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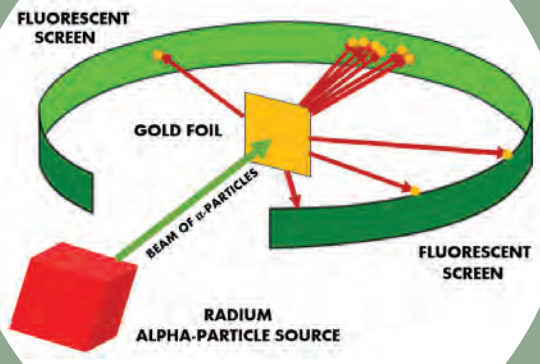

Schematic representation of Rutherford experiment

About the Journal

School Science is a peer-reviewed journal published quarterly by the National Council of Educa tional Research and Training, New Delhi. It aims to bring within easy reach of teachers and students the recent developments in the areas of science, mathematics, and environment by serving as a platform to disseminate research findings, sharing innovative pedagogies, theoretical work and other advances towards improving teaching-learning in such areas.

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Contents

EDITORIAL

In this issue, we are delighted to include articles written by experts from different fields of science and technology. These articles were presented by the experts in the Webinar Series—Listening to Learn, organised by the Department of Education in Science and Mathematics, NCERT. It was felt that the topics discussed in the webinars will be of great value to the readers of School Science journal and hence, they have been presented in this issue. The experts were kind enough to convert their webinar presentations in the form of articles.

The article 'Multilevel Contours on Complex Planes' introduces a new concept called multilevel contours on complex planes that was developed in 2021 for the benefit of students in the Higher Secondary Stage which will strengthen their understanding about geometry principles. The article on 'Nuclear Radiations and their Applications' highlights the advantages of nuclear technology and weighs the benefits it will bring than the possible problems from this technology.

Arguments based on symmetry are quite common in Physics. The article 'Reflection Symmetry in Physics' discusses about the less-emphasised symmetry and the space reflection symmetry.

India, by virtue of its rich ancient knowledge systems have contributed globally beyond measure in the field of science and technology, including mathematics. Unfortunately, such knowledge is not appreciated as much as it should be. The articles 'Snippets of Ancient Indian Mathematics' and 'The Forgotten Mathematical Legacy of Aryabhata' revisit India's landmark contributions in the field of mathematics. The former brings out the beauty and richness of studying problems from the perspectives of ancient Indian mathematics perspective while the latter brings out the pioneering contributions of Aryabhata to trigonometry.

Learning happens in the classroom but more learning happens outside of the classroom. There is so much we can learn when we step outside of the classroom or home—from the plants and animals that we see around. The article 'Learning Science from the Kitchen Garden' is a narration of experiences in a kitchen garden especially with respect to the morphology of flowering plants.

The challenges facing us due to environmental degradation is becoming more daunting by the day. Pollution of the soil, air and water or biodiversity loss are just some of the issues. The article 'Plastic Pollution: A Human Made Crisis' provides all the necessary information about plastic and its pollution. Soil pollution is another important issue that impacts not just the underground water but the whole soil ecosystem with many other implications. The article 'Soil-Water Quality Management' discusses on how to manage a polluted site.

Undoubtedly, India is now a leading player in the international space arena. We have seen several breakthroughs in the development of advanced technology in the area of space programme. Literally speaking, the sky is no more the limit! The article titled 'Indian Space Programme—A Brief Overview' takes

us to the journey India has taken in the field of space research and development.

A two-part article pertaining to all the presentations from the Listening to Learn webinars has also been included in this issue. It provides a ready-reference to access all the webinar presentations.

In addition to the articles, this issue also contains a section on Science News which provides information on the latest research findings, innovations, inventions, etc., in the area of science and technology.

We welcome your valuable suggestions. Happy reading and happy learning!

MULTILEVEL CONTOURS ON COMPLEX PLANES

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In this article, a new concept called multilevel contours on complex planes that was developed in 2021, is explained to senior high school students who are aware of the basics of real number systems and random variables. These ideas strengthen information geometry principles.

Keywords: Arcs, Contours, Length of an Arc, Continuous Functions

Introduction

Let $\mathbb{C}$ be the complex plane. Points in the complex plane are complex numbers which are defined as ordered pairs (a,b) of real numbers. Suppose $\mathbf{z}$ be a point in $\mathbb{C}$. The point $\mathbf{z}$ is denoted by,

$$z = (a,b) = a + ib \quad (1)$$

In (1), $i = \sqrt{-1}$ and the real number a is thought of as a point on the $x-axis$ and the real number b is thought of as a point on the $y-axis$ (or also called in this case as imaginary axis). The number a is called the real part of z and the number b is called the imaginary part of z. If z_1 is a complex number such that $z_1 = (a_1, b_1)$, then $z = z_1$ if, and only if, $a = a_1$ and $b = b_1$. Complex numbers gave us several insightful analyses and practically useful applications. Studying complex planes in combination with other branches of mathematics has been fascinating.

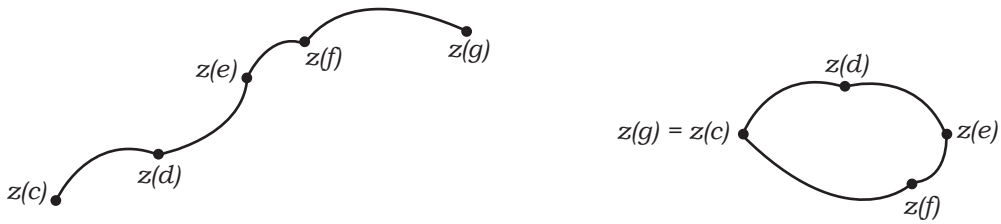
In 2021, a new concept called multilevel contours on complex planes was introduced by the author of this article and was published in 2022 with the title 'Multilevel Contours on Bundles of Complex Planes' in the *Geometry and Statistics*, Elsevier see Rao Arni SRS 2022. These news ideas were developed using geometry, analysis and probability models. Here, we learn about drawing such multilevel contours in an elementary approach.

Before we proceed to the new concept of multilevel contours, let us start with the basics of arcs and contours in complex planes.

An arc is a set of points $z = (a,b)$ in the complex plane such that:

$$z = z(t) = (a(t),b(t)) = a(t) + ib(t) \quad (c \le t \le d). \quad (2)$$

Here c and d are real numbers, $a(t)$ and $b(t)$ are continuous functions of the real parameter t. Let us denote this arc by γ. If $z(t_1) \neq z(t_2)$ for two different parameters t_1 and t_2 on the real line, then we say γ is a simple arc. If $z(c) = z(d)$ we say γ is a Jordan curve. A contour in the complex plane is defined as an arc formed by joining piecewise smooth arcs joined end-to-end of piecewise arcs formed. See Figure 1.



(a) Contour (b) Jordan Curve

Fig. 1: (a) A Contour is formed by joining four piecewise smooth arcs, $z = z(t)(c \le t \le d)$, $z = z(t)(d \le t \le e)$, $z = z(t)(e \le t \le f)$, c, d, e, f and g are real numbers. (b) A Jordan curve is formed by joining four piecewise smooth arcs, where $z(g) = z(c)$

Let L be the length of the contour that was formed by joining the piecewise arcs $z(c)$ to $z(g)$ in Figure 1 (a). The quantity L can be computed by,

$$L = \int_c^d L|z'(t)|dt + \int_d^e L|z'(t)|dt + \int_e^f L|z'(t)|dt + \int_f^g L|z'(t)|dt, \quad (3)$$

where $z'(t)$ is the derivative of $z'(t)$, and $|z'(t)| = \sqrt{|a'(t)|^2 + |b'(t)|^2}$ because $z'(t) = a'(t) + ib'(t)$. There are several textbooks available for further basics on complex numbers, arcs and contours. For example, students may refer to [Choudhary, 1992; Churchill, et al., 1984; Krantz, 2004; Pathak, 2019; Ponnusamy, 1995].

In the next few paragraphs, we will use the basics explained so far to form multilevel contours.

Let us consider five complex planes as shown in Figure 2. Suppose a complex number z_0 is chosen in $\mathbb{C}_1$ and a disk, say D_0 with a randomly chosen radius r_0 is drawn around z_0. A second random number within D_0 that is different from z_0 is randomly chosen and with another random radius, say r_1 a disk D_1 is formed with centre at z_1. An arc is constructed from z_0 to z_{01}. Similarly, a new arc is formed z_1 to z_2 by constructing a new disk D_2, and so on, to form new disks and new arcs.

When an arc, if it reaches the set $\mathbb{C}_1 \cap \mathbb{C}_5$, the next random number generated within a region $\mathbb{C}_1 \cap \mathbb{C}_5$ will have a scope to travel outside $\mathbb{C}_1$ and to reach $\mathbb{C}_2$. This travelling is possible due to creating the disks using the points in $\mathbb{C}_1 \cap \mathbb{C}_5$ and $\mathbb{C}_5$. Without having an intersecting plane $\mathbb{C}_1 \cap \mathbb{C}_5$, and not able to form arcs through the disks in $\mathbb{C}_1 \cap \mathbb{C}_5$, it is not possible to travel to $\mathbb{C}_2$ under the framework. Such piecewise arcs constructed could reach $\mathbb{C}_3$ (through $\mathbb{C}_2$) as well in a similar construction explained. We form a contour passing through more than two complex planes by joining the piecewise arcs end-to-end beginning from z_0 to z_1, z_1, and so on. A contour formed passing through multiple planes is called a multilevel contour. A more detailed description with a complete framework of the formation of multilevel contours with assumptions from

probability principles can be seen in [Rao, 2022]. More technicalities could be beyond the scope of the present article for high school students. Such multivariate contours could be associated with passing information from one plane to another and extending the ideas of information geometry to complex plane geometry. The subject of information geometry was laid out by Rao, C.R. through his groundbreaking article in 1945 [Rao, 1945]. Read articles in references [Amari, 2021 and Plastino, 2020] for understanding the impact of [Rao, 1945] in an easily understandable manner. A recent article on the role of information geometry and complex planes in virtual tourism can be found in [Rao and Krantz, 2020].

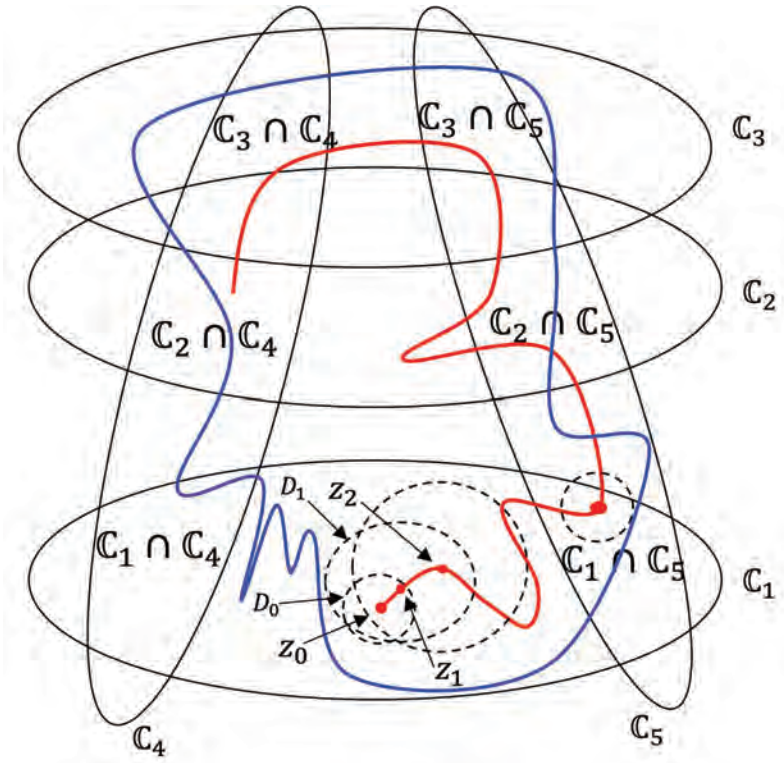


Fig. 2: Formation of multilevel contours passing through complex planes

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NUCLEAR RADIATIONS AND THEIR APPLICATIONS

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Atoms are tiny building blocks of matter that make up everything. The central part of the atom is called nucleus and the electrons revolve around it. The nucleus has protons that are positively charged while the neutrons are neutral. Electrons revolve around the nucleus in different orbits. In the year 1909, a famous scientist Ernest Rutherford, performed an experiment where alpha scattering on thin gold foil was studied and showed that almost entire mass of the atom is concentrated at its centre called the nucleus. We know that the nucleus is made up of protons and neutrons and these are compactly packed together because of strong forces. When some nuclei are not stable, they change and give off particles or energy. This helps them become stable. The time it takes for half of the atoms to convert into new more stable ones is called half-life. Marie Curie found out about radioactivity. She showed that there are three main types of radiation: alpha, beta and gamma. These types have many applications in medicine and other fields. In medicine, radio-isotopes help us to see inside the body. Technetium-99m is an example and has many applications in medical sciences. Radiation is also used to keep the food safe and clean by the process called food irradiation. Sometimes, people think radiation is not good for food but this is not the case. Caution needs to be taken to irradiate the food with controlled amount of radiation as prescribed by regulatory bodies. There are always risks with different activities we do, like making electricity from oil, coal, solar and nuclear energy. While we can't get rid of all risks, we try to make them as small as possible. The nuclear industry follows strict safety rules to reduce risks. Nuclear technology, in general, helps in medicine, industry, agriculture, energy and research. We must understand that nothing we do is completely risk-free but we want the benefits from nuclear technology to be higher than the possible problems. We need to educate people about the benefits of the nuclear radiations and use it safely for the benefit of mankind.

Keywords: Nuclear Radiation, Nuclear Technology, Nuclear Medicine, Sustaibaible Nuclear Energy, Radiation theraphy

Introduction

An atom is full of surprises. It has a structure that comprises a tiny central nucleus surrounded by electrons. The nucleus, has a very small size ($\approx 10^{-14}$ m) consisting of protons and neutrons. The protons carry positive charge and neutrons are electrically neutral. Negatively charged electrons orbit the nucleus in specific energy levels or electron shells. Ernest Rutherford, an eminent physicist, conducted the groundbreaking alpha-particle scattering experiment in 1909, revealing the nucleus as the central part of the atom, challenging the prevailing 'plum pudding' model proposed by J. J. Thomson. The nucleus, with most of the mass of the atom and positive charge is concentrated at the centre with electrons orbiting in energy levels. Protons are positively charged while neutrons are neutral, both protons and neutrons are called nucleons. These are held together by strong nuclear forces inside the nucleus. The nucleus is responsible for nuclear reactions, while electrons play a role in chemical reactions. In the realm of nuclides, the pursuit of their lowest energy

state leads to a stable nucleus. Unstable nuclides undergo radioactive decay. A typical nucleus is represented by the symbol ${}^{A}_{Z}X$, where X refers to the chemical symbol of the element, A is the atomic mass number which is equal to the sum of neutron number (N) and proton number (Z) inside the nucleus. For stable nuclides with lower atomic masses, the number of neutrons approximately equals to the number of protons. However, as the atomic mass number 'A' increases, stability necessitates a greater ratio of neutrons 'n' to protons 'p,' more than unity, to counteract electrostatic repulsion caused by an increased number of protons, requiring additional nuclear forces. A typical plot of atomic number (Z) versus neutron number (N) is shown in Fig. 1. Furthermore, excess energy can render the nucleus unstable, leading to an excited state. For instance, adding a neutron to ^{238}U results in an excited nuclide ($^{239}U^{*}$), which eventually transitions to a stable state by undergoing radioactive decay emitting radiation.

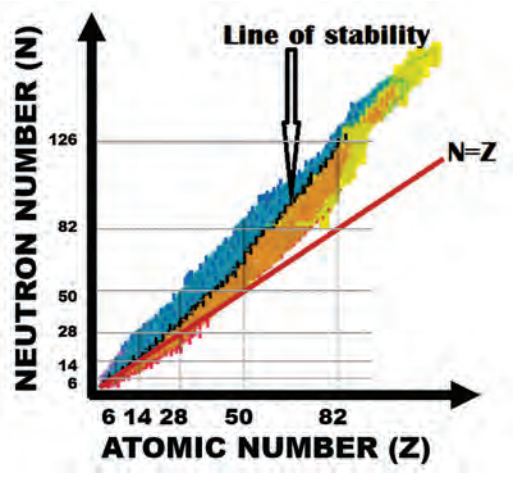

Fig. 1: A plot of proton versus neutron number of nuclides

Henry Becquerel conducted a study in 1886, in which he observed the effects of light on uranium salt. To his surprise, he discovered that the salt emitted radiation spontaneously, affecting photographic plates. This groundbreaking revelation led to the identification of the phenomenon now known as 'radioactivity'. The process of spontaneous radiation emission from a sample is termed 'radioactive decay'. Becquerel's significant contributions to the discovery of natural radioactivity were acknowledged and honored with the Nobel Prize in Physics in 1903. His pioneering work in this field opened the doors to a deeper understanding of atomic and nuclear processes and laid the foundation for further research in radiation and nuclear physics. [Singh, et al. 2022]

Radioactive decay is a natural and spontaneous process wherein certain unstable atomic nuclei undergo transformations to achieve more stable configurations by emitting electromagnetic radiation or particles. In the field of nuclear physics, a diverse array of nuclei has been extensively studied, revealing intriguing properties. When analysing the neutron and proton numbers of naturally occurring nuclei, these tend to cluster around a stability line. Nuclei positioned away from this line often exhibit radioactive behaviour, decaying to attain stability via emission of alpha, beta particles or gamma radiations or undergoing electron capture. Throughout decay, the unstable nucleus emits radiation eventually transmuting into a different nuclide with improved stability. The concept of half-life holds immense significance as it serves to predict decay rates and indicates the time required for half of the radioactive atoms in a sample to undergo decay, representing a

unique property for each radionuclide. The half-life of radiaoactive nuclides is pivotal in measuring decay rates, determining artefact and geological formations' age and managing radioactive waste. Moreover, it plays a crucial role in nuclear medicine, ensuring the efficacy and safety of radiopharmaceuticals utilised in medical imaging and cancer treatment.

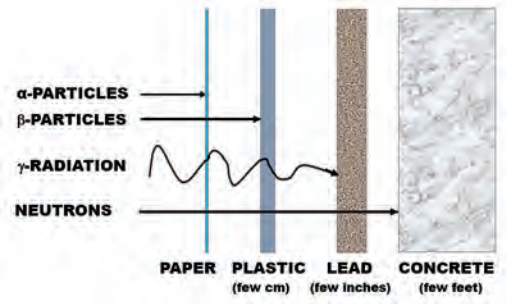

Fig. 2: Depth of penetration in different materials

Radiation, in general, refers to energy in the form of waves or particles. It can exist as waves or particles and is classified into ionizing and non-ionising radiation. In nuclear science, common types of radiation emitted from the nucleus include alpha particles, beta particles, gamma rays and neutrons. Additionally, X-rays are often associated with nuclear radiation due to their electromagnetic nature and ability to penetrate through materials, even though their origin lies in the de-excitation of atoms. However, not all types of radiation fall under the category of nuclear radiation. Each type of radiation exhibits different penetration capabilities into materials. Alpha particles can be stopped by a thin sheet of paper, while beta particles can be stopped by a few centimeters of plastic. Gamma radiation, on the other hand, can penetrate several inches of lead and neutrons possess the highest penetration capability, reaching a few feet within concrete. For the purpose of nuclear radiography, Fig. 2, illustrates the distinguishing capabilities of alpha, beta, gamma and neutron radiation, based on their depth of penetration in different materials. This figure also helps in understanding various radiation types and their respective penetrating abilities into materials.

The influential study of the effects of electrical and magnetic fields on radioactive emissions was undertaken by the renowned scientist, Marie Curie. Interestingly, the term 'radioactivity' was coined by Marie Curie in 1898 while conducting investigations into this phenomenon alongside her husband, Pierre Curie. During their experiments, they allowed the emitted radiation from uranium salt to pass through a magnetic field, leading to the observation that one type of particles was deflected in one direction, while another type of particles was deflected in the opposite direction. Some radiation remained unaffected. Subsequently, these distinct types of radiation were named alpha, beta and gamma radiation. Fig. 3, illustrates the effect of the magnetic field on the emitted radiation from uranium salt.

The study of radioactivity encompassed various substances and materials and Marie Curie's groundbreaking research revealed that pitchblende exhibited higher radioactivity than uranium. This discovery led her to hypothesize the presence of other radioactive elements. Later, she successfully isolated two unknown elements, polonium and radium, both displaying higher radioactivity than uranium. In recognition of their significant contributions, Marie Curie and her husband, Pierre Curie were jointly awarded the Nobel Prize in Physics in 1903 and the Nobel Prize in Chemistry in 1911. During her extensive

research, Marie Curie was exposed to a considerable number of radioactive materials and her health was seemingly disregarded in her later years. Spending long hours daily in the pursuit of her scientific endeavours, she may have fallen victim to the adverse effects of radioactivity, potentially leading to blood cancer. Tragically, she passed away at the age of 66 on 4 July, 1934, in a hospital in France. Her research works, books and even her cookbook, which are highly radioactive, are carefully stored in lead-lined boxes for safety. Anyone wishing to view her works is required to wear protective masks to minimize exposure.

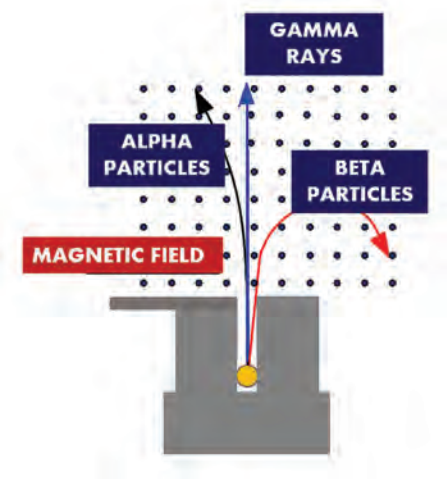

Fig. 3: Deflection of different types of radiations in a magnetic field

As already mentioned, the radioactive elements undergo a process called radioactive decay, wherein their unstable nuclei spontaneously transform into more stable forms, releasing radiation in the form of alpha particles, beta particles and gamma rays. The decay rate is quantified by the half-life, representing the time required for half of the original sample of radioactive atoms to decay. Various naturally occurring radioactive elements possess distinctive half-lives. Uranium-238, with a half-life of approximately 4.5 billion years, are found in the Earth's crust, rocks and minerals, and play a crucial role in radiometric dating and nuclear power generation. Potassium-40, with a half-life of about 1.25 billion years, is present in rocks and soils, and is vital for geological dating. Carbon-14, with a half-life of approximately 5,730 years, is produced in the atmosphere and is widely utilised in carbon dating for estimating the age of archaeological remains. Tritium or hydrogen-3, with a half-life of around 12.3 years, is formed in the atmosphere and nuclear reactors, serving as a valuable tracer in environmental research.

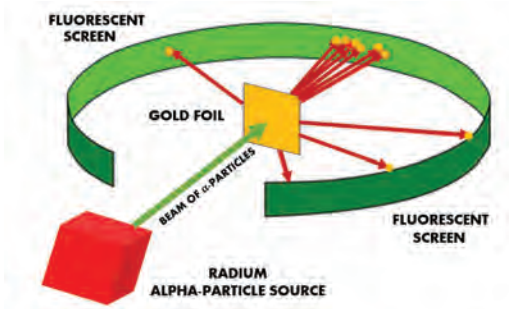

Fig. 4: Schematic representation of Rutherford experiment

In 1909, a renowned team led by Ernest Rutherford, along with Ernest Marsden and Hans Geiger, conducted the iconic alpha scattering experiment at Victoria University in Manchester, England. Rutherford and his team designed an ingenious setup, aiming to explore the structure of the atom, particularly the distribution of positive charge within it. The experiment involved bombarding alpha particles from a radioactive source on a thin

gold foil. Alpha particles, which are positively charged and relatively massive, were incident on to a thin foil of gold. A screen coated with a light-emitting material was placed behind the foil to detect the behaviour of the alpha particles after passing through it. A typical layout of the Rutherford's experiment is presented in Fig. 4. The results were striking and unexpected, defying the predictions of the existing 'plum pudding' model, which assumed a uniform distribution of positive charge within the atom. Most of the alpha particles passed straight through the gold foil, as anticipated. However, what surprised them were the few alpha paricles that were significantly deflected at large angles and a small fraction even bounced directly backward. These findings challenged the prevailing model and led to groundbreaking conclusions. This groundbreaking experiment led to the discovery of the atomic nucleus. Rutherford's reaction to the results was famously expressed as, "It was as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you." This unexpected outcome could only be explained by the assumption that the atom's nucleus, containing nearly all its mass and positive charge, is concentrated at the centre. By that time, significant advancements had already been made in understanding alpha, beta and gamma radiations. According to the current knowledge about atoms, a small, positively charged nucleus composed of protons and neutrons exists at the centre of an atom. Electrons orbit around this nucleus in various energy levels or orbits. This fundamental understanding of atomic structure has laid the groundwork for further advances in nuclear physics and chemistry, shaping our comprehension of matter and the universe.

The process of radioactive decay follows statistical laws, wherein a certain number of radioactive nuclei will become half in quantity after a specific time interval, known as the half-life. This phenomenon continues in subsequent half-lives, resulting in a rapid reduction of undecayed nuclei. Approximately six half-lives lead to a diminishment of the original nuclei count to a negligible 1.5 per cent of its initial value. The time required for the number of nuclei to halve is referred to as the 'half-life' of the radioactive substance. It's important to note that this statistical nature of decay is applicable only when considering a significant number of nuclei. Radiation exposure can arise from both natural and man-made sources [Krane, 1987]. In our daily lives, we encounter radioactive substances through dietary intake, water consumption and breathing air. Common natural sources of radiation include cosmic rays, solar radiation, radon, living organisms, soil and rocks. Conversely, man-made sources encompass activities such as medical and dental X-rays, nuclear and coal power plants, smoke detectors and various industrial, research, and university laboratory applications. Examples of natural radioactive sources and their respective half-lives include ^{238}U, found in soil, with a half-life of 4.5 billion years; ^{40}K, present in living organisms (humans, plants, trees) with a half-life of 1.3 billion years; and 3H (tritium), occurring in water with a half-life of 12.0 years. Each sample of radioactive substance exhibits distinct half-life values, which allow for valuable applications like carbon dating to determine the age of once-living objects. The ratio of ^{14}C to ^{12}C in living organisms provides insights into their lifespan once the supply of ^{14}C ceases.

In medical applications, common radioactive substances like ^{131}I (used in thyroid treatment) with a half-life of 8 days; ^{99m}Tc (used in nuclear medicine) with a half-life of 6 hours; and ^{198}Au (used in tumour therapy) with a half-life of 2.7 days are employed. Medical practices utilise both gamma radiation and emitted particles for various purposes. The slowing down of energetic charged particles within a medium is influenced not only by the medium's nature but also by its stopping power on the particles. For instance, in air, alpha particles with 3 MeV energy have a range of ≈ 2–3 centimetres, while beta particles of the same energy can traverse up to 10 metres in air. The Bethe-Bloch relation indicates that as monoenergetic charged particles enter a medium, their energy decreases, leading to an increase in the stopping power per unit path length due to ionization. This stopping power reaches a maximum and drops abruptly to zero at the boundary. At this boundary, the particles lose the maximum energy. Plotting the energy loss per unit path length as a function of depth in a medium result in the Bragg curve, Fig. 5. Such insights are crucial in understanding radiation interactions and are applicable in various scientific and medical contexts.

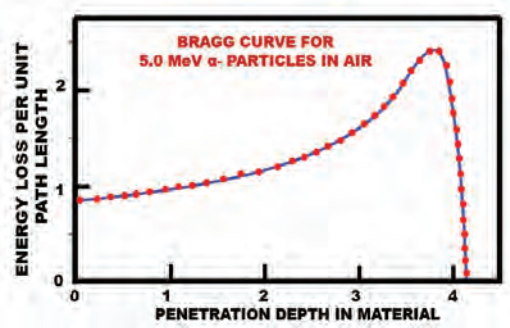

Fig. 5: A typical Bragg curve indicating maximum energy deposition towards the end of range

In Fig. 6, the plot of energy loss per unit path depth within a substance is shown for electrons, gamma rays and an appropriate initial energy for an incident proton particle. It has been observed that the gamma rays deposit more energy in the initial part and as these penetrate the medium, the relative deposited energy decreases. On the other hand, for the incident particle, the maximum energy is deposited towards the end of its path and the minimum relative deposited energy is towards the front of the medium. The Bragg curve holds significant importance in proton therapy, a form of cancer treatment that utilises a linear accelerator. This curve allows for precise energy deposition at a specific depth, as most of the energy is deposited towards the end of the range, with no excess energy beyond the target depth. Moreover, it results in relatively low energy deposition in the front part of normal tissues. This precise targeting of tumours enables the delivery of a high radiation dose to the tumour area, making the treatment more efficient.

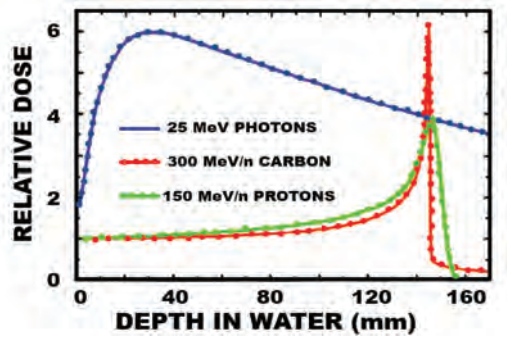

Fig. 6: Maximum energy is deposited towards the end of range for charged particles.

In the field of medical applications, different forms of radiation find use in both diagnosis and treatment. X-rays, commonly employed in radiographs, fluoroscopy, CT scans,

dental X-rays, mammograms and more, are utilised for imaging and involve low to moderate radiation exposure for short durations. In therapeutic applications, higher radiation doses are administered based on specific treatment needs. Nuclear medicine is one such therapeutic application, where radioisotopes are injected into the body and emitted gamma radiation is analysed via computer systems to detect tumours or assess the functioning of internal organs. An important radioisotope in nuclear medicine is Technetium-99m (^{99m}Tc), which acts as a radioactive tracer in over 80 per cent of nuclear medicine diagnostic procedures. The decay scheme of ^{99m}Tc is shown in Fig. 7. With a half-life of approximately 6 hours, Technetium-99m is well-suited for investigating various physiological processes and is rapidly cleared from the body. Emitting 140 keV gamma rays, it produces sharp and easily detectable images with gamma cameras. The use of ^{99m}Tc scans is crucial in diagnosing injuries, infections, tumours, heart diseases, thyroid disorders, kidney conditions and certain cancer processes. In the broader context, radiation oncologists consider factors like energy, particle type and contact time with the administered radioisotope to plan medical diagnosis and treatment. Beyond medical applications, nuclear radiation finds use in diverse areas such as industrial and manufacturing processes, food irradiation, consumer product safety, reactors, research applications, power supply in spacecraft and more all contributing to human welfare worldwide. It is essential to recognise varying levels of radiation hazards associated with different forms of radiation and the differing sensitivity of body tissues to various radiation types. Radiation oncologists diligently assess these factors to achieve the desired treatment outcomes.

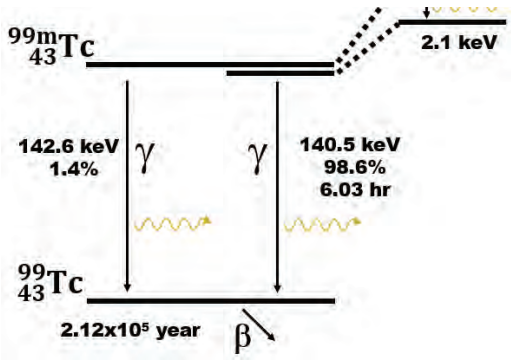

Fig. 7: Decay scheme of $^{99m}_{43}$Tc

As previously mentioned, nuclear radiation finds applications in the manufacturing industry for testing and measurement purposes. During production, radiation is utilised to accurately measure the thickness of various materials such as metal sheets, aluminum foil and paper. Measuring the thickness of very thin sheets or foils using traditional tools like vernier calipers or screw gauges becomes challenging due to their small increments, often in the range of 0.01 mm and 0.001 mm. However, with nuclear radiation techniques, precise measurements of extremely small thicknesses become possible. These radiation-based techniques are also employed for measuring wear on cutting and drilling tools, offering valuable insights into tool performance and longevity. Additionally, radiation is used to determine the amount of adhesive on postage stamps and to measure the liquid level in containerised beverages during the canning process. For automated container filling operations, a radiation source is positioned on one side, and the intensity of radiation is monitored

on the other side. As soon as the container is filled to the desired level, the radiation source is electronically moved, allowing the next container to take its place. This process ensures accurate and efficient container filling, as depicted in Fig. 8.

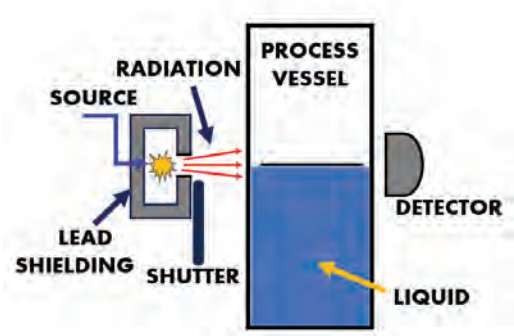

Fig. 8: Filling of liquid vessels being checked by radiation

As responsible and informed individuals, it is crucial to debunk common myths surrounding nuclear radiation and educate the public about its benefits. One such myth is the belief that irradiated food is dangerous and radioactive but, nuclear radiation effectively kills harmful bacteria and organisms in food, making it safe for consumption without rendering it radioactive or harmful [Diehl, 2002]. It is important to note that we are exposed to various forms of radiation in our daily lives such as from the air we breathe and the food we eat. Medical procedures involving radiation like X-rays and MRI scans, utilise low-level radiation that poses no long-term health risks or adverse effects to patients. Another misconception is related to nuclear power plants emitting dangerous levels of radiation and causing cancer in their vicinity. However, the truth is that a person receives minimal radiation exposure, approximately 0.01 millirem per year, within 50 miles of a nuclear power plant. Natural sources like the sun and rocks, expose us to about 300 millirem per year, far more than nuclear power plants. Even coal-fired power plants emit a slightly higher amount of radiation, around 0.03 millirem, due to uranium and thorium content in the coal. Nonetheless, the radiation from all these sources is very low and poses no cancer risk.

An important radioisotope, Plutonium-238, is a potent alpha particle source with 5.593 MeV of decay energy, making it ideal as a heat source (battery power) for delicate electrical components in satellites through its decay process. This isotope is produced from uranium in nuclear reactors and is a byproduct of nuclear energy and weapons production. It is 87.7 years half-life that makes it a reliable long-term battery power source. For instance, nuclear-powered pacemakers use a small amount of Plutonium-238 to generate electrical impulses that stimulate regular heartbeats in patients with irregular or malfunctioning natural electrical pacing systems. A pacemaker of Medtronic company that employs 238Pu radiactive source is shown in Fig. 9. These nuclear batteries offer extended life but cannot be buried with individuals due to the radiation risk. Nonetheless, they have revolutionised medical technology and significantly improved patients' lives. Understanding nuclear radiation and its applications allows us to make informed decisions and harness its safe use across various fields [Cutter, 2009]. Dispelling myths helps promote the responsible and beneficial use of nuclear radiation for the betterment of society.

Fig. 9: The picure of the pacemaker of Medtronic company that employs 238-Plutonium radioactive source

Radiation plays a crucial role in ensuring food security and preservation, addressing the significant issue of contaminated food causing illnesses and deaths worldwide. Each year, around 600 million people fall sick due to consuming unsafe food, resulting in approximately 420,000 deaths and the loss of 30 million healthy life years. This poses a significant economic burden, with low and middle-income countries facing an annual loss of about 100 billion US dollars in productivity and medical expenses. The impact is particularly severe on children under five years, accounting for 40 per cent of foodborne disease-related deaths, amounting to 130,000 fatalities annually. This not only strains healthcare systems but also affects national economies, tourism and businesses, hindering social and economic development. Apart from contamination issues, a considerable amount of food is lost globally due to pests, bacteria and spoilage after harvest, accounting for around 25 per cent of the world's food production. In the US alone, this leads to an annual economic loss of 10–15 billion dollars. Globally, approximately 14 per cent of produced food is lost between harvesting and retail sale, causing a loss of about 400 million dollars each year. Moreover, food losses and waste contribute to around 10 per cent of total greenhouse gas emissions, leading to the wastage of valuable land and water resources.

To address these challenges, food irradiation offers a valuable solution with various applications. It inhibits the sprouting of items like onion, ginger, garlic and sterilises insects in grains, pulses and dried fruits. The benefits of food irradiation are evident in reducing foodborne disease incidents, improving the global food supply and enhancing the quality assurance levels in domestic markets. During the food irradiation process, precautions are taken to control the dosage to food, damaging the DNA of pests and pathogens that spoil food and inhibiting their sprouting or reproduction. Importantly, nutrients, proteins, carbohydrates and fats in the food remain unaffected and there is no alteration in taste. As an example, strawberries, a valuable crop in regions like Mahabaleshwar, Uttarakhand, Punjab, Himachal Pradesh, and northeastern states of India, have a short shelf life and quickly deteriorates. Studies have shown that both gamma and electron beam irradiation can effectively preserve strawberries during storage, extending their shelf life by three weeks or more. By harnessing food irradiation, we can address critical food security challenges, reduce foodborne illnesses and ensure a safer and more sustainable food supply for the global population.

Fig. 10: Irradiation treated strawberries, with radura symbol

There is a common misconception surrounding irradiated food, often leading to concerns about its nature. However, it is crucial to understand that other food processing methods also bring about similar changes. When we heat, microwave or fry food, it undergoes transformations, just like irradiation. The effects of irradiation on food are not fundamentally different from these common cooking methods. To ensure consumers can make informed choices, it is essential to look for the 'radura' symbol when purchasing irradiated food. Regulatory bodies mandate the display of the 'radura' symbol and the statement "Treated with radiation" on packaged food items and wholesale containers of unpacked food items. Moreover, placards should be visible at the point of purchase for fresh produce and on invoices for irradiated materials and products sold to food processors.

India has several facilities for food irradiation, utilising three different types of technologies: electron beams, X-rays and gamma rays. Electron beam irradiation, for instance, accelerates a beam of electrons toward the food, acting like a steriliser. However, its limitation is that electrons can only penetrate slightly more than an inch into the food; meaning treated food should not be thicker than that. In such cases, two opposing beams can treat the food from both sides, doubling the thickness that can be treated. Importantly, electron beam irradiation does not require radioactive materials, making it easily controllable and safer, without the need for thick walls, control pools or handling of radioactive substances. Understanding the benefits and safety measures surrounding food irradiation is essential in making informed decisions about the food we consume. By dispelling myths and promoting proper information, we can ensure food security and safety for everyone.

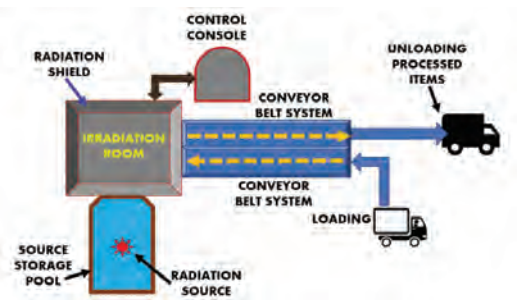

Fig. 11: A typical block diagram of food irradiation facility

The X-ray irradiation facility utilises advanced machines like those used in hospitals and dental clinics for taking X-ray images. These powerful X-rays can penetrate thick food packets, but to ensure safety, these require appropriate shielding. On the other hand, gamma rays have been effectively used for sterilising medical, dental and household products for over four decades, as well as for cancer radiation therapy. The advantage of gamma rays lies in their ability to penetrate several feet into food items without making them radioactive. These gamma rays are

emitted from a non-radioactive source, usually a 'pencil' made of non-radioactive cobalt-59 (^{59}Co), which is converted to radioactive cobalt-60 (^{60}Co) by bombarding it with neutrons in a reactor. Due to the continuous radiation emission from cobalt-60 (with a half-life of 5.27 years), the source can be safely stored in a storage pool, sealed for protection. According to the Department of Atomic Energy (DAE), Government of India, gamma irradiation effectively addresses the concerns of food producers and exporters. The high energy of gamma rays allows for the irradiation of spices even after packaging, regardless of the carton size, ensuring no contamination occurs when the package is opened. While it is true that like any food processing method, irradiation may increase the cost of food, with its widespread adoption, the cost is expected to decrease over time. Comparatively, specific food irradiation facilities may have slightly higher costs compared to other common fruit treatments like pasteurisation or small-scale steam heat treatment. Food irradiation is an essential aspect of food safety, complementing existing safety practices. It should be noted that irradiated food should be stored, handled and cooked just like non-irradiated food.

Currently, over 60 countries, including India, have approved food irradiation processing, with nearly 500,000 metric tons of food products being irradiated annually worldwide. Food irradiation has been approved and utilised in numerous countries worldwide to ensure food safety and preservation. Some of these countries include the United States, Canada, Australia, Japan, China, Brazil, Argentina, India and many European nations. In the United States, the Food and Drug Administration (FDA) and the US Department of Agriculture (USDA) have approved the use of food irradiation for various products such as fruits, vegetables, poultry and certain meat products. Similarly, Canada has approved the use of irradiation for a wide range of food items, including fruits, vegetables, spices and poultry. In Australia, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) regulates and approves food irradiation applications, primarily for fruits, vegetables and herbs. Japan, with its Ministry of Health, Labour and Welfare (MHLW), has approved the irradiation of various foods, including rice, wheat, potatoes and certain fruits. In China, the approval of food irradiation is overseen by the China National Center for Food Safety Risk Assessment (CFSA), permitting the irradiation of grains, fruits and vegetables. Across South America, countries like Brazil and Argentina have also embraced food irradiation to enhance food safety and extend shelf life. In India, the Food Safety and Standards Authority of India (FSSAI) regulates and approves the irradiation of various food products, including spices, onions and potatoes. European countries, including Germany, France, the United Kingdom and the Netherlands, have also approved food irradiation for specific applications such as herbs, spices and certain fruits. The approval of food irradiation in these countries demonstrates its widespread recognition as a safe and effective method to ensure food quality, reduce foodborne illnesses, and prevent food spoilage. By embracing this technology, these countries are taking proactive measures to safeguard public health and enhance food security for their populations.

However, it is essential to exercise caution and avoid excessive irradiation, as it can

make food radioactive like how anything burns if left in an oven for too long. In the context of human life, there is always some level of risk associated with various activities, including electricity generation from oil, coal, solar energy and nuclear energy. While risks can never be eliminated, efforts are made to minimise them. The nuclear industry maintains high safety standards to reduce risks as much as possible. In various fields such as medicine, industry, agriculture, energy and scientific research, nuclear technologies provide significant benefits to society. It is important to recognise that no human activity is entirely risk-free, and the goal is to ensure that the benefits derived from nuclear irradiation and other substances outweigh the potential harm. Our responsibility lies in educating the public about the benefits of nuclear irradiation and embracing its safe and beneficial applications for the betterment of humanity.

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REFLECTION SYMMETRY IN PHYSICS

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Arguments based on symmetry are quite common in Physics. Usually at the higher secondary stage, these involve spherical and axial symmetry. In this article, we discuss another interesting symmetry, the space reflection symmetry, that is less emphasised but can be easily incorporated in the school curriculum at that stage.

Keywords: Reflection Symmetry, Mechanics, Electrodynamics, Weak Interactions

Introduction

Arguments based on symmetry (spherical and axial) are commonly used in higher secondary physics. For example, a standard problem treated in NCERT, Class XII textbook is the calculation of electric field $\vec{E}$ outside and inside a uniformly charged spherical shell of total charge Q and radius R. We expect on the basis of spherical symmetry that the field is radial in direction (i.e., along the line from the centre of the shell O to the observation point P). Further, its magnitude can depend only on the radial co-ordinate r, but not on the angular co-ordinates θ, ϕ. Here, r, θ, ϕ are the usual spherical polar co-ordinates.

This is so since for the given problem, there is no privileged direction — all directions are on the same footing. By choosing a spherical Gaussian surface of radius r concentric with the shell, Gauss's law then gives the magnitude of electric field E to be $\frac{|Q|}{4\pi\epsilon_0 r^2}$ if $r > R$ (outside the shell) and zero if $r < R$ (inside the shell), as given in the text. At the shell itself $r = R$, there is a discontinuity at every point equal to $\frac{|Q|}{4\pi\epsilon_0 R^2} = \frac{|\sigma|}{\epsilon_0}$, where σ is the uniform surface charge density of the shell.

In the same way, to calculate $\vec{E}$ outside a long uniformly charged thin wire or the magnetic field $\vec{B}$ due to a long wire carrying a steady current, the use of axial (or cylindrical) symmetry is useful.

The electric field due to an infinite uniformly charged plane, however, involves a different symmetry (plane symmetry). Axial symmetry involves symmetry about a given direction fixed in the problem. In the case of the infinite uniformly charged plane, that axis can be any normal to the plane. This means all points and directions on the plane are on the same footing and the field must be normal to the plane at every point. The field in this case is found to be uniform throughout with magnitude $\frac{|\sigma|}{2\epsilon_0}$ but directed outward (inward) normal on either side for $\sigma > 0$ ($\sigma < 0$), resulting in a discontinuity in electric field of magnitude $\frac{|\sigma|}{\epsilon_0}$ at the plane, the same value as for the spherical shell.

This article describes another symmetry, called the space reflection or inversion symmetry, that is simple, useful and enriches our understanding of physics. We start with

This article is based on the talk 'Simple Arguments in Physics — Their Uses and Limitations' by the author on 4.3.2022 under the NCERT's Webinar Series 'Listening to Learn'.

some basic definitions and comments, and then see what this symmetry implies in a few examples.

Scalars and Vectors: Behaviour Under Reflections

We know that the scalar or vector character of each term in any equation in physics should match. We cannot add a scalar to a vector, which means one side of an equation cannot be a scalar when the other side is a vector. For example, Newton's II law of motion relates force $\vec{F}$ on the particle to the rate of change of its momentum $\vec{p}$:

$$\vec{F} = \frac{d\vec{p}}{dt} \qquad (1)$$

where each side is a vector. The II law leads to the Work Energy Theorem:

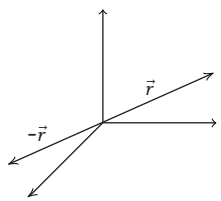
$$\vec{F}.d\vec{s} = dK\,;\; K = \frac{1}{2}mv^2 \qquad (2)$$

where each side is a scalar. The left side denotes work done by the force in the infinitesimal displacement $d\vec{s}$ and the right side is the infinitesimal change in kinetic energy K.

Let us now see the behaviour of quantities under reflection through the origin corresponding to the transformation:

$$\vec{r} \to -\vec{r} \qquad \text{Reflection (3)}$$

Here $\vec{r}$ is the position vector of a particle relative to some origin. This transformation is equivalent to changing a right-handed co-ordinate system to a left-handed one.



A. Polar and Axial Vectors

There are two types of vectors depending on how they behave under reflection. Vectors that change sign under reflection are called polar vectors. Vectors that do not change sign under reflection are called pseudo-vectors (also called axial vectors). From the definitions of the velocity $\vec{v}$, and momentum $\vec{p}$, they are obviously, like $\vec{r}$, polar vectors.

$$\vec{v} \to -\vec{v} \;\; ; \;\; \vec{p} \to -\vec{p} \qquad (4)$$

From the II law or the usual examples of forces, such as the gravitation force or Coulomb force, we infer that the force $\vec{F}$ is also:

$$\vec{F} \to -\vec{F} \qquad (5)$$

Next, see the vector product of two such vectors. Consider the vectors, orbital angular momentum $\vec{L} = \vec{r} \times \vec{p}$ and torque $\vec{\tau} = \vec{r} \times \vec{F}$. Clearly, under reflection:

$$\vec{L} \to +\vec{L}\,;\, \vec{\tau} \to +\vec{\tau} \qquad (6)$$

Thus, angular momentum $\vec{L}$ and torque $\vec{\tau}$ are pseudo-vectors. Let us next consider electric and magnetic quantities. Coulomb's law for electric field $\vec{E}$ due to a charge Q is:

$$\vec{E} = \frac{Q}{4\pi \epsilon_o r^3}\vec{r} \qquad (7)$$

Thus, $\vec{E}$ is a polar vector. Next, the Biot-Savart law for magnetic field $\vec{B}$ due to a line element $\vec{dl}$ of a wire carrying a steady current I is given by,

$$d\vec{B} = \frac{\mu_o}{4\pi}\frac{I\, d\vec{l} \times \vec{r}}{r^3} \qquad (8)$$

Since the right-hand side is a vector product of two polar vectors, the line element $\vec{dl}$ and the position vector $\vec{r}$, $\vec{B}$ is pseudo-vector.

In a similar way, we can see how other electromagnetic quantities transform under reflection using their definitions. For example, electric dipole moment $\vec{\mu}$, the polarisation vector $\vec{P}$ and electric displacement vector $\vec{D}$ are all polar vectors. In contrast, magnetic dipole moment $\vec{m}$, magnetisation $\vec{M}$ and magnetic intensity $\vec{H}$ are pseudo-vectors.

B. Scalars and Pseudo-scalars

Here again, they are two types of scalars depending on what happens to their value under reflection. We refer to scalars which do not change sign under reflection as proper scalars; those that change sign under reflection are called pseudo-scalars. In this context, the term scalar is generally taken to imply proper scalar, not pseudo-scalar.

Consider $\vec{F} \cdot \vec{v}$. It is a scalar product of two polar vectors. Under reflection, since each changes sign, the product does not change sign. So $\vec{F} \cdot \vec{v}$, which physically means power delivered by the force, is a proper scalar. Next, take the scalar product of a polar vector $\vec{E}$ and the pseudo-vector $\vec{B}$: $\vec{E} \cdot \vec{B}$. Since under reflection $\vec{E}$ changes sign but $\vec{B}$ does not, the product changes sign under reflection; so $\vec{E} \cdot \vec{B}$ is a pseudo-scalar.

In general, the scalar product of two polar vectors or two axial vectors is a proper scalar, while the scalar product of a polar and axial vector is a pseudo-scalar. On the other hand, the vector product of two polar vectors or two pseudo-vectors is a pseudo-vector, while the vector product of a polar vector and a pseudo-vector is a polar vector. These statements follow easily from the earlier definitions.

Invariance of Laws Under Reflections

The laws of mechanics and electrodynamics are invariant i.e. they retain the same FORM under reflections. This is called the reflection symmetry of the laws. Note that the quantities appearing in a law may or may not change under reflection. Invariance of the law means the equation describing the law remains the same for the transformed quantities. Another way to state reflection symmetry is that the laws look the same for right-handed and left-handed co-ordinate systems.

What this means is that the L.H.S and R.H.S of every equation always have the same character (polar or pseudo-vector) or (scalar or pseudo-scalar). This is evident in mechanics in the basic laws:

$$\vec{F} = \frac{d\vec{p}}{dt} \; ; \; \vec{\tau} = \frac{d\vec{L}}{dt} \qquad (9)$$

Note that in the first equation of (9), both sides of the equation are polar vectors. In the second equation of (9), both are pseudo-vectors. Likewise, both sides of the Work Energy Theorem (2) are proper scalars.

In the same way, we can check that the laws of electrodynamics satisfy reflection symmetry. For example, the Lorentz force law on a charge q with velocity $\vec{v}$ in external electric and magnetic fields, given by,

$$\vec{F} = q\vec{E} + q(\vec{v} \times \vec{B}) \qquad (10)$$

is invariant under reflection. To see this, note that the vector product of the polar vector $\vec{v}$ and the pseudo-vector $\vec{B}$ is a polar vector, so each term in (10) is a polar vector; hence, it retains its form under reflection. Another

familiar formula is the potential energy *U* of an electric dipole placed in an external electric field or that of a magnetic dipole in an external magnetic field is:

$$U = -\vec{\mu}.\vec{E}\ ; \quad U = -\vec{m}.\vec{B} \qquad (11)$$

We know in mechanics, *U* is a proper scalar. The right side of first equation in (11) involves the scalar product of two polar vectors, which is a proper scalar. The second equation in (11) is a scalar product of two pseudo- vectors, which again is a proper scalar. The character of both sides thus, matches, showing that (11) is reflection invariant.

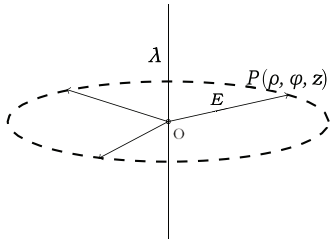
The fundamental laws of electrodynamics — the Maxwell's equations, are readily seen to be invariant under reflections. As they involve vector calculus, we will not write them down and show this explicity here.

Examples

A. Electric field outside an infinitely long uniformly charged wire

We wish to first find the direction of the electric field *E* at any point *P* in space, due to an infinitely long wire of uniform linear charge density λ.

Choose the origin *O* on the wire in the plane normal to the wire passing through *P*. The position vector of *P* is $\vec{\rho}$. There is no other relevant vector in the problem to determine the direction of $\vec{E}$. Both $\vec{E}$ and $\vec{\rho}$ are polar, so consistent with reflection symmetry, we can say that $\vec{E}$ must be along $\vec{\rho}$. That is $\vec{E} = E\hat{\rho}$, where $\hat{\rho}$ is a unit vector in the direction of $\vec{\rho}$.



What about the magnitude of $\vec{E}$? There is symmetry with respect to rotation around the wire taken to be the *z*-axis. This axial symmetry says that *E* cannot depend on ϕ. Further, since the wire is infinitely long, *E* cannot depend on *z* either. Thus, the symmetry arguments give:

$$\vec{E} = E(\rho)\hat{\rho} \qquad (12)$$

Reflection symmetry argument will not give you E(ρ) explicitly. Axial symmetry and use of Gauss's law on a cylindrical surface around the wire as its axis gives the standard textbook result:

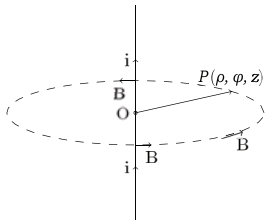
$$\vec{E} = \frac{\lambda}{2\pi \in_o \rho}\hat{\rho} \qquad (13)$$

B. Magnetic field outside an infinitely long wire carrying steady current

We wish to first find the direction of magnetic field $\vec{B}$ at any point *P* in space, due to an infinitely long wire carrying a steady current *i*. Here, a reflection symmetry-based argument again helps.

In this case, there are two relevant vectors in the problem: the line element $\vec{dl}$ of the wire in the direction of current and the radial vector $\vec{\rho}$, both polar. The magnetic field $\vec{B}$ is a pseudo-vector. The only way to get a pseudo-vector from the two relevant polar vectors is from the vector product $\vec{dl} \times \vec{\rho}$.

Taking the positive z-axis to be along the wire in the direction of current, the direction of $\vec{dl} \times \vec{\rho}$ is the unit vector $\hat{\phi}$. Thus, $\vec{B} = B\hat{\phi}$.



As before, B cannot depend on ϕ due to axial symmetry and not on z either, since the wire is infinitely long. Thus,

$$\vec{B} = B(\rho)\hat{\phi} \tag{14}$$

Again, reflection symmetry argument cannot give you B(ρ) explicitly. Axial symmetry and Ampere's law applied to a circular loop centred at the wire passing through P gives the standard textbook result:

$$\vec{B} = \frac{\mu_o i}{2\pi\rho}\hat{\phi} \tag{15}$$

Under reflection $\vec{\rho}$ changes sign, and the direction of current reverses, but $\vec{B}$ does not change its direction, since, it is a pseudo-vector.

Violation of Reflection Symmetry in Nature

One basic point needs to be noted. A symmetry in a force law does not mean say the orbit of a particle governed by that force must also show that symmetry. For example, the gravitational force on a planet due to the Sun is an inverse square force depending only on the distance between the two. Taking the Sun at the origin, the force is spherically symmetric about the origin. This does not imply that the planar orbit of a planet must necessarily be circular. In general, a planetary orbit is elliptical.

The same is true for the Coulomb force on an electron in an atom due to the nucleus at the origin. The electron orbits in an atom are in general elliptical. In more accurate terms, the quantum atomic orbitals need not be spherically symmetric functions, even though the Coulomb potential is spherically symmetric.

Similar reasoning holds for reflection symmetry. The laws of electrodynamics are invariant under reflection as seen in the section 'Invariance of Laws Under Reflection' in this article above. This does not mean that the shapes of molecules governed by electromagnetic forces must necessarily be reflection symmetric. It is well-known that there exist the so-called chiral molecules where the mirror image of a molecule is not identical to the molecule, i.e, they cannot be superposed on each other, much like our left and right hands that are mirror images of each other. Chirality is an important feature of most biological molecules. Their existence does not necessarily imply violation of reflection symmetry in the basic laws that determine their structure and shape.

The discussion in this article is rather elementary limited to some examples of laws in mechanics and electrodynamics. However, reflection symmetry is a topic of great significance in modern fundamental physics. This is because reflection symmetry is true for all basic interactions of the elementary particles of nature, except the so-called 'weak interactions' (which govern β decay and other such processes). β-decay means emission of electrons (or their antiparticles called positrons) from unstable nuclei or in other processes involving elementary particles.

That this emission violates reflection symmetry was first seen in the β decay of polarised Cobalt-60 nucleus decaying to Nickel-60. A polarised nucleus is associated with a kind of angular momentum vector denoted by $\vec{J}$. The experiment studied the direction of emitted electron's momentum $\vec{p}$ relative to $\vec{J}$. The scalar product of the pseudo-vector $\vec{J}$ and the polar vector $\vec{p}$, $\vec{J} \cdot \vec{p}$ is a pseudo-scalar. If weak interactions responsible for β decay satisfied reflection symmetry, the average value of $\vec{J} \cdot \vec{p}$ should be zero. In the experiment, this was found NOT to be zero — more nuclei emitted electrons in the direction opposite to $\vec{J}$ than in the direction towards $\vec{J}$. The discovery of violation of reflection symmetry in weak interactions is among the great discoveries in physics of the last century.

Conclusion

This article gives only one illustration of how simple qualitative arguments in physics are useful. Such arguments do not involve much mathematics but are insightful and often aid in solving problems. They, of course, have limitations and cannot be a substitute for more detailed physics.

Several other kinds of simple arguments in physics include those based on dimensional analysis, scaling, symmetry and conservation laws, counting degrees of freedom in mechanics and thermal physics, intensive and extensive nature of quantities in thermodynamics, identifying dimensionless ratios for making approximations, going to limiting cases of general equations or theories as the first check of their validity, etc. Such arguments are found at numerous places in any good introductory physics text. Some of these were briefly outlined in the talk by the author referred earlier.

SNIPPETS OF ANCIENT INDIAN MATHEMATICS

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It is important that mathematics is taught with a sense of its history. It is not as though one needs to study the history of mathematics as a separate subject. Rather, it is appropriate to bring in problems and contexts from history into the study of mathematical topics wherever feasible and relevant. This can add immensely to the appreciation and enjoyment of the subject. This article is based on a talk given on 11 November, 2022 for the "Listening to Learn" Webinar series of the National Council Educational Research and Training (NCERT). In the talk, we dealt with four problems, each of which has a connection with some topic from ancient Indian mathematics: (a) Magic squares of orders 3 and 4; (b) The mathematics of compositions and prosody, and the Fibonacci numbers, also known as the Virahanka-Gopala-Hemachandra numbers; (c) Aryabhata's kuttaka ('pulverizer') algorithm and the jugs-and-water-cups problem; (d) Brahmagupta triangles. The focus in each case was on the mathematics of the problem and not on the history; but we also touched upon the historical aspect. We have followed the same style in this article. There is great beauty and richness in studying such problems. It would have great value if high school mathematics were taught with glimpses of such gems.

Keywords: Magic square, pan-diagonal magic square, Virahanka-Fibonacci numbers, compositions, recursion, Kuttaka algorithm, Bhavana, Brahmagupta triangle

Magic Squares of Order 3

Magic squares have been known since ancient times and continue to be a source of great pleasure.

We begin by talking about magic squares of order 3. To start, we pose the following question:

In a magic square using the numbers 1, 2, 3, ..., 8, 9, what number must occupy the central square?

The wording of the question seems to suggest that there is only one possible answer. This is so. Here is an engaging and eye-opening proof of this claim found 'live' during a math club session with middle school students.

A Surprising Solution

Since 1+2+3+ ... +9 = 45, the magic sum is 45/3 = 15. Let be the central number; then is one of the numbers . Figure 1 shows what the configuration looks like:

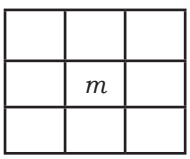

Fig. 1: Finding the central number of a third order Magic Square.

We now consider the different possibilities:

- Suppose $m = 9$. Then in the ring around the central cell, we must find the

number 8 somewhere. But 9 + 8 = 17 > 15 is already too large; the third number in the line corresponding to 9 and 8 would have to be -2 which is not permitted! Hence, this configuration cannot be successfully completed into a magic square. Therefore, the possibility $m = 9$ is ruled out.

- The same reasoning works for the possibilities $m = 8, 7, 6$. It follows that $m \neq 9, 8, 7, 6$.
- We now consider the remaining possibilities.
- Suppose $m = 1$. Then in the ring around the central cell, we must find the number 2 somewhere. But as 1 + 2 = 3, the third number in the line corresponding to 1 and 2 would have to be 12, which is too large! Hence, this configuration cannot be successfully completed into a magic square. Therefore, the possibility is ruled out.
- The same reasoning works for the possibilities $m = 2, 3, 4$. It follows that $m \neq 1, 2, 3, 4$.
- This means that $m \neq 9, 8, 7, 6$ and $m \neq 1, 2, 3, 4$.
- There is just one possibility left for the number in the central square! So, we have $m = 5$.

Armed with the knowledge that the magic sum is and the central number is , it is easy to construct the magic square:

8	1	6
3	5	7
4	9	2

Fig.2: The completed 3rd order Magic Square.

Another way of finding the central number

We now show a very different approach here to the same problem. It is worthy of close study.

Draw lines through the central square to cover all the squares (see Figure 3). Note that 4 such lines are needed. The sum of the numbers on each line is 15 (this being the magic sum of the square). Therefore, the total of these four sums is $4 \times 15 = 60$.

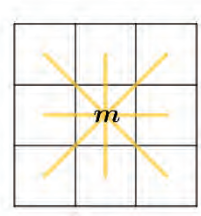

Fig.3: Another approach for finding the central number.

Now, observe that the central number is covered 4 times, as it lies on each line; the other numbers are covered exactly once each. This implies that

$60 = (1 + 2 + 3 + \ldots + 9) + 3m = 45 + 3m$

giving $m = 5$, we have obtained the same answer as earlier.

Pedagogic points to be kept in mind by the teacher

1. It is not possible to have a magic square of order two. Students should be invited to demonstrate this fact.
2. It is important that students get to see both the above proofs as they illustrate different kinds of reasoning and different approaches to proof:

   a. The first of these is proof by exhaustion (also called brute force

enumeration). In some settings this may well be the only approach available.

b. The second is more sophisticated as it depends on the use of algebra and equations, which have first to be set up.

3. There are four different arithmetic progressions in the magic square. This may provide a nice entry point into the study of APs. The topic enters in a very natural manner.

4. We noted above, after showing that the central number is 5, that the remaining cells are easy to fill in. At various points we are confronted with choices, but the different choices only lead to different orientations of the same basic design. This means that there is 'essentially just one' magic square of order three using the numbers from 1 to 9. The use of the phrase 'essentially just one' immediately points to the idea of symmetry. Therefore, playing with this most basic of magic squares introduces us to ideas of symmetry in a very natural manner.

5. Is it possible to use the basic design of the magic square of order three to make a magic square of order six, using the numbers from 1 to 36? This exploration holds great promise!

6. Is it possible to play around with the definition of a magic square and define the notion of a magic rectangle? This notion would be slightly more general than that of a magic square.

Magic Squares of Order 4

Next, we study magic squares of orders 4. Here the problem is that of arranging the numbers from 1 to 16 in a 4 × 4 square array so that the four rows, the four columns, and the two main diagonals, all have the same magic sum. Since the sum of the numbers from 1 to 16 is $\frac{16\times17}{2}$ = 8 × 17 = 156, it follows that the magic sum of such a square is 2 × 17 = 34.

Unlike the situation for the 3 × 3 magic square, where using the numbers 1, 2, ..., 8, 9 there is essentially just one design for the magic square, here we find many different designs possible. Indeed, it is a non-trivial problem to find the number of different designs.

We now look at a pair of fourth order magic squares associated with two famous historical artefacts (Figure 4).

Let us focus our attention on the magic squares in these two artefacts (Figure 5).

In Figure 6 we see the two magic squares displayed in plain text form.

Now, it turns out that all fourth order magic squares share a certain non-obvious and non-trivial property illustrated in Figure 7. But it is quite tricky to prove!

Albrecht Durer's Melencolia

Parshvanatha temple, Khajuraho

Fig. 4: Albrecht Dürer's Melencolia and Parshvanatha temple, Khajuraho. Source: [1]

Dürer's magic square

Khajuraho magic square

Fig. 5: Close ups of the magic squares. Source: [1]

16	3	2	13
5	10	11	8
9	6	7	12
4	15	14	1

7	12	1	14
2	13	8	11
16	3	10	5
9	6	15	4

Fig. 6: The two magic squares shown in plain text.

a			b
	c	d	

Fig. 7: For a 4 × 4 magic square, if *a, b, c, d* are as shown, then *a + b = c + d*. Moreover, this is true for each pair of symmetrically placed rows, columns, and diagonals!

Do these two fourth order magic squares have the property pointed out in Figure 7? Yes, they do!

For example, in Dürer's magic square we have:

$$16 + 13 = 15 + 14$$
$$5 + 9 = 13 + 1$$
$$5 + 8 = 6 + 7$$
$$6 + 11 = 16 + 1$$

And in the Khajuraho magic square we have:

$$7 + 14 = 6 + 15$$
$$2 + 16 = 14 + 4$$
$$2 + 11 = 3 + 10$$
$$3 + 8 = 7 + 4$$

But the Khajuraho magic square has additional properties — it is truly magical! We focus on one set of such properties: the pan-diagonal nature of the square. We illustrate the meaning of this in the displays shown below. Both the displays show the Khajuraho magic square, but with different numbers highlighted. In both cases, the highlighted numbers form a "broken diagonal'" — i.e., a diagonal with a 'wraparound' effect.

7	12	1	14
2	13	8	11
16	3	10	5
9	6	15	4

7	12	1	14
2	13	8	11
16	3	10	5
9	6	15	4

Fig. 8: The 'broken diagonals' add up to the magic sum.

Next, note the properties of the 2 × 2 sub-squares. For example, at the top left, we have a 2 × 2 sub-square with entries 7, 12, 13, 2:; the sum of these numbers is 34 which is the magic sum of the square. (See Figure 9.) This property holds for all the 2 × 2 sub-squares!

7	12	1	14
2	13	8	11
16	3	10	5
9	6	15	4

Fig. 9: The entries in each 2×2 sub-square add up to the magic sum.

Similarly, note the sub-squares. We find that for every such sub-square, the sum of the numbers at the corners of the square is half the magic sum of the square. (See Figure 10.)

7	12	1	14
2	13	8	11
16	3	10	5
9	6	15	4

Fig. 10: The corner entries in each 3 × 3 sub-square add up to half the magic sum.

For example, at the top left we have a 3 × 3 sub-square with corner entries 7, 1, 10, 16; observe the equalities 7 + 10 = 17 = 1 + 6. This property holds for every single sub-square!

The Khajuraho magic square is truly magical!

Who is the discoverer of this remarkable square? It is the mathematician Narayana Pandit of the 14th century. We list below some of his pioneering work on magic squares.

- His text Ganita Kaumudi describes how to construct magic squares of different orders. It also describes how to construct all possible pan-diagonal magic squares of order four. He proves that the total number of possible pan-diagonal magic squares of order four is 16 × 24 = 384. This is a non-trivial result! He also shows how to construct shapes such as circles, rectangles, and hexagons with similar properties.
- Very remarkably, he states that the purpose of studying this topic is "...to destroy the egos of bad mathematicians, and for the pleasure of good mathematicians."

An interesting insight comes when we realise that in medieval times, magic squares were truly regarded as magical. For example, in Narayana Pandit's text he states that a magic square with sum 20 is useful in cases of poisoning; a magic square with sum 28 is useful when one's paddy field is attacked by insects; and a magic square with sum 84 is useful to quieten children when they are crying.

Another insight into the nature of the Indian mind comes when we observe that combinatorial designs were of great interest in ancient India. The ancient Greeks, in contrast, were much more interested in pure geometry. (A common area of interest in both cultures was number theory).

In terms of pedagogy, the study of pan-diagonal magic squares holds the following significance:

It yields an entry point into the study of symmetry of different kinds.

It demonstrates that "trial-and-error" and experimentation are essential parts of mathematics.

The wraparound property of a pan-diagonal magic square yields a nice introduction to the study of an object like a torus.

The Virahanka-Gopala-Hemachandra-Fibonacci Sequence

The Fibonacci sequence is generally defined using an arithmetic rule: the specification that each number in the sequence after the first two is the sum of the previous two numbers. Starting with the numbers 0 and 1, we obtain the following sequence:

0,1,1,2,3,5,8,13,21,34,55,89,144,233,377,610,987,1597, ...

But these numbers can also be defined combinatorially. We now show how.

But first, we study another such problem: counting the compositions of the positive integers.

Compositions of the positive integers

A composition of a positive integer is an expression for as an ordered sum of positive integers; if we change the order of the summands, we get a different composition. The compositions of 3 are the following: 3; 2 + 1; and 1 + 2; and 1 + 1 +1. Let a_n denote the number of compositions of n; The above listing tells us that $a_1 = 1$ and $a_2 = 1$

1. We may generate more values through experimentation.

Problem: Find a formula for a_n .

n	Compositions of n	a_n
1	1	1
2	2; 1 + 1	2
3	3; 2 + 1; 1 + 2; 1 + 1 + 1	4
4	4; 3+1; 1+3; 2+2; 2+1+1; 1+2+1; 1+1+2; 1+1+1+1	8
5	5; 4+1; 1+4; 3+2; 2+3; 3+1+1; 1+3+1;1+1+3;2+2+1;2+1+2;1+2+2;2+1+1+1; 1+2+1; 1+1+2+1; ;1+1+1+2; 1+1+1+1	16

Examine the third column. What a lovely pattern! It invites us to find an equally lovely proof.

Conjecture: $a_n = 2^{n-1}$.

A proof using recursion

Observe that there is just one composition of having only one summand, namely: n itself. Let us set this composition aside and focus on the compositions with more than one summand.

Take any composition with more than one summand; let its first term be k, where $1 \leq k \leq n - 1$. So:

Here, note that the bracketed term (a+b+c+ ...) forms a composition of $n - k$. If we keep the first term fixed at k, we can complete the composition with any composition of $n–k$. It follows that there are a_{n-k} compositions in which the first term is k.

Now, sum this result over all values of k. Bringing back the composition with a single summand, we see that

$$a_n = 1 + a_1 + a_2 + \ldots + a_{n-2} + a_{n-1}$$

Replacing n by $n–1$, we get

$$a_n = 1 + a_1 + a_2 + \ldots + a_{n-3} + a_{n-2}$$

Examining these two relations, we conclude that $a_n = a_{n-1} + a_{n-1}$ i.e,

$$a_n = 2a_{n-1}$$

It follows that a_1, a_2, a_3 is a doubling sequence! Since $a_1 = 1 = 2^0$ we conclude that $a_n = 2^{n-1}$. We have proved the conjecture.

Mathematics of Poetry

In poetry, the term prosody refers to 'rhythm, intonation and speech'. We now study a problem whose origins lie in prosody. It was first studied by grammarians such as Pingala, in the second century BCE, and mathematicians such as Virahanka (700 CE), Gopala (1135 CE), and Hemachandra (1150 CE).

We start by classifying the syllables of the language into two categories: light and heavy. Light syllables (L) have weight 1, while heavy syllables (H) have weight 2. Words can be formed using both kinds of syllables.

There is clearly just one word possible with weight 1, namely: S. And there are just two words possible with weight 2: H and LL. The situation invites us to formulate the following problem:

Problem. Find the number of words with total weight n.

Let this number be c_n. Like earlier, we generate the relevant data by experimentation:

n	Words with total weight n	C_n
1	*L*	1
2	*H;LL*	2
3	*HL; LH; LLL*	3
4	*HH; HLL; LHL; LLH; LLL*	5
5	*HHL; HLH; LHH; HLLL; LHLL; LLHL; LLLH; LLLLL*	8
6	*HHH; HHLL; HLLH; HLHL; LHHL; LLHH; LHLH; HLLL; LLHLL*	13

Here is a table of values of c_n:

n	1	2	3	4	5	6
C_n	1	2	3	5	8	13

Observation: c_1, c_2, c_3 is a (displaced) Fibonacci sequence!

But how do the Fibonacci numbers enter the topic of prosody? It turns out that we can use an argument exactly like the one we used to count compositions.

- Consider all words with total weight where $n > 2$.
- Each of these must end L or H. Delete the last syllable from each word.
- If the deleted letter is L, then the reduced word has weight $n – 1$.
- If the deleted letter is H, then the reduced word has weight $n – 2$.
- In each case, complete families are obtained.

For example, $n = 5$. As the above table indicates, there are 8 words with total weight 5:

HHL; HLH; LHH; HLLL; LHLL; LLHL; LLLH; LLLLL

On deleting the last syllable of each word and separating the remaining words into two classes, depending upon whether the deleted letter was L or H, we obtain the following picture:

HH; HLL; LHL; LLH; LLL	*HL; LH; LLL*
Words where the deleted letter was L. All these words have total weight 4. There are five words in this collection, corresponding to $c_4 = 5$.	Words where the deleted letter was H. All these words have total weight 3. There are three words in this collection, corresponding to $c_3 = 3$.

It is easy to see from the argument developed above that c_5 must be equal to $c_4 + c_3$.

Though we have sketched the argument for the case $n = 5$, the argument is perfectly general, and it proves that

$c_n = c_{n-1} + c_{n-2}$ *for all* $n > 2$

In other words, the -sequence follows the Fibonacci recurrence.

At the same time, $c_1 = 1$ and $c_2 = 2$. So, the -sequence starts with a pair of consecutive Fibonacci numbers.

These conditions suffice to imply that every c-number is a Fibonacci number. It follows that the -sequence is a displaced Fibonacci sequence. Indeed, $c_n = F_{n+1}$ where F_k denotes the k-th Fibonacci number.

Comment: The Fibonacci numbers are also known as the *Virahanka-Gopala-Hemachandra numbers*, because the Indian mathematicians Virahanka, Gopala and Hemachandra discovered them much before Fibonacci. But they discovered these numbers using combinatorial reasoning. See [5].

Pedagogical Notes

Students going through this exploration, experience many things that are important from a pedagogical perspective:

- Generating a sequence empirically.
- Organising data systematically and efficiently.
- Spotting patterns in data and formulating a suitable conjecture.
- Proving the conjecture using recursion. Or disproving it by checking with more data.
- Formulating variations of the same basic problem.

Aryabhata and the Jug Problem

In the 5th century Aryabhata described an algorithm to solve linear Diophantine equations in a single variable. (The word 'Diophantine' tells us that we are interested only in integer solutions). He called this the kuttaka or the 'pulveriser.' See [6] for details.

Fig.11: displays the relevant verse from Aryabhata's famous text.

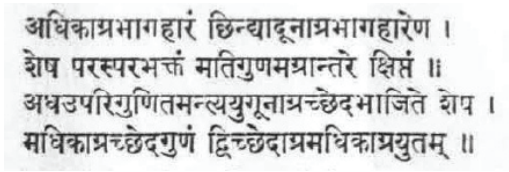
अधिकाग्रभागहारं छिन्द्यादूनाग्रभागहारेण ।
शेष परस्परभक्तं मतिगुणमग्रान्तरे क्षिप्तं ॥
अधउपरिगुणितमन्त्ययुगूनाग्रच्छेदभाजिते शेष ।
मधिकाग्रच्छेदगुणं द्विच्छेदाग्रमधिकाग्रयुतम् ॥

Fig. 11: A verse from Aryabhatiya. Source: [6]

On examination we find that the algorithm is largely like Euclid's division algorithm for the determination of the greatest common divisor (GCD) of two given positive integers. Euclid's algorithm may be described as follows. Given two positive integers a,b where $a > b$, we replace the ordered pair (a,b) by

$$(b,r)$$

where is the remainder $a \div b$. Since $r < b$, the numbers in the new pair are strictly smaller than those in the original pair. We now iterate this operation till it concludes (which it must). Aryabhata's algorithm is similar but uses subtraction rather than division. Its purpose is more general. Given two positive integers with GCD g, it seeks to find a pair of integers x, y such that

$$ax + by = g.$$

Note that if $(x,y) = (u,v)$ is a solution then so is $(x,y) = (u - nb, v + na)$ for any integer. The algorithm yields an algorithmic proof to the following theorem:

Given two positive integers a,b with GCD g, integers x,y can be found such that $ax + by = g$. If a, b are co-prime then integers x,y can be found such that $ax + by = 1$.

Our focus now will not be to dwell on the algorithm as such but to show an entertaining and unexpected connection between the solution offered by Aryabhata's algorithm and a well-known puzzle involving jugs and tumblers and a tank of water. Movie buffs will be interested to know that this puzzle played a part in one of the Die-Hard movies!

The puzzle may be stated as follows. Say we are given two cups with capacities a litres and b litres, and a tank with a large amount of water. Here, a, b are given positive integers. Using these two cups we must, through a series of exchanges (i.e., filling the cups and emptying them) end up with exactly 1 litre in one cup. Estimation is not permitted; we are not allowed to fill up or empty either cup by some fractional amount. The desired result is achievable if and only if a,b are coprime. Given that this condition holds, we now show how the *kuttaka* algorithm can indicate the steps needed. We start by finding a pair of integers such that $au + bv = 1$. The actions to be performed are now dictated by the values of u,v.

Example

Suppose that (a,b) = (7,5). These are co-prime integers. We easily verify that with (u,v) = (-2,3) we get $au + bv$ (i.e., $(-2) \times 7) + (3 \times 5) = 1$. This tells us that the 5-litre cup needs to be filled up 3 times, and the 7-litre cup needs to be emptied 2 times. The actions to be performed are the following:

Step	Action to be performed	Amount in 5-litre cup	Amount in 7-litre cup
1	Fill the 5-litre cup from the tank	5	0
2	Empty contents of 5-litre cup into 7-litre cup	0	5
3	Fill the 5-litre cup from the tank	5	5
4	Empty contents of 5-litre cup into 7-litre cup	3	7

5	Empty contents of 7-litre cup into the tank	3	0
6	Empty contents of 5-litre cup into 7-litre cup	0	3
7	Fill the 5-litre cup from the tank	5	3
8	Empty contents of 5-litre cup into 7-litre cup	1	7
9	Empty contents of 7-litre cup into the tank	1	0

Observe the following:

The 5-litre cup has been filled from the tank on three occasions: steps 1, 3, and 7.

The 7-litre cup has been emptied into the tank on two occasions: steps 5 and 9.

The figures agree with the relation ((-2) × 7) + (3 × 5). (The result may be achieved in different ways; the above sequence of actions is not the only one possible).

Before closing, we remark that Aryabhata's interest in solving linear indeterminate Diophantine equations come from astronomy: the problem of finding instances of occultation among the planetary bodies. This is of interest to astronomers and astrologers alike!

Brahmagupta Triangles

Consider a triangle with sides 3,4,5. Observe that:

Its sides are consecutive positive integers.

It has integer area; for, it is right-angled (with legs 3,4), so its area is $\frac{16\times17}{2} = 6$.

A triangle having all these specifications is called a Brahmagupta Triangle. If we only insist that the sides are integers (not necessarily consecutive integers), then the triangle is called a *Heron Triangle*.

Is it possible for us to find all possible Brahmagupta triangles? Are there infinitely many of them?

In the 7th century CE, Brahmagupta found many such triangles, with sides (3,4,5), (13,14,15), (51,52,53), (193,194,195), ... Looking carefully at his working, it seems clear that he knew how to generate infinitely many solutions to the problem. Let us see if we can unravel his approach.

Consider a triangle with sides $a-1$, a, a, where $a \geq 3$ is a positive integer. Its semi-perimeter is $\frac{3a}{2}$, so its area b is given by

$$b^2 = \frac{3a}{2}\left(\frac{a}{2}-1\right)\frac{a}{2}+1)$$

Hence:

$$16b^2 = a^2 \cdot 3(a^2-4)$$

Since $16b^2$ and a^2 are perfect squares, $3(a^2-4)$ is a perfect square as well, implying that

$$a^2-4 = 3c^2$$

for some integer . Therefore, to enumerate Brahmagupta triangles, we need to solve the equation

$$a^2 - 3c^2 = 4$$

over the set of positive integers. To get a sense of the family of solutions of this equation, let us generate some solutions using computer software:

n	1	2	3	4	5	...
a_n	4	14	52	194	724	...
c_n	2	8	30	112	418	

We immediately spot a striking pattern: both sequences show an identical two-term recurrence. Namely:

$$a_n = 4a_{n-1} - a_{n-2}$$
$$c_n = 4c_{n-1} - c_{n-2}$$

Only the initial terms are different: $a_1 = 4$, $a_2 = 14$, while $c_1 = 2$, $c_2 = 8$.

It is easy to show, using the principle of induction, that if the following are Brahmagupta triangles,

$$(a_{n-2} - 1, a_{n-1}, a_{n-2} + 1),$$
$$(a_{n-1} - 1, a_{n-1}, a_{n-1} + 1),$$

then so is $a_n - 1, a_n, a_{n+1}$ where is given by the recurrence relation shown above.

How do we explain this recurrence relation? To do so, we need to look more closely at the equation.

Analysis of the equation $a^2 - 3c^2 = 4$

If c is odd, then c^2 is of the form 1 (mod 4) which leads to $a^2 \equiv 3 \pmod 4$. But no perfect square is of the form 3 (mod 4). As this possibility does not work out, c is even. Therefore, a too is even. Let $a = 2x$ and $c = 2y$ where x, y are positive integers. Substituting in the above equation and simplifying the expressions, we get

$$x^2 - 3y^2 = 1$$

This is an instance of a Brahmagupta-Pell equation. Such equations were first studied by Brahmagupta in the 7th century. Much later they were studied by European mathematicians such as Fermat and Euler (who mistakenly attributed some results to a British mathematician named Pell; the name has stuck ever since).

The 'Bhavana' Operation

Brahmagupta discovered an extraordinary 'law of composition' governing the set of solutions of such equations. He found that if (a,b) and (c,d) are solutions of $x^2 - 3y^2 = 1$, then so is the pair $(ac + 3bd, ad + bc)$. We may thus write:

$$(a,b) \otimes (c,d) = (ac + 3bd, ad + bc)$$

He named this operation Bhavana. A law of composition of this kind is familiar to us from a modern standpoint. But Brahmagupta was the first mathematician to study such ways of composing elements of a set. Using this law, he was able to generate any number of solutions to the given equation!

Examples of Bhavana

Let us compose the solution (2, 1) with itself. We get:

$$(2, 1) \otimes (2, 1) = (4 + 3, 2 + 2) = (7, 4).$$

Recalling that a = 2x and c = 2y, we get the Brahmagupta triangle (13, 14, 15).

Let us compose the solutions (7,4) and (2,1); we get:

$$(7, 4) \otimes (2, 1) = (14 + 12, 7 + 8) = (26, 15).$$

From this solution we get the Brahmagupta triangle (51, 52, 53) .

It is easy to see once we have the law of composition in our possession, that we can generate infinitely many solutions to the given equation.

A Jewel of Ancient Indian Mathematics

Brahmagupta's law of composition is one of the jewels of ancient Indian mathematics. In later centuries, the idea was developed further by Bhaskara II (who wrote the Lilavati). And in recent years, Manjul Bhargava has published some beautiful results related to the Bhavana.

In conclusion, we ask ...

What is the value of studying topics from our ancient past? Does it have any significance?

To answer that, we quote a famous poem from John Keats.

A thing of beauty is a joy for ever:

Its loveliness increases; it will never

Pass into nothingness ...

That brings me to the end of the talk. I have shared with you some gems from ancient Indian mathematics. I hope we have been able to experience their beauty together!

Declaration

The author affirms that there has been no conflict of interest in the writing of this paper.

THE FORGOTTEN MATHEMATICAL LEGACY OF ARYABHATA

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Aryabhata made pioneering contributions to trigonometry. The sine function finds its first mention in the Aryabhatiya (499 CE), a cryptic work written by Aryabhata when he was 23 years old. The work also indicates how to obtain the difference of sines and cosines by ingenuously using the properties of similar triangles. It then exploits these formulae to obtain the values of the sine function for angles between 0 to 90 degrees. We describe how this was done. In order to make our presentation pedagogical, we take a unit circle and radians instead of the (now) archaic notation in the Aryabhatiya and its commentaries. These seminal contributions of Aryabhata seem forgotten. This is tragic since these methods can be gainfully taught to high and higher secondary school students. We also impress upon the reader the fact that there has been a continuity in the Indian mathematical tradition, starting from the intricate geometric thinking of the Sulbastura in the Vedic era (circa 1000 BCE) to the Calculus of Madhava and his disciples (1350–1600 CE).

Keywords: Aryabhatiya, Aryabhata, ardha-jya (sine), pi, trigonometry, finite difference calculus.

Introduction

As a student of science or engineering, we have sought out the value of a trigonometric function innumerable times. Often and unthinkingly, we press down on the mouse attached to our laptop or click on our mobile calculator. The old fashioned amongst us, reach out for the bookcase which houses our table of functions. Seldom do we stop to think how this value was first generated or why were the sine and cosine functions defined. And who defined them? The credit goes to the fifth century mathematician and astronomer Aryabhata. The great master enumerated the table of sines for closely spaced angles. His methods were based on general trigonometric identities and lend themselves to extensions. The first mention of the sine function is to be found in his (one and only) seminal work the Aryabhatiya (499 CE). Aryabhata describes it in picturesque terms as the half bow-string or Ardha-Jya. This is illustrated in Fig. 1. The arrow or saar is related to the cosine function. Aryabhata was only 23 years old when he wrote his masterpiece.

The *Aryabhatiya* consists of 121 cryptic verses, dense and laden with meaning [1, 2].

The work is divided into 4 parts or *padas*: the *Gitikapada* (13 verses), the mathematics or *Ganitapada* (33 verses), the *Kalkriyapada* (25 verses) and the astronomy or *Golapada* (50 verses). The astronomy is better known. There are two verses in the mathematics

Ganitapada describing the solution of the Linear Diophantine equation. This has received due recognition. Our focus here is on the trigonometry part in the *Ganitapada* which in our opinion has suffered neglect and is a pioneering achievement of this savant.

In this article, we describe the trigonometric identities used by Aryabhata to obtain the table of sines. This entails taking the difference of the sine of two closely spaced angles and then taking the second sine difference. We follow this up with a discussion.

The Indian mathematical tradition is largely word based and in Sanskrit verses. Results are mentioned and derivations are omitted. There are no figures. The *Aryabhatiya* (499 CE) with a little over 100 cryptic, super-compressed verses of dense mathematics is a prime example. Our presentation relies on commentary of Somaiyaji Nilakantha (1444 CE – 1544 CE) [3] and the works of Shukla Kripa Shankar and K. V. Sarma [2], as well as of P. P. Divakaran [4]. But our approach is pedagogical and one which will help the student and teacher to appreciate this pioneering work. Hence, we shall take some liberties and describe the great master's work in terms of unit circle and radians instead of degrees and minutes.

The Ardha-Jya or Sine Function

As mentioned earlier the *Aryabhatiya* has some 121 verses out of which 33 verses belong to the mathematics section (*Ganitapada*). Aryabhata works with, for the first time in the history of mathematics, the sine function. It is the half-chord AP of the unit circle in Figure. 1.

$$sin(\theta) = \frac{AP}{OA} = AP \ (OA = 1)$$

The circle may be large or small; correspondingly AP and OA maybe large or small, but the L.H.S. is a function of θ and is invariant. Further, all metrical properties related to the circle can be derived using trigonometric functions and the Pythagorean theorem (also described as the Baudhayana or Diagonal theorem [4]). For example, the geometric property of a triangle can be related to the arcs of the circumscribing circle using the sine and cosine functions or the diagonals of the inscribed quadrilateral can be related to its sides. (If a recent proof of the Pythagorean theorem using the law of sines holds up to scrutiny, then all metrical properties of a circle can be obtained by trigonometry alone [5].) By emphasising the role of this half-chord Aryabhata endowed circle geometry with metrical properties. This alone may qualify him as the founder of trigonometry. But he did more.

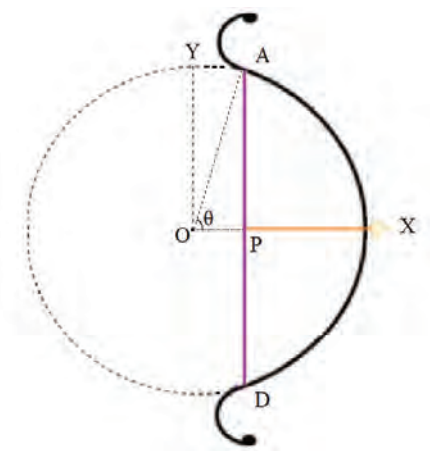

Fig. 1: The bow superposed on the unit circle. Half the bow string or half chord AP is sin(θ) as defined by Aryabhata. OP is cos(θ) while PX = 1-cos(θ) is called the saar.

It may help to note that the length of the half-chord AP is very close to the length of

the arc AX only when the angle is small for example ($\sin(\theta) \approx \theta$) if theta is small and in radians). This was known to Aryabhata in all likelihood by inspection. Similarly, the sine of 90 is 1, since then the half-chord is the same as the radius. In the ninth verse of the *Ganitapada*, he uses the property of an equilateral triangle and obtains the sine of 30 as 1/2.

We paused to note that Aryabhata also states the value of π as 62832/20000 in the tenth verse. This value is 3.1416 and he is careful enough to state that this is proximate (*Asanna*) which means we can obtain better and truer values for π presumably with more effort[1].

The Difference Formula for Sine and Cosine

The verse 12 of the *Ganitapada* plays a central role in the tabulation of the sine function. It is cryptic and to unravel its meaning, we first need to obtain the difference formula for the sine. The presentation below relies on a number of sources:

(i) The commentary of Somaiyaji Nilakantha [3]

(ii) the treatment of Shukla and Sarma and

(iii) for the sake of ease of understanding we follow Divarkaran [4] and take a unit circle as opposed to a radius of 3438 by earlier workers[2].

Figure 2: depicts a quadrant of the unit circle where OX = OY = 1.
The arcs XA, XB and XC trace angles θ, $\theta + \varphi$, and $\theta - \varphi$ respectively. The half-chords AP, BQ and CR are the corresponding sine functions. We drop a perpendicular CS from the circumference onto the half-chord BQ as shown. According to his commentator Nilakantha Somaiyaji [3], Aryabhata obtained the relationship between the difference in the trigonometric functions by demonstrating that the two triangles BSC and OPA are similar. We urge the reader to try and prove this. One then has:

$$\frac{BS}{OP} = \frac{BC}{OA}$$

Now OA = 1 (unit circle), OP = $\cos(\theta)$ and BC = 2 $\sin(\varphi)$. By inspection BS = BQ – CR = $\sin(\theta + \varphi) - \sin(\theta - \varphi)$. This yields the sine difference formula (Eq. (1)

$$\sin(\theta + \varphi) - \sin(\theta - \varphi) = 2\sin(\varphi)\cos(\theta) \qquad (1)$$

The difference in the sines is proportional to the cosine of the mean angle. Similarly, one has:

$$\cos(\theta + \varphi) - \cos(\theta - \varphi) = -2\sin(\varphi)\sin(\theta) \qquad (2)$$

The difference in the cosines is proportional to the (negative) of the sine of the mean angle.

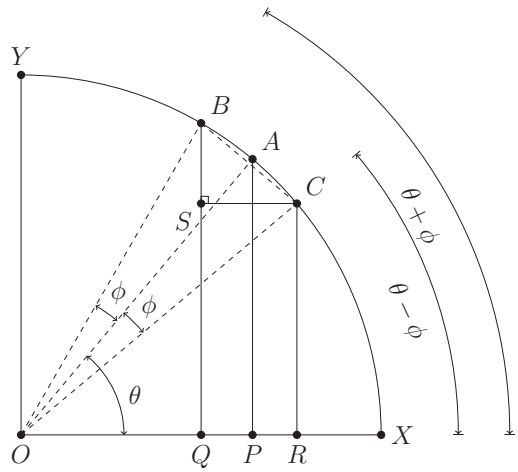

Fig. 2: Derivation of the sine difference relation. The figure depicts the quadrant of a unit circle of radii OX = OY = 1. The half-chords AP, BQ and CR are $\sin(\theta)$, $\sin(\theta + \varphi)$ and $\sin(\theta - \varphi)$ respectively. It is worth noting that (later) we shall take ϕ to be a small angle.

[1] The word Asana or proximate is to be distinguished from sthula which is approximate or roughly equal.
[2] One radian is 3438 minute

The Sine Table

Aryabhata obtained the values of the sines at fixed angles between 0 and $\pi/2$ thus, generating the sine table for $\pi/48 = 3.75$ degrees, 7.5 degrees up to 90 degrees. This table is stated in verse 10 of the first chapter, the *Gitikapada*. The table has been used by Indian astronomers (and astrologers) in some form or another since 499 CE up to the present. We shall see how the table was generated.

Let us take $\varphi = \epsilon/2$ where ϵ is small. We take $\theta = (n - 1/2)\epsilon$ where n is a positive integer from 1 to N. To fix our ideas $\epsilon = \pi/48 = 3.75° = 225'$ and N = 24. We re-state the sine and cosine difference formulae (Eqs. (1) and (2)) from the previous section:

$$\delta s_n = s_n - s_{n-1} = 2s_{1/2}c_{(n-1/2)} \quad (3)$$

$$\delta c_n = c_n - c_{n-1} = -2s_{1/2}s_{(n-1/2)} \quad (4)$$

where the symbol sn stands for $\sin(n\epsilon)$, cn stands for $\cos(n\epsilon)$ and $s_{1/2}$ for $\sin(\epsilon/2)$. The above is a pair of coupled equations and it was Aryabhata's insight to take the second difference, namely;

$$\delta 2sn = \delta sn - \delta sn{-}1 = 2s_{1/2}(c_{(n-1/2)} - c_{(n-3/2)})$$

$$= -4s^2_{1/2}s_{n-1} \text{ on using Eq. (4)} \quad (5)$$

Thus, the second difference of the sines is proportional to the sine itself. The next step is to represent the R.H.S in terms of a recursion. We observe sn on the R.H.S. of Eq. (5) may be written as $sn = sn_{-} sn_{-1} + sn_{-1} - sn_{-2} + sn_{-2} - \ldots = \delta s_{n-1} + \delta s_{n-2} + \ldots$ Thus,

$$\delta s_n - \delta s_{n-1} = -4s^2_{1/2}\sum_{m=1}^{n-1}\delta s_m$$

Thus, we get a recursion relation where the second difference of the sines is expressed in terms of all previously obtained first sine differences. To initiate the recursion we need δs_1 which is $s_1 - s_0 = \sin(\epsilon) - \sin(0) \approx \epsilon$ since for small angles the half-chord and the corresponding arc are equal as stated in the previous section.

Using the recursion relation of the sine, we can generate the celebrated sine table of Aryabhata, taking $\pi = 3.1416$ and $\sin(\epsilon) = \epsilon = 0.0654$ (= 225').

Table 2 depicts some typical values of the sine function as well as the value of the sine multiplied by 3438 (the so called *Rsine of Aryabhata*). We can see that this matches Aryabhata's celebrated sine table, up to 1 minute. For example, $\theta = \pi/6$ gives 1719 minutes. For comparison, we also showed the modern values of sine up to four decimal places. Note that Aryabhata takes angles up to $\pi/2$ and seemed aware of the fact that going further was unnecessary given the periodic nature of the sine function.

θ	sin(θ) Aryabhata	sin(θ) (Minutes)	sin(θ) Modern
$\pi/48$	0.0654	225	0.0654
$2\pi/48$	0.1305	449	0.1305
$3\pi/48$	0.1951	671	0.1951
$4\pi/48$	0.2588	890	0.2588

5π/48	0.3214	1105	0.3214
6π/48	0.3827	1315	0.3827
7π/48	0.4423	1520	0.4423
8π/48	0.5000	1719	0.5000
9π/48	0.5556	1910	0.5556
10π/48	0.6088	2093	0.6088
11π/48	0.6594	2267	0.6593
12π/48	0.7072	2431	0.7071
13π/48	0.7519	2585	0.7518
14π/48	0.7935	2728	0.7934
15π/48	0.8316	2859	0.8315
16π/48	0.8662	2978	0.8660
17π/48	0.8971	3084	0.8969
18π/48	0.9241	3177	0.9239
19π/48	0.9472	3256	0.9469
20π/48	0.9662	3322	0.9659
21π/48	0.9812	3373	0.9808
22π/48	0.9919	3410	0.9914
23π/48	0.9983	3432	0.9979
24π/48	1.0005	3439	1.0000

Table 2: Table of values of sine using the Aryabhatan method, taking epsilon = π/48 (= 3.75 = 225′) and pi = 3.1416, and comparison with the modern-day values. In column 3, we also quoted values in minutes as done in Verse 10, Gitika chapter of the Aryabhatiya [1,2].

Finite Difference Calculus

Of greater relevance is the fact that the sine (or cosine) difference formulae foreshadow finite difference calculus, a popular numerical technique in this age of computation.

Rewriting Eqs. (1) and (2) with $\varphi = \epsilon$,

$$\frac{\sin(\theta + \epsilon) - \sin(\theta - \epsilon)}{2\sin(\epsilon)} = \cos(\theta) \quad (7)$$

$$\frac{\cos(\theta + \epsilon) - \cos(\theta - \epsilon)}{2\sin(\epsilon)} = -\sin(\theta) \quad (8)$$

Aryabhata took ϵ to be π/48. But he also stated that its value is yateshtani or as per our wish (Verse 11, *Ganitapada*). Some took it to be π/96 and others like Brahmagupta took it as π/12 or 15 degrees. If we take ϵ to be sufficiently small we have our classic formula for finite difference calculus. Noting

that 2 sin(ϵ/2) ≈ ϵ we have the finite difference version of the derivative of sine:

$$\frac{\delta\sin(\theta)}{\delta\theta} = \cos(\theta)$$

and similarly for the cosine.

$$\frac{\delta\sin(\theta)}{\delta\theta} = -\sin(\theta)$$

Let us understand this with an example. We know that sine(37°) is close to 0.6 and sine (300) is 0.5. The difference in angle is 7° which in radians is 0.122. Thus, the derivative of sine of the median angle 33.5° from Eq. (7) is:

$\delta\sin(\theta)/\delta\theta$ = (0.6 – 0.5)/0.122 = .82

Looking up the sine table or the calculator yields cos (33.5) = 0.83. Similarly Eq. (5) yields the second derivatives namely:

$\delta 2\sin(\theta)/\delta 2\theta \approx -\sin(\theta)$

$\delta 2\cos(\theta)/\delta 2\theta \approx -\cos(\theta)$

The above are now called central difference approximations to the derivative and the second derivative. Aryabhata does not mention the term finite difference calculus (let alone calculus). But similar methods are now used to numerically solve our differential equations. A student can readily recognise the above as a standard solution of the classical simple harmonic oscillator. Note also that Newton's II Law and the famous Schrodinger equation of quantum mechanics are both second order differential equations.

Discussion

One can discern a continuity in Indian mathematics, howsoever tenuous, from pre-Vedic times (← 1000 BCE) up and until 1800s. The Sulbasutras (circa 1000 BCE) reveal intricate geometric thinking. Baudhayana foreshadowed Pythagoras by a few centuries. Recursive thinking whose examples are evidenced in equations (3 to 5) has its roots in Pingala's Combinatorics (300 BCE). Aryabhata was an inheritor of this tradition. Equally relevant is the influence the Aryabhatiya exercised on Indian mathematicians. Bhaskara I (600 CE) wrote a commentary on it. Brahmagupta (600 CE) was influenced by it. Bhaskara II (1150 CE) used the trigonometric difference formulae to obtain the area and the volume of the sphere. Our presentation here is based on the voluminous work (Maha Bhashya) of the fifteenth century mathematician Nilakantha Somaiyaji (1444 CE – 1544 CE) who was part of the Kerala school which, beginning with Madhava (1350 CE – 1420 CE), founded the calculus of trigonometric functions. Aryabhata serves as a crucial link in Indian mathematics [4,5].

The sine table can also be generated using the half-angle formula. This was demonstrated in the *Panchasiddhantika* a text written barely 50 years after the appearance of the *Aryabhatiya* [7]. As pointed out, a feature of the Aryabhata's difference relation is how contemporaneous it is. It can be easily recognised as finite difference calculus. This perhaps led to the development of the calculus of trigonometric functions by the Madhava (1350 CE) and his disciples along the banks of the Nila river in Kerala. This school is variously called the Nila [4] and even as the Aryabhata school [6]. Another aspect to note is that Bhaskara II (1100 CE) used the canonical 2 π/96 division of the great circle to carry out discrete integration and obtain the (correct) expressions for the surface area and volume of the sphere. Jyesthdeva of the Nila (or Aryabhta) school in his work Yuktibhasa

derived the same results using calculus (circa 1500 CE). Aryabhata can legitimately be called the founder of trigonometry.

To sum up, the *Arybhatiya* exercised a tremendous influence over Indian mathematicians and for over a thousand years. For a book with just over 100 pithy (short) verses, its legacy remains unparalleled in the scientific world. We hope that our article will give our young audience an introduction to his work and will serve as an inspiration.

Acknowledgements

One of the authors (VAS) would place on record the many useful discussions he had with Prof. P. P. Divakaran. He would also like to thank Dr. Gagan Gupta of NCERT for discussions.

Exercises

1. We can generate the sine table as per Aryabhata's suggestion but not exactly using the same value for ϵ he used. We choose $\epsilon = \pi/80.93$ which is the same as 2.250. We take $\sin(\epsilon) = \epsilon$. If you have a simple calculator generate all values of sine from 2.25 to 18 degrees in equal steps using Eq. (6). Alternatively, if you have a programmable calculator or a computer generate all values of sine from 2.25 to 90 degrees. Compare with the results your calculator will otherwise yield.
2. Show that the two triangles BSC and OPA in Fig. 2 are similar.
3. In the last section reference is made of the text Panchasiddhantika wherein the half-angle forumla is mentioned, *viz*.

$$\cos(2\theta) = 1 - 2\sin^2(\theta)$$

How would you (i) derive this by a geometrical construction; (i) employ this to generate the sine table?

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This work is in Sanskrit and there is no English (or Hindi) translation of this seminal text to the best of our knowledge. The other works mentioned herein are in English.

LEARNING SCIENCE FROM THE KITCHEN GARDEN

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In this article, the author shares his experience of learning about plants by looking around with childlike curiosity in the kitchen garden. Using the common garden variety of chilli, tomato, eggplant, etc., as examples, he illustrates how they are classified as belonging to the Solanaceae family, based on their floral structure. They share a lot at the genomic level and flowers with five-fold symmetry of some of the other members of the same family go back in time by several million years. Following the splitting of the Gondwana land nearly 200 million years ago, some of the flora must have survived the tectonic movement and evolved differently depending upon the geophysical conditions. It is not necessary that all flowers with five-fold symmetry belong to the Solanaceae family. Flowers of some of the other members of the plant kingdom exhibit four-fold and six-fold symmetry too. Practically all the flowers that we see around us have two-fold symmetry, perhaps because of the bilateral vision of the pollinators.

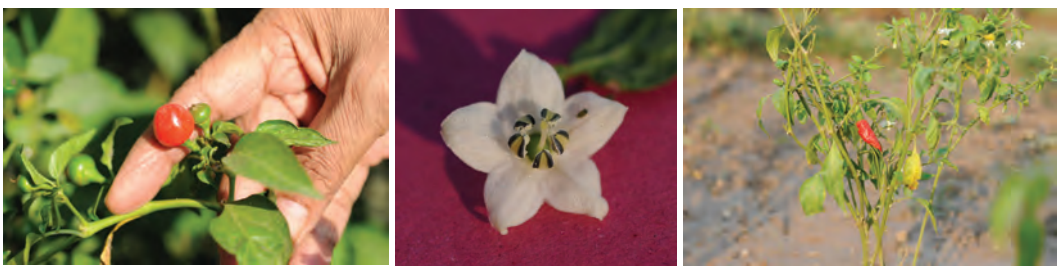
Keywords: chilli, tomato, eggplant, Solanaceae family, fossil flowers

Introduction

From the time we are born till we die; we are driven by curiosity. The children, soon after birth start looking around and sense what is happening around them. Soon, they start probing through other senses and try to figure things out. As we grow older, the curiosity continues, and we learn as we go along. Although we learn a lot from the teachers and textbooks in a classroom environment, we learn much more outside the classroom. This article illustrates how one could learn a lot by looking around in a kitchen garden.

Curiosity About a Plant

I was looking at a plant with cherry-like fruits in our garden (See Fig. 1). I knew it was not a cherry. Therefore, I asked the *mali* (gardener) what it was. He told me that it was a *mirchi* (chilli). I asked him how; he said that as it looked different from the common garden variety. He told me that it was a particular



(a) (b) (c)

Fig. 1: (a) Cherry like chilli; (b) the characteristic white flower of a chilli plant, with five petals and a stigma surrounded by five anthers; (c) a common garden variety chilli with characteristic leaves and flowers. (Credit: N G Prasad)

kind of hot chilli. When I asked him how hot it was, he told me that it was VERY hot. Therefore, I asked a colleague (Professor N. G. Prasad) who was trained as a botanist what the plant was. He responded by saying that it looked like it was a chilli plant. When I asked him how he could identify it, he told me that the leaves had a characteristic shape, and the white flower with five-fold symmetry was characteristic of a chilli plant. Then he showed me the more common types of chilli plants in the garden, which had similar leaves and flowers like the one I saw.

Once I knew that it was a chilli, I wanted to know how hot (pungent) it was! Another colleague (Professor T. R. Rao) took a bite of the chilli and confirmed that it was indeed extremely hot. He told me that the hotness of a chilli is measured by the amount of capsaicin present in it and is measured in Scoville Heat Units (SHU). He also told me that the hottest chilli on earth is Naga *Bhut Jolokia*, from Nagaland. It is hot by 1.6 M (million) SHU. In comparison, pure capsaicin, responsible for the pungency of a chilli is hot by 16 M SHU. The common garden variety of chilli, in comparison, has a pungency of 0.001 M SHU. The hottest chilli powder could, in principle, be used as a weapon in the form of a spray. The enemy would run for his life. When attempts were made to grow Naga *Bhut Jolokia* in some other parts of India, it became clear that the pungency of the chilli declined dramatically. The soil and the climate conditions in Nagaland clearly contribute to the pungency of its chilli.

Plants of the Same Family

My colleague told me that chilli belongs to the Solanaceae family and that potato,

(a) (b)

Fig. 2: The flowers of (a) eggplant and (b) tomato have a characteristic five-fold symmetry. (Credit: N G Prasad)

(a) (b)

Fig. 3: The fruits of (a) eggplant and (b) tomato have a characteristic crown and a stock. (Credit: N G Prasad)

tomato, eggplant and tobacco also belonged to the same family. One thing they all have in common is that their flowers have a five-fold symmetry (and similar floral diagrams) as can be seen from Figure 2, the fruits have a crown and a stock as illustrated in Figure 3.

I learned that some of the other members of the Solanaceae family are *Datura alba*

Fig. 4: The top panel has the image of a flower and fruit of ***Datura alba***; the middle panel has the image of the flower and fruit of ***Physalis***; the bottom panel has the image of the flower and fruits of ***Solanum torvum***. (Credit: N. Sathyamurthy)

(Oomathai in Tamil), *Physalis* (Chinese lantern), *Solanum Torvum* (Turkey berry, Sundaikkai in Tamil). All of them have their characteristic five-fold symmetric flowers and fruits having a crown and a stock as illustrated in Figure 4.

Molecular Basis

I learned that the Solanaceae family is one of the largest in the plant kingdom. While the members of the family could be identified on the basis of their floral diagrams and the characteristic fruits, I wanted to know if they had common characteristics at the molecular level. It turned out that genomic studies confirmed that potato, tomato, eggplant and chilli have a lot in common at the genomic level. It is worth adding that (the late) Professor J. P. Khurana of Delhi University was part of the international consortium for sequencing the tomato genome.

Do all plants having flowers of five-fold symmetry belong to the Solanaceae family?

While the flowers of all members of the Solanaceae family have a five-fold symmetry, all plants with five-fold symmetric flowers DO NOT necessarily belong to the same family. Some of them are shown in Figure 5.

Why do many flowers have part of their names reflecting the name of places from different parts of the world?

When I asked my friend geologist and a paleontologist, Professor Ashok Sahni, if there was any geological connection between different plants, he told me that in the beginning, there was one united land mass called *Gondwana* (incidentally, *Gond* refers

Fig. 5: Some of the flowers with five-fold symmetry belong to different families. Top panel left: cucumber (Cucurbetaceae), top middle: Plumeria alba, Top right: *Nerium*, middle right: Rangoon Creeper (*Quisqualis indica L.*); bottom left: Madagaskar periwinkle (*Vinca rosea*) and bottom right: Egyptian star (*Pentas lanceolata*). (Credit: N. Sathyamurthy)

to an ancient tribe and *vana* refers to forest). When the *Gondwana* split about 200 million years ago, part of the land mass started moving up north and a part of it split into Africa, Madagascar, the Indian subcontinent, Australia, etc. They all moved away from each other due to tectonic movements and the Indian subcontinent moved up north until it hit against the Eurasian plate. A close examination of the geological maps would reveal that the east coast of Africa matches with the west coast of Madagascar and the east coast of Madagascar matches with the west coast of India. During these tectonic movements, there were several volcanic eruptions. Some of the flora and fauna of yesteryears disappeared while some survived and fluorished in different landmasses and evolved differently. Sahni pointed out that there were fossils of flowers uncovered in the Himalayan foothills and date back by several millions of years. Some of them belong to the Solanaceae family and exhibit five-fold symmetry as illustrated in Figure 6.

Fig. 6: Microscopic image of a fossil flower, *Kasaulipushpam sahnii*, uncovered by Sahni and collaborators. This flower belonging to the Solanaceae family dates back by about 18 million years. (Credit: Ashok Sahni)

Fig. 7: Flowers of mustard (left) and cabbage (right) exhibiting a four-fold symmetry. (Credit: N. Sathyamurthy)

Is the five-fold symmetry in flowers exclusive?

The answer is, NO! There are plants of different symmetry. Flowers of mustard, radish, cabbage, etc., belonging to Cruciferaceae family exhibit four-fold symmetry as illustrated in Figure 7.

Flowers of plants like onion and *Argemone mexicana* exhibit a six-fold symmetry as is evident from their images in Figure 8. In other words, flowers of different plants can have different symmetry. Interestingly, they all exhibit bilateral symmetry. That means that if each flower is to be divided vertically, the left side and the right side would be found to be (approximately) mirror images of each other as shown in Figure 9. Could this be due to the fact that most of the animal species have bilateral vision? Why do the flowers blooming


Fig. 8: Flowers of onion (left) and ***Argemone mexicana*** (right) exhibit six-fold symmetry. (Credit: N. Sathyamurthy)



Fig. 9: Bilateral symmetry of flowers of pancy (left) and snowtop (middle). To drive home the point of bilateral vision, the author's face is included along with the images of the flowers in the right. (Credit: N. Sathyamurthy)

Fig. 10: Five-fold symmetry of the flower of ***Mirabalis jalapa*** (***Andhi mantharai*** in Tamil) that blooms in the night.

in the night, like the one illustrated in Figure 10, have bilateral or higher symmetry? Maybe to attract nocturnal pollinators? Do they need to be symmetric to attract the pollinators? Do they need to emit fragrance to attract them? If wind can do the pollination, flowers need not be symmetric and they do not have to be fragrant either.

Summary and Conclusion

Based on the characteristics of the flowers (floral diagram), flower-bearing plants (angiosperms) are classified into different families. Despite chilli, eggplant and tomato looking so different and tasting so different,

their floral characteristics are similar. Their fruits have similar crowns and stocks. They are identified as members of the Solanaceae family. At the genomic level also, they have a lot in common. Some of the available fossils of flowers that are several million years old, reveal five-fold symmetry suggesting that some of the florae have survived the tectonic movements and volcanic eruptions over the eons and evolved as per the available weather and soil conditions. While all members of the Solanaceae family have flowers with five-fold symmetry, not all flowers with five-fold symmetry belong to the same family. Flowers of some families have four-fold and six-fold symmetry too. On closer examination, we realise that regardless of the order of symmetry of the flowers of different families, they exhibit bilateral symmetry. This is presumably linked to the bilateral vision of most of the pollinators.

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PLASTIC POLLUTION: A HUMAN-MADE CRISIS

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Plastics are the most pervasive material on the planet. Plastic items are affordable, lightweight, easy to make, resist decay and may persist for centuries in the environment. These versatile qualities have made plastics a notorious villain of the global environment. Birds, crabs, fish and other animals get trapped in plastic litter, restrict their movement and may die eventually from starvation. Often plastic waste is mistaken for food by cattle and other animals, affecting them adversely. Over time plastic waste breaks down into small size particles of 5 millimetres and less are called microplastics. Fish and other aquatic organisms ingest microplastics as they cannot differentiate between food and plastic particles. Microplastics move along food chains and reach up to the top predator. Presence of miroplastics has been reported in human blood and different organs. Plastic waste has become a significant source of pollution in India requiring urgent attention and action. Use of single use plastic has been banned in the country and the government have notified Plastic Waste Management (Amendment) Rules 2021 and also issued detailed guidelines on Extended Producer Responsibility (EPR) whereby producers are held responsible for the entire lifecycle of their plastic products and packaging toward controlling the menace of plastic pollution.

Keywords: Extended Producer Responsibility (EPR), Great Pacific Garbage Patch, Microbeads, Microplastics, Plastic Pollution, Single Use Plastic, Plastic Waste Management Rules.

Introduction

Plastics are one of the most pervasive materials on the planet. The benefits of plastic are undeniable. Being low cost, versatile, durable, high strength-weight ratio and ease of making, led to a boom in plastics production over the past century. From 1950s to 1970s, only a small amount of plastic was produced. Since 1970s, the rate of plastic production has grown faster than that of any other material. If historic growth trends continue, global production of primary plastic is forecasted to reach 1,100 million tonnes by 2050.

Plastic items are affordable, lightweight, easy to produce and long lasting. The same properties that make plastics so useful — durability and strength — also make it impossible for nature to decompose it completely. The versatile qualities of plastics have made them a notorious villain of the global environment. Plastic waste — whether in a river, the ocean or on land — can persist in the environment for centuries. Plastic pollution has grown into an epidemic and has become one of the most important global environmental challenges to modern society. Evidence of plastic pollution has been found even in the most remote places, including Mount Everest, the deep sea Mariana Trench, the Arctic and the Antarctica. Plastic particles have been found in sea ice, surface water, sea floor and possibly also in the outer space, including moon surface, where waste and

obsolete items are left behind by various space missions.

Globally, since the early 1950s, over nine billion tonnes of plastic has been produced and about 60 per cent of that has ended up in landfills or in the natural environment. About 6.5 million tonnes of plastic is used annually in the country, of which, a large amount is used for packaging. India generates 9.46 million tonnes of plastic waste, of which, about 40 per cent remains uncollected. Plastic waste disturbs land and its dwellers in a multiple ways. However, the negative fall-out of plastic waste often gets masked by the accelerating economic growth and material affluence.

Reckless dumping of plastic waste is one of the main causes of urban flooding as many plastic items like carry bags, wrappers *gutkha* sachets and packets block waterways and exacerbate the natural water-related disasters. Sewers are often clogged, providing breeding grounds for mosquitoes and pests, thus encouraging the spread of vector-borne diseases like malaria, dengue and chikungunya. The animals get trapped and injured by plastic waste. Plastic litter is often mistaken for food by foraging animals that accidentally eat plastic, suffer and often die as a result of it. The swallowed plastic fills the stomach and not surprisingly this reduces the feeling of hunger. Plastic waste consumption by milking cows reduces milk yield and affects their health adversely. Plastic bags can choke the respiratory and digestive systems, posing serious existential threat to animals. Plastic waste strangles birds, crabs, fish and other animals, restricts movement and hinders their normal life. Plastic debris disrupts habitats, making it hard for some species to live and breed normally. Plastic affects all life forms, microscopic animals, right up the foodchain to large predators, even human being.

Much of the plastic waste disposed of on land is transported to the ocean by sewage systems and rivers, serving as express highways for off-loading plastic litter into the seas. Plastic waste spoils beaches and clogs harbours. In the ocean, plastic waste often gathers forming 'garbage patches' formed by sea currents. The largest Great Pacific Garbage Patch that revolves between California and Hawaii consists of trillions of floating pieces of plastic and still growing (Thomson, et al, 2004). Apart from this, there are four other plastic patches, one more in the Pacific, two in the Atlantic and one in the Indian Ocean. A study by Ellen MacArthur Foundation (2016) claimed that at the current rate of primary plastic production and disposal, by 2050, there could be more plastic in the ocean than fish (by weight). A report titled, 'Breaking the Plastic Wave', shows that by 2040, if we fail to act, the volume of plastic on the market will double, the annual volume of plastic entering the ocean will almost triple (from 11m tonnes in 2016 to 29m tonnes in 2040), and ocean plastic stocks will quadruple (reaching over 600m tonnes Ellen MacArthur Foundation, 2020).

Small plastic particles soak up toxic chemicals from the seawater, poisoning the creatures that swallow them. Because plastic pellets absorb toxic chemicals like DDT and PCBs, they effectively become poison pills. Plastic objects themselves can leach endocrine-disrupting chemicals like BPA (bisphenol A) phthalates. In general, plastic debris reduces marine biodiversity and degrades marine ecosystem.

Plastics contribute to climate change. Plastics are made from petroleum, a non-renewable resource. Greenhouse gas (GHG) emissions exacerbate climate change problems. Plastics are made from fossil fuels. Plastic industry accounts for about six per cent of the global oil consumption. Petroleum production and oil distillation are energy intensive processes, generating enormous amounts of GHG emissions which exacerbate climate change. Plastic pollution has also wide-ranging economic implications. Plastic waste creates aesthetic blight, giving rise to unhygienic conditions. Having indiscriminately disposed of plastic litter around adversely affects the tourist-based economy of hill resorts, river fronts and coastal sites, including impacting employment, businesses and livelihoods of the local communities.

Microplastics

Plastic waste never disappears, but breaks down into smaller pieces and tiny particles, which are called microplastics. The term 'microplastics' was coined by Thompson, et al. (2004), and the United Nations Environment Programme (UNEP) defines microplastics as plastic particles smaller than five millimetres. In general, small plastic particles are classified according to their size into the following four categories:

Macroplastics: →2.5 cm

Mesoplastics: 5 mm – 2.5 cm

Microplastics: ←5 mm (← 000 µm)

Nanoplastics: 1 – 1000 nm (0.001 – 1 µm)

Microplastics originate from a variety of sources and are found in growing quantities in the oceans. According to the UN, there are as many as 51 trillion microplastic particles in the seas, 500 times more than the stars in our galaxy. Depending on their source, microplastics are categorised into primary and secondary microplastics. Primary microplastics, also called microbeads are solid particles made of synthetic polymers, used in personal care products, toiletries and cosmetics. Primary microplastics enter the environment directly through any of the various channels—for example, product use, spills during manufacturing and transport, as well as microfibres shed from clothing and other textiles such as fishing nets. In addition, tyre wear and tear is another source of microplastics, since tyres are made of rubber, which is also a polymer. Secondary microplastics, on the other hand, are formed from the breakdown of discarded water bottles and larger plastic debris. Weathering and breakdown of plastic debris results from the combined action of physical, chemical, biological factors, wave action, wind abrasion and exposure to ultra-violet radiation.

Microplastics are now ubiquitously found just about everywhere in our environment. Microplastics are transported from the land by air and rivers into the sea and back out of the sea. When it is raining on the land microplastics are blown back up into the air again, to move somewhere else (Zhang, et al., 2020). They appear to be moving in the biosphere through air-land-water endlessly. The scale of the problem is devastating.

In India, microplastics have been found in air, water, lakes, rivers, estuaries (Unnikrishnan, 2023) soils and various living organisms. A study carried out by the State University of New York in 2018, involving 19 global cites, including Chennai, Mumbai and New Delhi found that 90 per cent of the bottled water

sold worldwide contained tiny pieces of plastic (Times of India, 2018).

Microbeads and other microplastics are mistaken as food and ingested by all kinds of organisms, thus, easily entering the foodchain of aquatic organisms, undergoing bioaccumulation in their tissues, gradually working their way upto the trophic levels through zooplankton, small fish, larger fish and other organisms that consume them. Blue whales may swallow roughly 10 million microplastic pieces daily or up to about 43.5 kg (95 pounds) of plastic.

Many organisms in the oceans remain starved due to the presence of such particles in their digestive tracts or because of a damaged stomach lining. Apart from microplastics being non-nutritive and indigestible, they are able to concentrate toxic pollutants from the surrounding aquatic medium and organisms that ingest them also get a toxic dose of pollutants (Osman, et al., 2023).

Microplastics can enter the human body through inhalation and absorption, and accumulate in organs. Microplastics have been found in our lungs, livers, spleens, kidneys, sputum, saliva and blood. A study recently detected microplastics in placenta of new born babies, Ragusa, et al. (2021). The full extent of the impact of this on the human health is still unknown. There is, however, substantial evidence that plastics-associated chemicals such as methyl mercury, plasticisers and flame retardants, can enter the body and are linked to health concerns.

These small particles pollute waterways, soil, plants, animals and humans. Microplastics have been shown to affect the soil quality, the microbes that live in it and the tiny insects responsible for decomposition.

Microplastics also affect larger animals in many ways, stunting their growth, damaging reproductive organs and more. The effects of microplastics are being studied. The economic, environmental and health cost of plastic pollution remains to be assessed, but it is likely to be staggering with serious implications.

Plastic Policy in India

The plastic waste has become a significant source of pollution in India. The country produces around 3.4 million tonnes (MT) of plastic waste, out of which, only 30 per cent of it is recycled according to the Ministry of Environment, Forest and Climate Change (MoEFCC). The per capita plastic consumption in India reached 15 kg per person in 2021. The demand for polymers has been steadily growing over the past three decades; rising from just one kg per capita in 1990. Overall, plastic consumption in India reached almost 21 million tonnes in 2021. Nearly half of all the plastic produced around the world is deployed for single-use purposes. However, due to poor segregation of waste and disposal of plastic waste, a significant amount of single-use plastic ends up in rivers, lakes, oceans and landfills. According to the UN Environment Programme (UNEP), single-use plastic products are defined as "an umbrella term for different types of products that are typically used once before being thrown away or recycled", which include food packaging, bottles, straws, containers, cups, cutlery and shopping bags.

The Honourable Prime Minister Shri Narendra Modi, in his Independence Day speech in 2019, gave a clarion call to make India free from single-use plastic. The Ministry of

Environment, Forest and Climate Change have notified the Plastic Waste Management (Amendment) Rules, 2021 on 12 August 2021, prohibiting manufacture, import, stocking, distribution, sale and use of the identified single-use plastic items (including polystyrene and expanded polystyrene), with effect from 1 July 2022.

To curb pollution caused by littered and unmanaged plastic waste, MoEFCC, Government of India, has adopted the following strategy with two pillars:

- Ban on the identified single-use plastic items, viz., ear buds with plastic sticks, plastic sticks for balloons, plastic flags, candy stick, ice-cream sticks, polystyrene thermocol for decoration, plates, cups, glasses, cutlery such as forks, spoons, knives, straw, trays, wrapping or packing films around sweet boxes, invitation cards, cigarette packets, plastic or PVC banners less than 100 microns and stirrers.
- Extended Producer Responsibility (EPR) for managing plastic packaging waste. The Government has issued detailed guidelines for EPR in February 2022. Extended producer responsibility refers to a waste and pollution management concept that encourages companies to design more sustainable and recyclable products and manufacturing processes. EPR makes producers responsible for environmentally sound waste management. EPR promotes the minimum level of recycling of plastic packaging waste. Single-use plastic products, with low utility and high littering potential, should be phased out and replaced by reusable products based on a circular economy approach.

Public participation and active co-operation by policy makers, industry, businesses, regulators, NGOs and the media is necessary for the successful elimination of single-use plastic products in the country.

Global Governance of Plastic Pollution

Plastic governance needs to strengthen across the fulllife cycle of plastics and associated chemicals. To be effective and impactful, efforts should be made to identify opportunities for promoting safe and non-toxic circularity for plastics, including global elimination of leakage or discharge of plastics, thus preventing harmful plastic pollution (UNEP, 2023). In March 2022, the United Nations Environmental Assembly (UNEA) adopted resolution 5/14 entitled 'End plastic pollution towards an international legally binding instrument'. In accordance with this resolution, an Intergovernmental Negotiating Committee (INC) has been formed to develop an international legally binding instrument on plastic pollution, including in the marine environment. The G20 New Delhi Leaders' Declaration has expressed support for the resolution UNEP/EA. 5/Res.14, which established INC to develop an international legally binding instrument, with the ambition of completing its work by the end of 2024.

Progress to reduce plastic pollution has been rather slow and the consequent damage to the natural environment, biodiversity and human health is likely to increase further. Global stakeholder alliances as suggested by Lampitt et al. (2023), are essential to reduce the onslaught of plastic pollution.

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SOIL-WATER QUALITY MANAGEMENT

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The soil-water system acts as a substratum composed of organic matter, minerals, water, air, and microorganisms, which features ecosystem health. Soil, acting as a natural filter, ensures water quality, which includes its physical, chemical, biological and microbiological characteristics. Deforestation, unsustainable land use practices and climate change contribute to soil erosion, undermined soil quality, and altered precipitation patterns, affecting the balance of the soil-water system, and leading to more frequent droughts and floods. Moreover, various point sources and non-point sources of pollution have put the soil-water system at risk, eventually leading to groundwater contamination. Various kinds of pollutants, such as arsenic, fluoride, selenium, uranium, iron and petroleum hydrocarbons (non-aqueous phase liquid) have been found to contaminate soil-water systems. This article discusses a systematic a systematic undertaking, starting with a preliminary site assessment, examining historical records and inspecting the area for visible signs of contamination that is crucial to identify and manage a polluted site. The article provides insights on expertise approach for the polluted landscape management, which highlights local and climatic solutions.

Keywords: Soil, Groundwater, Contamination, Risk, Remediation, Management

Understanding Soil-Water Quality

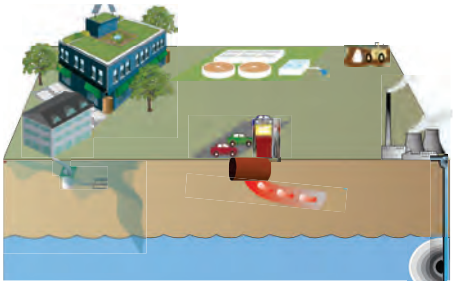
Soil is a living system of a complex mixture of organic matter, minerals, water, air, and microorganisms, and water being the universal solvent, is essential for the survival of all living organisms. Dynamic interaction between soil and water, including the movement, storage and availability of water within the soil, creates a system that can be delineated as a soil-water system (Gobat et al., 2004). Soil acts as a natural filter, purifying water as it percolates through the different soil layers it ultimately reaches the groundwater table. Soil quality refers to the ability of soil to perform its functions effectively and sustainably (Lal, 2019), which encompasses various physical, chemical and biological properties that influence the soil's ability to perform ecological services i.e., benefits people obtain from ecosystems, including provisioning (for example, food, water), regulating (climate, disease), supporting (nutrient cycling), and cultural (aesthetic, recreation) services (Suding, 2011). Whereas, water quality refers to the physical, chemical, biological and microbiological characteristics of water (Karr and Dudley, 1981), which determine its suitability for specific uses and its impact on the environment and human health. Soil-water systems are crucial for sustaining ecosystems and providing clean water. They play a vital role in agriculture, portable water supply and flood regulation, while also contributing to

nutrient cycling and carbon sequestration, supporting both human well-being and environmental health (Visser et. al., 2019). But in recent decades, health and functionality of the soil-water system has become more susceptible to several threats.

Pollution from agricultural return or runoff, industrial discharges, and improper waste disposal introduce harmful contaminants into the soil, leading to groundwater contamination and reduced water quality (Gupta, 2020). Over-extraction of groundwater for agriculture, industry, and urbanization without adequate recharge can deplete aquifers, causing a depletion in the water table and adversely impacting ecosystems and water availability (Dubey et al., 2022). Deforestation, unsustainable land use practices, and climate change contribute to soil erosion, undermined soil quality, and altered precipitation patterns, affecting the balance of the soil-water system, and leading to more frequent droughts and floods (Mainville et. al., 2006; Eekhout et. al., 2022). Urban development and impervious surfaces disrupt natural infiltration, causing increased stormwater runoff carrying pollutants into the water (Joshi and Gupta, 2018). It can also contribute pollution into the groundwater system, which originates from precipitation, snowmelt or surface water bodies and infiltrate into the soil through the unsaturated zone, also known as the vadose zone (Gupta and Sharma, 2019; Surinaidu et al. 2023). Eventually, groundwater contamination has now emerged as one of the major global challenges caused by various sources (Figure 1), ranging from human activities to natural processes. Some common sources of groundwater contamination include industrial activities, agricultural practices, landfills and waste sites, septic systems, fuel and oil spills, stormwater runoff, mining activities, geogenic sources, saltwater intrusion, and microbial contamination (Gupta, 2020).

Groundwater pollution can be categorized into point-source and nonpoint-source pollution based on the origin and the way contaminants enter the groundwater system (Kourakos et. al., 2012). Point-source pollution refers to contamination that originates from identifiable and discrete sources. These sources release pollutants at specific locations, making them easier to locate, monitor, and control. Some common examples of point-source pollution of groundwater include industrial outfalls, underground storage tank leaks (Gupta and Yadav, 2020), landfills and waste sites, septic systems and chemical spills, etc. Non-point source pollution refers to the contamination that comes from diffuse and widespread sources. These sources are harder to pinpoint because the pollutants enter the groundwater from multiple, dispersed origins. Examples of non-point source pollution of groundwater include agricultural runoff, urban runoff, atmospheric deposition, natural sources, saltwater intrusion, etc. Various kinds of pollutants such as arsenic, fluoride, Selenium, Uranium, Iron, and Petroleum Hydrocarbons (Non-aqueous phase liquid) have been found to contaminate soil-water systems (Gupta, 2020). For example, Rania-Khan Chandpur (Kanpur Dehat, UP); Lohiya Nagar (Ghaziabad, UP); Ranipet (A.P) and other places in India are famous for the Chromium contaminations in the soil-water systems (Prakash et. al., 2011; Vijay Kumar et. al., 2023). Chromium from the (COPR) Chromium Ore Processing Residue dump leakage, is a specific environmental issue related to the improper disposal and containment of waste

from chromium ore processing (Matern et. al., 2017). As per MoEF&CC, contaminated sites are delineated areas in which the constituents and characteristics of the toxic and hazardous substances, caused by humans, exist at levels and in conditions that pose existing or imminent threats to human health and/or the environment. There are 240 major contaminated sites in India affected by industrial and geogenic pollutants (CPCB, 2023).



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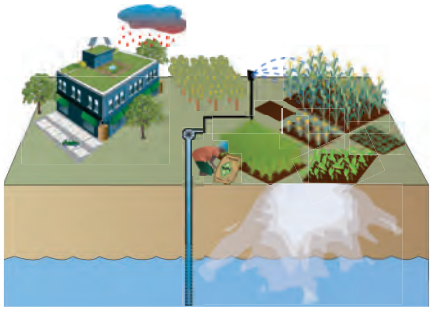

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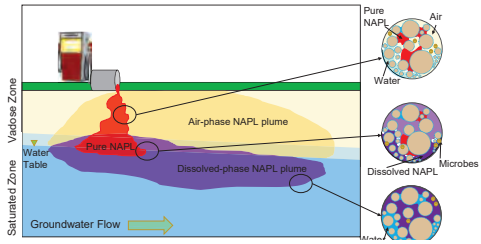

(c)

Fig. 1. Schematic diagram representing (a) point sources of contaminations; (b) non-point sources of contaminations; (c) leakage of petrochemicals (NAPL: Non-Aqueous Phase Liquid) from an underground storage tank in the subsurface environment.

Ways to manage such polluted sites

A systematic endeavour beginning with a preliminary site assessment, examining historical records, and inspecting the area for visible signs of contamination is indispensable to identify and manage a polluted site (Figure 2). A detailed site investigation follows, sampling and analysing soil, water, and air for pollutants (Ashraf et al. 2014; Saha et al. 2017). Risk assessments examine the potential hazards to human health and a suite of ecosystem services (Kuppusamy et al. 2017). The severity of contamination plays a crucial role; sites with larger areas or higher concentrations of pollutants may be prioritized. Additionally, the site's proximity to vulnerable populations and its ecological significance should be considered (Gupta and Bharagava, 2021). Moreover, sites with active or potential pathways of exposure should be given priority to prevent the further spread of contamination (Gupta and Yadav, 2020). To examine the state of contamination, performing a hydrogeological investigation at a contaminated site is a prerequisite which involves a systematic approach to understand the groundwater flow and the behaviour of

contaminants (Gupta, 2020). This step is important to estimate the static properties (structure, depth, porosity, permeability—the ability of a fluid to flow through connected pores) and aquifer strength (good or low permeability), and dynamic properties (Relative permeability, capillary pressure, initial saturations, etc) of the soil-water system (Pepper et al., 2011). The process includes site characterization, installation of monitoring wells, groundwater sampling and analysis, hydraulic testing, and groundwater modelling. Site characterization helps to identify geological features and aquifers, while monitoring wells provide groundwater samples for contaminant analysis. Hydraulic testing determines aquifer properties, aiding in understanding groundwater flow patterns. Groundwater modelling simulates contaminant transport, predicting contamination extent and potential risks (Almaliki et. al., 2022; Guleria et al. 2023a).

To capture the behaviour of pollutants, characterizing the fate and transport of pollutants in the groundwater system involves a series of multiscale laboratory experiments and field tests to determine parameters like sorption, degradation rates, and dispersion coefficients, etc (Gupta and Yadav 2020; Gupta et al. 2023). Sorption is a crucial mechanism, whereby pollutants can adhere to soil particles, reducing their mobility and potentially leading to long-term retention in the subsurface. Additionally, biodegradation by microorganisms can break down some contaminants (Fouad et. al., 2023; Gupta and Gandhi, 2023), mitigating their impact over time. The flow of groundwater, governed by hydraulic conductivity and porosity, plays a significant role in transporting pollutants through the aquifer (Gupta and Yadav, 2020; Sarma and Singh, 2021). Dispersion and diffusion processes cause the spreading and dilution of contaminants within the groundwater flow, affecting their overall movement (Guleria et al., 2023b). The process typically includes conducting laboratory tests and field studies to determine key parameters influencing pollutant mobility. Groundwater flow and contaminant transport modelling are essential tools to simulate and predict the movement of pollutants over time. By integrating data from various sources, scientists can identify potential contaminant pathways, assess the risk to receptors and design appropriate remediation strategies to effectively manage and mitigate groundwater pollution, safeguarding water resources and human health.

The appropriate remediation technologies include methods such as pump-and-treat (Zha et. al., 2019), in-situ chemical oxidation (Wei et. al., 2022), bioremediation (Janssen et. al., 2020), permeable reactive barriers (Budania and Dangayach, 2023) or monitored natural attenuation (Ding et. al., 2022). The chosen remediation approach should align with site-specific conditions, hydrogeological properties, and the type of pollutants present. For bioremediation, suitable indigenous microbial populations or engineered microorganisms are selected to enhance the biodegradation of contaminants. Factors such as groundwater flow rates, nutrient availability and environmental conditions are considered to optimize microbial activity. The design may involve the installation of injection wells or bioventing systems to deliver nutrients or oxygen to contaminated zones (Gupta et al., 2021). Monitoring wells are established to assess the progress of bioremediation, and regular sampling is performed to analyse

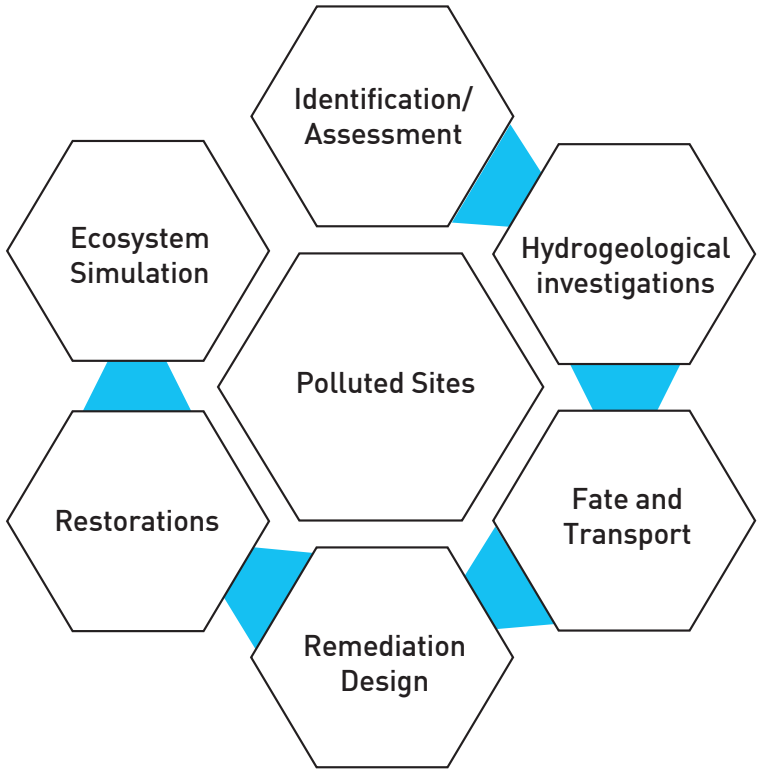

Fig.2: Flow of work plans or approaches for the remediation restoration and management of polluted sites.

pollutant concentrations and the effectiveness of the remediation process. Implementation involves the proper installation and operation of the selected remediation system, with regular monitoring to assess its effectiveness. Continuous adjustments and optimization may be necessary as the remediation progresses. Regular communication with stakeholders and compliance with regulatory requirements are critical throughout the remediation process.

During the post-implementation of any technological solution at a contaminated site, careful execution of the chosen methods is ensured, and progress is continuously monitored to assess effectiveness. Then, establishing a diverse planting scheme using a mix of native species to promote biodiversity and ecosystem health can anchor the success of restoration strategies. Monitor the growth and performance of the vegetation regularly and assess the plants' ability to uptake and sequester contaminants. Over the time, the selected native vegetation will aid in pollutant removal through phytoremediation and contribute to the site's rejuvenation, providing numerous ecological benefits and eventually transforming the polluted area into a thriving, self-sustaining habitat. Post-remediation, restoration efforts focus on reintroducing

native vegetation, rehabilitating habitats, and ensuring the site's long-term health through regular monitoring and maintenance (Rivett et. al., 2002). Community engagement and education are integral to gain local support and participation in the restoration process. The ultimate goal is to achieve effective, sustainable and cost-efficient remediation that ensures the protection of soil-water quality and the environment while minimizing potential risks to human health.

Conclusion

Managing a polluted site requires a comprehensive and systematic approach to ensure effective remediation and environmental protection. Key messages for managing a polluted site include conducting a thorough site assessment to understand the extent of contamination and potential risks, adopting cost-effective integrated approach that combines appropriate remediation technologies and ensure compliance with environmental regulations and permits. Engagement with local communities and stakeholders throughout the process is crucial to address concerns and garner support. Regular monitoring and verification of remediation efforts, along with a focus on safety and health precautions for workers, contribute to successful site management. Emphasizing environmental sustainability, practicing adaptive management and maintaining transparent communication with all stakeholders are essential for achieving long-term restoration and safeguarding the health of the ecosystem and human populations. We must develop a restoration culture in India to manage polluted sites to produce safe drinking water for the world's largest population, which has safe drinking water as their fundamental right.

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INDIAN SPACE PROGRAMME — A BRIEF OVERVIEW

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India is now a leading player in the international space arena. However, the beginnings of the country's space missions were modest. Early milestones included the first rocket launch of Rohini-75 from Thumba near Thiruvananthapuram in Kerala in 1969 and fabrication of the first Indian satellite Aryabhata in a work shed at Peenya Industrial Estate, Bengaluru in 1975. In 1967, the first 'Experimental Satellite Communication Earth Station (ESCES)' located in Ahmedabad was operationalised, which also doubled as a training centre for the Indian as well as international scientists and engineers. INCOSPAR subsequently grew and became ISRO on August 15, 1969, also under the Department of Atomic Energy (DAE). In 1972 Government of India set up a Space Commission and the Department of Space (DOS), bringing ISRO under the DOS. ISRO subsequently developed two other rockets: the Polar Satellite Launch Vehicle (PSLV) for launching satellites into polar orbits and the Geosynchronous Satellite Launch Vehicle (GSLV) for placing satellites into geostationary orbits. These rockets have launched numerous communications satellites and Earth observation satellites. Satellite navigation systems like GAGAN and IRNSS have been deployed. In January 2014, ISRO used an indigenous cryogenic engine in a GSLV-D5 launch of the GSAT-14. Another milestone in the history of ISRO is sending a lunar orbiter, Chandrayaan-1, on October 22, 2008 and a Mars orbiter, Mars Orbiter Mission, on November 5, 2013, which entered Mars orbit on September 24, 2014, making India the first nation to succeed on its first attempt to Mars, and ISRO the fourth space agency in the world as well as the first space agency in Asia to reach Mars orbit. On June 18, 2016, ISRO launched twenty satellites in a single vehicle, and on February 15, 2017, ISRO launched 104 satellites in a single rocket (PSLV-C37), a world record. ISRO launched its heaviest rocket, Geosynchronous Satellite Launch Vehicle-Mark III (GSLV-Mk III), on June 5, 2017 and placed a communications satellite GSAT-19 in orbit. With this launch, ISRO became capable of launching ton heavy satellites. Future plans of ISRO include development of the Unified Launch Vehicle, Small Satellite Launch Vehicle and development of a reusable launch vehicle, human spaceflight, a space station, controlled soft lunar landing, interplanetary probes and a solar spacecraft mission.

Keywords: GSLV, PSLV, DAE, IRNSS, GAGAN

Introduction

India is now a leading player in the international space arena. However, the beginnings of the country's space missions were modest. Early milestones included the first rocket launch of Rohini-75 from Thumba near Thiruvananthapuram in Kerala in 1969 and fabrication of the first Indian satellite Aryabhata in a work shed at Peenya Industrial Estate, Bengaluru in 1975.

Space research activities were started in India during the early 1960s. Even advanced countries were only conducting experiments on the applications of satellites at that time. When the live transmission of Tokyo Olympic Games in 1964 across the Pacific by the American Satellite 'Syncom-3' displayed the power of communication satellites, Dr. Vikram Sarabhai, the founder of Indian space programme, recognised the benefits of space technologies for India. Sarabhai realized that the resources in space have the potential to address the real problems of people. He had already set up Physical Research Laboratory (PRL) in Ahmedabad, where a big team of brilliant scientists,

anthropologists, communicators and social scientists were ready to spearhead the Indian space programme.

But even earlier, modern space research in India can be traced to the 1920s, when scientist, S K Mitra, conducted a series of experiments leading to the sounding of the ionosphere by applying ground-based radio methods in Kolkata. Later, Indian scientists like C V Raman and Meghnad Saha contributed to scientific principles applicable in space sciences.

The period after 1945 saw important developments in space research. Two scientists led the initiatives, Vikram Sarabhai and Homi Bhabha. Bhabha established the Tata Institute of Fundamental Research in 1945. Initial experiments in space sciences included the study of cosmic radiation, high altitude and airborne testing, deep underground experimentation at the Kolar mines and studies of the upper atmosphere. Studies were carried out at research laboratories, universities and independent locations.

In 1950, the Department of Atomic Energy was founded with Bhabha as its Secretary. The department provided funding for space research throughout India. During this time, tests continued on aspects of meteorology and the Earth's magnetic field. In 1954, the Uttar Pradesh state observatory was established at the foothills of the Himalayas. The Rangpur Observatory was set up in 1957 at Osmania University, Hyderabad. Space research was further encouraged by the government of India. In 1957, the Soviet Union launched Sputnik 1 and opened up possibilities for the rest of the world to conduct a space launch. Subsequently the Indian National Committee for Space Research (INCOSPAR) was set up in 1962 by the efforts of India's first Prime Minister, Jawaharlal Nehru. Since its inception, the Indian space programme has maintained three distinct elements: Satellites for communication and remote sensing, the space transportation system and application programmes.

In 1967, the first 'Experimental Satellite Communication Earth Station (ESCES)' located in Ahmedabad was operationalised, which also doubled as a training centre for Indian as well as international scientists and engineers. INCOSPAR subsequently grew and became ISRO on August 15, 1969, also under the Department of Atomic Energy (DAE). In 1972, the Government of India set up a Space Commission and the Department of Space (DOS), bringing ISRO under the DOS. The establishment of ISRO thus institutionalised space research activities in India. It is managed by the Department of Space, which reports to the Prime Minister of India. Realising that a satellite system can contribute to the national development and that it need not wait for its own satellites to begin application development, ISRO used foreign satellites in the initial stages. Accordingly, a TV programme on agricultural information to farmers 'Krishi Darshan' was started and it received good response. The next step was the Satellite Instructional Television Experiment (SITE), hailed as 'the largest sociological experiment in the world' during 1975-76. This experiment benefited around two lakh people, covering 2,400 villages of six states and transmitted

development-oriented programmes using the American Technology Satellite (ATS-6). It also trained 50,000 science teachers in primary schools in one year. SITE was followed by the Satellite Telecommunication Experiments Project (STEP), a joint project of ISRO and, Post and Telegraphs Department (P&T) using the Franco-German Symphonie satellite during 1977–79. Conceived as a sequel to SITE which focused on television, STEP was for telecommunication experiments. STEP was aimed to provide a system test of using geosynchronous satellites for domestic communications, enhance capabilities and experience in the design, manufacture, installation, operation and maintenance of various ground segment facilities and build up requisite indigenous competence for the proposed operational domestic satellite system, INSAT, for the country.

SITE was followed by the 'Kheda Communications Project (KCP)', which worked as a field laboratory for need-based and locale specific programme transmission in the Kheda district of Gujarat State. KCP was awarded the UNESCO-IPDC (International Programme for the Development of Communication) award for rural communication efficiency in the 1984. Meanwhile, the first Indian satellite 'Aryabhata' was developed and launched using a Soviet launcher. The ISRO-built satellite was sent to space by the Soviet Union on April 19, 1975. It was named after the mathematician Aryabhata. In 1980, Rohini became the first satellite to be placed in orbit by an Indian-made launch vehicle, SLV-3.

ISRO subsequently developed two other rockets: the Polar Satellite Launch Vehicle (PSLV) for launching satellites into polar orbits and the Geosynchronous Satellite Launch Vehicle (GSLV) for placing satellites into geostationary orbits. These rockets have launched numerous communications satellites and Earth observation satellites. Satellite navigation systems like GAGAN and IRNSS have been deployed. In January 2014, ISRO used an indigenous cryogenic engine in a GSLV-D5 launch of the GSAT-14.

Another milestone in the history of ISRO is sending a lunar orbiter, Chandrayaan-1, on October 22, 2008 and a Mars orbiter, Mars Orbiter Mission, on November 5, 2013, which entered Mars orbit on September 24, 2014, making India the first nation to succeed on its first attempt to Mars and ISRO the fourth space agency in the world as well as the first space agency in Asia to reach Mars orbit. On June 18, 2016, ISRO launched twenty satellites in a single vehicle, and on February 15, 2017, ISRO launched 104 satellites in a single rocket (PSLV-C37), a world record. ISRO launched its heaviest rocket, Geosynchronous Satellite Launch Vehicle-Mark III (GSLV-Mk III), on June 5, 2017 and placed a communications satellite GSAT-19 in orbit. With this launch, ISRO became capable of launching ton heavy satellites.

Future plans of ISRO include development of the Unified Launch Vehicle, Small Satellite Launch Vehicle and development of a reusable launch vehicle, human spaceflight, a space station, controlled soft lunar landing, interplanetary probes and a solar spacecraft mission.

Fig. 1: Dr. Vikram Sarabhai — Architect

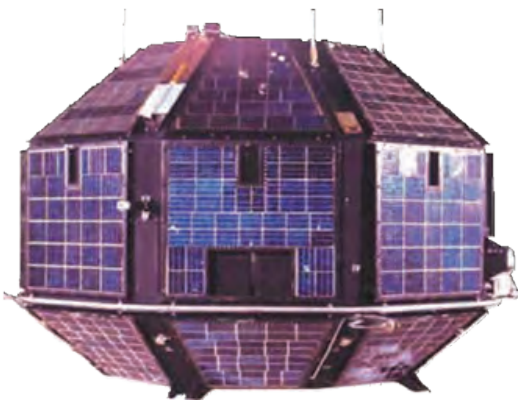

Fig. 2: First Indian Satellite Aryabhata of India's Space Programme

Early Landmarks

An early landmark of ISRO was the development of the first launch vehicle SLV-3 with a capability to place 40 kg in Low Earth Orbit (LEO), which had its first successful flight in 1980. Through the SLV-3 programme, competence was built up for the overall vehicle design, mission design, material, hardware fabrication, solid propulsion technology, control power plants, avionics, vehicle integration checkout and launch operations.

Development of multi-stage rocket systems with appropriate control and guidance systems to orbit a satellite was a major milestone. In the experimental phase during 1980s, end-to-end capability demonstration was done in the design, development and in-orbit management of space systems together with the associated ground systems for the users.

Bhaskara-I & II missions were pioneering steps in the remote sensing area whereas 'Ariane Passenger Payload Experiment (APPLE)' became the forerunner for future communication satellite systems. Development of the complex Augmented Satellite Launch Vehicle (ASLV), also demonstrated newer technologies like use of strap-on, bulbous heat shield, closed loop guidance and digital autopilot. This paved the way for learning many nuances of launch vehicle design for complex missions, leading the way for realisation of operational launch vehicles such as PSLV and GSLV. During the operational phase in 1990s, major space infrastructure was created under two broad classes: one for the communication, broadcasting and meteorology through a multi-purpose INSAT and the other for IRS system. The development and operationalisation of Polar Satellite Launch Vehicle (PSLV) and development of Geo-synchronous Satellite Launch Vehicle (GSLV) were significant achievements during this phase.

Some ISRO Success Stories

Vikram Sarabhai, the founder of the Indian space programme, had realised the potential of space communication systems in putting television to use as a mass education tool throughout the country. He visualised and suggested this as early as 1966–67, just three years after the first geosynchronous satellite, Syncom, was launched. In 1967 he initiated studies with a view to using space communication systems for operational television broadcasting. A joint study by ISRO and the National Aeronautics and Space Administration (NASA) of the United States was conducted in 1967 which recommended a hybrid system of direct broadcast by satellite combined with terrestrial TV transmitters as the most effective means of countrywide TV coverage.

In 1968, a National Satellite Communication (NASCOM) study group was set up by the government. These studies and deliberations paved the way for the acceptance in 1969 by the government of the proposal to conduct the Satellite Instructional Television Experiment (SITE) with NASA's ATS-6 satellite. In 1969 studies were also conducted on the use of communication satellites for meteorological earth observations.

Based on these studies and a joint study with the Massachusetts Institute of Technology (MIT) in 1970, ISRO evolved in the early 1970s the unique multipurpose nature of the INSAT system that included direct TV broadcasting, communications and meteorological observations and it was firmed up during 1975–77. Laboratory for Electro-Optics Systems (LEOS) is situated at Peenya Industrial Estate, Bengaluru where the first Indian Satellite Aryabhata was fabricated in 1975.

The Experimentation Phase

The 1980s were times for experimentation for launch vehicle technologies to demonstrate the country's ability to develop Augmented Satellite Launch Vehicle (ASLV) with a payload capability of 150 kg into Low Earth Orbit, a more capable launch vehicle compared to SLV-3 which was capable of putting a 40 kg satellite into a low earth orbit.

During the same period, ISRO acquired extensive experience in the design, development, building, launching and in-orbit maintenance of a variety of satellites including communication and remote sensing satellites. INSAT-1B, India's first multipurpose operational satellite launched in 1983, demonstrated the country's ability to bring about a rapid and major revolution in India's telecommunications, television broadcasting and weather forecasting. Today, communication satellites are an integral part of our economic infrastructure.

The world got an inkling of India's ability to design, build and maintain a complex remote sensing satellite in 1988 when IRS-1A, the first operational satellite built in India, started imaging the earth from orbit. The images sent by satellite circling the Earth from its 900-km-high polar orbit were utilised in diverse fields such as agriculture, groundwater prospecting, mineral survey, forestry, etc.

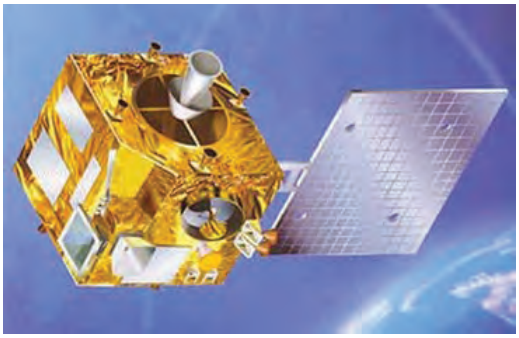

Fig. 3: IRS-1A Satellite

The Growth Phase

During the 1990s, ISRO began building the INSAT-2 series of multipurpose satellites indigenously. At the same time, systematic usage of imagery from our remote sensing satellites for tasks like crop yield estimation, groundwater and mineral prospecting, forest survey, urban sprawl monitoring and wasteland classification, and fisheries development began.

Today, India has a fleet of advanced remote sensing satellites equipped with high resolution and multispectral cameras dedicated to cartography, resource survey and ocean and atmospheric applications. Apart from these, polar orbit-based observation satellites, weather watching satellites INSAT-3D and INSAT-3DR—circling the earth in the 36,000 km high geosynchronous orbit, are providing valuable inputs for weather forecasting.

The Indian National Satellite (INSAT) system today is one of the largest domestic communication satellite systems in the Asia-Pacific region and has become an integral part of our telecommunications and TV broadcasting infrastructure including DTH services driving the country's communications revolution. Besides, our geostationary satellites are providing vital inputs to the task of nationwide weather forecasting, especially in the provision of advance warning of cyclones, saving lives and mitigating the loss of property. One of them

Fig. 4: Communication Satellites (Image credit: ISRO)

carries a satellite-aided Search and Rescue transponder and has helped in speedy rescue of people in distress in the open seas.

High throughput satellites such as GSAT-11, GSAT-29 and GSAT-19 are supporting the Digital India campaign by boosting broadband connectivity to the rural and inaccessible Gram Panchayats in the country. The transponders on these satellites will also bridge the digital divide of users including those in Jammu & Kashmir and North-Eastern regions of India.

Perfecting the launch vehicle technology is an immensely difficult and challenging task, which only a few countries possess. Till now ISRO has developed five launch vehicles (SLV-3, ASLV, PSLV, GSLV and GSLV Mk III, which is also known as LVM3) and mastered the technology of rockets that use solid, liquid as well as cryogenic propellants.

Polar Satellite Launch Vehicle (PSLV) is the third generation launch vehicle of India. It is the first Indian launch vehicle to be equipped with liquid stages. With 51 successful flights over the years, PSLV has emerged as the reliable and versatile workhorse launch vehicle of India. In fact, it has launched 342 foreign satellites as on 22 June 2021 and has carved out a niche in the commercial satellite launch arena.

On 15 February 2017, PSLV created a world record by successfully placing 104 satellites in orbit during a single launch. Well, as numbers go, it was undoubtedly a record, but the real significance is the immense confidence reposed by foreign countries, including the USA, in the capability of ISRO. This success was the result of meticulous planning and flawless execution of the mission by ISRO.

Expanding the Horizon

In the early twenty first century, the Indian launch vehicle programme has ventured beyond the PSLV resulting in the development of the Geosynchronous Satellite Launch Vehicle (GSLV) with more payload capability, efficiency and sophistication. GSLV, with the capability to launch two-ton satellites into Geosynchronous Transfer Orbit (GTO), employs cryogenic propulsion technology in its third stage.

Geosynchronous Satellite Launch Vehicle Mark II (GSLV Mk II) is the fourth generation launch vehicle having three stages (including the cryogenic upper stage) with four liquid strapons. Cryogenic technology involves storage of liquid hydrogen and liquid oxygen at very low temperatures. Materials used to operate at these very low temperatures, chilling processes and interplay of engine parameters make the development of cryogenic stage a very challenging and complex task.

With the successful qualification of the indigenously developed Cryogenic Upper Stage (CUS) in the GSLV-D5 flight on 5 January 2014, ISRO demonstrated its mastery of cryogenic rocket propulsion. Since January 2014, the vehicle has achieved six consecutive successes.

GSLV Mk III, India's fifth-generation satellite launch vehicle has two solid strapons, a core liquid booster and a cryogenic upper stage. The vehicle is designed to carry four-ton class of satellites into Geosynchronous Transfer Orbit (GTO) or about ten tons to Low Earth Orbit (LEO). LVM3-X/ CARE Mission, the first experimental suborbital flight of GSLV Mk III on 18 December 2014 injected the Crew

Module Atmospheric Re-entry Experiment (CARE) in December 2014. The CARE module began its return journey and a little later, re-entered the earth's atmosphere. It was successfully recovered over the Bay of Bengal about 20 minutes after its launch.

Subsequently, after two successful developmental flights and with the successful injection of Chandrayaan-2 into the Earth Parking Orbit in July 2019, GSLV Mk III successfully entered into its operational phase. Besides these, India's Reusable Launch Vehicle Technology Demonstrator (RLV TD) was successfully flight tested in May 2016 and several critical technologies were successfully validated. The first experimental mission of ISRO's Supersonic Combustion Ramjet (SCRAMJET) engine towards the realisation of air breathing propulsion system was also successfully conducted in August 2016. With this, India became the fourth country to flight test the SCRAMJET engine.

The Indian space programme has always focused on the development and utilisation of space technologies to achieve overall development of the country. Despite its emphasis on applications, ISRO has pursued many space science projects in earnest to perform meaningful exploration of space. India's first satellite Aryabhata was a scientific satellite.

After Aryabhata, ISRO entered into the realm of science missions again with a unique mission that caught the attention of the world—the Space Capsule Recovery Experiment-1 (SRE-1). Launched by PSLV in January 2007, SRE-1 with its scientific experiments orbited the Earth for 12 days and was successfully de-orbited and recovered over the Bay of Bengal. This proved several technologies necessary for reusable launch vehicles and human spaceflight.

Fig. 5: GSLV MK III

Fig. 6: PSLV XL LAUNCH

Venturing into Space

The space science missions of India—Chandrayaan-1, Mars Orbiter Mission, Astrosat and Chandrayaan-2, have caught the attention of millions of Indians as well as the outside world.

Launched by PSLV on 22 October 2008, the 1380 kg Chandrayaan-1 spacecraft was successfully navigated to the Moon in three weeks and was put into an orbit around the moon. On 14 November 2008, when a TV set sized 'Moon Impact Probe' separated from Chandrayaan-1 spacecraft and successfully impacted on the surface of the Moon, India became the fourth country to send a probe to the lunar surface after the United States, the Soviet Union and Japan and the fifth individual country to put a spacecraft into an orbit around the Moon. Later, when Chandrayaan-1 conclusively discovered water molecules on the lunar surface, it was widely hailed as a pathbreaking discovery. Encouraged by the success of Chandrayaan-1, ISRO endeavoured to realise the Mars Orbiter Mission for demonstrating India's capability to build, launch and navigate an unmanned spacecraft to Mars. Launched by PSLV on 5 November 2013, the 1340 kg Mars Orbiter Spacecraft encountered Mars on 24 September 2014. With this, ISRO became the fourth space agency to successfully send a spacecraft to Mars orbit. Achieving success in the first such mission itself is yet another accomplishment of ISRO.

AstroSat launched by PSLV in September 2015 is the first dedicated Indian astronomy mission aimed at studying celestial sources in X-ray, optical and UV spectral bands simultaneously. AstroSat recently made a major breakthrough by discovering one of the earliest galaxies in extreme-Ultraviolet light.

The Chandrayaan-2 mission, India's second mission to the moon, was successfully

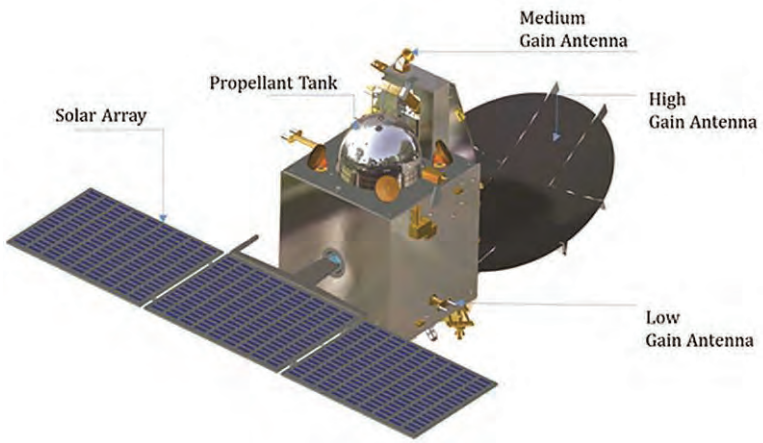

Fig. 7: AstroSat (Image Credit: isro.gov.in)

launched on 22 July 2019. Chandrayaan-2 Orbiter spacecraft was placed in its intended orbit. The eight instruments onboard the Orbiter are continuously providing useful science data which will enrich our understanding of the Moon's evolution and mapping of the minerals and water molecules in the Polar regions.

Having successfully built many communications, meteorological (weather monitoring), remote sensing and scientific satellites, ISRO has successfully established and operationalised the Navigation with Indian Constellation (NavIC) with eight satellites in orbit, which are providing accurate position, navigation and time information to users in India and its surroundings. Further, through GPS Aided GEO Augmented Navigation (GAGAN), ISRO is providing satellite-based navigation services with accuracy and integrity required for civil aviation applications and to provide better Air Traffic Management over Indian Airspace.

Fig. 8: Mars Satellite (Image Credit: isro.gov.in)

Apart from this, ISRO has also facilitated students in building and launching satellites for various applications. So far, 14 student satellites have been launched by ISRO.

Human Space Flight Endeavour

The 'Gaganyaan Programme' approved by the Government of India in 2018 is a point of inflexion in the growth profile of India's space endeavour. With the Gaganyaan Programme, a new vertical has been created within ISRO and a new ISRO centre namely Human Space Flight Centre (HSFC) was established on 10 January 2019 and started functioning.

Gaganyaan is a national programme wherein ISRO is leveraging the domain expertise of various national agencies like Indian Armed Forces, DRDO labs, CSIR labs, academic institutions, partners. MoUs or contracts are also in effect with concerned participating agencies. ISRO has organised various Industry meets and workshops to apprise the industries about the requirements of Gaganyaan. The crew selection and basic space flight training of four astronaut trainees have been completed at the Gagarin Cosmonaut Training Centre (GCTC), Russia and ISRO are gearing up for the mission-specific training in India. The preliminary design of major subsystems has been completed and ISRO has entered into the realisation phase. The test plan for various systems is also finalised.

Fig. 9: Human Space Flight Mission (Image Credit: isro.gov.in)

ISRO has initiated the process of encouraging micro-gravity research in academic institutes. Five microgravity experiment proposals have been shortlisted for flying in Gaganyaan unmanned flights. ISRO will be supporting the activities of payload design and qualification. In addition, to meet the programmatic schedule targets, foreign collaboration is being planned in areas that require establishing large infrastructure and long lead research and development. The major areas of collaborations are astronaut training, life support systems, spacesuit, wind tunnel testing, flight surgeon training, etc. ISRO has entered into contracts and agreements with various international agencies like M/s Glavkosmos Russia; NRC Canada; INCAS Romania and CNES France. In the framework of ISRO-CNES collaboration, a three-week training programme for flight surgeons was conducted at ISRO. An International Symposium on Human Space Flight and Exploration was organised by ISRO in Association with the International Academy of Astronautics (IAA) to bring together national and international experts, scientists, professionals and academicians for the exchange of technical information and policy details on human space flights.

Future Challenges

The Indian space programme has many challenges ahead. There are plans to build heavier, more capable and efficient satellites. And, space science missions like Chandrayaan-3, Aditya-L1, Mission to Venus to further explore the solar system, are in progress. Pursuit of research and development activities pertaining to small satellite launch vehicle, air-breathing rocket propulsion and demonstration of reusable rocket technology, are also progressing.

The space programme in the country is poised for several major breakthroughs in the development of advanced technology needed for the realisation of the future launch vehicle and spacecraft missions in the coming years. Efforts are on to establish the necessary infrastructure for casting large boosters,

liquid-propellant engines, heavy cryo-boosters for advanced heavier launchers and missions in the area of remote sensing, communications and navigational satellites as well as space science systems. Necessary ground infrastructure for providing mission support during the launch phase and in-orbit support for the planned missions is under realisation.

The continuing expansion of space applications programmes like Village Resources Centres, telemedicine, tele-education, disaster management support and outreach through Direct-To-Home (DTH) television, reiterates the increasing role played by the Indian space systems in providing direct benefits to society.

The Indian space programme continues to pursue successful goals on all fronts in meeting the objectives of achieving self-reliance in space technology and its applications for national development.

WEBINAR SERIES: LISTENING TO LEARN—SESSIONS DURING 2021–2022

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During the COVID-19 pandemic in August 2021, the Department of Education in Science and Mathematics (DESM), National Council of Educational Research and Training (NCERT) had initiated an online live interactive sessions with experts from different fields titled 'Webinar Series: Listening to Learn' to provide an opportunity to learn about diverse issues related to the contemporary and relevant issues with the school education. These were telecast live on PMeVidya TV channels and NCERT Official YouTube channel. This short article provides the details of the interactions held till March 2022 for easy access of different stakeholders.

Keywords: Webinar, Webinar Series: Listening to Learn, PM e-Vidya

Introduction

In today's time, the television, the internet and the World Wide Web connect people all over the world. A webinar is an online presentation that is telecast over the television and internet. This is a popular format that makes use of the television and internet's possibilities for presentation purposes. The term 'Webinar' is an acronym of two words: 'web' (from world wide web) and 'seminar'. During a webinar, the exchanges between speaker and participants usually take place in real time. The organiser or the speaker has the possibility to present media content, slides, on screen, etc., and sometimes also to talk to the participants. The telecast through the television and networking through the internet, makes it possible that the speaker and participants do not have to be in the same place. The real-time audio and video communication also provides a practical possibility of recording complete lectures and sharing or viewing them afterwards. All that is needed is a laptop or a desktop or a tablet or even a not-so-complex smart phone with an internet connection and the respective access data. The use of television for telecasting these sessions provides opportunity to those who may not be having such gadgets or an internet connection.

In one way, webinars do not differ in any way from the traditional face-to-face seminars. However, the format of webinars, i.e., the format of online presentation also demonstrates its strengths in being convenient; in providing an easier method to exchange information before, during, and after the event; in providing anonymous participation possible and providing no limit to the number of participants, etc.

During the COVID-19 pandemic times in August 2021, National Council of Educational Research and Training, New Delhi, started a webinar series to provide an opportunity

to learn about diverse issues related to the contemporary and relevant issues with the school education. Besides addressing the societal challenges and problems, this forum is also created for connecting the Global Indian Science and Technology community. NCERT has also collaborated with the Pravasi Bharatiya Academic and Scientific Sampark (PRABHASS) programme of the Government of India for connecting the Indian Diaspora with the motherland. This collaboration has facilitated NCERT also to have sessions with Indian scientists and technocrats working outside India through this forum.

Webinar Series: Listening to Learn

The sessions on Webinar Series: Listening to Learn are organised LIVE on various PM e-Vidya TV Channels (#9, #10, #11 and #12) as well as on NCERT's YouTube Channel 'NCERT Official'. The sessions that are organised in collaboration with the PRABHAAS were also streamed LIVE on the 'CSIR INDIA' Youtube channel of the Council of Scientific and Industrial Research (CSIR), Government of India. During the financial year 2021–22, 31 sessions were organised with 25 speakers.

The Table below lists all the sessions organised during the financial year 2021–22 with their respective Youtube links. The same may also be assessed through the event section of NCERT's website (www.ncert.nic.in).

S. No.	Date	Speaker	Title of the Talk and its YouTube link
1 – 5.	3, 6, 13, 21 and 27 September 2021	Rashmi Kulkarni Hydroponics, Integrated Group, Qatar (In collaboration with PRABHASS)	How Human are We? Our Microbiome, Nutrition and Long – Term Health https://youtu.be/79r0LHNUq_w (also on https://youtu.be/Wm1zmvWipzQ) https://youtu.be/SckxStR5_9I (also on https://youtu.be/ZFJA7QhgT4U) https://youtu.be/dCvfDXrfDr8 (also on https://youtu.be/QT52ud0Wlf4) https://youtu.be/Dqp4ZTwa62Q (also on, https://youtu.be/cyxXkdEkoCk) https://youtu.be/fJUyV68Trao (also on, https://youtu.be/_7ab4jVybr8)
6 – 7.	17 September and 21 September 2021	Prabhat Ranjan D. Y. Patil International University, Akurdi, Pune	Nuclear Fusion: Dream Source of Energy https://youtu.be/jByU0y1qkQs https://youtu.be/G7qVX6DJLUE

8	24 September 2021	Sahana Singh Houston, USA (In collaboration with PRABHAAS)	Relevance of India's Educational Heritage in Modern Times https://youtu.be/swM9Z1A1eEE (also on, https://youtu.be/pCGQPUmftF0)
9	1 October 2021	Mridula Ramanna SIES College of Arts and Commerce, Mumbai	Women Physicians in Colonial Bombay https://youtu.be/TBF--FV1ovE
10	8 October 2021	Arni S.R.S. Rao Medical College of Georgia, USA (In collaboration with PRABHAAS)	Indian Ancient and Modern Mathematics and Artificial Intelligence https://youtu.be/EAyUV6y6x4c (also on https://youtu.be/oLk5blpQ7LU)
11	21 October 2021	Sunil Shrivastav Union Public Service Commission, New Delhi	The Saraswat Civilization and Three Steps of Vishnu https://youtu.be/s47zqRr-bbg
12	29 October 2021	Praful Krishna San Francisco, USA	Potential Uses of Artificial Intelligence https://youtu.be/rg81-OxMjCw
13	12 November 2021	Sahotra Sarkar University of Texas at Austin, USA	Har Gobind Khorana: A Life in Science https://youtu.be/GQuZJpTI0wI
14	16 November 2021	Anil Bhardwaj Physical Research Laboratory, Ahmedabad	Indian Planetary Missions https:// youtu.be/bG2UQfDL2Vs
15	26 November 2021	Syed Hasan Shahid Rizvi Aligarh Muslim University, Aligarh	Institution of Nobel Prizes https:// youtu.be/nl2BIGVrYso
16	03 December 2021	Chandra Mohan Nautiyal Birbal Sahni Institute of Palaeosciences, Lucknow	Radiocarbon Dating: Principles and Applications https://youtu.be/tZpwwyBIrQo
17	10 December 2021	Rohit Kumar Sharma Panjab University, Chandigarh	Organic Catalysts: Envisioning Future Molecules https://youtu.be/nQ_wBIxR5P4

18	17 December 2021	Randeep Singh Bhadauria Department of Forest, U.P., Lucknow	Wild-Life Conservation https://youtu.be/2rs4JUC8l-Y
19	04 January 2022	Rajani Ranjan Rashmi The Energy and Resources Institute, New Delhi	Stabilisation of Climate: Challenges and Opportunities for India https://youtu.be/M2LY0vCZLjM
20	07 January 2022	Arvind Ranade Vigyan Prasar, Noida	Mission Aditya https://youtu.be/OS9iwne1p5s
21	12 January 2022	N Sathyamurthy IISER, Mohali	Learning Science from Kitchen Garden https://youtu.be/nh2xG5J3C34
22	21 January 21, and 24 January 2022	KP Mohanan Indian Institute of Science Education and Research, Pune ThinQ	How to Learn to Reason by Listening https://youtu.be/iOdxojv7D1o https://youtu.be/Y8ruZHsWcDQ
23	28 January 2022	DM Banerjee University of Delhi, Delhi	The Beautiful World of Gemstones https://youtu.be/Hjy4X-XYBGg
24	04 February 2022	KK Talwar Post Graduate Institute of Medical Education and Research, Chandigarh	Circulatory System https://youtu.be/Z1SoiLN-IoQ
25	11 February 2022	Rajkumar Buyya University of Melbourne, Australia	Computers and Internet: Technological Progression and Applications https://youtu.be/HfHo5u-B-y8
26	18 February 2022	AK Nandakumaran Indian Institute of Science, Bengaluru	Critical Thinking: General, Mathematics and Logic https://youtu.be/HCDTJb_1_M
27	25 February, 2022	CK Varshney Jawaharlal Nehru University, New Delhi	Plastic Pollution: A Human Made Global Crisis https://youtu.be/c2hWYY8-QdA
28	04 March 2022	Arvind Kumar Homi Bhabha Center Science Education, Mumbai	Simple Arguments in Physics: Their Uses and Limitations https://youtu.be/-0jCp4XK5so

29	11 March 2022	Deepak Mishra Space Application Centre, Ahmedabad	Indin Space Programme https://youtu.be/OMWYXHtULgI
30	16 March 2022	Randeep Guleria All India Institute of Medical Sciences, New Delhi	How to Stay Healthy in Today's Time? https://youtu.be/iHGTkhdm-NE

The entire playlist of all the sessions can be accessed at https://youtube.com/playlist? list= PLUgLcpnv1YifsVlYiNsbEBF7vPg9YdEnm or at https://www.ncert.gov.in/webinar_series.php. This playlist can also be seen by scanning the following QR Code:

PHR072005905954

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WEBINAR SERIES: LISTENING TO LEARN—SESSIONS DURING 2022–23

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Introduction

The NCERT's Telecast Programme Webinar Series: 'Listening to Learn' continued during the financial year 2022–23. During the year; twenty-one sessions were organised on a wide range of topics related to school education. It included astronomy—gravitational lensing and James Webb Telescope; environment—soil-water quality, rivers, hydroelectric cells and water; biological sciences and medicine—genetic engineering, biosecurity, radiology, superbugs and brain; archeology and earth sciences—dinosaurs, geophysics and radionuclides; engineering sciences and applications—nuclear radiations, materials, wind tunnels, cells and batteries, and biomimicry. A session for motivating children for entrepreneurship was also organised by the Mumbai Dabbawallas.

As in 2021–22, in 2022–23 as well, these sessions were streamed LIVE on four PM e-Vidya television channels #9–#12, and also on the NCERT's YouTube channel: NCERT OFFICIAL. With the gradual improvement in the pandemic situation, experts were able to be present in the Central Institute of Educational Technology (CIET) studio for the session. Out of the total twenty-one sessions, fourteen sessions took place having experts in the studio while seven were organised connecting experts through video-conferencing. Two experts joined the telecast from abroad (one from USA and another from UK). In 2022–23 as well, NCERT has collaborated with the Pravasi Bharatiya Academic and Scientific Sampark (PRABHASS) programme of the Government of India for connecting the Indian diaspora with the motherland.

Suggestions are being received for topics and areas that can be taken up for discussion in the series. At the same time, interest expressed by a good number of experts from India as well as from Indian diaspora to be part of this platform for interacting with children in their respective areas of expertise is encouraging. Sincere efforts have been made to include them. An earnest attempt is being made to incorporate all other possible suggestions in the forthcoming sessions.

The Table below provides a list of all the twenty-one sessions organised during the financial year 2022–23 with their respective Youtube Links. The same may also be accessed through the event section of the NCERT's website (www.ncert.nic.in).

S. No.	Date	Speaker	Title of the Talk and its YouTube link
1.	06 May 2022	Ashok Sahni Panjab University, Chandigarh	Dinosaurs of India: Dead but Doing Well https://youtu.be/CqYW_9bsinM
2.	20 May 2022	Jasjeet Singh Bagla Indian Institute of Science Education and Research, Mohali	Gravitational Lensing https://youtu.be/vmHtajiVLLY
3.	10 June 2022	Pankaj Kumar Gupta University of Waterloo, Canada	Soil-Water Quality Management https://youtu.be/8HWl3Vb6w3k
4.	24 June 2022	Abhishek Mishra Houston Methodist Research Institute, Texas, USA	Genetic Engineering: The Life beyond Imagination https://youtu.be/IdMHYzTqZdM
5.	8 July 2022	Bhanu Prakash Singh Aligarh Muslim University, Aligarh	Nuclear Radiations and their Applications https://youtu.be/18uaQKFSOkk
6.	22 July 2022	Avanish Kumar Srivastava CSIR - Advanced Materials & Processes Research Institute, Bhopal	Self-Reliant India: A Materials Perspective https://youtu.be/ri6ChmzctQ4
7.	12 August 2022	Shalivahan Indian Institute of Petroleum and Energy, Visakhapatnam	Geophysics: Knowledge of Depth https://youtu.be/DoC4YfbZ89g
8.	26 August 2022	Priyank Kumar Birla Institute of Technology, Mesra, Ranchi	Wind Tunnels and Their Applications https://youtu.be/gNFSANS-aj4
9.	09 September 2022	Venimadhav Adyam Indian Institute of Technology, Kharagpur	Battery Manufacturing in India – Technological Challenges and Opportunities https://youtu.be/Iz1EVQ39J3A
10.	23 September 2022	Arnab Sen ICAR Research Complex for NEH Region, Barapani, Meghalaya	Biosecurity: Threats and Control https://youtu.be/xrDtCUZL9o
11.	07 October 2022	V. Subramanian TERI School of Advanced Studies, New Delhi	What Do Our Revers Carry? https://youtu.be/2BMqKGzBlyE

12.	28 October 2022	Debopam Das Indian Institute of Technology, Kanpur	Biomimicry and Innovation: A Fluid Dynamics Perspective https://youtu.be/a0xLUj9SV7c
13.	11 November 2022	Shailesh Shirali Sahyadri School, KFI, Rajgurunagar, Pune	Snippets from Ancient Indian Mathematics https://youtu.be/watch?v=4q2llxXV4-I
14.	09 December 2022	R.K. Kotnala CSIR – National Physical Laboratory, New Delhi	Hydroelectric Cell: The Biggest Invention in Green Energy https://youtu.be/qlm_FolhXh0
15.	23 December 2022	Pankaj Kumar Inter University Accelerator Centre, New Delhi	Decoding the Geological Past with Radionuclides https://youtu.be/MK5L6QM4fWw
16.	06 January 2023	Anand Narayanan Indian Institute of Space Science and Technology, Thiruvananthapuram	James Webb Space Telescope: Out Where The Stars Do Not Twinkle https://youtu.be/IBd-IDEeCq8
17.	27 January 2023	Abhishek Mahajan Clatterbridge Cancer Centre, University of Liverpool, UK	Radiology in the Service of Mankind https://youtu.be/wWodurYVCyATo
18.	10 February 2023	Pawan G. Agrawal Kamlabai Educational and Charitable Trust, Mumbai	Let's Touch the Sky (Story of Mumbai Dabbawalas) https://youtu.be/C16E9bawYDY
19.	17 February 2023	Rajesh Bhatia Food and Agriculture Organization of the United Nations, New Delhi	Silent Pandemic of Superbugs https://youtu.be/nucLdEpNa-w
20.	10 March 2023	Arun Deep Ahluwalia Shoolini University, Solan, HP	Story of Water https://youtu.be/1XoWhRrvg8w
21.	17 March 2023	Arpan Banerjee National Brain Research Centre, Gurugram, Haryana	Brain – An Exploration like No Other https://youtu.be/nkYB4R7jnZ8

The programme is being continued during 2023–2024. All the sessions are available on the NCERT's YouTube Channel: NCERT OFFICIAL. Each recording has information about the speaker as well as brief about the talk. The entire playlist of all the sessions can be accessed at https://youtube.com/playlist?list=PLUgLcpnv1YifsVlYiNsbEBF7vPg9YdEnm.

These videos are uploaded on YouTube to make sure that these can be accessed by children and public in general at their convenience. The same can also be accessed through the event section of the NCERT's website (https://ncert.nic.in/webinar_series.php). The same can also be accessed by scanning the QR Code.

It is hoped that the viewers will enjoy these sessions and provide their feedback. Suggestions about the areas or topics that can be taken up in this series are welcome.

Acknowledgements

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SCIENCE NEWS

Sweet Smell of Success: Simple Fragrance Method Produces Major Memory Boost

Date: 1 August 2023

Source: University of California, Irvine

Summary: When a fragrance wafted through the bedrooms of older adults for two hours every night for six months, memories skyrocketed. Participants in this study by University of California, Irvine neuroscientists reaped a 226 per cent increase in cognitive capacity compared to the control group. The researchers say the finding transforms the long-known tie between smell and memory into an easy, non-invasive technique for strengthening memory and potentially deterring dementia.

The team's study appears in Frontiers in Neuroscience.

The project was conducted through the UCI Center for the Neurobiology of Learning and Memory. It involved men and women aged 60 to 85 without memory impairment. All were given a diffuser and seven cartridges, each containing a single and different natural oil. People in the enriched group received full-strength cartridges. Control group participants were given the oils in tiny amounts. Participants put a different cartridge into their diffuser each evening prior to going to bed, and it activated for two hours as they slept. People in the enriched group showed a 226 per cent increase in cognitive performance compared to the control group, as measured by a word list test commonly used to evaluate memory. Imaging revealed better integrity in the brain pathway called the left uncinate fasciculus. This pathway, which connects the medial temporal lobe to the decision-making prefrontal cortex, becomes less robust with age. Participants also reported sleeping more soundly.

Scientists have long known that the loss of olfactory capacity or ability to smell, can predict development of nearly 70 neurological and psychiatric diseases. These include Alzheimer's and other dementias, Parkinson's disease , schizophrenia and alcoholism. Evidence is emerging about a link between smell loss

due to COVID and ensuing cognitive decrease. Researchers have previously found that exposing people with moderate dementia to up to 40 different odors twice a day over a period of time boosted their memories and language skills, eased depression and improved their olfactory capacities. The UCI team decided to try turning this knowledge into an easy and non-invasive dementia-fighting tool.

"The reality is that over the age of 60, the olfactory sense and cognition starts to fall off a cliff," said Michael Leon, Professor of neurobiology and behaviour and a CNLM fellow, "But it's not realistic to think people with cognitive impairment could open, sniff and close 80 odorant bottles daily. This would be difficult even for those without dementia." The study's first author, project scientist Cynthia Woo, said, "That's why we reduced the number of scents to just seven, exposing participants to just one each time, rather than the multiple aromas used simultaneously in previous research projects. By making it possible for people to experience the odors while sleeping, we eliminated the need to set aside time for this during waking hours every day."

The researchers say the results from their study bear out what scientists learned about the connection between smell and memory.

"The olfactory sense has the special privilege of being directly connected to the brain's memory circuits," said Michael Yassa, Professor and James L. McGaugh Chair in the Neurobiology of Learning and Memory. The Director of CNLM, he served as collaborating investigator, "All the other senses are routed first through the thalamus. Everyone has experienced how powerful aromas are in evoking recollections, even from very long ago. However, unlike with vision changes that we treat with glasses and hearing aids for hearing impairment, there has been no intervention for the loss of smell."

The team would next like to study the technique's impact on people with diagnosed cognitive loss. The researchers also say they hope the finding will lead to more investigations into olfactory therapies for memory impairment. A product based on their study and designed for people to use at home is expected to come onto the market this fall.

Global Diet Study Challenges Advice to Limit High-Fat Dairy Foods

Date: 6 July 2023

Source: European Society of Cardiology

Summary: Unprocessed red meat and whole grains can be included or left out of a healthy diet, according to a study conducted in 80 countries across all inhabited continents. Diets emphasising fruit, vegetables, dairy (mainly whole-fat), nuts, legumes and fish were linked with a lower risk of Cardiovascular Disease (CVD) and premature death in all world regions. The addition of unprocessed red meat or whole grains had little impact on outcomes.

"Low-fat foods have taken centre stage with the public, food industry and policy makers, with nutrition labels focused on reducing fat and saturated fat," said study author Dr. Andrew Mente of the Population Health Research Institute, McMaster University, Hamilton, Canada. "Our findings suggest that the priority should be increasing protective foods such as nuts (often avoided as too

energy dense), fish and dairy, rather than restricting dairy (especially whole-fat) to very low amounts. Our results show that up to two servings a day of dairy, mainly whole-fat, can be included in a healthy diet. This is in keeping with modern nutrition science showing that dairy, particularly whole-fat, may protect against high blood pressure and metabolic syndrome." The study examined the relationships between a new diet score and health outcomes in a global population. A healthy diet score was created based on six foods that have each been linked with longevity. The PURE diet included 2–3 servings of fruit per day, 2–3 servings of vegetables per day, 3–4 servings of legumes per week, 7 servings of nuts per week, 2–3 servings of fish per week, and 14 servings of dairy products (mainly whole fat but not including butter or whipped cream) per week. A score of 1 (healthy) was assigned for intake above the median in the group and a score of 0 (unhealthy) for intake at or below the median, for a total of 0 to 6. Dr. Mente explained, "Participants in the top 50 per cent of the population — an achievable level — on each of the six food components attained the maximum diet score of six."

Associations of the score with mortality, myocardial infarction, stroke and total CVD (including fatal CVD and non-fatal myocardial infarction, stroke and heart failure) were tested in the PURE study which included 147,642 people from the general population in 21 countries. The analyses were adjusted for factors that could influence the relationships such as age, sex, waist-to-hip ratio, education level, income, urban or rural location, physical activity, smoking status, diabetes, use of statins or high blood pressure medications, and total energy intake.

The average diet score was 2.95. During a median follow-up of 9.3 years, there were 15,707 deaths and 40,764 cardiovascular events. Compared with the least healthy diet (score of 1 or less), the healthiest diet (score of 5 or more) was linked with a 30 per cent lower risk of death, 18 per cent lower likelihood of CVD, 14 per cent lower risk of myocardial infarction and 19 per cent lower risk of stroke. Associations between the healthy diet score and outcomes were confirmed in five independent studies including a total of 96,955 patients with CVD in 70 countries.

Dr. Mente said: "This was by far the most diverse study of nutrition and health outcomes in the world and the only one with sufficient representation from high-, middle- and low-income countries. The connection between the PURE diet and health outcomes was found in generally healthy people, patients with CVD, patients with diabetes and across economies."

"The associations were strongest in areas with the poorest quality diet, including South Asia, China and Africa, where calorie intake was low and dominated by refined carbohydrates. This suggests that a large proportion of deaths and CVD in adults around the world may be due to under-nutrition, that is, low intakes of energy and protective foods, rather than over nutrition. This challenges current beliefs," said Professor Salim Yusuf, senior author and principal investigator of PURE.

In an accompanying editorial, Dr. Dariush Mozaffarian of the Friedman School of Nutrition Science and Policy, Tufts University, Boston, US stated, "The new results in PURE, in combination with prior reports, call for a

re-evaluation of unrelenting guidelines to avoid whole fat dairy products. Investigations such as the one by Mente and colleagues remind us of the continuing and devastating rise in diet-related chronic diseases globally and of the power of protective foods to help address these burdens. It is time for national nutrition guidelines, private sector innovations, government tax policy and agricultural incentives, food procurement policies, labelling and other regulatory priorities, and food-based healthcare interventions to catch up to the science. Millions of lives depend on it."

For Experimental Physicists, Quantum Frustration Leads to Fundamental Discovery

Date: 14 June 2023

Source: University of Massachusetts, Amherst

Summary: A team of physicists, including University of Massachusetts, Assistant Professor Tigran Sedrakyan, recently announced in the journal *Nature* that they have discovered a new phase of matter called the 'chiral bose-liquid state,' the discovery opens a new path in the age-old effort to understand the nature of the physical world. Under everyday conditions, matter can be a solid, liquid or gas. But once you venture beyond the everyday into temperatures approaching absolute zero, things smaller than a fraction of an atom or which have extremely low states of energy—the world looks very different. "You find quantum states of matter way out on these fringes," says Sedrakyan, "and they are much wilder than the three classical states we encounter in our everyday lives." Sedrakyan has spent years exploring these wild quantum states, and he is particularly interested in the possibility of what physicists call 'band degeneracy,' 'moat bands' or 'kinetic frustration' in strongly interacting quantum matter. Typically, particles in any system bump into each other, and in so doing they cause predictable effects, like billiard balls knocking into each other and then reacting in a predictable pattern. In other words, the effects and the particles are correlated. But in a frustrated quantum system, there are infinite possibilities that stem from the interaction of particles perhaps the billiard ball levitates or zooms off at an impossible angle and some of these infinite possibilities can lead to novel quantum states. What Sedrakyan and his colleagues have done is to engineer a frustration machine: a bilayer semiconducting device. The top layer is electron-rich and these electrons can move freely. The bottom layer is filled with 'holes,' or places that a roving electron can occupy. Then the two layers are brought extremely close together—interatomic close. If the number of electrons in the top layer and holes in the bottom layer were equal, then you would expect to see the particles acting in a correlated manner, but Sedrakyan and his colleagues designed the bottom layer so that there is a local imbalance between the number of electrons and holes in the bottom layer. "It's like a game of musical chairs," Sedrakyan says, "designed to frustrate the electrons. Instead of each electron having one chair to go to, they must now scramble and have many possibilities in where they 'sit'."This frustration kicks off the novel chiral edge state, which has a number of surprising characteristics. For instance, if you cool quantum matter in a chiral state down to absolute zero, the electrons freeze into a predictable pattern, and the emergent

charge-neutral particles in this state will all either spin clockwise or counter-clockwise. Even if you smash another particle into one of these electrons or you introduce a magnetic field, you can't alter its spin—it's surprisingly robust and can even be used to encode digital data in a fault-tolerant way.

Even more surprisingly is what happens when an outside particle does smash into one of the particles in the chiral edge state. To return to the billiard ball metaphor, you would expect to send the eight-ball flying when the cue ball smacks into it. But if the pool balls were in a chiral bose-liquid state, all 15 of them would react in exactly the same way when the eight-ball was struck. This effect is due to the long-range entanglement present in this quantum system.

It is difficult to observe the chiral bose-liquid state, which is why it has remained hidden for so long. To do so, the team of scientists, including theoretical physicists Rui Wang and Baigeng Wang (both of Nanjing University) as well as experimental physicists Lingjie Du (Nanjing University) and Rui-Rui Du (Peking University) designed a theory and an experiment that used an extremely strong magnetic field that is capable of measuring the movements of the electrons as they race for chairs.

"On the edge of the semiconductor bilayer, electrons and holes move with the same velocities," says Lingjie Du, "This leads to helical-like transport, which can be further modulated by external magnetic fields as the electron and hole channels are gradually separated under higher fields." The magneto-transport experiments therefore successfully reveal the first piece of evidence of the chiral bose-liquid, which the authors also call the 'excitonic topological order' in the published paper.

High-quality Sleep Promotes Resilience to Depression and Anxiety

Date: 13 July 2023

Source: University of York

Summary: Research has shown quality sleep can help bolster resilience to depression and anxiety. The study, led by researchers at the University of York, highlights that chronic stress is a major risk factor for a number of mental health disorders, including depression and pathological anxiety, but high-quality sleep and coping strategies—such as the ability to reframe a situation to see the positive side which can help to prevent poor mental health when faced with negative or stressful experiences. The research studied data from over 600 participants during the COVID-19 pandemic in 2020—an extended stressful period of time. They aimed to test the theory that coping strategies supported positive mental health outcomes, which could be strengthened by high-quality sleep.

Emma Sullivan, PhD student from the Department of Psychology at the University of York, said, "As the COVID-19 pandemic has been a prolonged period of stress for people across the entire world, it offered us with a unique context with which to address our research questions." This is the first study to investigate the ways in which positive coping strategies and sleep quality influence depression and anxiety when experiencing a real-world chronic stressor. We found that better sleep quality was associated with fewer symptoms of both depression and anxiety during the initial months of the COVID-19 pandemic. "These findings highlight the importance of targeting both positive coping strategies and sleep quality when enduring

periods of chronic stress." The team analysed data from the Boston College Daily Sleep and Well-being Survey where participants regularly self-reported their sleep quality and mental well-being during the pandemic. They also completed a baseline demographic survey to obtain information such as their age, gender and ethnicity. As well as collecting information on participants' sleep and mental well-being, the surveys also collected a wealth of additional information such as participants' alcohol consumption, their quarantine status and physical activity levels.

Dr Scott Cairney, PhD supervisor on the project from the Department of Psychology at the University of York, said, "We have known for a long time that high-quality sleep is associated with better health and well-being outcomes, but we wanted to know whether this would change if sleep and coping strategies were put under intense and prolonged periods of stress, as it was for so many during the pandemic."

"We found that sleep plays a hugely important role in the management of chronic stress and can sustain well-being over a long period of time, reducing symptoms of depression and anxiety."

Reinventing Cosmology: New Research Puts Age of Universe at 26.7 — Not 13.7 — Billion Years

Date: 11 July 2023

Source: University of Ottawa

Summary: Our universe could be twice as old as current estimates, according to a new study that challenges the dominant cosmological model and sheds new light on the so-called 'impossible early galaxy problem.' "Our newly-devised model stretches the galaxy formation time by a several billion years, making the universe 26.7 billion years old, and not 13.7 as previously estimated," says author Rajendra Gupta, adjunct professor of physics in the Faculty of Science at the University of Ottawa. For years, astronomers and physicists have calculated the age of our universe by measuring the time elapsed since the Big Bang and by studying the oldest stars based on the red-shift of light coming from distant galaxies. In 2021, thanks to new techniques and advances in technology, the age of our universe was thus estimated at 13.797 billion years using the Lambda-CDM concordance model. However, many scientists have been puzzled by the existence of stars like the Methuselah that appear to be older than the estimated age of our universe and by the discovery of early galaxies in an advanced state of evolution made possible by the James Webb Space Telescope. These galaxies, existing a mere 300 million years or so after the Big Bang, appear to have a level of maturity and mass typically associated with billions of years of cosmic evolution.

Furthermore, they're surprisingly small in size, adding another layer of mystery to the equation. Zwicky's tired light theory proposes that the red shift of light from distant galaxies is due to the gradual loss of energy by photons over vast cosmic distances. However, it was seen to conflict with observations. Yet Gupta found that, "by allowing this theory to coexist with the expanding universe, it becomes possible to reinterpret the red-shift as a hybrid phenomenon, rather than purely due to expansion."

In addition to Zwicky's tired light theory, Gupta introduces the idea of evolving "coupling

constants," as hypothesised by Paul Dirac. Coupling constants are fundamental physical constants that govern the interactions between particles. According to Dirac, these constants might have varied over time. By allowing them to evolve, the time-frame for the formation of early galaxies observed by the Webb telescope at high red-shifts can be extended from a few hundred million years to several billion years. This provides a more feasible explanation for the advanced level of development and mass observed in these ancient galaxies. Moreover, Gupta suggests that the traditional interpretation of the 'cosmological constant,' which represents dark energy responsible for the accelerating expansion of the universe, needs revision. Instead, he proposes a constant that accounts for the evolution of the coupling constants. This modification in the cosmological model helps address the puzzle of small galaxy sizes observed in the early universe, allowing for more accurate observations.

Greenhouse Gas Emissions at 'an All-time High' — And It is Causing an Unprecedented Rate of Global Warming, Say Scientists

Date: 8 June 2023

Source: University of Leeds

Summary: Human-induced warming, largely caused by the burning of fossil fuels, reached an average of 1.14°C for the most recent decade (2013 to 2022) above pre-industrial levels. This is up from 1.07°C between 2010 and 2019. Human-induced warming is now increasing at a pace of over 0.2°C per decade. The analysis also found that greenhouse gas emissions were 'at an all-time high', with human activity resulting in the equivalent of 54 (+/-5.3) giga tonnes (or billion metric tonnes) of carbon dioxide being released into the atmosphere on average every year over the last decade (2012–2021). Given the speed at which the global climate system is changing, the scientists argue that policymakers, climate negotiators and civil society groups need to have access to up-to-date and robust scientific evidence on which to base decisions.

The authoritative source of scientific information on the state of the climate is the UN's Intergovernmental Panel on Climate Change (IPCC) but the turnaround time for its major assessments is five or ten years, and that creates an 'information gap,' particularly when climate indicators are changing rapidly.

Critical decade for climate change

The Indicators of Global Climate Change Project is being co-ordinated by Professor Piers Forster, Director of the Priestley Centre for Climate Futures at Leeds. He said, "This is the critical decade for climate change. Decisions made now will have an impact on how much temperatures will rise and the degree and severity of impacts we will see as a result."

Long-term warming rates are currently at a long-term high, caused by highest-ever levels of greenhouse gas emissions. But there is evidence that the rate of increase in greenhouse gas emissions has slowed. We need to be nimble footed in the face of climate change. We need to change policy and approaches in the light of the latest evidence about the state of the climate system. Time is no longer on our side. Access to up-to-date information is vitally important.

Writing in the journal Earth System Science Data, the scientists have revealed how key indicators have changed since the publication of the IPCC's Sixth Assessment Working Group 1 report in 2021 which produced the key data that fed into the subsequent IPCC Sixth Synthesis Report.

What the updated indicators show

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There has been positive move away from burning coal, yet this has come at a short-term cost in that it has added to global warming by reducing particulate pollution in the air, which has a cooling effect.

'Indicators critical to address climate crisis'

Professor Maisa Rojas Corradi, Minister of the Environment in Chile, IPCC author and a scientist involved in this study, said, "An annual update of key indicators of global change is critical in helping the international community and countries to keep the urgency of addressing the climate crisis at the top of the agenda and for evidence-based decision-making.

"In line with the 'ratchet-mechanism' of increasing ambition envisioned by the Paris Agreement we need scientific information about emissions, concentration and temperature as often as possible to keep international climate negotiations up-to-date and to be able to adjust and if necessary correct national policies.

"In the case of Chile, we have a climate change law that aims at aligning government-wide policies with climate action."

Remaining carbon budget

One of the major findings of the analysis is the rate of decline in what is known as the remaining carbon budget, an estimate of how much carbon that can be released into the atmosphere to give a 50 per cent chance of keeping global temperature rise within 1.5°C.

In 2020, the IPCC calculated the remaining carbon budget was around 500 giga tonnes of carbon dioxide. By the start of 2023, the figure was roughly half that at around 250 giga tonnes of carbon dioxide.

The reduction in the estimated remaining carbon budget is due to a combination of continued emissions since 2020 and updated estimates of human-induced warming.

Professor Forster said, "Even though we are not yet at 1.5°C warming, the carbon budget will likely be exhausted in only a few years as we have a triple whammy of heating from very high CO_2 emissions, heating from increases in other GHG emissions and heating from reductions in pollution.

If we don't want to see the 1.5°C goal disappearing in our rear view mirror, the world must work much harder and urgently at bringing emissions down.

Our aim is for this project to help the key players urgently make that important work happen with up-to-date and timely data at their fingertips."

Dr. Valérie Masson-Delmotte, from the Université Paris Saclay who co-chaired Working Group 1 of the IPCC's Sixth Assessment report and was involved in the climate indicators project, said, "This robust update shows intensifying heating of our climate driven by human activities. It is a timely wake up call for the 2023 global stocktake of the Paris Agreement—the pace and scale of climate action is not sufficient to limit the escalation of climate-related risks."

As recent IPCC reports have conclusively shown, with every further increment of global warming, the frequency and intensity of climate extremes, including hot extremes, heavy rainfall and agricultural droughts, increases.

Evidence of Conscious-like Activity in the Dying Brain

Date: 1 May 2023

Source: Michigan Medicine, University of Michigan

Summary: A new study provides early evidence of a surge of activity correlated with consciousness in the dying brain.

Reports of near-death experiences—with tales of white light, visits from departed loved ones, hearing voices, among other attributes—capture our imagination and are deeply engrained in our cultural landscape.

The fact that these reports share so many common elements begs the question of whether there is something fundamentally real underpinning them and that those who have managed to survive death are providing glimpses of a consciousness that does not completely disappear, even after the heart stops beating. A new study published in the Proceedings of the National Academy of Science, provides early evidence of a surge of activity correlated with consciousness in the dying brain.

The study, led by Jimo Borjigin, Ph.D., associate professor in the Department of Molecular and Integrative Physiology, and the Department of Neurology and her team is a follow-up to animal studies conducted almost ten years ago in collaboration with George Mashour, M.D., Ph.D., the founding director of the Michigan Center for Consciousness Science.

Similar signatures of gamma activation were recorded in the dying brains of both animals and humans upon a loss of oxygen following cardiac arrest.

"How vivid experience can emerge from a dysfunctional brain during the process of dying is a neuroscientific paradox. Dr. Borjigin has led an important study that helps shed light on the underlying neurophysiologic mechanisms," said Mashour.

The team identified four patients who passed away due to cardiac arrest in the hospital while under EEG monitoring. All four of the patients were comatose and unresponsive. They were ultimately determined to be beyond medical help and with their families' permission, removed from life support.

Upon removal of ventilator support, two of the patients showed an increase in heart rate along with a surge of gamma wave activity,

considered the fastest brain activity and associated with consciousness. Furthermore, the activity was detected in the so-called hot zone of neural correlates of consciousness in the brain, the junction between the temporal, parietal and occipital lobes in the back of the brain. This area has been correlated with dreaming, visual hallucinations in epilepsy and altered states of consciousness in other brain studies.

These two patients had previous reports of seizures, but no seizures during the hour before their deaths, explained Nusha Mihaylova, M.D., Ph.D., a clinical associate professor in the Department of Neurology who has collaborated with Dr. Borjigin since 2015 by collecting EEG data from deceased patients under ICU care. The other two patients did not display the same increase in heart rate upon removal from life support nor did they have increased brain activity.

Because of the small sample size, the authors caution against making any global statements about the implications of the findings. They also note that it's impossible to know in this study what the patients experienced because they did not survive.

"We are unable to make correlations of the observed neural signatures of consciousness with a corresponding experience in the same patients in this study. However, the observed findings are definitely exciting and provide a new framework for our understanding of covert consciousness in the dying humans," she said.

Larger, multi-center studies including EEG-monitored ICU patients who survive cardiac arrest, could provide much needed data to determine whether or not these bursts in gamma activity are evidence of hidden consciousness even near death.

Researchers Identify 135 New Melanin Genes Responsible for Pigmentation

Date: 11 August 2023

Source: University of Oklahoma

Summary: The skin, hair and eye colour of more than eight billion humans is determined by the light-absorbing pigment known as melanin. An article recently published in the journal Science features research from Vivek Bajpai, Ph.D., lead author and an assistant professor in the School of Sustainable Chemical, Biological and Materials Engineering at the University of Oklahoma, and collaborators from Stanford University. Their research has identified 135 new genes associated with pigmentation.

Melanin is produced within special structures called melanosomes. Melanosomes are found inside melanin-producing pigment cells called melanocytes.

Although all humans have the same number of melanocytes, the amount of melanin they produce differs and gives rise to the variation in human skin color.

"To understand what actually causes different amounts of melanin to be produced, we used a technology called CRISPR-Cas9 to genetically engineer cells," Bajpai said. "Using CRISPR, we systematically removed more than 20,000 genes from hundreds of millions of melanocytes and observed the impact on melanin production."

To identify which genes influence melanin production, cells that lost melanin during the gene removal process needed to be separated from millions of other cells that did not.

Using in vitro cell cultures, Bajpai developed a novel method to achieve this goal that detects and quantifies the melanin-producing activity of melanocytes.

By passing light through the melanocytes, he could record if the light was either absorbed or scattered by the melanin inside.

"If there are a lot of melanin-producing melanosomes, the light will scatter much more than in cells with little melanin," Bajpai said.

"Using a process called side-scatter of flow cytometry, we were able to separate cells with more or less melanin. These separated cells were then analysed to determine the identity of melanin-modifying genes. We identified both new and previously known genes that play important roles in regulating melanin production in humans."

The researchers found 169 functionally diverse genes that impacted melanin production. Of those, 135 were not previously associated with pigmentation.

They further identified the function of two newly discovered genes: KLF6 and COMMD3.

The DNA-binding protein KLF6 led to a loss of melanin production in humans and animals, confirming the role KLF6 plays in melanin production in other species as well.

The COMMD3 protein regulated melanin synthesis by controlling the acidity of melanosomes.

Historically, darker pigmentation has been needed to protect against ultraviolet radiation in areas closer to the equator and for people who spend hours in direct sunlight. As humans moved into areas with less direct sunlight or fewer hours of daylight overall, less melanin was needed.

Over time, this resulted in melanosomes that produced less melanin, thus absorbing more sunlight.

"By understanding what regulates melanin, we can help protect lighter-skinned people from melanoma, or skin cancer," Bajpai said. By targeting these new melanin genes, we could also develop melanin-modifying drugs for vitiligo and other pigmentation diseases."

The technological processes developed and used by the research team could also be applied to identify genes that regulate melanin production in fungi and bacteria.

Melanin production in fungi and bacteria enables them to be more pathogenic to humans or crops. Researchers could develop effective interventions against these microbes and their diseases by discovering and targeting such melanin-producing genes.

Bajpai's role in the study was completed during his professorship at the University of Oklahoma. However, a portion of this research took place during his postdoctoral research fellowship at Stanford University. A grant from the Oklahoma Center for Adult Stem Cell Research supported the study. Additional funding was provided by the U.S. Department of Defense, CA160997; Howard Hughes Medical Institute; National Institute of General Medical Sciences, NIH R35 GM131757; Stinehart-Reed Award; and the Ludwig Center for Cancer Stem Cell Research and Medicine.

Scientists Slow Aging by Engineering Longevity in Cells

Date: 27 April 2023

Source: University of California, San Diego

Summary: Researchers have developed a biosynthetic 'clock' that keeps cells from reaching normal levels of deterioration related to aging. They engineered a gene oscillator that switches between the two normal paths of aging, slowing cell degeneration and setting a record for life extension. As described 28 April 2023 in Science, they have now extended this research using synthetic biology to engineer a solution that keeps cells from reaching their normal levels of deterioration associated with aging. Cells, including those of yeast, plants, animals and humans, all contain gene regulatory circuits that are responsible for many physiological functions, including aging.

"These gene circuits can operate like our home electric circuits that control devices like appliances and automobiles," said Professor Nan Hao of the School of Biological Sciences' Department of Molecular Biology, the senior author of the study and co-director of UC San Diego's Synthetic Biology Institute.

However, the UC San Diego group uncovered that, under the control of a central gene regulatory circuit, cells don't necessarily age the same way. Imagine a car that ages either as the engine deteriorates or as the transmission wears out, but not both at the same time. The UC San Diego team envisioned a 'smart aging process' that extends cellular longevity by cycling deterioration from one aging mechanism to another.

In the new study, the researchers genetically rewired the circuit that controls cell aging. From its normal role functioning like a toggle switch, they engineered a negative feedback loop to stall the aging process. The rewired circuit operates as a clock-like device, called a gene oscillator, that drives the cell to periodically switch between two detrimental 'aged' states, avoiding prolonged commitment to either and thereby slowing the cell's degeneration.

These advances resulted in a dramatically extended cellular lifespan, setting a new record for life extension through genetic and chemical interventions.

As electrical engineers often do, the researchers in this study first used computer simulations of how the core aging circuit operates. This helped them design and test ideas before building or modifying the circuit in the cell. This approach has advantages in saving time and resources to identify effective pro-longevity strategies, compared to more traditional genetic strategies.

"This is the first time computationally guided synthetic biology and engineering principles were used to rationally redesign gene circuits and reprogram the aging process to effectively promote longevity," said Hao.

Several years ago the multidisciplinary UC San Diego research team began studying the mechanisms behind cell aging, a complex biological process that underlies human longevity and many diseases. They discovered that cells follow a cascade of molecular changes through their entire lifespan until they eventually degenerate and die. But they noticed that cells of the same genetic material and within the same environment can travel along distinct aging routes. About half of the

cells age through a gradual decline in the stability of DNA, where genetic information is stored. The other half ages along a path tied to the decline of mitochondria, the energy production units of cells.

The new synthetic biology achievement has the potential to reconfigure scientific approaches to age delay. Distinct from numerous chemical and genetic attempts to force cells into artificial states of 'youth,' the new research provides evidence that slowing the ticks of the aging clock is possible by actively preventing cells from committing to a pre-destined path of decline and death, and the clock-like gene oscillators could be a universal system to achieve that.

"Our results establish a connection between gene network architecture and cellular longevity that could lead to rationally-designed gene circuits that slow aging," the researchers note in their study.

During their research, the team studied Saccharomyces cerevisiae yeast cells as a model for the aging of human cells. They developed and employed microfluidics and time-lapse microscopy to track the aging processes across the cell's lifespan.

In the current study, yeast cells that were synthetically rewired and aged under the direction of the synthetic oscillator device resulted in an 82 per cent increase in lifespan compared with control cells that aged under normal circumstances. The results revealed "the most pronounced lifespan extension in yeast that we have observed with genetic perturbations," they noted.

"Our oscillator cells live longer than any of the longest-lived strains previously identified by unbiased genetic screens," said Hao.

"Our work represents a proof-of-concept example, demonstrating the successful application of synthetic biology to reprogram the cellular aging process," the authors wrote, "and may lay the foundation for designing synthetic gene circuits to effectively promote longevity in more complex organisms."

The team is currently expanding their research to the aging of diverse human cell types, including stem cells and neurons.

Controlled Cruelty: New Study Finds Aggression can Arise from Successful Self-control

Date: 13 July 2023

Source: Virginia Commonwealth University

Summary: A new study by a Virginia Commonwealth University researcher has found that aggression is not always the product of poor self-control but, instead, often can be the product of successful self-control in order to inflict greater retribution.

The new paper, 'Aggression As Successful Self-Control,' by corresponding author David Chester, Ph.D., an associate professor of social psychology in the Department of Psychology at VCU's College of Humanities and Sciences, was published by the journal Social and Personality Psychology Compass and uses meta-analysis to summarise evidence from dozens of existing studies in psychology and neurology.

"Typically, people explain violence as the product of poor self-control," Chester said. "In the heat of the moment, we often fail to inhibit our worst, most aggressive impulses. But that is only one side of the story."

Indeed, Chester's study found that the most aggressive people do not have personalities characterized by poor self-discipline and that training programs that boost self-control have not proved effective in reducing violent tendencies. Instead, the study found ample evidence that aggression can arise from successful self-control.

"Vengeful people tend to exhibit greater premeditation of their behaviour and self-control, enabling them to delay the gratification of sweet revenge and bide their time to inflict maximum retribution upon those who they believe have wronged them," Chester said. "Even psychopathic people, who comprise the majority of people who commit violent offenses, often exhibit robust development of inhibitory self-control over their teenage years."

Aggressive behaviour is reliably linked to increased—not just decreased—activity in the brain's prefrontal cortex, a biological substrate of self-control, Chester found. The findings make it clear that the argument that aggression is primarily the product of poor self-control is weaker than previously thought.

"This paper pushes back against a decades-long dominant narrative in aggression research, which is that violence starts when self-control stops," Chester said. "Instead, it argues for a more balanced, nuanced view in which self-control can both constrain and facilitate aggression, depending on the person and the situation."

The findings also argue for more caution in the implementation of treatments, therapies and interventions that seek to reduce violence by improving self-control, Chester said.

"Many interventions seek to teach people to inhibit their impulses, but this new approach to aggression suggests that although this may reduce aggression for some people, it is also likely to increase aggression for others," he said. "Indeed, we may be teaching some people how best to implement their aggressive tendencies."

The findings surprised Chester, a psychologist whose team frequently studies the causes of human aggression.

"Over the years, much of our research was guided by the field's assumption that aggression is an impulsive behaviour characterized by poor self-control," he said. "But as we started to investigate the psychological characteristics of vengeful and psychopathic people, we quickly realised that such aggressive individuals do not just have self-regulatory deficits; they have many psychological adaptations and skills that enable them to hurt others by using self-control."

Chester and his team plan to continue exploring questions around aggression and self-control based on the study's findings.

"Our research going forward is now guided by this new paradigm shift in thinking: that aggression is often the product of sophisticated and complex mental processes and not just uninhibited impulses," Chester said.

This research was supported by a grant from the National Institute on Alcohol Abuse and Alcoholism, part of the National Institutes of Health.

Decoding How Molecules 'Talk' to Each Other to Develop New Nano-Technologies

Date: 15 August 2023

Source: University of Montreal

Summary: Scientists recreate and compare molecular languages at the origin of life—opening new doors for the development of novel nano-technologies.

Two molecular languages at the origin of life have been successfully recreated and mathematically validated, thanks to pioneering work by Canadian scientists at Université de Montréal.

Published this week in the Journal of American Chemical Society, the breakthrough opens new doors for the development of nano-technologies with applications ranging from bio-sensing, drug delivery and molecular imaging.

Living organisms are made up of billions of nano-machines and nano-structures that communicate to create higher-order entities able to do many essential things such as moving, thinking, surviving and reproducing.

"The key to life's emergence relies on the development of molecular languages—also called signalling mechanisms—which ensure that all molecules in living organisms are working together to achieve specific tasks," said the study' s principal investigator, UdeM bioengineering professor Alexis Vallée-Bélisle.

In yeasts, for example, upon detecting and binding a mating pheromone, billions of molecules will communicate and coordinate their activities to initiate union, said Vallée-Bélisle, holder of a Canada Research Chair in Bioengineering and Bionano-technology.

"As we enter the era of nanotechnology, many scientists believe that the key to designing and programming more complex and useful artificial nano-systems relies on our ability to understand and better employ molecular languages developed by living organisms," he said.

Two types of languages

One well-known molecular language is allostery. The mechanism of this language is 'lock-and-key': a molecule binds and modifies the structure of another molecule, directing it to trigger or inhibit an activity.

Another, lesser-known molecular language is multi-valency also known as the chelate effect. It works like a puzzle: as one molecule binds to another, it facilitates (or not) the binding of a third molecule by simply increasing its binding interface.

Although these two languages are observed in all molecular systems of all living organisms, it is only recently that scientists have started to understand their rules and principles—and so use these languages to design and program novel artificial nano-technologies.

"Given the complexity of natural nano-systems, before now nobody was able to compare the basic rules, advantage or limitations of these two languages on the same system," said Vallée-Bélisle.

To do so, his doctoral student Dominic Lauzon, first author of the study, had the idea of creating a DNA-based molecular system that could function using both languages.

"DNA is like Lego bricks for nano-engineers," said Lauzon. "It's a remarkable molecule that offers simple, programmable and easy-to-use chemistry."

Simple mathematical equations to detect antibodies

The researchers found that simple mathematical equations could well describe both languages, which unravelled the parameters and design rules to program the communication between molecules within a nano-system.

For example, while the multivalent language enabled control of both the sensitivity and cooperativity of the activation or deactivation of the molecules, the corresponding allosteric translation only enabled control of the sensitivity of the response.

With this new understanding at hand, the researchers used the language of multi-valency to design and engineer a programmable antibody sensor that allows the detection of antibodies over different ranges of concentration.

"As shown with the recent pandemic, our ability to precisely monitor the concentration of antibodies in the general population is a powerful tool to determine the people's individual and collective immunity," said Vallée-Bélisle.

In addition to expanding the synthetic toolbox to create the next generation of nano-technology, the scientist's discovery also shines a light on why some natural nano-systems may have selected one language over another to communicate chemical information.

Gravitational Waves from Colossal Black Holes Found Using 'Cosmic Clocks'

Date: 29 June 2023

Source: National Science Foundation

Summary: You can't see or feel it, but everything around you, including your own body, is slowly shrinking and expanding. It's the weird, spacetime-warping effect of gravitational waves passing through our galaxy. New results are the first evidence of the gravitational wave background—a sort of soup of spacetime distortions pervading the entire universe and long predicted to exist by scientists.

The findings published today in The Astrophysical Journal Letters are from the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), a collaborative team of researchers from more than 50 institutions in the U.S. and abroad. The team conducted an analysis of burned-out stars known as millisecond pulsars, which rotate hundreds of times per second and emit radio pulses like ticks from highly accurate cosmic clocks. The team discovered what appeared to be variations in the 'ticking rate' of such pulsars by comparing observations of more than 60 pulsars within radio telescope data spanning 15 years. Their analysis provides evidence that the variations are caused by low-frequency gravitational waves which are distorting the fabric of physical reality known as spacetime.

According to the NANOGrav team's findings, the spatial distortion from the gravitational waves creates the appearance that the pulsars' radio-signal ticking rates are

changing. But really, it's the stretching and squeezing of space between Earth and the pulsars which causes their radio pulses to arrive at Earth billionths of seconds earlier or later than expected. The results are the first evidence of the gravitational wave background—a sort of soup of spacetime distortions pervading the entire universe and long predicted to exist by scientists.

"The NSF NANOGrav team created, in essence, a galaxy-wide detector revealing the gravitational waves that permeate our universe," said NSF Director Sethuraman Panchanathan. "The collaboration involving research institutions across the U.S. shows that world-class scientific innovation can, should and does reach every part of our nation."

Gravitational waves were first predicted by Albert Einstein in 1916. They would not be confirmed until 2015, when the Laser Interferometer Gravitational-Wave Observatory (LIGO) detected spacetime ripples passing through the Earth. Although the source of those gravitational ripples was a collision of two far-off black holes, the resulting spatial distortion that LIGO detected was smaller than the nucleus of an atom.

By comparison, the apparent pulsar time shift measured by the NANOGrav team is a few hundred billionths of a second and represents a flexing of spacetime between Earth and the pulsars about the length of a football field. Those spacetime distortions were caused by gravitational waves so immense that the distance between two crests is 2–10 light-years or about 9–90 trillion kilometers.

"These are by far the most powerful gravitational waves known to exist," said West Virginia University astrophysicist Maura McLaughlin, co-director of the NANOgrav Physics Frontiers Center. "Detecting such gargantuan gravitational waves requires a similarly massive detector and patience."

Using 15 years of astronomical data recorded by radio telescopes at NSF-supported observatories—including Green Bank Observatory in West Virginia, the Very Large Array in Socorro, New Mexico and Arecibo Observatory in Puerto Rico — the NANOGrav team created a 'detector' of 67 pulsars distributed all across the sky and compared the ticking rate of pairs of those pulsars. Through a sophisticated data analysis, they deduced the presence of the gravitational wave background causing the distortion of space and thus explained the apparent timing changes of the pulsars.

This is the first evidence for gravitational waves at these low frequencies," said Vanderbilt University astrophysicist Stephen Taylor, chair of the NANOGrav collaboration and co-leader of the research effort. "The likely source of these waves are distant pairs of close-orbiting, ultra-massive black holes."

"There is so much we have yet to understand about the physical nature of the universe and that's why the National Science Foundation supports daring team efforts like NANOGrav—to expand our knowledge for the benefit of society," said NSF Assistant Director for Mathematical and Physical Sciences Sean L. Jones.

The team's results are providing new insights into how galaxies evolve and how super massive black holes grow and merge. The widespread spacetime distortion revealed in their findings implies that extremely massive pairs of black holes may be similarly widespread across the universe, numbering

perhaps in the hundreds of thousands or even millions. Eventually, the NANOGrav team expects to be able to identify specific super massive black hole pairs by tracing the gravitational waves they emit. They may even uncover traces of gravitational waves from the very early universe.

"While our early data told us that we were hearing something, we now know that it's the music of the gravitational universe," said NANOGrav co-director and Oregon State University astrophysicist, Xavier Siemens. "As we keep listening, individual instruments will come to the fore in this cosmic orchestra."

Half of World's Largest Lakes Losing Water

Date: 18 May 2023

Source: University of Colorado at Boulder

Summary: Fifty-three percent of the world's largest freshwater lakes are in decline, storing less water than they did three decades ago, according to a new study. The study analysed satellite observations dating back decades to measure changes in water levels in nearly 2,000 of the world's biggest lakes and reservoirs. It found that climate change, human consumption and sedimentation are responsible.

More than 50 percent of the largest lakes in the world are losing water, according to a ground breaking new assessment published today in Science . The key culprits are not surprising: warming climate and unsustainable human consumption. But lead author Fangfang Yao, a CIRES visiting fellow, now a climate fellow at University of Virginia, said the news is not entirely bleak.

With this new method of tracking lake water storage trends and the reasons behind them, scientists can give water managers and communities insight into how to better protect critical sources of water and important regional ecosystems.

"This is the first comprehensive assessment of trends and drivers of global lake water storage variability based on an array of satellites and models," Yao said.

He was motivated to do the research by the environmental crises in some of Earth's largest water bodies, such as the drying of the Aral Sea between Kazakhstan and Uzbekistan.

So he and colleagues from the University of Colorado Boulder, Kansas State University, France and Saudi Arabia created a technique to measure changes in water levels in nearly 2,000 of the world's biggest lakes and reservoirs, which represent 95 per cent of the total lake water storage on Earth.

The team combined three decades of observations from an array of satellites with models to quantify and attribute trends in lake storage globally.

Globally, freshwater lakes and reservoirs store 87 per cent of the planet's water, making them a valuable resource for both human and Earth ecosystems. Unlike rivers, lakes are not well monitored, yet they provide water for a large part of humanity, even more than rivers.

But despite their value, long-term trends and changes to water levels have been largely unknown, until now.

"We have pretty good information on iconic lakes like Caspian Sea, Aral Sea and Salton Sea, but if you want to say something on a

global scale, you need reliable estimates of lake levels and volume," said Balaji Rajagopalan, a CIRES fellow, professor of engineering at CU Boulder and co-author. "With this novel method ...we are able to provide insights into global lake level changes with a broader perspective."

For the new paper, the team used 250,000 lake-area snapshots captured by satellites between 1992–2020 to survey the area of 1,972 of Earth's biggest lakes. They collected water levels from nine satellite altimeters and used long-term water levels to reduce any uncertainty. For lakes without a long-term level record, they used recent water measurements made by newer instruments on satellites. Combining recent level measurements with longer-term area measurements allowed scientists to reconstruct the volume of lakes dating back decades.

The results were staggering: 53 per cent of lakes globally experienced a decline in water storage. The authors compare this loss with the magnitude of 17 Lake Meads, the largest reservoir in the United States.

To explain the trends in natural lakes, the team leveraged recent advancements in water use and climate modeling. Climate change and human water consumption dominated the global net decline in natural lake volume and water losses in about 100 large lakes, Yao said. "And many of the human and climate change footprints on lake water losses were previously unknown, such as the desiccations of Lake Good-e-Zareh in Afghanistan and Lake Mar Chiquita in Argentina."

Lakes in both dry and wet areas of the world are losing volume. The losses in humid tropical lakes and Arctic lakes indicate more widespread drying trends than previously understood.

Yao and his colleagues also assessed storage trends in reservoirs. They found that nearly two-thirds of Earth's large reservoirs experienced significant water losses.

"Sedimentation dominated the global storage decline in existing reservoirs," said Ben Livneh, also a co-author, CIRES fellow and associate professor of engineering at CU Boulder. In long-established reservoirs — those that filled before 1992 — sedimentation was more important than droughts and heavy rainfall years.

While the majority of global lakes are shrinking, 24 per cent saw significant increases in water storage. Growing lakes tend to be in underpopulated areas in the inner Tibetan Plateau and Northern Great Plains of North America and in areas with new reservoirs such as the Yangtze, Mekong, and Nile river basins.

The authors estimate roughly one-quarter of the world's population, 2 billion people, resides in the basin of a drying lake, indicating an urgent need to incorporate human consumption, climate change and sedimentation impacts into sustainable water resources management.

And their research offers insight into possible solutions, Livneh said. "If human consumption is a large factor in lake water storage decline, then we can adapt and explore new policies to reduce large-scale declines."

This happened in one of the lakes the team studied, Lake Sevan in Armenia. Lake Sevan has seen an increase in water storage, in the last 20 years, which the authors linked to enforcement of conservation laws on water withdrawal since the early 2000s.

Notes

Notes

Guidelines for Contributors

Manuscripts should be in editable Word 2007 or higher version (normal, plain font, 12-point Times New Roman, double-spaced) with headings not more than three levels, abbreviations defined at first mention and used consistently thereafter, footnotes wherever relevant, abstract not more than 200 words and 5-6 keywords. The initial submission of articles should not exceed (excluding references)- 5000 words for research papers, 4000 words for analytical, interpretive and persuasive essays and theoretical papers; 1000 words for short popular articles. Diagram, photographs, and line drawings must be supplied separately, numbered neatly for identification and their position in the text clearly indicated. Photographs must be of high resolution. Tables may be given as part of the text. The soft copy of the manuscript with an undertaking of originality and plagiarism report should be emailed to the Academic Editor, School Science at:

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