature of the ions, electrons, and neutrals. Non-thermal plasmas have the ions and neutrals at a very lower temperature compared to electrons which have a much higher

temperature. On the other hand, thermal plasmas have electrons and therefore, the heavy particles at the similar temperature.

Cold atmospheric plasma is called non-thermal because it has electrons at a higher temperature than the heavy particles that are at room temperature. Helium, Argon, Nitrogen, Heliox, and air are used to produce cold atmospheric plasma which is a mixture of reactive oxygen species, reactive nitrogen species, charge particle, UV and so on. Numerous methods to produce consist of atmospheric pressure plasma jet, dielectric barriers discharge, plasma pencil and plasma needle.

Plasma is vastly used in various fields like agriculture, medicine, food industry and others. In this article we will discuss how plasma is used in these industries.

MEDICAL SCIENCE

Plasma Medicine is a rapidly growing field of plasma science. It comprises variety of fields like physics, chemistry, engineering science, biological science and also medicine. Plasma medicine involves direct treatment of human cells with the help of plasma. Professor Gary

Friedman of Drexel University and his research collaborators first identified the application of plasmas directly or indirectly on human skin. The International Society of Plasma Medicine was founded in 2009.

Sterilization of medical device and Cauterization use plasma. Plasmas are also used in hospital hygiene, in the treatment of diverse skin infections and diseases, in dentistry and in the cosmetic field. Besides these, Plasmas can also be used in packaging in the food industry, implants, blood coagulation, and so on. The reason for the wide applicability of plasma is due to its bactericidal effectiveness and its easy access into narrow and confined spaces.

The application of plasma in medical science depends on the thermal effects of plasma. High temperature and heat are used in medicine for tissue removal, sterilization and surgical procedure. Argon plasma coagulation is the useful application of thermal plasma and it is used to cut tissue and especially endoscopic. Here highly conductive plasma allows passing a current through the tissue. Ion species have a major role to play in plasma cell interactions by instigating



intracellular biochemistry. In some plasma cell interaction pathways neutral species have a primary role to play. It is observed that many plasma effects are very selective. Various species can have either “plasma killing” (such as O) or “plasma healing” (such as NO) effects. The roles of other species like O₃, OH etc., are not clear. Cold plasmas help blood to coagulate and tissue to sterilize. Again thermal plasma treatment is extremely useful in blood coagulation and sterilization, however it encourages considerable damage while, non-thermal cold plasmas will give similar results but without any side effect.

It has been observed in recent researches about cold atmospheric plasmas that there is immense possibility of using it in the field of medical science. Plasma helps in effective medical treatment of various diseases such as cancer, antifungal treatments, wound healing, skin diseases, dental care, cosmetics targeted cell and tissue removal.

Moreover, a cold plasma jet can be used to target certain cancers, such as those of the bladder, head, brain, and neck, while sparing healthy cells in the process. The treatment of cancer leaves a patient drained both physically and also emotionally. Plasma activated media can be both a real substitute and effective in killing cancer cells through direct treatment by cold atmospheric plasma. This has anti-proliferative and killing results against numerous cancers as well as ovarian, gastric, breast cancer etc.

Cold atmospheric plasma therapy is most effective for cancer treatment which kills only cancer cells and protects healthy cells. It induces apoptosis, necrosis, cell detachment and senescence by disrupting the S phase of cell replication in tumor cells. In fact it was determined that Cold atmospheric plasma affects cell through a programmed cell death. Programmed cell death means death of a cell mediated by an intracellular program.

Cold atmospheric plasma has been successfully and effectively used in dental treatment as well as dental caries, root canal disinfection, elimination of biofilms, increase in bond strength at the dentition / composite interface and bleaching. Some limited treatment is conventional such as teeth brushing; fluoride uptake,

antibiotics and vaccines have been used as treatment of dental caries, intraoral disease and periodontal disease. Heat kills bacteria however the applying of this methodology to normal cells is dangerous.

Root canal treatment and bleach teeth (tooth whitening) can be successfully done today with the help of cold atmospheric plasma therapy. As Plasma species can easily reach inside the cavity and it has the ability to kill *Escherichia coli*, plasma is able to treat dental cavities without drilling.

Like every technology, plasma medicine has also some benefits and some constrains. As plasma medicine has been recently introduced in the market, this form of treatment requires special care on the safety of the machines besides the price of the machine, marketing, servicing and accessibility.

FOOD INDUSTRY

Preserving food properly is a matter of concern not only for consumers, food industry but also for regulatory agencies. One basic challenge the food industry faces is the failure to store the food in the right process. Problematic microbes like food-borne pathogens and spoilage microorganisms in food industries are serious threat both for public and financial impact. Now a day's consumers are becoming aware of food preservation and thus, the demands related to food preservation is also increasing with



modern technology. Number of methods of sterilization to kill the microorganism has evolved namely heat sterilization, chemical sterilization, radiation sterilization, plasma sterilization.

The thermal technology to preserve food safety has severe side effects on nutritional sensory and functional properties of treated foods. Therefore, alternative non-thermal pasteurization methods like high hydrostatic pressure, oscillating magnetic field, ionizing irradiation, pulsed electric fields and high power ultrasound have flourished recent years. These new process not only help maintaining quality of food better than traditional method that are equally cost effective. But consumer's acceptances and safety of process should also be proved.

However, nonthermal plasma has proven much more effective in preserving food quality than thermal technology. In 1968 plasma as a method of sterilization was first patented while plasma produced from oxygen was first applied 1989. After that numerous researches on mechanisms of microbial inactivation by plasma agents have been conducted. Recently prototype plasma device creates ozone to kill germs in packaged food.

One important aspect related to purchase of any fruit or vegetable is its color. Bright colored fruits and vegetables attract our attentions. When the food and vegetable are stored by cold plasma treatment then the color of food and vegetable have no significant changes. Some scientist claim that there are some minor changes in color with cold plasma treatment, but this change is not visible with naked eyes.

Today by using plasma technology we can find bacteria free egg. Plasma is used for killing bacteria like salmonella on egg shells. After successful application of plasma sterilization on egg (which is 99.5% free from bacteria), the egg remains unaffected.

Agriculture

Since food is essential to human survival, agriculture is a scientific field with a strong research base. Increasing agricultural productivity per unit of land area is crucial to ensuring food safety as the world's population grows and lifestyles



change. Agronomy is using cold plasma technology, namely cold atmospheric pressure plasma, to boost grain yield and enhance plant physiology and seed germination. Studies have demonstrated that cold atmospheric pressure plasma treatment can enhance seed development and germination without appreciably damaging seeds. Research has indicated that plasma therapy can raise levels of chlorophyll, but not the carotenoid content. Pre-sowing seed treatment with plasma technology can minimise pesticide use, increase agronomic yield, and lessen environmental harm. The goal of seed-plasma treatment research is to improve food quality in eco-friendly, sustainable agriculture.

Research has confirmed that atmospheric cold plasma has a number of beneficial impacts on crops, including enhancing seed germination, breaking of seed dormancy, raising enzyme activity, and enhancing the seedling growth.

A useful technique for enhancing plant immunity and development, promoting seed growth, and reducing the pathogenic and chemical contamination is non-thermal plasma. It modifies the characteristics of water absorption and decreases harmful microbial layers. The kind of seed, its state, and its surroundings all affect how effective plasma treatments are. Given its demonstrated effective antibacterial activity, atmospheric pressure non-thermal plasma is a valuable tool for eliminating harmful microorganisms.

Around 150 kinds of plant pathogenic bacteria cause a variety of diseases and in agricultural areas they cause major economic damage. Spots, rots, tumours, blights, and cankers are some of the symptoms. By preventing and slowing the growth of germs, non-thermal atmospheric pressure plasma has demonstrated antibacterial potential.

In order to successfully eradicate mycotoxins and spores during food decontamination, plasma has been utilised to inactivate fungal pathogens. *Aspergillus*, *Fusarium*, *Cladosporium*, *Penicillium*, *Phomopsis*, *Colletotrichum*, *Ascochyta*, *Chaetomium*, and *Rhizoctonia* are just a few of the phytopathogenic fungi in which this approach has been demonstrated to inhibit the development of illness.

In conclusion, the widespread application of plasma technology in fields including medicine, agriculture, and food processing demonstrates the technology's adaptability. Further investigation and development are needed to fully realise the potential of plasma technology and address any unresolved issues.

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SPEED BREEDING: Revolutionizing Plant Breeding for **Global Food Security** and **Sustainable Agriculture**



In response to the pressing need to double global food production by 2050 to accommodate a growing population, agricultural scientists are turning to innovative approaches such as speed breeding. This emerging strategy involves cultivating plants in controlled environments with optimal conditions, including extended photoperiods, to accelerate physiological processes like photosynthesis and flowering, thereby reducing the generation time of crops. Speed breeding has proven successful in achieving higher genetic

gains by enabling up to 4–6 generations per year, compared to the 2–3 generations in normal greenhouse conditions. While challenges such as variable climate factors, adaptability to different cultivars, and cost considerations exist, speed breeding presents opportunities for integration with advanced breeding technologies like genomic selection and gene editing to address these obstacles. By serving as a foundational platform for high-throughput phenotyping, genotyping, and trait improvement, speed breeding emerges as a crucial tool in the context of

climate change-induced environmental uncertainties and the increasing demand for food resources.

Background

Since the early 1900s, plant breeding has been crucial for global food security. However, conventional breeding programs focused on high yield and varietal development are struggling to keep pace with the escalating food demand driven by a rapidly growing global population. The traditional phases of crossing, testing, and selection in breeding programs, though

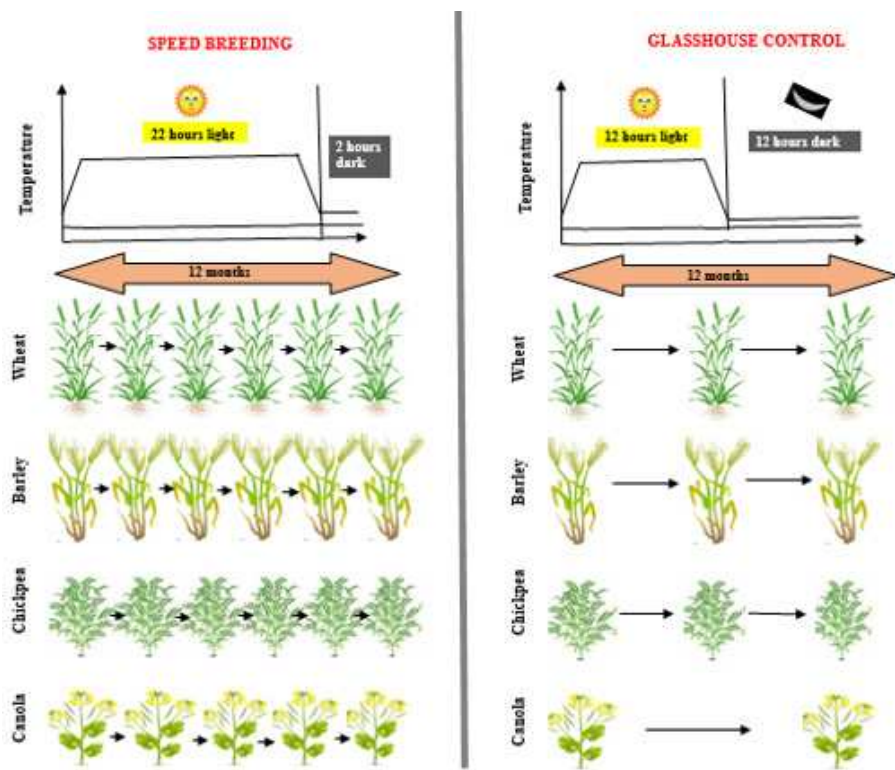


Figure 1 Speed breeding revolutionizes crop research and breeding. While a traditional glasshouse with a natural photoperiod typically yields only 2-3 generations of wheat, barley, chickpea, and canola per year (right), speed breeding boosts this to 4-6 generations annually (left), significantly accelerating progress in agricultural innovation (Modified image from Watson et al., 2018).

effective, have been hindered by significant time constraints. Innovations such as shuttle breeding and double haploid lines technology have been introduced as improvements over the traditional methods. Despite these advancements, the protracted timeline of one or two decades for varietal development poses a challenge, especially when food insecurity arises urgently due to factors like population growth, natural disasters, and plant stresses. Additionally, changing climatic conditions have led to variations in plant habit and habitat, necessitating flexibility in breeding programs. Breeders play a crucial role in staying informed about present and future market aspects, introducing farmer-friendly inventions, and anticipating upcoming circumstances due to the decade-long varietal development process. Recognizing the need for a more rapid response to

the growing food demand, breeders have turned to a novel strategy known as Speed breeding. The annual improvement rate in plant yield, currently at 0.8% - 1.2%, must be doubled to meet the demands of the increasing population, making Speed breeding an essential innovation in plant breeding.

Speed breeding stands as a potent tool for expediting the varietal development process, leading to a notable increase in the number of generations achievable within a single year for crops with long growth durations. Dr. Lee Hickey and his colleagues devised a non-GM route for speed breeding, addressing the need for genetically stable lines for agronomic and yield trait evaluations, which typically require four to six generations of inbreeding. Traditional field crop breeding methods are time-consuming, yielding only one to two generations

per year. In response, speed breeding introduces a flexible strategy by extending the photoperiod duration for field crops, enabling the attainment of 4-6 generations in crops like wheat, which previously managed only 1-2 generations annually (Figure 1). The established photoperiod protocol in speed breeding not only boosts crop generation but also hastens the germination of immature seeds and the overall harvesting time of plants.

Techniques

The assessment of speed breeding was conducted using standard genotypes of wheat, durum wheat, barley, and *Brachypodium distachyon* in a controlled-environment room with an extended photoperiod of 22 hours of daylight and 2 hours of darkness. Results were compared with plants grown under glasshouse conditions during the spring and early summer without supplemental lights. In the speed breeding setup, the time to anthesis was observed to be half that of the glasshouse-conditioned plants. Seed germination rates were consistent across all species, and the viability of harvested seeds remained unaffected by speed breeding. A similar protocol was applied at the University of Queensland to evaluate speed breeding in barley, spring wheat, canola, and chickpea varieties. High-pressure sodium lamps were used in a temperature-controlled glasshouse to extend the photoperiod to 22 hours of daylight, with a natural 12-hour control photoperiod glasshouse as a reference. Both setups maintained the same temperature regime of 22/17 degrees Celsius. The experiment demonstrated that speed breeding achieved six generations of wheat, barley, and chickpea, and four generations of canola per year, using a photoperiod of 22 hours of light and 2 hours of darkness. In contrast, the control treatment in the glasshouse, with 12 hours of light and 12 hours of night, resulted in only 2 or 3 generations in the same crops. Various speed breeding approaches, such as growth chambers with a combination of light-emitting diode (LED) and metal halide lighting to create an extended photoperiod, were also implemented.

Speed breeding set up

- **Light:** Any light source that emits a spectrum covering the Photosynthetic Active (PAR) region (400-700 nm), with a specific emphasis on the blue, red, and far-red ranges, is suitable for use in speed breeding.
- **Photoperiod:** A photoperiod of 22 hours of daylight followed by 2 hours of darkness has been demonstrated to be effective in speed breeding protocols.
- **Temperature:** Speed breeding is conducted at a temperature of 22 degrees Celsius during the day and 17 degrees Celsius at night.
- **Humidity:** Maintaining a humidity level of 60-70% is essential in the execution of speed breeding programs.

Achievements

The Single Seed Descent (SSD) method is a commonly employed approach in speed breeding, particularly for handling large segregating populations over multiple generations to develop homozygous lines with fixed traits. This method is crucial in cultivar development, necessitating high-density plantings. Speed breeding facilitates rapid cycling with healthy and viable seeds by increasing sowing density. Research conducted by Watson and Ghosh on wheat and barley demonstrated that, even with high sowing density, all plants produced spikes with sufficient seeds for SSD. This underscores the significance of high-density planting under speed breeding conditions to cultivate plants suitable for efficient and resource-effective generation turnover in SSD programs

Moreover, the application of speed breeding has led to the development of six generations per year in plants such as wheat, barley, and chickpea without the need for embryo rescue (Figure 1). The premature harvest of barley and wheat seeds produced under speed breeding, performed two weeks post-anthesis, followed by a brief drying period, has been shown to result in uniform germination rates and the production of healthy plants at an accelerated pace. Additionally, efforts have been made to design a low-cost bench-top growth cabinet for trialing

speed breeding, aiming to enhance the accessibility and applicability of this innovative method.

Future aspects

The introduction of various genome editing technologies such as CRISPR and Genomic Selection (GS) has marked significant strides in plant breeding. However, incorporating speed breeding into these genome editing technologies holds the potential to revolutionize the field further. The flexibility offered by speed breeding allows for the exploration of new allelic diversity and the preservation of extinct or endangered cultivars by leveraging gene banks. Given the inverse relationship between genetic gain and the length of the breeding cycle interval, the integration of genomic selection and speed breeding approaches could expedite the process of gene bank mining, paving the way for more efficient and impactful advancements in plant breeding.

Challenges

- The success of Speed Breeding (SB) in short-duration crops may pose a challenge, as it requires a photoperiod shorter than the critical day length needed for flowering.
- Plants exhibit rhythmic patterns in gene expression and metabolism corresponding to the day-night cycle, regulated by the internal circadian clock. The adaptation of some crops to diurnal and nocturnal light influencing clock gene expression levels could be a hindrance.
- The next challenge lies in adapting the speed breeding approach for use in farmers' fields.
- The cost associated with the SB approach, starting at tens of thousands of dollars, may present a challenge for its widespread implementation in various projects.
- The generation cycle of a plant depends on factors such as variety, light duration, sunlight intensity, and soil climate, necessitating multi-location trials with the proper protocol. Alternatively, developing and trialing plant varieties that align

with speed breeding standards is crucial.

- The changing climate, driven by factors like increased carbon dioxide concentration, poses a challenge for plant breeders as it directly or indirectly affects plant yield. However, adapting speed breeding to cope with the consequences of climate change presents both potential and challenges in the field of plant breeding.

Conclusions

The success of speed breeding in staple cereal crops such as wheat, barley, and chickpea, showcasing higher genetic gains and improved yield performance, is a notable achievement. However, the extent of its success in common horticultural crops like fruits and vegetables remains a subject of curiosity for the world. Speed breeding has demonstrated more robust simulations than genomic selection, achieving a high rate of genetic gain in its targeted crops. Addressing the significant challenge posed by the prolonged duration of varietal development, speed breeding offers a ray of hope for the development of unique breeding strategies. Its success suggests the potential for program redesign in the field of plant breeding, simplifying challenges and seizing opportunities that may arise along the path of innovation in breeding methodologies.

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COMPACT DISKS MAKE A BOUNCEBACK WITH 1.6 PETABIT DATA STORAGE

“Why can’t we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?”

Richard Feynman, Nobel Laureate & Father of Nanotechnology

Whether you are on the family trip, or want to record the sweet memories of your marriage, or honeyed moments spent with your better half, or mesmerizing ticks of your first child, or your important documents to business records, everything require storage and need to be managed digitally. In this world of digitization, data storage capacity has always been a major concern. Data storage devices have evolved drastically from being large trunks with the capacity to hold few kilobytes of data, to microchips able to hold a few gigabytes of data. In a world where the amount of data generated and consumed is growing at an unprecedented pace, the need for efficient and reliable data storage has become more critical than ever before. The ability to safely store and retrieve information digitally is now essential in almost every aspect of modern life.

In the digital age, the amount of data being generated, processed, and stored has increased exponentially. As a result, storage devices have become a crucial component of our daily lives, from the computers and smartphones we use to the cloud servers that power the internet. The evolution of storage devices has been remarkable, with



Credit: copilot.microsoft.com

technological advancements enabling us to store more data in smaller and more efficient formats. This article explores the history of storage devices, their evolution, and the current state of the art.

History of Storage Devices

The evolution of storage devices is a fascinating journey through the history of data processing and computing technology.

Punch Card

Punch cards, also referred to as punched cards, Hollerith cards, or IBM cards, are paper cards where data and instructions are represented by holes punched in specific positions. These holes can be created manually or by machine. The concept of using punched cards dates back to 1801 when Joseph Marie Jacquard invented a loom that used punched cards to automate complex weaving patterns. In 1890, Herman Hollerith improved this technology for data processing with his tabulating machine. IBM played a crucial role in the development of punched card technology by standardizing the 80-column punched card in 1928, making it essential for data input, output, and storage in early computing systems.

Data entry on a punched card, as shown in the picture above, involves punching holes in each column, with each column representing one character. A typical punched card had 80 columns, allowing it to store 80 bytes of information. Once the card is filled or the Return key is pressed, the card “stores” the information. Since each card holds a limited amount of data, writing a program using punch cards (with one card for each line of code) required a

stack of punched cards. Storing 5MB of data typically required 62,500 punched cards. One of the greatest concerns for users was dropping the cards. If the cards were dropped or became disordered, it could take days or weeks to reorganize the program. By the 1940s, punched cards had become crucial tools for programming and data handling in pioneering electronic computers such as the ENIAC (Electronic Numerical Integrator and Computer), laying the groundwork for modern data processing and computing technology.

Magnetic Tape and Disk Storage

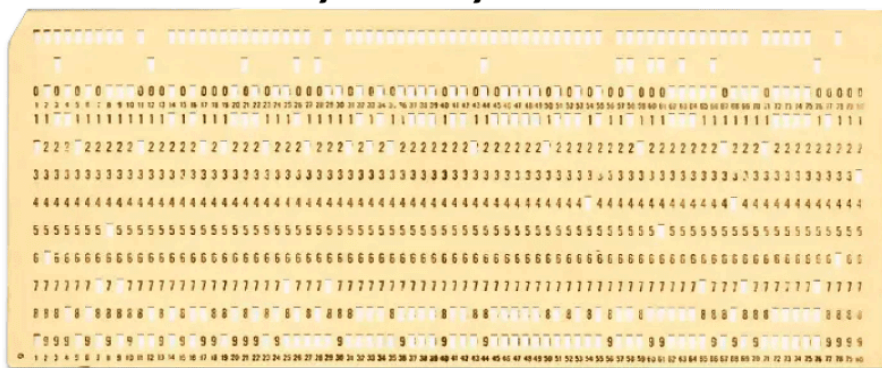
In the 1950s and 1960s, magnetic tape and disk storage emerged as revolutionary technologies. Magnetic tape was a thin strip of plastic coated with magnetic material, and it was used to store data sequentially. This method of data storage was particularly suited for the era’s computing needs, where large amounts of data needed to be stored and accessed in a linear fashion. The advent of commercial magnetic tape storage was marked by the introduction of the IBM 726 in 1952. As the first of its kind, the IBM 726 set a significant precedent in the field of data storage. It utilized a half-inch wide magnetic tape and had an impressive storage capacity of 2.3 megabytes, a substantial amount for the time. This capacity allowed organizations to store and manage their data more effectively than ever before.

In parallel, disk storage technology was also gaining traction. Unlike magnetic tape, disk storage allowed for random access to data, providing a faster and more flexible alternative. The first commercial



disk storage device was the IBM 350, which was introduced in 1956. The IBM 350 featured a stack of 50 disks, each with a substantial diameter of 24 inches. This configuration allowed it to achieve a storage capacity of 5 megabytes, which was the equivalent of storing around 64,000 punch cards. At the time, this was an impressive amount of storage, providing businesses with unprecedented capabilities to store and retrieve large volumes of data. One of the most significant advancements of the IBM 350 was its ability to allow random access to data. Unlike magnetic tape, which required data to be accessed in a linear sequence, the IBM 350 enabled users to retrieve and write data at any point on the disk. This random-access capability drastically reduced the time needed to locate and manipulate data, leading to much faster read/write speeds. The combination of these two technologies—magnetic tape for large-scale, sequential data storage and disk storage for quick, random access—laid the foundation for modern data storage systems.

Example of a punch card



The Age of the Floppy Disk & Hard Drives

By the end of the 1980s, floppy disks had established themselves as faster, more reliable, and offering greater storage capacities compared to previous storage solutions. These small, portable storage devices could be easily inserted into a computer’s disk drive, making them convenient for data transfer and storage.



The evolution of floppy disks began in 1971 when IBM introduced the first floppy disk with a storage capacity of 80 kilobytes. By the 1980s, floppy disks had become the primary storage device for personal computers. Initially, the industry standard was the single-sided 5.25-inch floppy disk, but this soon evolved into a double-sided version, which could record data on both sides, increasing storage capacity to 1,200 kilobytes, or 1.2 megabytes (MB). This progression continued with the introduction of the 3.5-inch floppy disk, known as the micro-floppy, which debuted on the market in 1982. These disks were more compact and offered several advantages over their predecessors. The initial versions of 3.5-inch floppy disks could hold 790 kilobytes of data. However, subsequent improvements led to the creation of disks with a capacity of 1.44 megabytes, which became the most widely adopted format. Although there were also 3.5-inch disks

with a capacity of 2.88 megabytes, the 1.44 MB version remained the market standard due to its optimal balance of storage capacity and reliability. By the 1990s, the 3.5-inch floppy disk had effectively driven the 5.25-inch floppy disk out of the market, becoming the dominant form of storage media. This shift was driven by the superior durability, portability, and storage capacity of the 3.5-inch disks. During this period, it is estimated that over a billion floppy disks were in use within the personal computer market, underscoring their critical role in the data storage landscape of the time.

Hard disk drives (HDDs) entered the

As technology progressed further, modern HDDs evolved to store several terabytes of data in increasingly compact and efficient forms.

consumer market in the early 1980s but did not achieve widespread prominence until the 1990s. Unlike floppy drives, which had their data-storage disk platters exposed to the air, hard drives housed their platters in an air-tight compartment. This design protected the platters from dust and other contaminants, significantly enhancing the reliability and longevity of the storage medium. Hard drives offered a substantial leap in performance compared to earlier storage technologies. They were far faster than CD-ROMs, floppy

disks, or tape backup systems, making them an attractive option for both consumers and businesses. However, the initial hard drives were quite large and had limited storage capacities, only able to store a few megabytes of data. These early models were expensive and primarily used in business environments where the cost could be justified by the need for higher data capacity and faster access times.

Over the decades, continuous technological advancements led to a dramatic surge in the storage capacity of hard disk drives while simultaneously reducing their physical size. Improvements in data density, the introduction of more precise read/write heads, and better error correction algorithms all contributed to this evolution. By the 1990s, HDDs had become standard in personal computers, offering users gigabytes of storage—an exponential increase compared to the early models. As technology progressed further, modern HDDs evolved to store several terabytes of data in increasingly compact and efficient forms. Innovations such as perpendicular magnetic recording (PMR), shingled magnetic recording (SMR), and helium-filled drives allowed for higher data densities and more reliable performance. This made hard drives indispensable for a wide range of applications, from personal computing to enterprise data centers.

The era of CDs, DVD & Blue-Ray

In the 1990s, a new storage medium called Compact Disc-Read Only Memory, or CD-ROM, gained widespread popularity. CD-ROMs are a type of write-once, read-many (WORM) storages, meaning data can be written to the disc



only once, but it can be read an unlimited number of times. These discs are optical in nature, utilizing a laser to both record and read data. This technology revolutionized data distribution, allowing companies to distribute a wide array of software and multimedia. Office productivity suites, video games, and operating system installation discs were commonly found on CD-ROMs.

Compared to the 1.44 MB floppy disks that were prevalent at the time, CD-ROMs offered a substantial improvement. They boasted a storage capacity of 650 MB, which was a significant leap forward. Additionally, CD-ROMs provided faster



data retrieval speeds, making them a more efficient and practical choice for both consumers and businesses. The increased capacity and speed of CD-ROMs facilitated the development and distribution of more complex and sophisticated software, paving the way for advancements in various fields of technology.

In 1996, Digital Versatile Disk (DVD) technology made its debut. With a substantial initial storage capacity of 4.5 gigabytes, DVDs quickly supplanted CD-ROMs as the predominant medium for delivering computer software as the 21st century began. Like CD-ROMs, DVDs rely on optical disc and WORM (write-once, read-many) technology, albeit in a significantly more advanced form.

The arrival of DVDs marked a significant advancement over CD-ROMs. Not only did DVDs offer nearly seven times the storage capacity of CD-ROMs, but they also supported higher data transfer rates, enabling faster access to multimedia

and larger software applications. This increased capacity and speed allowed for the distribution of more complex content, including high-definition video and expansive software suites, which were beyond the capabilities of CD-ROMs.

Furthermore, DVDs emerged as a versatile medium beyond software distribution, becoming widely adopted for storing and sharing digital movies, music albums, and archival data. Their compatibility with existing CD technology and the development of dual-layer discs further enhanced their utility and popularity.

The reign of floppy disks came to an end with the arrival of USB flash drives around 2000. These compact devices, based on Universal Serial Bus (USB) technology, revolutionized portable storage.

In 2003, Blu-ray Disc (BD) technology emerged as a higher-capacity evolution of DVDs. Concurrently, a rival format known as HD-DVD also surfaced, but Blu-ray ultimately prevailed in the market. While Blu-ray discs have not completely replaced DVDs as the primary medium for software distribution, they have become the exclusive content delivery format for the PlayStation 3, a gaming console developed by Sony, one of the creators of Blu-ray technology.

Blu-ray discs, also known as BD-ROMs, offer significantly greater storage capacity than DVDs, making them

increasingly popular among computer users for storing and archiving personal data. This increased capacity supports the storage of larger files, high-definition video content, and extensive multimedia collections with greater ease and efficiency compared to previous optical disc formats.

Despite their initial competition with HD-DVD, Blu-ray discs have established themselves as a robust and versatile medium, not only for entertainment purposes but also for data storage and backup needs. Their adoption in consumer electronics and computing reflects their technological advancements and growing acceptance in various sectors of digital media and information management.

USB, Flash Storage & Solid-state Drives (SSDs)

Hard disk drives made their debut in the consumer market during the early 1980s, yet it wasn't until the 1990s that they truly gained widespread recognition. In contrast to floppy drives, hard drives safeguard their data-storage disk platters within a sealed compartment, shielding them from exposure to air. This design not only enhances reliability but also prevents contamination that could jeopardize data integrity. In terms of performance, hard drives outpace other storage mediums of their time, including CD-ROMs, floppies,



and tape backup systems. Their superior speed and efficiency quickly positioned them as the preferred choice for storing and accessing large volumes of data.

The evolution of portable storage began with the introduction of floppy disks, offering a convenient means to carry and transfer data. However, the reign of floppy



disks came to an end with the arrival of USB flash drives around 2000. These compact devices, based on Universal Serial Bus (USB) technology, revolutionized portable storage. Resembling miniature hard drives but without any moving parts, USB flash drives are durable and offer a wide range of storage capacities, from modest 256 Mb sizes to several Terabytes.

Flash drives serve a dual purpose in modern computing—they not only function as portable storage devices capable of carrying diverse data types such as ebooks, music, and movies but also can be used to boot up computers, providing essential flexibility in managing digital content and system operations.

Accompanying the rise of flash drives, technology like Secure Digital (SD) memory cards has emerged, offering a compact, card-shaped alternative widely utilized in digital cameras, cell phones, and tablets. SD cards, akin to flash drives in speed and storage capacity, have become integral for capturing and storing multimedia content on portable devices.

During the same period, Solid-State Drives (SSDs) began to gain momentum as a groundbreaking storage technology. Unlike conventional Hard Disk Drives (HDDs), SSDs do not have any moving parts and use flash memory to store data. The first commercial SSD was introduced

by SanDisk in 1991 and had a storage capacity of 20 megabytes. SSDs leverage flash-based memory to deliver numerous advantages over HDDs. These include faster data access and transfer speeds, enhanced reliability, reduced power consumption, and superior resistance to physical impact—a significant benefit for portable devices and industrial applications alike. Despite their initial higher cost, these advantages have made SSDs a preferred choice for many users and industries over time.

The evolution of SSD technology has seen substantial improvements in storage capacities alongside declining prices. By the 2010s, SSDs had become a viable alternative to traditional hard drives, with faster read/write speeds, lower power consumption, and increased durability. Today, SSDs are the primary storage device for most laptops and desktops, with storage capacities ranging from a few hundred gigabytes to several terabytes.

Cloud Storage

Cloud storage involves the practice of storing data on remote servers accessible via the internet, rather than on local devices or personal computers. Cloud storage has become increasingly popular in recent years, with the growth of the internet and the increasing amount of data being generated. The benefits of cloud storage lie in its scalability, cost-effectiveness,

and accessibility, enabling users to store extensive amounts of data while providing the flexibility to access it from anywhere with an internet connection. Cloud storage providers offer different types of storage services to accommodate various data needs. Object storage, for example, is ideal for storing unstructured data like images, videos, and audio files, providing a scalable and durable repository for multimedia content. File storage, on the other hand, is suitable for structured data such as documents, spreadsheets, and presentations, facilitating organized data management and retrieval. Block storage is tailored for storing data in blocks, commonly used for database storage and supporting virtual machines, ensuring efficient and reliable performance for critical applications.

Latest development in Data Storage

Recent strides in optical data storage technology mark a remarkable resurgence in the realm of compact disks (CDs) technology. Researchers from the University of Shanghai for Science and Technology, in collaboration with the Shanghai Institute of Optics and Fine Mechanics and other institutions, have achieved a significant breakthrough: they have developed a DVD-sized optical disc capable of storing an unprecedented 1.6





petabits of data, equivalent to a staggering 200 terabytes. This achievement not only pushes the boundaries of data storage but also holds transformative potential for the future of data centers and information storage technologies worldwide. The newly developed 1.6 petabits CD resembles a DVD in size but leverages innovative techniques to achieve its extraordinary data capacity. By utilizing a light-sensitive material known as AIE-DDPR and employing a dual-laser system for data writing and reading, the researchers have achieved data densities previously unimaginable. The disc achieves this feat by encoding data across an astonishing 100 layers, with individual data spots as diminutive as 54 nanometers in width—approximately one-tenth the size of the wavelengths of visible light typically used in data reading and writing processes.

In practical terms, the storage capacity of the 1.6 petabits CD surpasses existing optical storage mediums by leaps and bounds. It boasts approximately 4,000 times the data density of a Blu-ray disc and is 24 times more capacious than the most advanced hard disks available today. To put the 1.6 petabits (Pb) capacity into perspective, 1 petabit equals 1,000,000 gigabits or 1,000 terabits, and 1.6 petabits is equivalent to 200 terabytes (TB). This massive storage capacity means a single CD could potentially hold approximately 45,000 high-definition movies (assuming an average size of 4.5 GB per movie),

over 2 million high-quality music tracks (assuming an average size of 5 MB per track), or the entire contents of large databases, making it an attractive option for archival and backup purposes.

The evolution of storage devices has been a testament to human ingenuity and technological advancement. From the early days of punch cards and magnetic drums to the current era of SSDs and cloud storage, each generation has seen exponential growth.

This leap in storage capability promises to revolutionize data storage facilities, potentially enabling the storage of an exabit (one billion gigabits) of data within a space as compact as a room, rather than the vast areas currently required, thus drastically reducing both physical footprint and energy consumption. Despite its groundbreaking potential, commercial availability of the 1.6 petabits CD remains on the horizon. Challenges remain, particularly in enhancing data writing speeds—which currently stand at about 100 milliseconds—and improving overall energy efficiency. Nevertheless, the progress made by researchers underscores a promising future for this technology, with ongoing advancements likely to pave the way for broader adoption and integration into real-world applications.

The evolution of storage devices has been a testament to human ingenuity and technological advancement. From the early days of punch cards and magnetic drums to the current era of SSDs and cloud storage, each generation has seen exponential growth in capacity, speed, and efficiency. Looking forward, the trajectory of storage technology is poised to embrace even more revolutionary developments. Concepts such as quantum computing and DNA-based storage systems are on the horizon, promising to push the boundaries of what is possible in terms of data capacity and processing speed.

In summary, the bounce back of CD technology with a data storage capacity of 1.6 petabits represents a fascinating intersection of old and new technologies. While the 1.6 petabits CD represents a monumental achievement in optical storage, it is just one chapter in the ongoing saga of data storage evolution. As researchers continue to innovate, the future holds immense promise for storage technologies that will shape how we store, access, and utilize data in the years to come.

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