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InScight

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From Director's Desk

It is with immense pride and joy that I introduce the inaugural issue of InScight, IISER Kolkata's Science Communication Magazine. This initiative embodies our collective aspiration to make scientific knowledge accessible and engaging for a broader audience. As an institution committed to research and education, we are always searching for ways to bridge the gap between cutting-edge science and society, and InScight is a testament to this mission.

In an era where information is at our fingertips, the ability to communicate science effectively is more crucial than ever. Our endeavour to convey scientific concepts in a way that resonates with individuals beyond specialized fields reflects the core philosophy of IISER Kolkata: to inspire curiosity, foster inquiry, and build a community that appreciates the value of science. The magazine's foundation on a Class 11 and 12 level of understanding ensures that students, educators, and the public alike can find inspiration in these pages.

The team behind InScight has set an ambitious vision not just to present scientific achievements but to tell stories that connect the intricacies of scientific discoveries with their broader implications. It is indeed encouraging to see this inaugural issue feature interviews with luminaries like Dr. Shyama Narendranath from ISRO, alongside contributions from our talented students across various programs. Such an inclusive effort strengthens our belief that science communication can transcend conventional boundaries and foster a culture of open dialogue.

I would also like to express my sincere appreciation to the faculty mentors—Prof. Somnath Basu, Prof. Subhajit Bandopadhyay, and Prof. Anindita Bhadra—for their guidance in nurturing this endeavor. InScight not only highlights the research at IISER Kolkata but also shines a spotlight on the perspectives, ideas, and stories that can inspire the next generation of scientists.

As we publish this first issue, I extend my best wishes to the entire editorial team and contributors. May this magazine grow as a beacon of scientific literacy, and evolve into a multilingual platform that transcends barriers, expanding its reach to audiences far and wide. With my warmest regards,

Prof. Sunil Kumar Khare
Director, IISER Kolkata

Editor's Note

Welcome to this inaugural edition of InScight!

We are a dedicated team comprising BSMS students from the second year up to senior PhD scholars, all of whom have collaborated to breathe new life into this publication as a revival of Cogito 137, continuing its legacy while aiming to broaden its reach and impact. Our shared goal is to make science accessible to everyone, bridging the gap through science writing and communication that connects with an even wider audience. You can meet the team on our website!

InScight is designed as a web-based, English-language publication for an audience with a foundational knowledge of science across domains. While our articles cover diverse and often complex topics, we strive to make them highly engaging, appealing even to those outside academic circles. In the coming years, we hope to expand this platform into multiple languages to reach an even larger global audience.

This issue features articles spanning a wide range of scientific fields, from the intersection of artificial intelligence and biology to groundbreaking research in physics. Under the guidance of Prof. Somnath Basu, Prof. Subhajit Bandopadhyay, and Prof. Anindita Bhadra, we aim to maintain both rigor and readability throughout. We also enjoyed interviewing some of the most distinguished scientists—such as Dr. Shyama Narendranath from the U.R. Rao Satellite Centre, ISRO, and Prof. Sunil Khare, Director of IISER Kolkata—who have shared their insights on various scientific themes. In this issue, we have contributions from BS-MS and PhD/I-PhD students, both within and outside IISER Kolkata. This diverse authorship reflects our commitment to inclusivity and varied perspectives.

We encourage readers to respond through letters, as thoughtfully and constructively as possible. Your feedback is essential to shaping future editions. We also invite students, faculty, and staff to submit articles on diverse scientific topics for the magazine; we would love to publish them after review. Links for submission are included in this issue. And of course, we're just one email away!

Thank you for being part of InScight. We hope you enjoy this issue as much as we enjoyed creating it! With warm regards,

Chief Editor,
InScight

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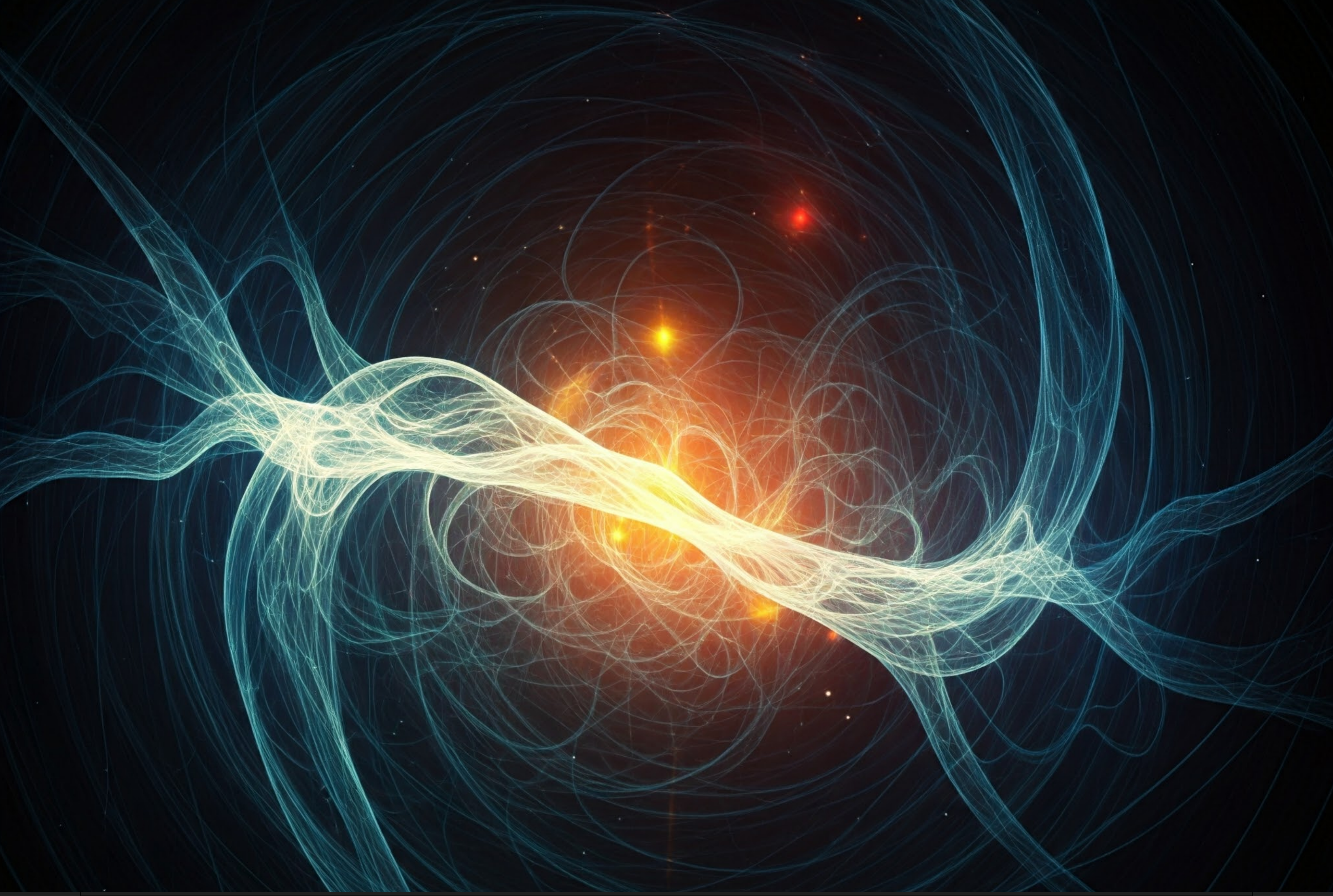

Revolutionising Biology with Artificial Intelligence

Suryadip Sarkar (IBAB Bengaluru),
Tathagata Chatterjee (RKMVERI Kolkata)

Suryadip and Tathagata offer an engaging exploration of how AI is transforming biological sciences. From the early days of rule-based AI to cutting-edge deep learning applications like AlphaFold, this article traces the evolution of AI's role in biology. It highlights AI's power in solving complex problems such as protein folding, drug discovery, and genomics. With groundbreaking examples like DeepVariant and DrugGPT, readers will gain insight into AI's monumental impact on research and healthcare. Dive into the future of biology where data meets innovation!

Artificial Intelligence (AI), the talk of the town right now, has revolutionised various fields and the life sciences is no exception. Before we go further into how exactly AI is changing the course of life as we speak, let us get up to speed with a few concepts.

Marvin Minsky defined artificial intelligence as "**the science of making machines do things that would require intelligence if done by men**". Ideally one would apply AI for problems where it is impossible to define consolidated rules. A very simple example could be the spam filters in our emails. It is virtually impossible for programmers to identify a set of rules to identify all types of spam. This is because these messages constantly keep evolving with newer wordings and patterns. Therefore AI models are trained using examples of both spam and legitimate emails to help identify subtle patterns and adapt to the new spam techniques over time. This is exactly why biology is such a beautiful candidate for AI applications, owing to its inherent complexity.

Machine Learning (ML) is a subset of AI that focuses on the development of algorithms that allow computers to learn from and make predictions based on data. **Deep Learning** (DL) is a further subset of ML that utilises neural networks (inspired from, but in no way similar to biological neurons) with many layers (hence "deep") to analyse various factors of data (especially non-linearity). These two branches of AI are the most prevalently used in biology to date.

Early Days: From Symbolic AI to ML and DL

It all dates back to the 1950s, when **Alan Turing** proposed the concept of machines being able to simulate any form of human reasoning through algorithmic approaches [1]. As a result, during the early years, AI was largely rule-based (aka **Symbolic AI**) which was based on logical representations of the world. This led to the birth of expert systems, which used knowledge bases of rules to solve specific problems. One such expert system was called **MYCIN** (1978) (Fig 1) [2]. It was developed by **Edward Shortliffe** as part of his doctoral dissertation, under the guidance of **Bruce G. Buchanan, Stanley N. Cohen**, and others at Stanford University. MYCIN was used to identify the bacteria causing severe bacterial infections like meningitis and bacteremia and to subsequently recommend appropriate antibiotics and their dosages according to the patient's body weights.

The advent of the internet and a substantial increase in computational power led to the growth of enormous volumes of data. This led to the next big break in the early 2000s in the form of Machine Learning algorithms. These algorithms were able to learn from data and perform tasks such as predicting outcomes, classifying objects or clustering them based on similarity, as opposed to following predefined rules. Further, the introduction of DL opened even more avenues and a whole new range of applications in tasks such as image processing, signal processing, natural language processing etc. Nowadays, AI has extended its branches into any and all fields of human endeavour with an especially serial impact on healthcare, medicine, and biological research.

AI and the era of Structural Biology

Applications of AI for solving complex problems in the life sciences can be dated back to the late 1990s. This was the era of structural biology. Proteins are the molecular machines that carry out all biological processes in a cell, and their structure dictates their function [3] Therefore, scientists were devoted to finding solutions to identify and manipulate said protein structures.

Proteins are unbranched polymers constructed from 22 standard amino acids. They have four levels of structural organisation (primary, secondary, tertiary and quaternary). **Primary structure** refers to the amino acid sequence that is specified by the genetic information contained within the DNA. As the polypeptide folds, it forms certain localised arrangements of adjacent amino acids that constitute of the **secondary structures** (mainly in the form of **α**-helices and **β**-sheets). Tertiary structure refers to the three-dimensional shape of a protein formed by the overall folding of the polypeptide chain onto itself. It results from interactions among the various R groups (side chains) of the amino acids, including hydrogen bonds, ionic bonds, van der Waals forces, and disulfide bridges. A protein quaternary

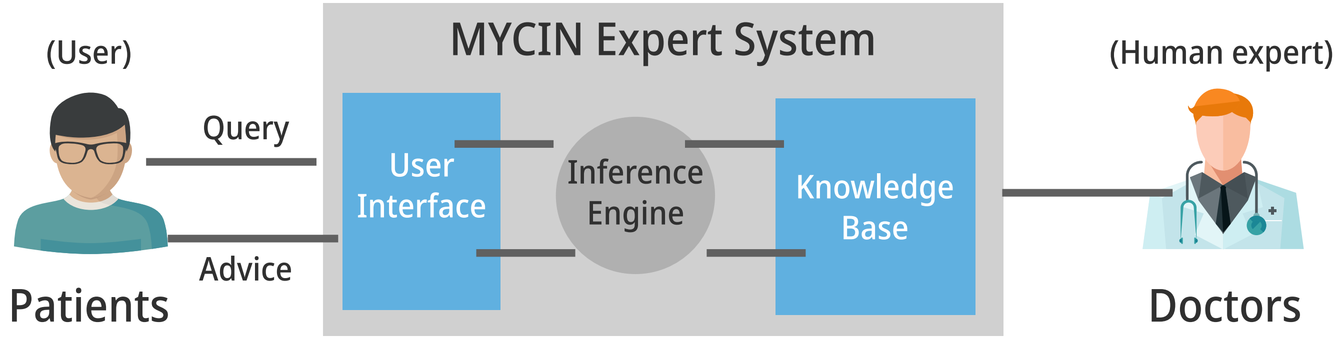

Fig 1. MYCIN: An early AI system that assists doctors in diagnosing infectious diseases and suggesting treatments by using a set of rules and logical reasoning (inference engine).

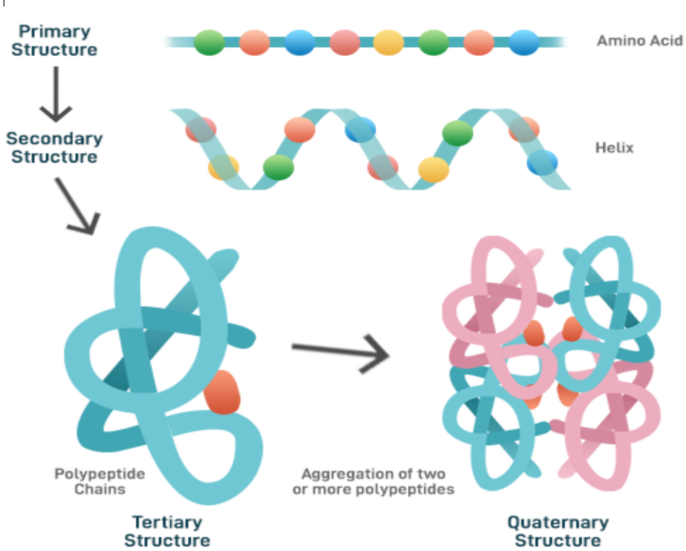

Fig 2. Protein Structure Hierarchy

structure arises when two or more polypeptide chains (subunits) come together to form a larger functional protein complex. The arrangement and interaction of these subunits are crucial for the protein's function. Together, these levels of structure are essential for a protein's biological activity and functionality (Fig 2) [4].

During this time, **X-Ray Crystallography and Nuclear Magnetic Resonance Spectroscopy** (NMR-Spec) were heavily being used to determine the complicated 3D structures of proteins. Due to the complexity of the protocols associated with these techniques coupled with low success rate, scientists started to look for more feasible solutions. In 1990, the labs of **Ross King** (Chalmers University of Technology, Sweden) and **Michael Sternberg** (Imperial College London) came up with an ML program called **PROMIS** (PROtein Machine Induction System) that could generalise rules to characterise the relationship between primary and secondary structures of globular proteins. These rules could further be used to predict unknown secondary structures from a known primary structure of a protein [5]. **Quantitative Structure Activity Relationship Modeling** (QSAR) is an extensively used approach in drug design and discovery that devises mathematical models connecting the biological activity of these drugs to their complex chemical features [6]. In 1994, the pair of King and Sternberg modelled the QSAR of a series of drugs using a technique called **Inductive Logic Programming** (ILP) [7]. ILP is a machine learning technique that uses a combination of logic programming and data driven decision making [8]. With the application of ILP, they were able to elucidate complex and interpretable patterns within the data that might have originally been overlooked while investigating using traditional statistical approaches.

Further, in the year 2000, the lab of R. Casadio used a class of artificial neural networks known as a **Feed Forward Network** (FFN), to predict protein folding and structure from only their corresponding amino acid sequence [9]. A feed forward network is basically composed of several layers of interconnected computational units called neurons (inspired from biological neurons) (Fig 3). Each neuron in a layer has a weight factor (think of it as a scalar value that denotes the neuron's contribution to the output) associated with it and receives numerical inputs from other neurons in the previous layer, processes them by applying a weighted sum and an activation function, and passes the result to the neurons in the next layer. This allows the network to model complex, non-linear patterns [10]. Therefore, hypothetically speaking, **the non-linear relationship between a protein's primary amino acid sequence and its folded 3D structure can be modelled efficiently using this FFN**. By capturing these subtle relationships, FFNs provided insights into how specific sequence motifs correspond to structural motifs underscoring the massive applications of AI in the field of structural biology.

Genomics and the Rise of AI

The **Human Genome Project** (HGP) was an international research initiative with the goal of sequencing the entire human genome. Launched in 1990, the HGP was completed in 2003 with the submission of the 1st draftt of the human genome. Its goals included identifying all human genes, determining their sequences, and exploring the functions of these genes. The project has had profound implications for medicine, genetics, and our understanding of human biology. Following that, in the early 2000s, vast amounts of genomic data were generated which warranted the need for advanced analytical methods. **Michael Schatz** and his colleagues applied ML techniques to genome assembly, enhancing the efficiency of sequence alignment [11]. In 2004, David Heckerman demonstrated the use of **Bayesian Networks**, a type of probabilistic graphical model, to predict gene functions from **microarray data** [12]. Bayesian networks as the name suggests were based on the concept of Bayesian statistics that provides a way to update the probability of a hypothesis as new evidence becomes available, forming the foundation of Bayesian inference [13]. Heckerman used microarray data that contains information

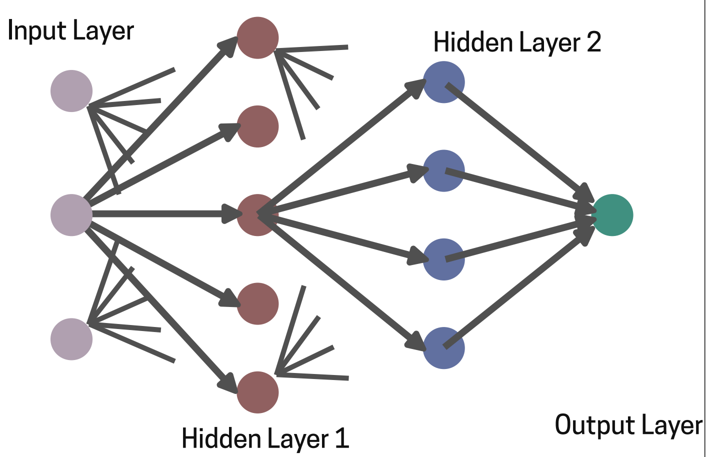

Fig 3. A 4 layer FFN with 1 input layer, 2 hidden layers and 1 output layer

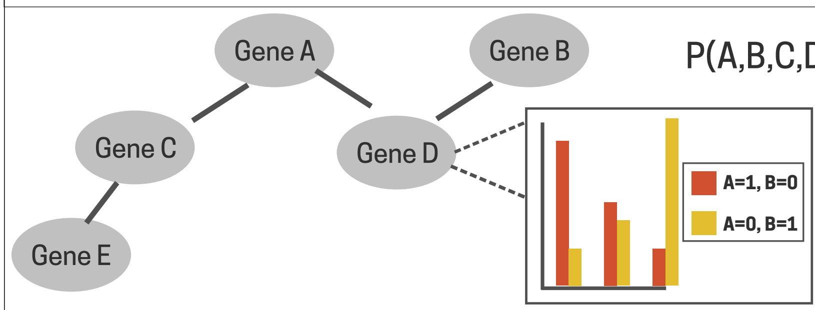

Fig 4. Bayesian Network for gene interaction studies. Each node is a random variable (gene) indicating the mRNA level expression of that gene. The arrows indicate direct probabilistic relationships. See [28].

about the activity level (how active or inactive the gene is) of thousands of genes across specific conditions. In his approach, variables such as the genes were represented as nodes and the probabilistic dependencies between them as edges, making them particularly effective for capturing complex, uncertain relationships (Fig 4). This enabled Heckerman to identify the **complex crosstalks between genes and their functional relationships to each other based on expression patterns**.

Through these networks, it became possible to model how changes in the expression of one gene influence others, uncovering hidden dependencies and regulatory mechanisms [12]. In 2016, Angermueller's lab utilised **Convolutional Neural Networks** (CNN), which were traditionally used to process image data, on DNA sequences to predict gene expression, with accuracies comparable to traditional methods [14]. CNNs are comprised of layers of neurons that utilise **convolutional filters** to capture local patterns and hierarchical features. A convolutional filter is a matrix of weights that is slid along the entire sequence effectively learning hidden patterns and features from them, much like detecting edges or textures within an image which is nothing but a sequence of pixel values. Moreover, since the same filter is being slid along the entire sequence, it can capture both local and global dependencies among these sequences potentially identifying important motifs such as transcription factor binding sites [15].

Most recently in 2018, Google developed a DL based tool called the **DeepVariant** that employs a deep CNN architecture to identify variants in DNA sequences, outperforming traditional state of the art tools and pipelines such as **GATK and Augustus** [17] (Fig 6).

AI in Biomedical Imaging, Diagnostics and Drug Discovery

CNNs being at the forefront of computer vision at the time also inspired biologists to actually use them for biomedical image analysis and predictive modelling based on biomedical image data. In 2017, **Andre Esteva** and his colleagues developed a CNN model that could diagnose and differentiate skin cancer from other standard skin lesions with accuracy comparable to dermatologists by analysing dermoscopic images [18]. **U-Net**, a CNN architecture developed by **Olaf Ronneberger**, is widely used nowadays for segmenting biological images, especially in the field of histopathology which is the study of tissue changes and diseases at the microscopic level, often involving the examination of biopsies to diagnose conditions (see Fig. 5). **It has shown remarkable performance in analysing histological slides accurately diagnosing cancerous tissues, thereby improving patient outcomes** [19].

ML has contributed significantly towards the **drug discovery space** as well, including applications in drug target identification, biomarker discovery, QSAR modelling and predicting efficacy of drug candidates, thereby accelerating the drug development process. **Biomarker discovery**—the identification of measurable indicators such as genes, proteins, or metabolites linked to specific diseases—has benefited from ML's ability to analyze complex datasets and uncover subtle patterns, aiding in personalized medicine and early diagnosis [20]. **Yuesen Li**

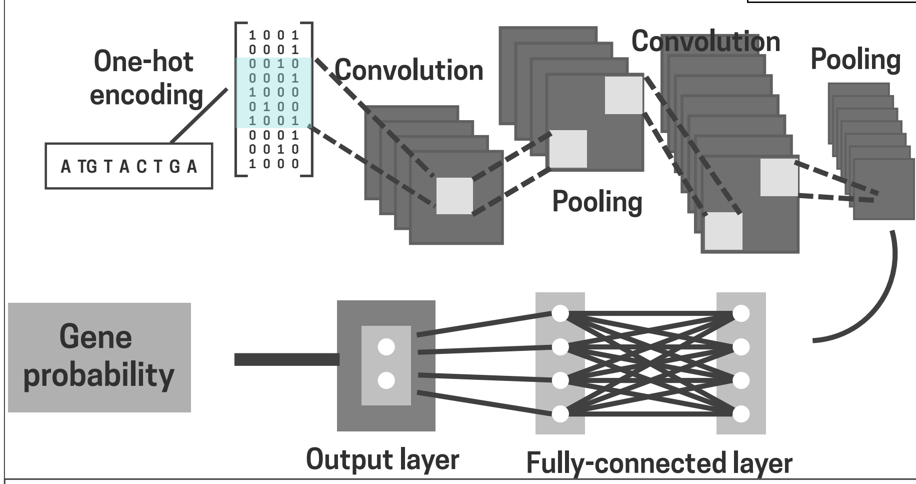

Fig 5. CNN for gene prediction. An ORF is first one-hot encoded and then fed into a CNN-MGP model chosen based on its GC content. The model has 6 layers: a convolutional layer with 64 filters (window size of 21), followed by a max-pooling layer (pool size of 2), another convolutional layer with 200 filters (window size of 21), and another max-pooling layer (pool size of 2). The output is flattened into a 1D vector, which is passed through a fully connected layer with 128 neurons. Finally, the output layer produces a probability indicating whether the sequence represents a gene.

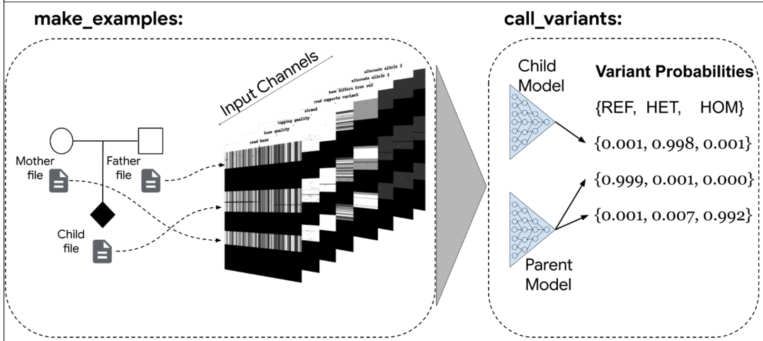

Fig 6. Google DeepVariant Workflow. Input data, such as genomic reads, are processed to extract features like base quality, mapping quality, and strand information. These features are transformed into tensors (format compatible with neural networks) and fed into deep neural networks, enabling accurate identification of genomic variants.

and his colleagues in 2023 developed **DrugGPT** focusing on chemical space exploration of protein ligand complexes, which refers to navigating the enormously complex universe of chemical compounds to identify potential drug molecules targeting specific proteins[21].

A Leap Forward with AlphaFold

In the realm of structural biology, we have come a long way as well. In the year 2021, **John Jumper** and his team at Google Deepmind rocked the world of biology with their groundbreaking model called **AlphaFold**. AlphaFold redefined the age-old problem of predicting protein 3D structures from just their amino acid sequence information. It uses a pseudo-bayesian genetic algorithm based deep neural network to model the physical and geometric properties of proteins from just their amino acid sequence and **gives highly accurate 3D structures of proteins solving the bottleneck of time, complexity and low success rate** associated with methods like X-ray crystallography, NMR-spec and Cryo Electron microscopy (Cryo-EM) [22]. In 2024, Jumper was awarded the Nobel Prize in Chemistry for AlphaFold emphasizing the importance and relevance of AI in biology even further.

Biology Inspiring AI models

Interestingly enough, the relationship between AI and biology has been quite symbiotic. It is not only biology that has gained from AI models, biology has also inspired AI models on more than one occasion. The most prevalent of them all is actually that of the neural networks (the building blocks of DL). In 1943, **Warren McCulloch and Walter Pitts** built a mathematical model of the functioning of a single neuron [23]. Taking inspiration from human perception, Frank Rosenbahlt modelled the first neural network in 1957 that was able to recognize some handwritten symbols effectively and could model basic logical operations such as AND and OR gates. This was known as the **Perceptron** and it would lay the foundation for further development of DL and neural network architectures [24].

Our immune system only allows lymphocytes, that recognize certain antigens, to be cloned and proliferated with such identical antigenic receptors. This phenomenon known as **clonal selection** presents itself as a learning problem driven by context (antigen) and an appropriate response. This led to the invention of the **Artificial Immune System**, a class of computationally intelligent, rule-based machine learning systems, inspired by the intricacies of the immune system of vertebrates [25]. Akin to their living counterparts these models excel in recognizing something presented to it as an "antigen" and take the most appropriate response making them ideal for applications such as antiviruses and anti-spams.

Towards the Future

The synergy between AI and biology has set the stage for groundbreaking discoveries and innovations. From protein structure prediction with AlphaFold to the use of neural networks in genomics and drug discovery, biology has been transformed into a data-driven, predictive and multi-disciplinary branch of science. Whether it's predicting disease, designing drugs, or deciphering the mysteries of life at the molecular level, AI is now an indispensable tool in every biologist's toolkit. So, if you're curious, now's the time to dive into this captivating intersection of science and technology—where the future of biology is being driven by AI.

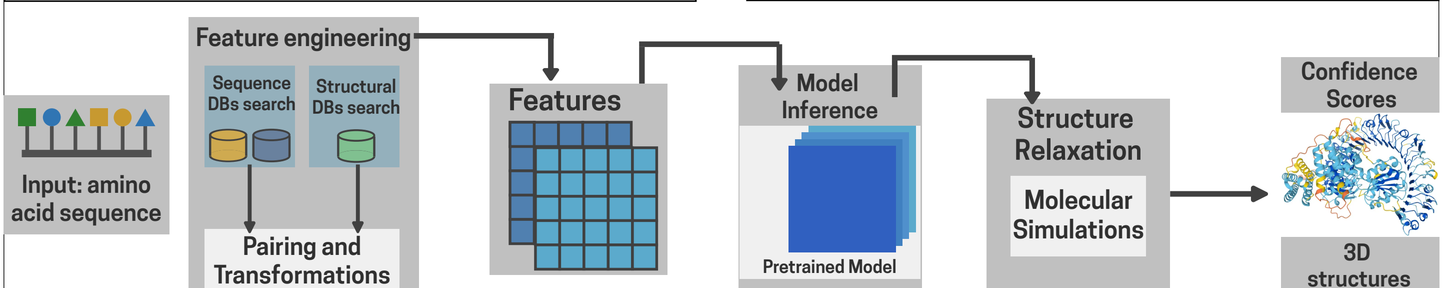

Fig 7. AlphaFold Inference Workflow

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Suryadip Sarkar, a 2nd-year master's student in Big Data Biology at the Institute of Bioinformatics and Applied Biotechnology, Bengaluru, is driven by a passion for applying AI and ML to solve complex challenges in life sciences.

Tathagata Chatterjee, a 1st-year master's student in Medical Biotechnology at Ramkrishna Mission Vivekananda Educational and Research Institute, Kolkata, has a keen interest in cancer biology and applied immunology, aspiring to make impactful contributions in these fields

Cracking the Ammonia Code: Balancing Global Food Security and Environmental Sustainability

Sobitri Sen (NIT Manipur & IISER Kolkata)

Ammonia, a simple yet critical molecule, feeds half of the world's population, thanks to the Haber-Bosch process. However, its energy-intensive production and environmental impacts raise urgent questions about sustainability. The rising demand for ammonia-based fertilisers fuels a global environmental dilemma, as nitrogen runoff creates dead zones and contributes to climate change. A promising solution lies in "green ammonia," which could revolutionise the industry by replacing fossil fuels with renewable energy. While the costs remain high, breakthroughs in catalysts and new methods could unlock a sustainable future for ammonia production.

Ammonia, an invisible gas, sounds deceptive. It consists of one nitrogen atom bound to three hydrogen atoms in a trigonal pyramidal shape. That's it! The Nitrogen we breathe daily, which makes up 78% of Earth's atmosphere, is locked in a powerful triple bond (N≡N). The real challenge lies in breaking and activating this bond.

It feels like one of those unrequited scientific loves, with no perpetual remedy! From the vast cornfields of the Midwest to the rice paddies of Asia, this simple compound is **essential for sustaining** nearly half of the global population. Its silent yet **immense contribution to global energy** dynamics is paradoxical, demanding an urgent verdict in favour of nature. Yet, it remains the linchpin in the production of all nitrogenous fertilisers, without which global food production would collapse. Over 150 million metric tons of ammonia are produced each year—80% of which is used globally to make crops grow faster, healthier, and more robust, ultimately feeding the world.

The Haber-Bosch Process: A Century of Innovation and Beyond

In the early 20th century, two German scientists—**Fritz Haber and Carl Bosch**—cracked the code and devised a method for the mass production of ammonia. Their process, known as the Haber-Bosch process, made history and transformed the world. Initially, it relied on a combination of iron-based (Fe) catalysts, nitrogen (N_2) from the air, and hydrogen (H_2) typically sourced from natural gas. These elements were subjected to extreme conditions: heat up to 400-500°C and pressure between 200-400 atmospheres. Later, a modified version of the process, incorporating a Palladium (Pd) promoter, was introduced, and was deemed promising for **maximising ammonia output while minimising energy input**.

On paper, the reaction seems straightforward:

$$N_2 + 3H_2 \longrightarrow 2NH_3$$

However, this simple equation masks the massive energy cost involved. The Haber-Bosch process is an **energy-intensive behemoth**, consuming around 1-2% of the world's total energy. This is because breaking the N≡N triple bond requires vast amounts of energy. Specifically, natural gas (methane, CH_4) is reacted with steam (H_2O) in the presence of a catalyst to produce hydrogen (H_2) and carbon monoxide (CO), followed by the water-gas shift reaction to convert CO to carbon dioxide (CO_2) and produce additional hydrogen. Hydrogen and nitrogen gases are then combined under high pressure and high temperature to form ammonia (NH_3). This entire process generates an estimated **420 million tons of CO_2 annually**, making the fertiliser industry a key perpetrator of global greenhouse gas emissions.

Fig 1. Carl Bosch (left) and Fritz Haber (right). They made groundbreaking contributions to chemistry by developing the Haber-Bosch process, which synthesises ammonia from nitrogen and hydrogen gases under high pressure and temperature. Fritz Haber discovered the reaction in the early 20th century, creating a way to convert atmospheric nitrogen into ammonia. Bosch's innovations enabled mass production of ammonia, leading to more abundant fertilizer supplies

The Ammoniated-Environmental Reckoning: Beyond CO_2 and towards sustainability

The environmental impact of ammonia production stretches far beyond its carbon footprint. Misusing ammonia-based fertilisers leads to eutrophication, while excess nitrogen runoff contaminates water bodies, triggering algal blooms. This effect **depletes oxygen levels and creates dead**

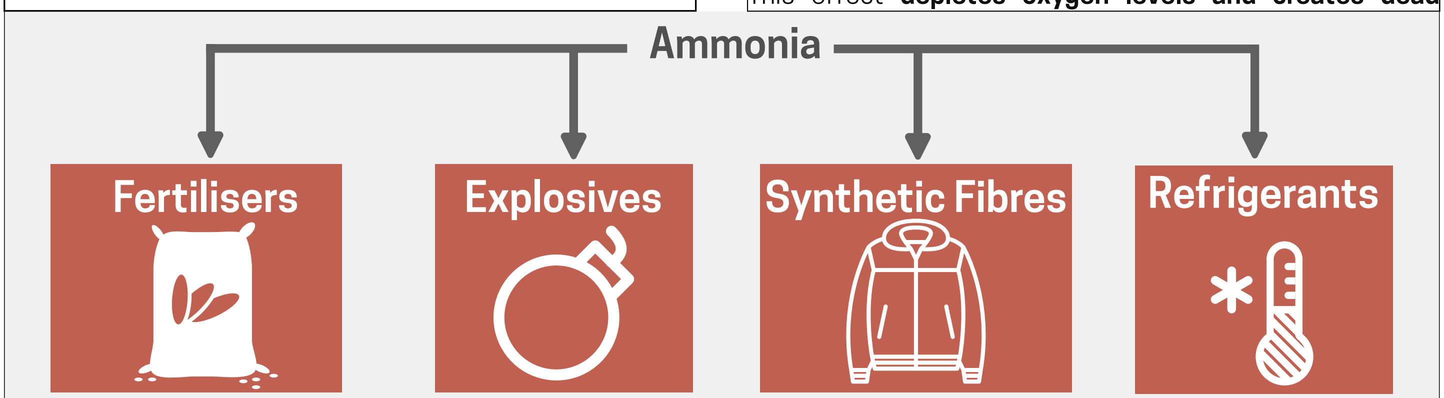

Fig 2. Ammonia has diverse uses across industries: it supplies nitrogen in fertilizers to boost plant growth, forms the basis of explosives like ammonium nitrate for mining and agriculture, and helps manufacture synthetic fibers such as nylon for textiles. Its high heat absorption also makes ammonia an efficient refrigerant, specially in industrial cooling systems.

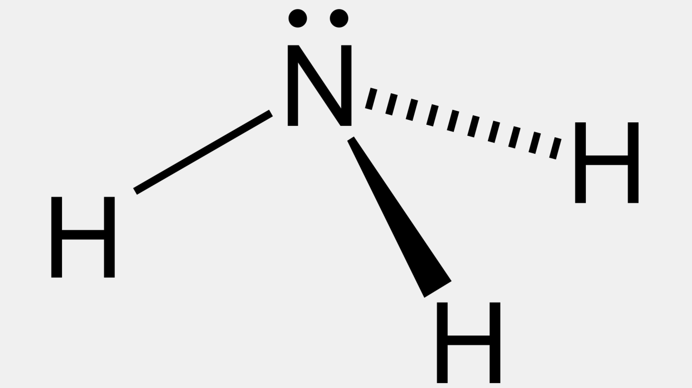

Fig 3. Ammonia (NH_3) is a simple molecule composed of one nitrogen atom and three hydrogen atoms, arranged in a trigonal pyramidal shape. This geometry is due to the lone pair of electrons on the nitrogen atom, which repels the hydrogen atoms downward, creating an angle of about 107.8° between the hydrogen atoms. The nitrogen atom has a partial negative charge, while the hydrogens have a partial positive charge, making ammonia a polar molecule.

zones—such as the one in the Gulf of Mexico. As the global population rapidly escalates, the demand for ammonia in agriculture grows exponentially, establishing a critical environmental reckoning. These ecological disruptions highlight the urgent need to address the hidden environmental costs and make us wonder whether true sustainability would require immediate action on these broader consequences.

Our reliance on ammonia, once hailed as a breakthrough, now presents a paradox: **how do we sustain its benefits without compromising the environment**? Reflecting on this, environmental scientist Dr. Sarah Patel states, “The challenge isn’t just making ammonia sustainable at the production stage. We also need to rethink how we use it to minimise its downstream environmental impact.”

“Green” Ammonia: A Vision for the Future?

So, is there a solution to this issue? Yes! The answer lies in the concept of **green ammonia**, a futuristic vision that offers hope to the entire scientific community. It seeks to replace fossil fuels with **renewable energy sources in hydrogen production**. Instead of deriving hydrogen from natural gas, **water electrolysis** can be used to produce hydrogen using solar, wind, or hydroelectric power, leading to zero carbon emissions from the hydrogen production stage.

As always, the catch is **the cost**. Today, producing green ammonia is significantly more expensive than the traditional method. But as renewable energy becomes more affordable, scientists hope that green ammonia will eventually compete with its fossil-fueled counterpart. In this regard, Dr. Maya Jensen, a sustainable chemistry expert, notes, "If we can crack the cost barrier, green ammonia could be the solution to feeding the world without cooking the planet."

The Quest for Smarter Catalysts and Innovative Methods in Ammonia Production

The bottleneck in sustainable ammonia production is discovering an **effective catalyst** for the nitrogen-hydrogen reaction. Traditional iron (Fe)-based catalysts require **extreme heat and pressure**, which leads to high energy demands in the Haber-Bosch process. Researchers are now exploring new materials, from **ruthenium (Ru)-based catalysts to exotic compounds**, in hopes of optimising temperature and pressure requirements to reduce energy costs.

There has been a recent surge in innovative strategies that aim to revolutionise ammonia (NH_3) synthesis by activating molecular nitrogen (N_2) under ambient conditions. Pioneering research is being carried out along diverse

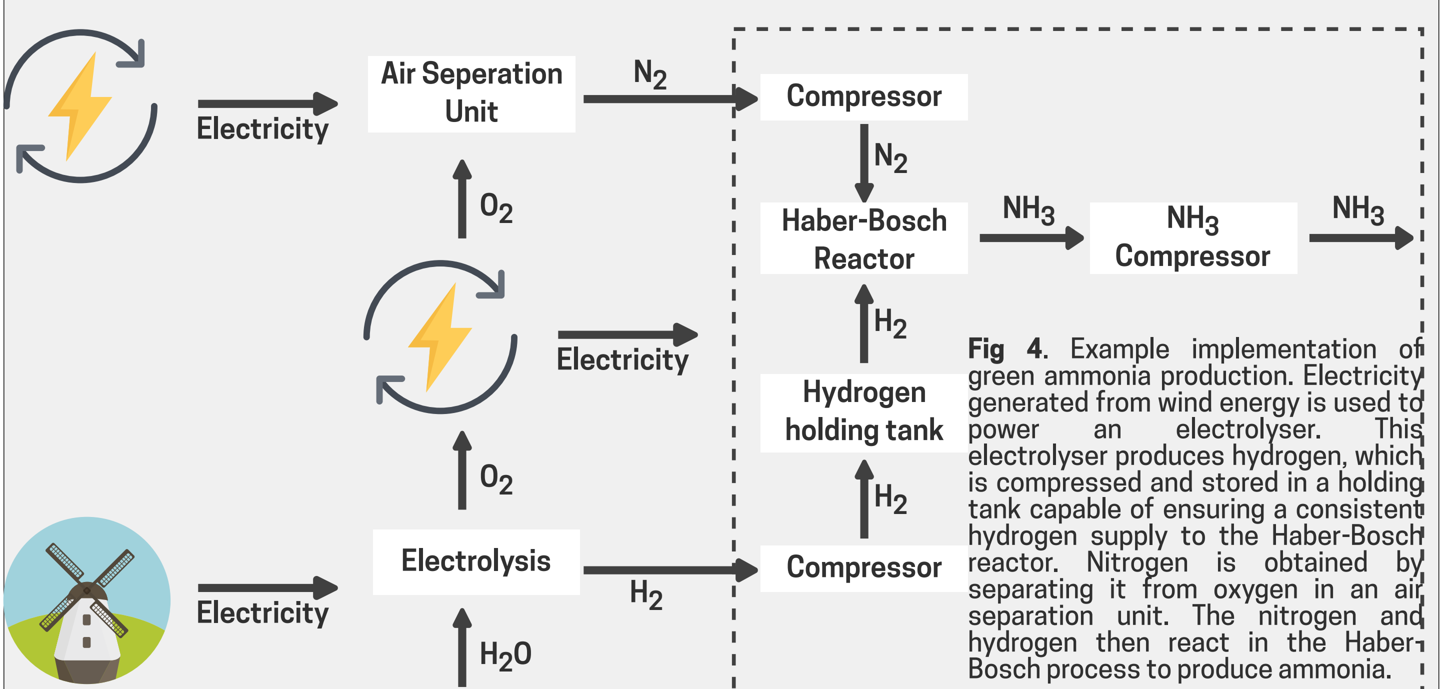

Fig 4. Example implementation of green ammonia production. Electricity generated from wind energy is used to power an electrolyser. This electrolyser produces hydrogen, which is compressed and stored in a holding tank capable of ensuring a consistent hydrogen supply to the Haber-Bosch reactor. Nitrogen is obtained by separating it from oxygen in an air separation unit. The nitrogen and hydrogen then react in the Haber-Bosch process to produce ammonia.

approaches—from **photochemical and electrochemical methods to advanced metallic and organometallic pathways**.

Electrochemical methods, powered by renewable electricity, aim to reduce nitrogen to ammonia in low-energy setups, although current systems struggle with low yields and high energy demands. Meanwhile, photocatalysis harnesses sunlight to drive ammonia synthesis, with hopes of creating a solar-powered process in the future. Other studies have demonstrated the potential of **organometallic compounds, metallic clusters, frustrated Lewis pairs (FLPs), and carbenes** to activate N_2 and facilitate NH_3 fixation.

These cutting-edge discoveries and novel inventions bring hope for transforming the traditional Haber-Bosch process. Yet, despite their promising results in the lab, **upscaling these methods to industrial applications remains a formidable challenge**.

Where We Stand

Ammonia's journey is a unique one—marked by scientific promise and significant challenges. It has sustained billions and now stands at a critical juncture, with scientists working to secure its future in a greener, more sustainable way. Whether through advanced catalysis, renewable hydrogen, or innovative synthesis methods, ammonia's future promises to be one of the most pivotal developments in modern chemistry.

Efforts to develop green ammonia and cutting-edge catalytic technologies are transforming the ammonia-production process into a more sustainable endeavour. As Dr. Patel notes, "The future of ammonia will help decide the future of our planet. With stakes this high, it's not just about chemistry—it's about survival." The story of ammonia extends beyond chemistry, reflecting past and present constraints while offering hope for sustainability and innovation in one of the world's most energy-intensive industries.

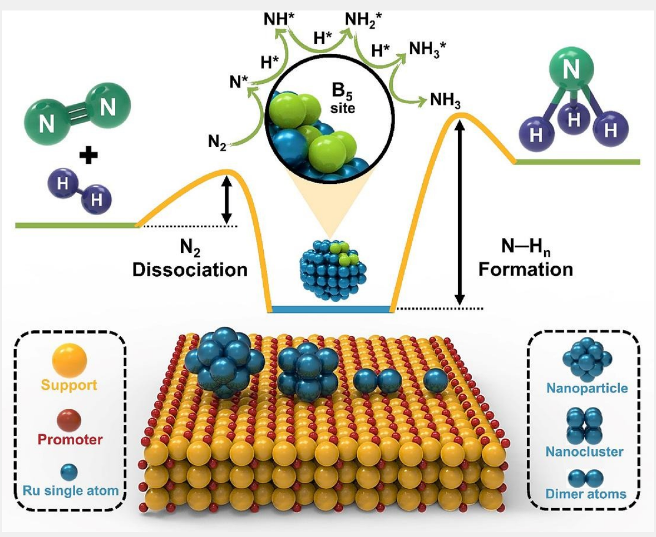

Fig 5. New advancements in ammonia synthesis include the use of single-atom ruthenium (Ru) catalysts, which significantly increase catalytic efficiency by maximising active site exposure and enhancing structural sensitivity. These Ru catalysts enable efficient ammonia production through thermocatalysis, photocatalysis, and electrocatalysis while reducing reaction energy requirements.

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In Conversation with ISRO Scientist Dr. Shyama Narendranath

Swarnendu Saha, Suman Halder (IISER Kolkata)

"**Often, our work is viewed as something exotic, while in reality, science is fundamental to our daily lives**", Shyama Narendranath remarks on the perception of research in India. She is a scientist at U R Rao Satellite Centre, ISRO. She is a part of Chandrayaan-2 and other Indian planetary programs. She has been awarded the Zubin Kembhavi award by the Astronomical Society of India.

SS. Good afternoon, ma'am. So, to start off, can you tell us about your background? Starting from when you were a student, how did you eventually reach the place you're in now after all these years?

SN. I can't say that I started out thinking I wanted to be a scientist. I come from Palakkad, a small town in Kerala. Back then, things were very different. The mobile phone, for instance, came into my life during my MSc. So, your generation can't even imagine a time without the internet or such technology. Exposure to the outside world was quite low.

Academically, I was a good student, but I was really interested in dance. I trained in classical dance, and most of my school days were focused on dancing. In Kerala, school youth festivals are taken very seriously, and every school participates. So, I was always involved in that.

SS. Oh, have you been trained in Kathakali, or was it another form of classical dance?

SN. Actually, I started with Bharatanatyam, and have been training in Odissi for the past 15 years. I'm still passionate about dance, and I continue to perform. So, initially, I wanted to be a dancer. I even had a short story published when I was in the 6th grade. At that time, I thought maybe I'd become a writer. But becoming a scientist was never something I considered when I was young. Probably, my interest in science began during my post-graduation. I had excellent teachers who really made the subject interesting. For young children, it's so important to have good teachers. If you love the subject, it's often because you had an amazing teacher.

I always had good English teachers, so I loved English, even though I was pursuing a degree in Physics. In fact, during my undergraduate years, I looked forward to my English classes more than my Physics ones. But things changed during my MSc when I had some excellent professors in Physics. They made me understand what I was doing. That's when I had a turning point.

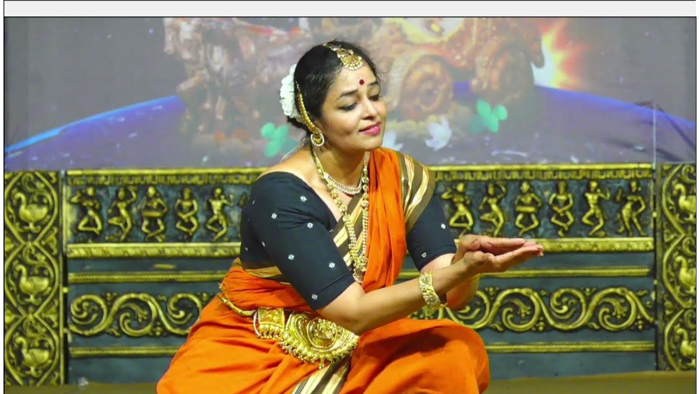

Fig 1. SN performing the Indu Sairisiri at Udupi krishna temple in Karnataka.

Fig 2. SN completed her PhD from the Indian Institute of Science, Bangalore.

SH. So, did you realize that you wanted to pursue research during your MSc?

SN. Yes, it was during a small summer project that I first thought research might be an option. I had the opportunity to visit Bangalore and stay there alone for the first time. I met many PhD scholars, and that's when I realized research could be something I'd like to pursue. Before that, I never considered it seriously.

SH. And did you think about teaching as a career?

SN. Yes, like many girls of my time, the plan was to finish MSc, do a B.Ed., and then teach. That's the path I was following. Teaching was seen as a suitable career for women. In my MSc Physics class, there were actually more girls than boys. But when I did my short summer project, I realized there was more I could do, and I became really interested in research.

SS. But at that time, societal expectations must have been a challenge, especially for women pursuing PhDs.

SN. Absolutely. There was definitely pressure. I got married soon after my MSc and moved to Bangalore. Fortunately, I continued my studies. I taught as a guest

lecturer at a college for six months, even though I didn't have a B.Ed. at the time. Then, I joined as a Junior Research Fellow (JRF). But within a few months, I was pregnant, so I had to take a break. After my daughter was born, I resumed when she was three and half months old.

SS. Wow, that must have been quite a challenge - balancing motherhood and studies.

SN. Yes, it was. I did my coursework for the PhD while working as a JRF in the Astronomy Program at the Indian Institute of Science (IISc), and I was able to complete it with the support of my family, especially my mother. I also had an excellent PhD supervisor, which is very important for a successful PhD journey.

SH. You mentioned working with international space agencies. Can you tell us about that?

SN. Yes, I was fortunate to be part of India's first lunar mission, Chandrayaan-1. I worked on an instrument that was developed in collaboration with the European Space Agency. It was built at the Rutherford Appleton Laboratory in the UK, so I got the opportunity to go and work. It was a difficult period because I had to leave my daughter behind, but with the support of my family, I managed. It was a new experience, and it gave me significant exposure. Working on Chandrayaan-1 was a turning point in my career. That project really helped shape my future work in space missions.

Fig 3. PSLV C11 carrying Chandrayaan-1. SN was involved in developing the Chandrayaan-1 X-ray spectrometer, in collaboration with the Rutherford Appleton Laboratory in the UK.

Fig 4. Aerial view of Rutherford Appleton Laboratory, where SN worked towards Chandrayaan-1.

SH. You've spent a lot of time as a student and as a scientist at major space agencies like NASA, the European Space Agency, and JAXA. How do their approaches compare to ours? Especially with the perception that ISRO achieves a lot with significantly less funding.

SN. There's no debate—NASA is far ahead in terms of technology. They landed the first humans on the moon in 1969, and we haven't sent humans to space yet. Their technological advancement is evident. However, in India, we are conditioned to work with limited resources. It's not just in space research—across sectors, there's always a resource crunch. Our approach is more about optimizing what we have. In many cases, we spend more time on things and make up for the lack of resources with extra effort. In NASA, industries take on parts of the technology development. Here, we still rely heavily on academic institutions and agencies like ISRO to develop technology in-house. But India is in a phase of transition. Over the next 10-20 years, I believe we'll see more involvement of private industries in space missions.

SS. There's a lot of pride in India about the Mars mission, Mangalyaan. It was achieved on a limited budget, but how does it compare to missions from NASA?

SN. Yes, Mangalyaan was a great achievement in terms of engineering. However, from a scientific perspective, it's not on the same scale as NASA's Maven mission to Mars. The amount of science that came out of Maven is much greater. The Indian mission was more about demonstrating that we could navigate a spacecraft to Mars and make it work within our constraints.

SH. Could you talk a bit about Chandrayaan-3 and how that mission was planned?

SN. I think Chandrayaan-3 was very critical for ISRO and India's planetary program. After Chandrayaan-2's near-success, we needed Chandrayaan-3 to work to ensure the continuation of our planetary missions. The success of Chandrayaan-3 proved that we could achieve a soft

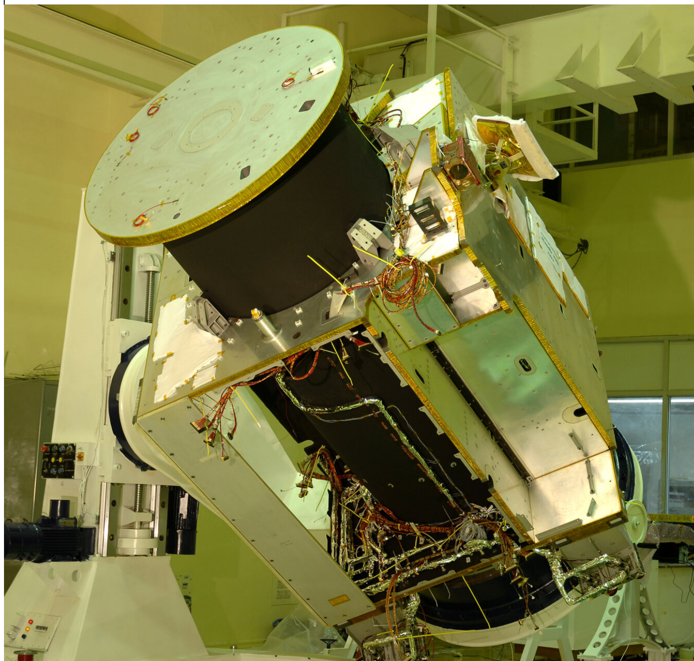

Fig 5. European Lunar X-Ray Camera, employed on Chandrayaan 1. SN was the Instrument Operations Scientist at ISRO at that time.

landing on the moon, and now we are well-positioned to plan future lunar missions.

SH. When it comes to research funding in India, especially in space research, how do you feel about the current budget allocations?

SN. Without adequate funding, research progress is slow. In order to innovate, we need new funding. There is a push from the government to involve academic institutions more, which is a positive development. We need to focus on core research, while industries can undertake more of the technology development. This transition will take time, but it's necessary for the future.

SS. What about the Chandrayaan-3 mission's scientific studies? What have we learned from it?

SN. The mission included several instruments, bothon the lander and the rover. The rover analyzed the composition of the surface, and it seemed to be a fairly homogeneous area. The lander carried a Langmuir probe to measure the electron density in the moon's exosphere, and a seismometer to measure moonquakes, though the data we collected over 10.5 days did not record any significant seismic activity. The mission was a great success overall, contributing valuable data for future lunar exploration.

SS. And the Aditya L1 mission? How is that going?

SN. Aditya L1 launched in September, and it's doing well so far. The spacecraft is in a halo orbit around the Lagrange point L1. The payloads are still being calibrated, but the mission is on track, and we expect some significant scientific findings from it soon.

SS. When you look back at your journey, from a student to a scientist, and the progress of ISRO, how do you feel about the way society views scientists in India?

SN. I think there is still a gap, but missions like the Chandrayaan and Mangalyaan are making people more aware of ISRO and the work we do. That being said, I believe there's still a need for better science communication. People should know the time and effort it takes to make scientific progress. Often, our work is viewed as something exotic, while in reality, science—especially physics—is fundamental to our daily lives.

SH. Do you think the current system supports students interested in pursuing research careers?

SN. There are challenges. Many bright students are discouraged from pursuing research because of financial insecurity. The stipends are often not enough, and delays in funding can make life difficult for students. I've seen students struggle just to pay rent while pursuing their passion for research. This situation can dissuade many from continuing in science, and it's something that needs attention.

SH. Do you think the research ecosystem in India needs improvement, especially in terms of job opportunities?

SN. Yes, definitely. Many of our postdocs don't return to India because there aren't enough job opportunities here. We need to create more positions and ensure that talented researchers have a place to contribute. Other countries, like China, have programs where they send postdocs abroad with the requirement that they return and work for their space agencies. We could benefit from similarinitiatives in India.

SS. As we conclude, do you have any final thoughts or advice for the next generation of scientists?

SN. I would encourage students to be patient and persistent. Success in science doesn't come quickly. It requires time, effort, and the willingness to face failures along the way. But the satisfaction of contributing to knowledge and discovery is worth it. Focus on the long-term impact of your work, not just the number of papers you publish. At the end of the day, it's about making a meaningful contribution to the field.

The views and opinions expressed in this document are solely those of SN and do not necessarily reflect the views or positions of any other individual or organization.

Kolkata Connection with 2020 Physics Nobel Prize: The Role of A K Raychaudhuri

Alekhya Kundu (IISER Kolkata)

The 2020 Nobel Prize in Physics honored groundbreaking work on black holes, but a lesser-known contributor to this discovery was Kolkata-born physicist A K Raychaudhuri. His 1955 paper laid the foundation for the Penrose-Hawking Singularity Theorems, reshaping our understanding of spacetime singularities. Raychaudhuri's equation demonstrated that singularities were a natural outcome of Einstein's gravity, a pivotal insight that influenced the Nobel-winning research. Despite his profound contributions, Raychaudhuri remains relatively unknown in India. His story connects Kolkata to one of our time's most significant scientific achievements.

In 2020, Roger Penrose shared the Physics Nobel Prize with Andrea Ghez and Reinhard Genzel. If Stephen Hawking had been alive, he might have also won a share of the pie. Penrose, Hawking's colleague at Cambridge University, got the prize for discovering that black holes are a robust prediction of Einstein's general theory of relativity, a work in which Hawking was also involved. More generally, Penrose's work involves the singularities of black holes.

In the 1950s, scientists were still trying to make sense of various solutions of Einstein's equations, such as the Schwarzschild metric, the FLRW metric as well as the Reissner-Nordström solution, and the Oppenheimer-Snyder solution. Several cosmologists, including Einstein, were puzzled by the existence and nature of spacetime singularities in these solutions. A singularity refers to a point in spacetime where the equations of general relativity break down, and gravity becomes so intense that our current understanding of physics can no longer describe what's happening.

Are these singularities an artifact of the assumptions of these specific models, or are they a generic feature of Einstein's theory? It was in 1955 that a paper was published by a young physicist of Kolkata, Amal Kumar Raychaudhuri, that showed that these singularities were an inevitable consequence of Einstein's gravity, independent of the symmetries of the model. This paper acted as the precursor of the 1969 paper published by Hawking and Penrose together, now famous as Penrose-Hawking Singularity Theorems.

Personal Life of AKR

In 1961, at Presidency University, a distinguished figure stepped out of a black ambassador car, dressed in a dhoti coat, white Punjabi, simple chappals, wearing thick glasses. If this had been Albert Einstein at the University of Berlin, the entire city might have come to a standstill. Amal Kumar Raychaudhuri, however, was approached by only a handful of his students and remained relatively unknown in Bengal and India despite his profound contributions. Fondly known as AKR among his students, his theory paved the way towards solving one of the deep problems of Einstein's equations, and it even found its way into Stephen Hawking and Roger Penrose's Nobel prize-winning work.

Born in Barisal, Bangladesh, on September 14th, 1923, A K R was the son of a mathematics teacher. His fascination with numbers began in childhood, and his numerical prowess gained notice day by day. He once proposed a solution to a math problem during an exam that surpassed the one the teacher gave. The headmaster was so impressed that he published the solution in the school magazine, giving due credit to AKR. While initially drawn to mathematics, he heeded his father's advice and pursued physics instead. Graduating with a B.Sc. in 1942 from Presidency College and an M.Sc. in 1944 from Calcutta University, he joined the Indian Association for the Cultivation of Science (IACS) as a researcher in 1945. Here, he became interested in Einstein's General Theory of Relativity. He conducted extensive research on the implications of Einstein's theory, leading to the publication of his groundbreaking paper in 1955.

Einstein's Theory of Gravity and The Problem of Singularities

Einstein's general theory of relativity describes how gravity works as the curvature of spacetime rather than as a force in the classical (Newtonian) sense. Through these equations, mass tells spacetime how to curve, and curved spacetime tells matter how to move. For example, a planet orbiting a star follows a "straight line" in the curved spacetime around the star, but it looks like an orbit because the spacetime itself is curved. The Einstein field equations essentially link two essential things: the geometry of spacetime (how spacetime is shaped or curved) and matter and energy (what's in that spacetime, like stars, planets, and energy fields). Karl Schwarzschild, a German physicist, made a groundbreaking contribution to general relativity shortly

Fig 1. The 2020 Nobel Prize in Physics honored Roger Penrose (left) for his work demonstrating that black hole formation is a natural consequence of general relativity, as well as Reinhard Genzel (center) and Andrea Ghez (right) for discovering a supermassive object—now understood to be a black hole—at the center of our galaxy.

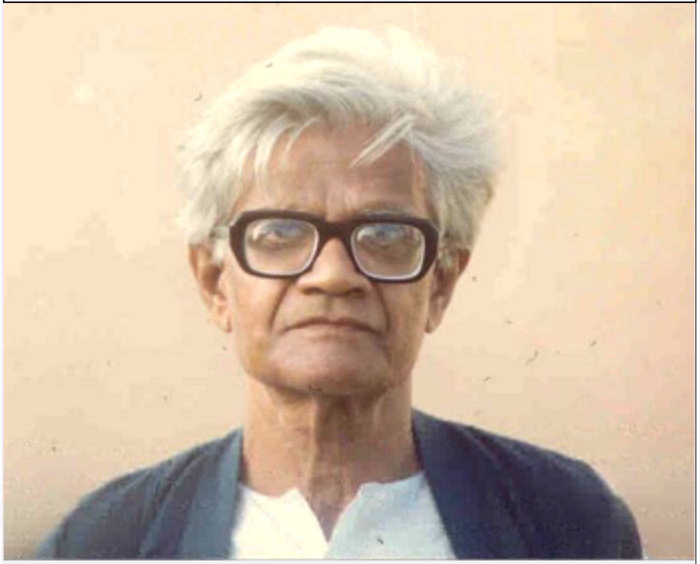

Fig 2. Dr. Raychaudhuri was born into a Baidya family from Barisal (now in Bangladesh) on September 14, 1923.

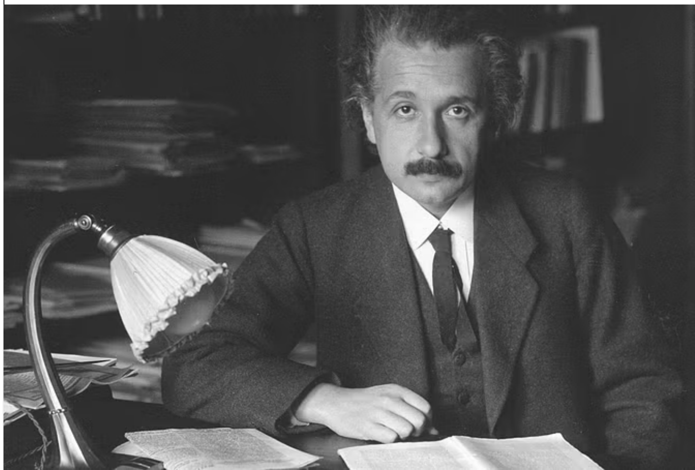

Fig 3. In 1919, Arthur Eddington's team confirmed Einstein's General Theory of Relativity by observing the bending of light from stars near the Sun during a solar eclipse, with observations made in Principe (West Africa) and Sobral (Brazil). This groundbreaking discovery validated Einstein's ideas about gravity and spacetime, propelling him to global fame.

after Einstein published his theory in 1915. He found a solution to Einstein's field equations that describes the gravitational field around a spherical, non-rotating mass, like a planet, a star, or, more famously, a black hole. Intriguingly, at the center of Schwarzschild's solution, the spacetime curvature becomes infinite, meaning that the gravitational pull is infinitely strong, and matter is crushed to an infinitely small point.

In the following decades, theoreticians like Alexander Friedmann and Abbe Georges Lemaitre proposed their expanding universe models, which astronomical observations made by Edwin Hubble later corroborated. Their model used the well-known Robertson-Walker (RW) metric (independently obtained by Friedmann, Lemaitre, Robertson, and Walker). A metric describes the shortest distance between two points in any given spacetime. On a flat space like a sheet of paper, the shortest path is the straight line connecting the points, while on a curved space like the surface of the earth, the path will be longer because one must travel along the surface. The peculiar feature of these models was that they contained a point in time t=0, referred to as the Big Bang epoch, where the density and temperature become infinite. This was again a signature of a spacetime singularity, where the laws of physics would break down.

The presence of singularities in so many of these models is a dilemma: Are these singularities a consequence of the specific assumptions made in these models, or are they a fundamental aspect of Einstein's theory in general? To get rid of these singularities, cosmologists proposed different ideas. One of them was the assumption of a spinning universe, where a centrifugal force would arise to prevent the collapse of matter at the axis, thus preventing the singularity. However, these models could not describe what was observed in reality.

The Raychaudhuri Equation and Penrose's Nobel-winning work

A breakthrough was made in the problem of singularities by A K Raychaudhuri in 1955. He proposed a general equation, now named after him, which predicts the convergence of an endless stream of particles at a singular point governed by Einstein's theory. This singularity exhibits infinite matter density and spacetime curvature. Because of the infinite curvature at the singularity, even light couldn't escape from that point, and time ceased to flow. For the more interested readers, we write down the famous Raychaudhuri equation here

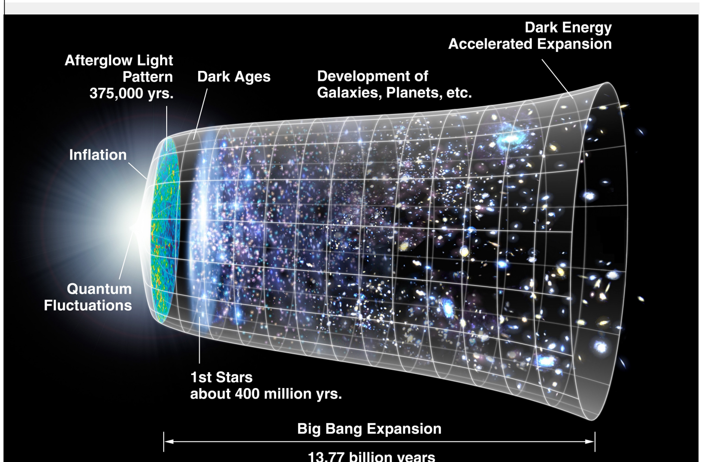

Fig 4. The timeline of the universe's expansion is illustrated with circular sections representing space, including hypothetical, unobservable regions, at each point in time. At the very beginning is the big bang epoch. followed by a rapid expansion during the inflationary epoch, while at the center, the expansion begins to accelerate.

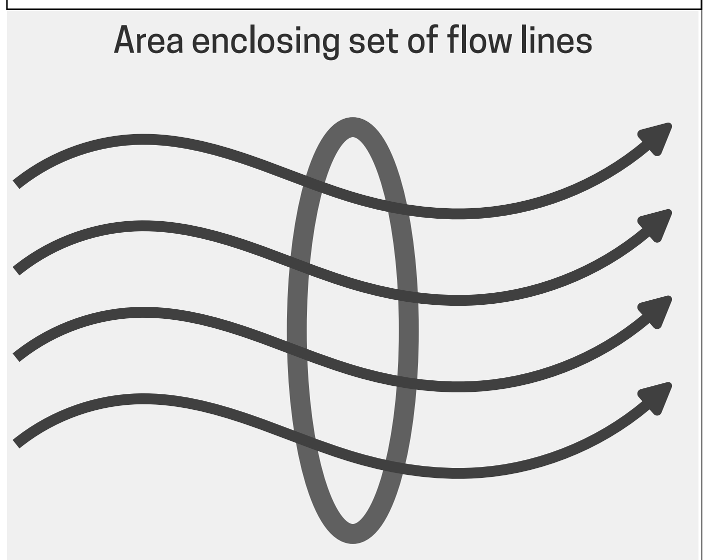

Fig 5. Trajectories of particles governed by Einstein's equations can be thought of as a fluid moving through space. The Raychaudhuri equation describes how the area of the flow depends on various factors.

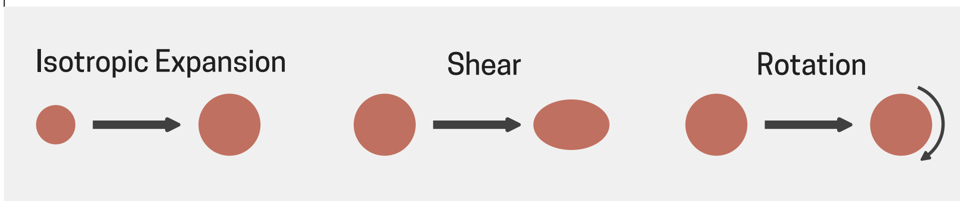

Fig 6. Flows moving under Einstein's gravity undergo various distortions such as expansion, shear and rotation. The Raychaudhuri equation tells us how these changes affect the rate of expansion of the flow.

$$\frac{d\theta}{ds} + \frac{1}{3}\theta^2 = -2\sigma^2 + 2\omega^2 + R_{\alpha\beta}u^\alpha u^\beta + [\frac{du^\beta}{ds}]$$

Even though the equation looks rather daunting, its physical import is apparent. It describes the motion of particles under gravity in the form of fluid-like flows. The paths of the particles can expand, contract, or distort, just like a fluid. The symbol u^α is a (four-)vector representing the velocity of particles moving in the presence of gravity. The quantity θ, the main subject of the equation, is the divergence of the flow vector u^α; it tracks whether the particles are coming into each other (converging, $\theta < 0$) or moving away from each other (diverging, $\theta > 0$). ω measures the rotation of the motion of the particles and is called the vorticity tensor. σ is the shear tensor that describes the deformation of the flow paths. The derivative *du/ds* measures the acceleration of the particles along their paths. $R_{\alpha\beta}$ is the Ricci tensor; it represents the curvature in spacetime compared to flat Euclidean space. As mentioned above, this curvature arises from the field equations of general relativity - mass tells spacetime how to curve, and curved spacetime tells matter how to move.

A spacetime singularity occurs when the divergence θ goes to infinity in either the positive or the negative direction. This can happen, for example, when the term with the Ricci tensor dominates over all the other terms. Since that term is typically negative, it will always drive the right-hand side of the equation to be negative and allow θ to flow to -∞. Alternatively, if the spin term ω^2 dominates over all the other terms, the right hand is necessarily positive, so θ then flows to -∞. Both of the cases lead to singularities. Singularities can be avoided if all the terms of the equation conspire to restrict the value of θ within a small neighborhood around zero; this requires terms of either sign to balance and compensate each other and fine-tune.

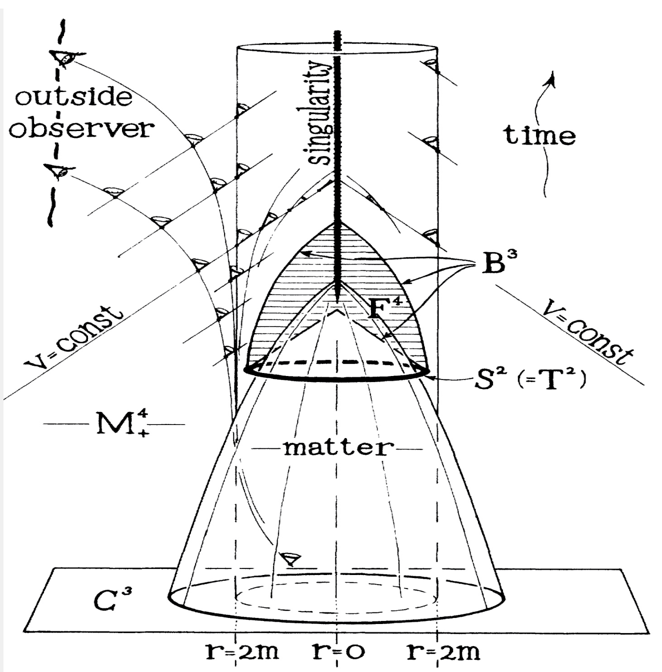

Fig 7. In his 1965 paper, Penrose included this diagram to illustrate how matter undergoes gravitational collapse during the formation of a black hole. Time is represented along the vertical axis, while light rays travel at 45-degree angles, entering the black hole and continuing toward the central singularity. See [9].

In summary, these considerations imply that singularities arise naturally in Einstein's gravity, and this equation was later incorporated into the 'Penrose-Hawking Singularity Theorems'. Thus, this equation, which Raychaudhuri derived to describe the behaviour of matter and spacetime near a singularity, provided a mathematical foundation for understanding the extreme conditions in such regions of the universe. The beauty of AKR's work was that it presented, in a more general fashion, the mathematical formulation of the motion of a system of particles in spacetime. He also related his observations to singularity while studying Schwarschild's solution. This equation paved the way for later research into the singularity problem. The Raychaudhuri Equation, with insights into the behaviour of matter and spacetime near singularities, was instrumental in shaping the mathematical tools and concepts that Penrose used in his work. Both Penrose and Hawking have acknowledged Raychaudhuri's contribution occasionally in published papers and books.

The Lasting Legacy of AKR

Prof. Soumitro Sengupto, a former student of AKR and now a professor at IACS, remarked that Penrose always acknowledged his inspiration from Raychaudhuri. "AKR always set his research agenda, not motivated by what would likely bring him awards." Prof. Narayan Banerjee of IISER Kolkata, another of AKR's students, highlighted that AKR used geometry to identify a singularity where the laws of physics fail and physical quantities become infinite, specifically in the context of gravity and spacetime. Banerjee explained that this work laid the foundation for the Penrose-Hawking singularity theorems published in 1969. Banerjee also recalled being present when AKR first met Penrose at a workshop at Jadavpur University in 1987.

In his later life, AKR continued to explore the problems of this type in general relativity. He also returned to the earliest problem of finding singularity-free models of the universe,

Fig 7. The Indian Association for the Cultivation of Science (IACS), founded in 1876 in Kolkata, is India's oldest research institute, established with a focus on advancing scientific research and education. It was here that A K Raychaudhuri derived the groundbreaking Raychaudhuri equation.

which violated the singularity theorems of Penrose and Hawking. Later, with Naresh Dadhich, he published a paper where they obtained a singularity-free spherical model of the universe. On 6th October 2020, the Nobel committee announced that Roger Penrose had been awarded the Nobel Prize "for discovering that black hole formation is a robust prediction of the general theory of relativity." While their press release explained that "Roger Penrose used ingenious mathematical methods in his proof that black holes are a direct consequence of Albert Einstein's general theory of relativity", his achievements were illuminated by the legacy of Bengali luminary Amal Kumar Raychaudhuri.

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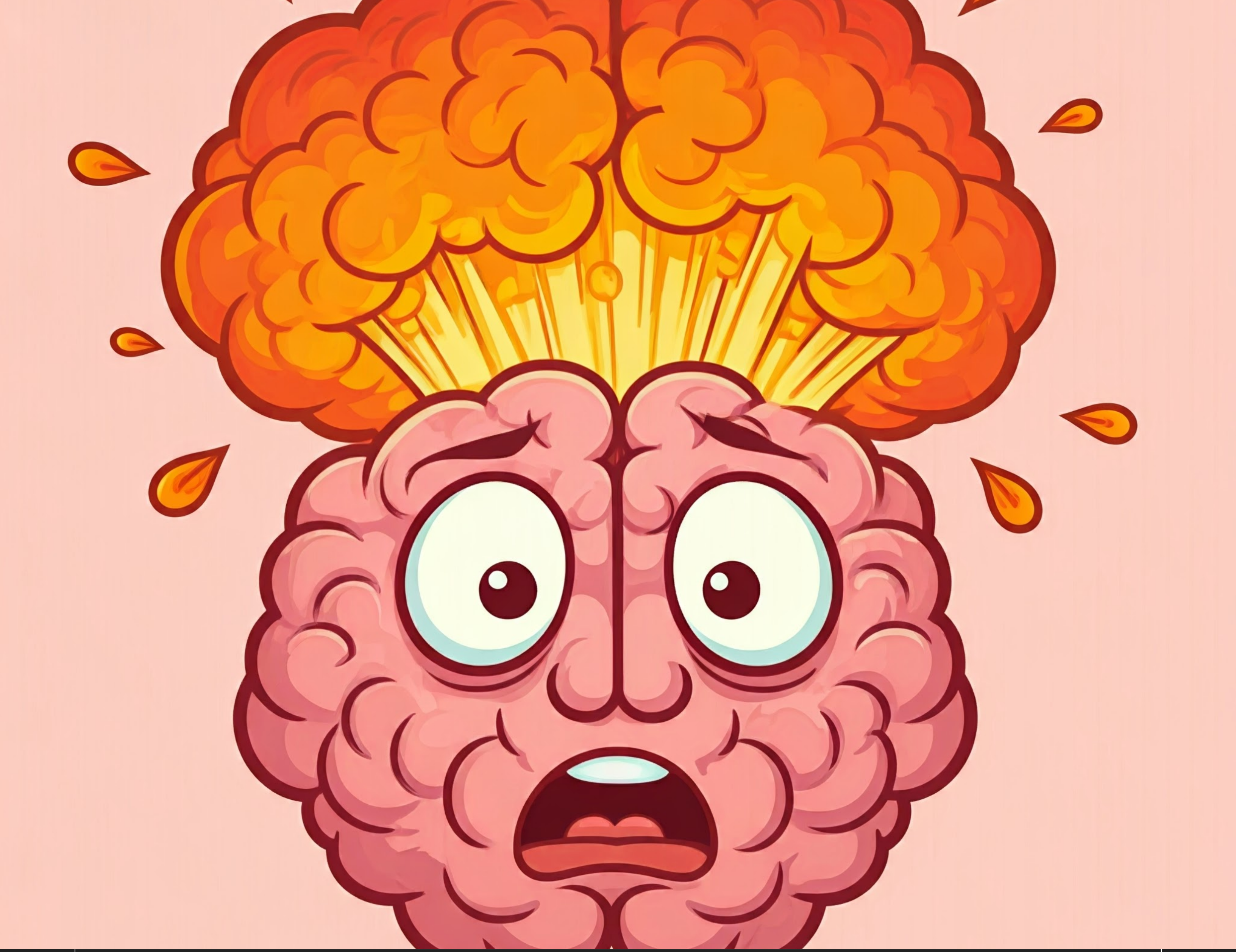

Why We Follow Trends, Even When They're Bad for Us

Swarnendu Saha (IISER Kolkata)

In a world where trends shape our decisions, we often find ourselves following them even when they're harmful. Why do we conform? The answer lies in our brain chemistry, where dopamine creates a reward loop that makes trend-following irresistible. Our psychological need to belong, a trait from our evolutionary past, further drives us to fit in with the crowd. By understanding these biochemical and social influences, we can break free from harmful trends and make decisions that align with our values.

Fig 1. A survey conducted in the US among various age group and regions of residence have shown that most Americans overspend and overpay for leisure and luxury items when other cheaper items serve the same purpose. They also overspend in order to upgrade to the "latest and greatest" product. See [7].

Have you ever wondered why it has become so hard to resist buying things in this age of online transactions? In a world driven by social media, trends emerge rapidly, often influencing our actions in ways we don't fully understand. Whether it's a viral challenge, a new fashion, or a lifestyle choice, the urge to join in can be overwhelming. But why do we follow trends, even when they're bad for us? The answer lies in a combination of psychological and biochemical factors that drive our behaviour.

Our tendency to follow trends is rooted in an evolutionary need for social connection, which has always been essential for human survival. Psychologist Pamela B. Rutledge emphasises that this behaviour isn't a flaw but a natural drive to belong to a group. This need for social connection, considered as crucial as food and shelter, has been crucial since early humans collaborated to survive. While following trends today may not be as vital as escaping predators, our brains remain attuned to social signals, compelling us to align with others.

The Brain's Chemistry: Dopamine and the Reward System

One of the key players in our tendency to follow trends is dopamine, a neurotransmitter in the brain. This chemical plays a crucial role in transmitting signals within the brain and other critical areas. Dopamine is associated with pleasure, reward, and motivation. When we participate in a popular trend, especially one that's exciting or socially rewarding, our brain releases dopamine. This creates a sense of satisfaction and reinforces the behaviour, making us more likely to continue following the trend. The problem arises when this reinforcement happens regardless of the trend's value or potential harm. The rush of dopamine can cloud one's judgement, leading them to ignore risks in favour of immediate pleasure.

The Psychological Need to Belong

Our desire to fit in with others is another powerful force behind trend-following. Humans are inherently social beings, and our survival historically depended on being part of a group. This evolutionary trait still influences us today, as we instinctively seek approval from our peers. When everyone around us is adopting a new trend, we feel a psychological pull to do the same, fearing exclusion or judgement if we don't. This need for belonging can be so strong that it overrides our logical thinking, pushing us to engage in trends even when they conflict with our values or well-being.

This psychological phenomenon, where we look to others to determine what's right or acceptable, is termed social proof. If many people do something, we assume it must be the correct choice. This is amplified by cognitive biases like the bandwagon effect, where the popularity of an idea or behaviour makes it seem more credible. As a trend gains momentum, more people join in, creating a feedback loop that's hard to resist. Confirmation bias further compounds this by leading us to seek out information that supports our decision to follow the trend, ignoring evidence that it might be harmful.

Our brains are wired to prefer familiar, easy-to-process

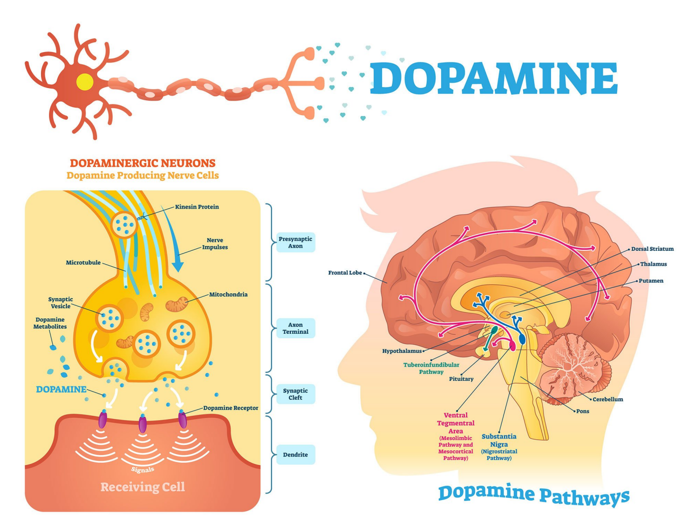

Fig 2. Dopamine is transferred between neurons in the brain through a process called synaptic transmission, where dopamine molecules are released from the presynaptic neuron into the synaptic gap and bind to dopamine receptors on the postsynaptic neuron, thereby transmitting signals between neurons. See [5].

Fig 3. Social proof suggests that our actions are shaped by observing those around us; we often seek validation from others to confirm our decisions. For example, a line outside a restaurant or a celebrity endorsing a brand of coffee can imply a sense of quality or desirability. Similarly, in the bio-pharmaceutical field, acknowledgment by peers or influential figures can be pivotal, potentially determining whether a new drug, vaccine, or technology secures investment. See [6].

information—a concept known as cognitive ease. Trends often become familiar quickly through repetition and widespread adoption, making them feel safe and desirable. This ease of processing reduces the mental effort required to evaluate the trend critically, leading us to follow it without questioning its merits or consequences.

Another factor that drives trend-following is the illusion of control. People often believe they can engage in a trend without suffering negative consequences, thinking they're different or smarter than others who have been harmed. This sense of invulnerability, combined with the excitement of trying something new, can lead to risky behaviour, all in the name of keeping up with what's popular.

Everyone is Susceptible

Rutledge says that everyone must follow trends, observe fads, and show their membership in social groups, without exception. However, Rutledge states that tweens, teenagers, and young adults are especially likely to embrace trends, including risky ones.

As children begin their journey towards independence as adults, they seek out ways to show their individuality. Ironically, this leads to desperate efforts to demonstrate belonging to socially accepted groups - and can fuel the urge to distinguish oneself through popular trends.

Rutledge suggests that you need to find a way to navigate through life successfully - "To achieve that, you must identify your true self". She goes on to explain that because we are social beings, our development occurs within a social setting, and as we become more attuned to social cues, our interest in following (or disregarding) trends also increases. Popularity doesn't hold much significance, even though it may seem important. However, from a biological standpoint, it is important for finding a partner.

Thus, the adolescent brain experiences quick growth in the crucial regions for social cognition. Research shows that adolescents reach their peak in facial recognition and reading abilities, leading to heightened awareness of their peers. At the same time, the prefrontal cortex, which is linked to reasoning and making choices, is the final part of the brain to mature completely (see fig 2), which explains why teenagers may resort to consuming Tide pods or snorting cinnamon to show off to their peers.

In the same way, Rutledge states that older individuals usually feel more confident in who they are, which can shield them from being easily influenced by current trends. Research indicates that social attention levels differ among age groups, as older individuals tend to pay less attention to social cues compared to younger individuals.

Understanding and Resisting Harmful Trends

Avoiding trends, though challenging, requires a nuanced understanding of how our biology, psychology, and evolutionary history shape our behaviour. Biochemically, trends stimulate dopamine release, the brain's reward signal, making conformity feel gratifying. Physiologically, this dopamine-driven reward loop reinforces the behaviour, locking us into cycles of trend-following. Psychologically, we are programmed to seek social approval—a legacy of our

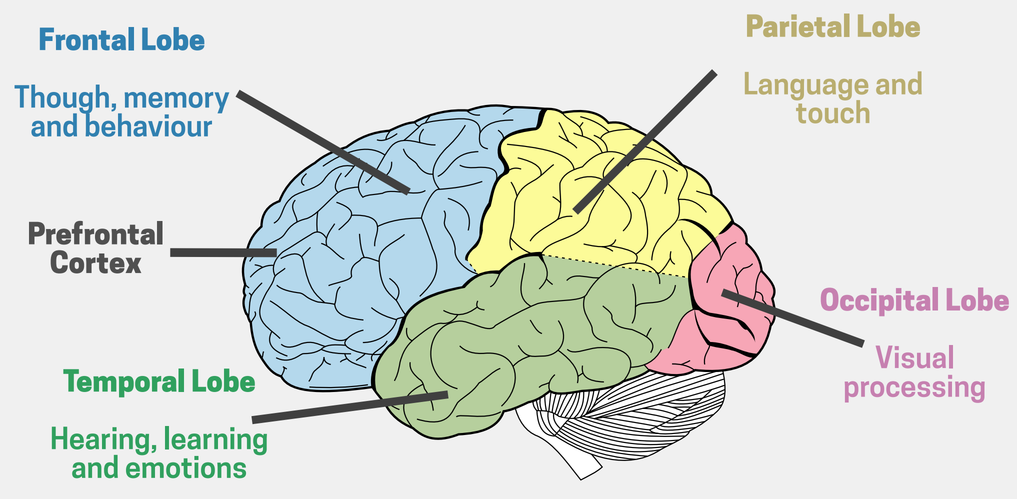

Fig 4. Schematic structure of the human brain. The part of the brain behind the forehead, called the prefrontal cortex, is one of the last parts to mature. This area is responsible for skills like planning, prioritising, and making good decisions.

evolutionary need for belonging. Behavioural biology further shows that our ancestors survived by adhering to group norms, a trait still embedded in us. However, by cultivating self-awareness and critical thinking, we can consciously override these deep-seated impulses.

Recognizing the biochemical and psychological factors that drive us to follow trends is the first step toward making better decisions. By understanding how all of these factors influence our behaviour, we can start to question trends more critically. Asking ourselves why we want to join a trend and considering its long-term impact can help us resist the pull of harmful behaviours and make choices that align with our true values. By seeking fulfilment in personal values rather than societal approval, we reduce our dependence on external validation. This helps foster individuality in a world that often prizes conformity.

In conclusion, while trends can be fun and socially rewarding, it's important to approach them with a critical mind. By being aware of the psychological and biochemical forces at play, we can make more informed decisions and avoid blindly following trends that may not be in our best interest.

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A fifth year BS-MS student of IISER Kolkata, **Swarnendu Saha** is a student working with Prof. Rajesh Kumble Nayak, and is a travel enthusiast, who loves to travel anywhere below the sky. Instead of mentioning his preferred fields in science, he would rather say that chemistry is the one he doesn't like at all!

In Conversation with Director Sunil Khare

Swarnendu Saha, Abhirup Mukherjee (IISER Kolkata)

"**Addressing global issues ... requires an interdisciplinary approach and collaboration. No single discipline can tackle these problems from a whole perspective**". Prof. Sunil Kumar Khare brings over 30 years of experience in both academic and industrial research, and has received notable awards, including the United Nations-Amway Award in 1998 and the Malaviya Memorial Award for Senior Faculty by BRSI in 2018. Swarnendu and Abhirup met up with the newly-appointed director of IISER K to discuss his life, his experiences as an educator and his vision for the institute.

SS: To start, could you briefly share your journey in Indian science and academia, highlighting your experiences as both an administrator and a global academic, leading to your current role as director?

SKK: Thank you for your question. I'm honoured and privileged to be here. My journey in Biochemistry and Microbiology began at IIT Delhi, where I could leverage my passion for teaching over 30-35 years. I have guided a number of master's and Ph.D. students and researched Industrial enzymes and -Extremophiles. I could attract a high level of externally funded projects. I held administrative roles as House Master of Student Affairs, President of- the Board of Student Publications, Chairman, GATE, and JAM for joint entrance for all IITs. and served as Dean of Research & Development, and Dean of Corporate Relations before joining as Director of IISER Kolkata.

SS: You mentioned being at IIT.

SKK: Yes, that's correct. I was the university topper, and based on advice to pursue science, I attended Pantnagar University for my master's in Biochemistry and minor in Microbiology.

SS: Where is that?

SKK: This is in Nainital. I completed my master's at Pantnagar University, a renowned institution for allied subjects. Established in the 1960s with support from the University of Illinois, it offers rigorous education and has excellent faculty. Weekly quizzes and regular monthly exams fostered a concept-based learning approach. After my master's, I joined CSIR as part of the first batch to receive fellowships through a written test. Then I thought about where to put my in this fellowship, and I was told that IITs are the best places to pursue work for research, which emphasise application orientations and translational research. So I chose the IIT Delhi.

Prof. Khare did his doctoral research work at IIT Delhi. He later joined his alma mater as a professor of Biochemistry.

AM: What about your postdoctoral experience?

SKK: Then, for postdoc exposure, I went to Japan, and I also went to the USA and returned. I joined as a scientist in the Government of India for some time. Thereafter I joined IIT Delhi as a faculty member and continued.

SS: You are in a unique position where you have experienced the same institute both as a student and as a teacher. How does that feel?

SKK: Experiencing an institution as a student and as a faculty gives a dual perspective and deepens insights into the system's impact on students. My student time at IIT revealed its strengths and areas for improvement, allowing me to implement those insights as a teacher. This unique exposure provides a valuable advantage that others may not have. IITs provide lots of flexibility in teaching and research to students and faculty.

SS: Since you have worked in other countries like Japan and USA, what do you feel are the major differences between the way research is carried out in those countries and the way it is carried out in ours?

SKK: My postdoc experience in Japan and the USA profoundly shaped my research habits. Their approach emphasises precision and perfection, with an intense work ethic and meticulously checking every detail. Their advanced instrumentation and strict standards greatly influenced me, as I had the freedom to work and try out my ideas; I learned a lot from their disciplined, curiosity-driven, and question-based approach to science.

AM: You've spent significant time in Indian academia, at IITs as well as IISERs. IITs are much larger, with multiple departments and a vast number of students, while IISERs are smaller, focusing on just a few core departments. Given the presence of IITs with their established brand and scale, what role do you think IISERs play in the Indian academic landscape?

SKK: IITs are primarily engineering institutions focused on science-based engineering education, whereas IISERs emphasise fundamental science and research education. IISERs aim to build a strong foundation in science and interdisciplinary science, which can later translate into applications for various kinds , including in engineering.

At IITs, students spend initial semesters learning basic sciences before moving on to core engineering disciplines

and technology research. In contrast, IISERs offer more advanced science courses, providing a deeper understanding of scientific principles for science research.

For instance, while IITs might focus on quantum applications like quantum communication and computing, IISERs concentrate on the foundational aspects of quantum physics and chemistry. This distinction highlights the differing focus of these institutions.

SS: On a lighter note, will you tell us a little about your school life? How has school life shaped you?

SKK: I come from a very modest background. My father worked for the Government of India, so we moved frequently, and I attended various government schools. Early on, I realised that to succeed; I had to work harder and be among the top students to secure fellowships that would support my education. This drive pushed me to always put in extra effort, and I was fortunate to receive fellowships throughout my academic journey, which allowed me to continue studying. To this day, I remain committed to learning.

SS: During the INYAS inauguration, the director of the SN Bose National Centre for Basic Sciences noted that India's scientific initiatives often operate in isolation. Despite various government scholarships and outreach programs, overall progress appears limited. We need a cohesive framework to integrate these efforts and enhance collaboration among scientists, students, faculty, and administrators to improve scientific progress and outreach. What is your take on this?

SKK: Yeah, that is a good question. Addressing global issues like healthcare challenges, drug resistance, climate change, and sustainable energy requires an interdisciplinary approach and collaboration. No single discipline can tackle these problems from a whole perspective. For example, at IISER, researchers developing anti-snake venom needed input from collaboration with AIIMS medical experts to ensure efficacy. Mission-bound projects involving multiple institutions and disciplines are essential for meaningful progress.

The city of Tsukuba in Japan, where Prof. Khare carried out his post-doctoral research.

SS: It's essential to recognize that different societal strata, including rural and marginalised groups, face unique challenges. Their issues must be addressed, as their lack of access to resources is a significant problem that requires our attention. How can we involve the rural and impoverished populations in the main stakeholder process? While discussing interdisciplinarity, we often include various professionals, but we frequently hear that the lower strata feel excluded. What role should science administration play to ensure their inclusion?

SKK: The Government of India has launched several initiatives to address societal issues through science. For example, the Department of Science and Technology has a "Science for Society" division that funds projects for science based solutions for the problems faced in rural areas. As an example, one such project in Rajasthan focused on desalinating salt water using a simple, low-cost solar evaporation setup, providing a simple solution for areas having no access to large desalination plants.

Similarly, the Department of Biotechnology and other ministries support projects that apply scientific solutions to such problems. At IISER Kolkata, we also contribute through outreach initiatives like "Ek Pehel," wherein we engage with school children, exposing and motivating them to science and education.

AM: A more academic question now. Considering your experience in both academia and industry, which role did you find creatively more demanding? Which one was more interesting?

SKK: Science stems from a natural curiosity to understand the phenomenon. Basic science begins with questions about phenomena, while translational science applies these discoveries to provide solutions. Lab research leads need to be scaled up, tested for cost-effectiveness, and adapted for practical use. Some scientists focus on discovery, while others aim to translate those findings into applications, illustrating the journey from science to technology.

SS: My next question comes from my experience as a student. In the past few years, the KVPY program has been discontinued; moreover, many PhD scholars are concerned about insufficient funding for their research. Some of my seniors who have worked abroad mention a stark contrast in funding between India and many western countries.. What are your thoughts on this?

SKK: The government isn't cutting science funding; we have launched Anusandhan National Research Foundation (ANRF). The ANRF aims to seed, grow and promote research and development (R&D) and foster a culture of research and innovation throughout India's universities, colleges, research institutions, and R&D laboratories. ANRF will act as an apex body to provide high-level strategic direction of scientific research in the country as per recommendations of the National Education Policy (NEP). Though the US has more resources, India is progressing at a faster pace similar support for science. . KVPY is subsumed with the INSPIRE fellowship scheme, as an answer to your next part of question.

AM: From institutes such as the IISERs and the IITs, what often happens is, after receiving their B.Sc or M.Sc degree, lots of students take up their doctoral work outside the country. Do you feel that this is a problem that needs to be addressed?

SKK: It is not a problem, it is a question of choice. Some people stay back also, such numbers are on increase with Indian institutions coming at par with global institutions. Some students want to go for a job, some want to go for industry. So it depends what one is aspiring for.

AM: That is certainly true, but the problem I was referring to is the fact that we might potentially be losing a large section of the intelligent population in this process. So you feel that this is not an issue?

SKK: I am saying it is their choice actually. Opportunities are here also, and there also, it is your choice and path

National Centre for Agricultural Utilization Research-USDA Peoria USA, where Prof. Khare was a visiting fellow.

you want to choose.

AM: Should we do something to make it more lucrative for them to stay here? Can something be done in that regard?

SKK: I think there are many examples where people stayed back in the country and did great. I think incubation centres, research parks , industry-academia interactions and Start ups promotions are good initiatives.

SS: Would you say that that constitutes a brain drain?

SKK: The term "brain drain" has become outdated, as the boundaries for scientific pursuit have blurred. Contributions to global problems can be made from anywhere, whether in India or abroad. Whether addressing climate change here or in the US, the aim is to serve humanity.

AM: Okay, a bit of a mundane question now. In this institute, the IPhD program has been discontinued in DMS and DCS in recent years. Do you see any future of this program, or do you think other departments will also follow suit? Do you think such a program benefits the institute?

SKK: I think this program is in tune with or in sync with the NEP, which mandates multiple entry and exits. So, this program to me appears a very good example of NEP implementation, wherein if students want to exit, they can exit after master, or can continue for Ph.D. To me it appears a good program. I do not think that it is dying, it's actually very much vibrant.

AM: Another IISER-specific question. You have been here for around three months now. How do you wish to see this institute five years down the line?

SKK: I aim to advance the institution by fostering interdisciplinary collaboration among departments. For instance, I envision biologists and physicists working together on biophysics issues to create structured, problem-based partnerships. One initiative I proposed is to develop a Chemical Biology Programme to be offered jointly by Departments of Chemical and Biological Sciences. Additionally, I plan to create online certificate courses that leverage our faculty's expertise , benefiting students and the wider community.

SS: Are you thinking of something along the lines of NPTEL?

SKK: I'm exploring online certificate courses at IISER Kolkata, similar to NPTEL. For example, I suggested our Computer Science faculty create a course on AI in healthcare for our students and AIIMS doctors. Another one thought is on Bio-economics.

I'm also thinking of new programs like a BS-MS in

Sustainable Sciences with cross-department collaboration and a BS-MBA program with IIM Calcutta, focusing on research and industrial management to equip students with a strong science foundation and valuable management skills.

SS: If other institutes can have BA-MBA, why not science and MBA, right?

SKK: Yes! Why not science and MBA, this is what I was thinking. Another thing I have in mind is the generation of more eternally funded projects. By external, I mean external research grants from various funding agencies.

AM: Such research grants must come from the government, right?

SKK: Funding from SERB, DST, DBT, and NARF is vital for research. Focussed projects based on National and global priority We should focus on generating our own funds for more flexibility and self sustainability.

SS: All IITs in general have some sort of program that supports the EWS students, but you typically don't hear of such programs at the IISERs. This is not to demean anyone, but certain categories of students do receive fee waivers as per government norms, but the EWS students don't. Is there any way we can address this?

SKK: Actually the EWS fee waiver is the government's defined scheme, and we are trying to get it considered for IISERs as well.

SS: IITs and IISERs often promote a vibrant system of sports and cultural meets that encourage interaction among diverse ideas. However, within the IISER system, no such structure exists for promoting scientific interactions among the students. How do you feel about establishing an Inter-IISER Science Meet to complement our existing discipline-focused meetings? This will allow students from all IISERs, including the undergraduates, to present their research and ideas, fostering collaboration and innovation across various backgrounds and disciplines.

SKK: This is a very welcome idea. I will put it to all IISERs Directors meetings and I will be happy to take it forward.

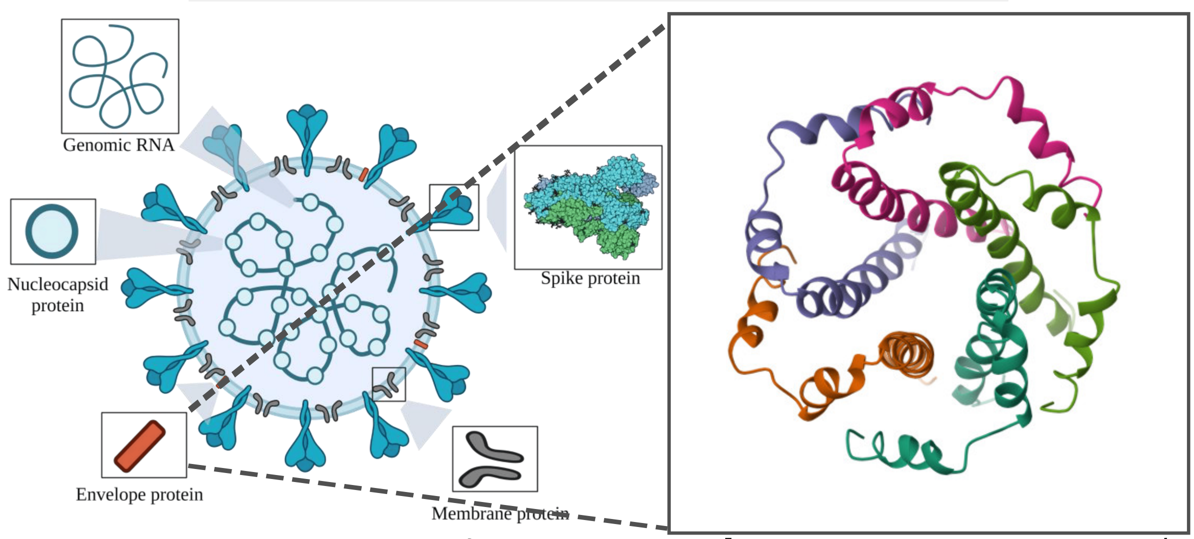
SS: Having joined recently as director, which aspects of the institute do you think need improvement?

SKK: The new student hostel approved by the government will enhance comfort, so we must expedite its construction. We should also improve facilities, like developing an athletic ground and Indoor sports infrastructure. I plan to prioritise these improvements, but need time to understand the situation, having been here for only three months.

AM: We are almost at the end of the interview. Do you have any message for the InScight team, and more broadly, for the IISER Kolkata community?

SKK: Congratulations on this great initiative! My message is to strive for excellence, and let you know that we are here to support your educational aspirations. Please make the most of the opportunities and excel in your careers. Best wishes to all of you. Thank you!

InScight is grateful to **Aritra Das** (21MS, IISER Kolkata) for providing creative assistance while preparing for this interview.



Structure and protein visualisation of SARS-CoV-2 virus [Shahenvaz Alam et al., 10.21203/rs.3.rs-41688/v1.] Prof. Khare has made noteworthy contributions in the field of Microbial Biochemistry.

Gluten – Not For All Gluttons!

Shrestha Chowdhury (IISER Kolkata)

In "Gluten – Not for All Gluttons," Shrestha Chowdhury takes readers on an informative journey exploring the science, history, and health impacts of gluten. Readers are introduced to gluten's role in food, and the fascinating yet complicated composition of this protein complex found in wheat. From Celiac disease to gluten ataxia, this article provides a clear overview of gluten's potential health impacts, as well as alternative solutions for those with sensitivities. The article is an engaging resource for readers curious about gluten or seeking to better understand the growing demand for gluten-free diets and products.

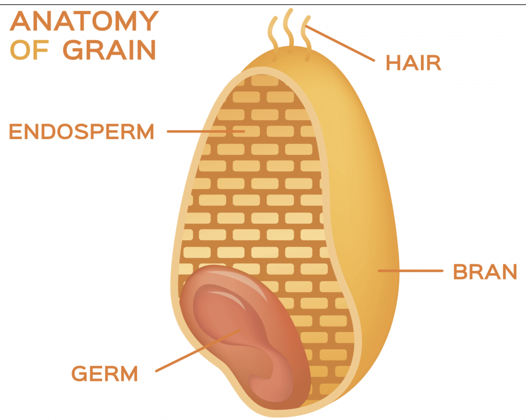


Fig 1. Different parts of a wheat grain. Ref [16]

Shreya and Shruti are two good friends. They always stay together and often share food. One day, Shreya brought sandwiches for lunch to school, and she shared them with Shruti. They ate happily, but suddenly Shruti started feeling nauseous, and her stomach became upset. She remembered experiencing similar symptoms when she had a piece of paratha at home, though this time it felt more intense. Shreya took her to the medical room, where their favorite Doctor Kaka was present. Doctor Kaka asked Shruti many questions about her food habits and suggested a blood test. When the blood test results came back, it revealed that Shruti has 'Celiac Disease' and is allergic to gluten. Since they were still in school, they were hearing this for the first time. Curiously, they asked, "Doctor Kaka, can you tell us more about this gluten?" Doctor Kaka replied, "Sure, why not? Let's start the story of gluten."

Definition, origin, and whereabouts

In simple terms, gluten is the rubbery substance that remains in wheat dough after the starch has been removed by washing it with water or a brine solution. Technically, gluten is a complex mix of hundreds of different proteins found in wheat and similar grains, like rye, barley, and oats. More specifically, these storage proteins are located in the endosperm of wheat kernels, where they help with future seed germination. Additionally, factors such as the type of wheat, the time of harvest, and the growing location all influence the amount of gluten present in the grain.

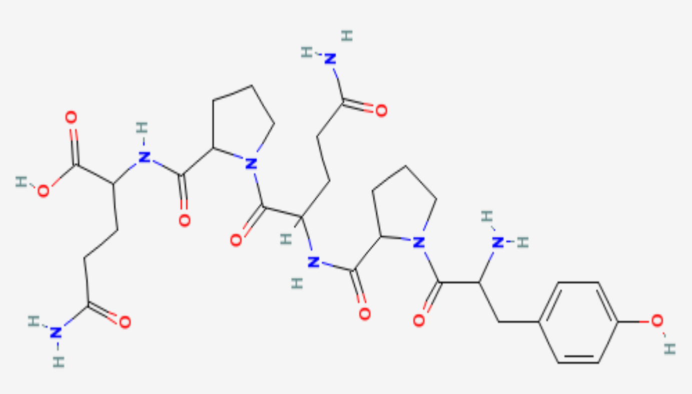


Fig 2. Chemical structure of gliadin $C_{29}H_{41}N_7O_9$. Simple protein, one of the prolamines, derived from the gluten of wheat. Associated with celiac disease. See [3].

Discovery of glutens

One of the first proteins to be investigated scientifically was wheat gluten. Jacopo Beccari, a chemical professor at the University of Bologna, carried out the first such investigation in 1745. Prior to the 1970s, when gel electrophoresis was invented, Dr. T. B. Osborne, a plant protein chemist from Connecticut, was able to successfully extract proteins from a range of seeds in several solvents with different polarities between 1886 and 1928. His method, which is being used today, is called the Osborne fractionation. The four protein fractions identified by this method are albumins, which are soluble in water, globulins, which are soluble in diluted saline, prolamins, which are soluble in 60–70% alcohol, and glutenins, which are insoluble in other solvents but can be extracted in alkali. During the extraction procedure, Dr. T.B. Osborne discovered a high concentration of amino acids, such as proline, in a particular class of protein, which he named Prolamins. He also went on to identify the different prolamin subclasses according to the grains' origins. Gliadin in wheat, hordein in barley, secalin in rye, zein in maize, and so on are other examples.

Components of gluten: gliadins and glutenins

In simple terms, gluten is primarily made up of two proteins: gliadins and glutenins, collectively known as prolamins. But how are these proteins produced inside a wheat grain? The genes responsible for synthesizing gluten proteins in developing wheat grains include the Gli-1 and Gli-2 loci, which code for gliadin proteins, and the Glu-1 and Glu-3 loci, which code for glutenin polypeptides. To understand how glutenins are synthesized and developed, we need to explore the underlying chemistry of their polypeptide production.

On a molecular level, gliadins are monomeric proteins with molecular weights (MW) ranging from approximately 28,000 to 55,000. In contrast, glutenins are polymers, particularly composed of high molecular weight (HMW) subunits, with weights varying from about 67,000 to over 88,000. Gliadins are further classified into three main types: **α**/**β**-, **γ**-, and **ω**-gliadins. The distribution of these types varies based on wheat genotype and environmental factors like climate, soil, and fertilization. Typically, **α**/**β**- and **γ**-gliadins are more abundant than **ω**-gliadins in the wheat grain.

Closer examination reveals that gliadin proteins are composed almost entirely of repetitive sequences rich in glutamine and proline (such as PQQPFPQQ [2]). Among the gliadins, **α**/**β**- and **γ**-gliadins share similar molecular weights and have lower amounts of glutamine and proline compared to **ω**-gliadins. In contrast, glutenins consist of both high molecular weight (HMW) and low molecular weight (LMW) subunits, with the LMW glutenin subunits (LMW-GS) being truncated forms of their HMW counterparts. LMW-GS

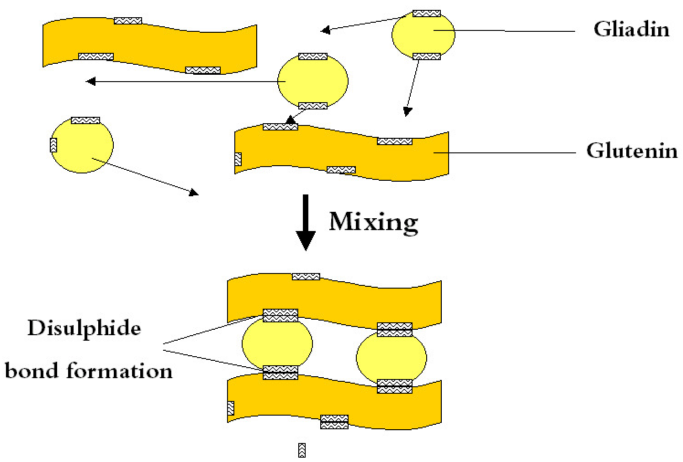


Fig 3. Structure formation of gluten upon mixing, See [6]

account for approximately 20% of the total gluten proteins. These LMW subunits are similar to **α/β**- and **γ**-gliadins in both molecular weight and amino acid composition.

As HMW-GS does not occur in flour and dough as monomers, it is generally assumed that they form interchain disulfide bonds. Fun fact, the largest polymers termed 'glutenin macropolymer (GMP) make the greatest contribution to dough properties and their amount in wheat flour (E20–40 mg/g) is strongly correlated with dough strength and loaf volume.

Polymer chemistry in glutens

The study of gluten polymers is especially important in bread making, as bread is a staple food in many cultures worldwide. Gluten proteins are highly hydrophobic, meaning they tend to bond more readily with lipids than with water. In dough, hydrated gliadins and glutenins behave differently: gliadins are less elastic and less cohesive, contributing mainly to the dough's viscosity and extensibility. In contrast, hydrated glutenins are both cohesive and elastic, providing dough with its strength and elasticity. In simple terms, gluten acts as a two-part adhesive, where gliadins function as a "solvent" for the glutenins, supporting the formation of the dough's structure.

Glutenin subunits through hydrogen bonds, form large three-dimensional networks via inter-chain disulfide bonds. These bonds interact with gliadins and with other glutenin networks. Throughout the processing of bread, the

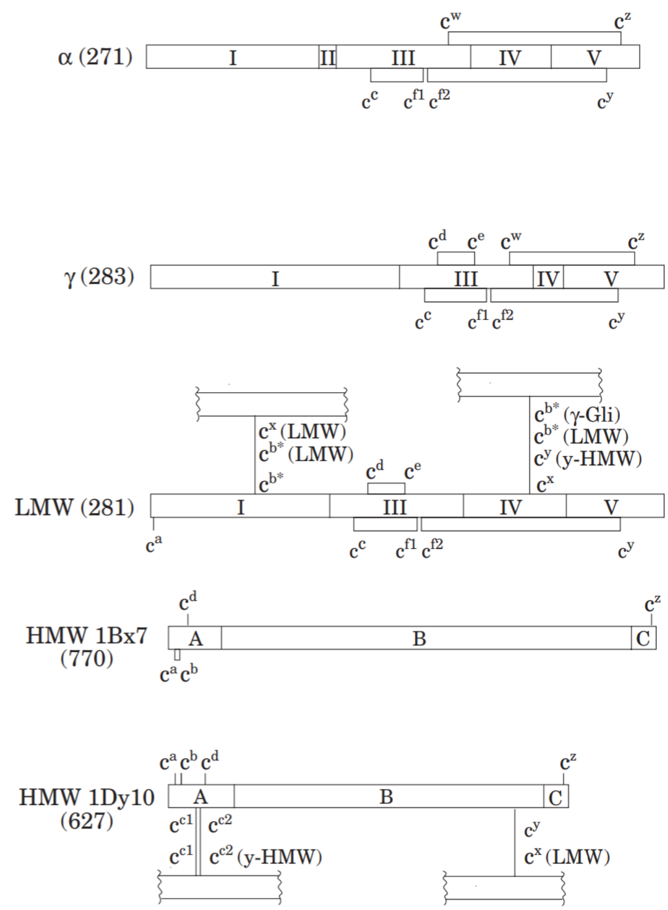


Fig 4. Parts of gliadin and glutenin proteins. See [5].

condition of large glutenin polymers is characterized by three competitive redox reactions

1. the oxidation of free SH groups (thiol) in the peptide chains which support polymerization
2. the presence of 'terminators' that stop polymerization and,
3. SH/SS interchange reactions between glutenins and thiol compounds such as glutathione that depolymerize polymers.

Notably, the overriding importance of disulfide bonds can be demonstrated by the addition of reducing agents weakening dough and of thiol-blocking or oxidizing agents strengthening dough.

Type	MW × 10^{-3}	Proportions[a] (%)	Partial amino acid composition (%)				
			Gln	Pro	Phe	Tyr	Gly
ω5-Gliadins	49–55	3–6	56	20	9	1	1
ω1,2-Gliadins	39–44	4–7	44	26	8	1	1
α/β-Gliadins	28–35	28–33	37	16	4	3	2
γ-Gliadins	31–35	23–31	35	17	5	1	3
x-HMW-GS	83–88	4–9	37	13	0	6	19
y-HMW-GS	67–74	3–4	36	11	0	5	18
LMW-GS	32–39	19–25	38	13	4	1	3

Table 1. Characterisation of gluten protein types. See [5].

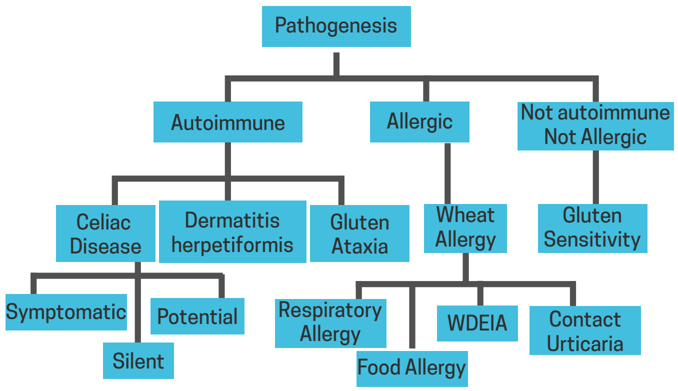


Fig 5. Flowchart showing various health disorders related to gluten consumption.

On the other hand, oxygen is found to be crucial for the formation of large glutenin polymers during the mixing of the dough. Oxidizing agents such as potassium bromate, potassium iodate, and L-ascorbic acid exhibit the same effect as atmospheric oxygen. Finally, the baking process leads to dramatic changes in the glutenin structure and functionality. For example, extractability in the urea or SDS is strongly reduced and most cysteine-containing **α**, **β**- and **γ**-gliadins are covalently bound to glutenin polymers after baking. Disulphide interchange reactions between gliadins and glutenins have been also postulated to be involved in the heat-induced effects.

To put it succinctly, gluten proteins are one of the most complicated protein networks seen in nature because of their many distinct parts, varying sizes, and unpredictability brought on by technologies, growing environments, and genetics. They are crucial in establishing wheat's distinct rheological dough characteristics and baking quality.

As their curiosity grew, Shreya and Shruti questioned, "But Kaka, why are only some of us gluten intolerant?" Doctor Kaka continued with this story.

Harmful effects

It is unfortunate that some individuals are unable to consume gluten-based products due to various health conditions. Gluten can trigger adverse reactions in susceptible people.

Celiac Disease is a serious autoimmune disorder where gluten consumption triggers an immune response that damages the small intestine. This damage can lead to malabsorption of nutrients, leading to symptoms such as diarrhea, abdominal pain, fatigue, and weight loss.

Non-Celiac Gluten Sensitivity (NCGS) is a condition where individuals experience symptoms similar to celiac disease, but without the intestinal damage. These symptoms may include digestive issues, fatigue, headaches, and skin problems.

Gluten Ataxia is a neurological disorder caused by gluten exposure. It affects the cerebellum, a part of the brain responsible for coordination and balance. Symptoms can include clumsiness, difficulty walking, and slurred speech.

Dermatitis Herpetiformis is a skin condition characterized by itchy, blistering skin rashes. It is often associated with celiac disease and improves with a gluten-free diet.

While the exact mechanisms by which gluten triggers these conditions are not fully understood, genetic factors and immune system responses play significant roles. In individuals with celiac disease, for example, specific genes increase the likelihood of developing the condition. When these individuals consume gluten, their immune system mistakenly identifies it as a harmful substance, triggering an immune response that damages the small intestine. In non-celiac gluten sensitivity, the immune response is different but can still cause symptoms like digestive discomfort, fatigue, and headaches. These immune-mediated responses lead to inflammation and tissue damage, which can impact nutrient absorption and overall health. For individuals with these conditions, a strict gluten-free diet is the only effective treatment.

What makes bread so tasty? Are there healthier alternatives?

Since the dawn of human civilization over 10,000 years ago, wheat has been a staple food. Bread, its primary form of consumption, is beloved for its texture and crunch, thanks to the unique viscoelastic properties of dough. However, gluten, a protein complex in wheat, can cause serious health issues for many. A gluten-free diet is often the preferred choice for these individuals. According to the U.S. Food and Drug Administration, gluten-free foods must contain less than 20 parts per million of gluten.

Fig 6. Mapping of a-gliadin motifs. Those exerting cytotoxic activity are shown in red, immunomodulatory activity in yellow, zonulin release and gut permeating activity in blue, and CXCR3-dependent IL-8 release in celiac disease patients in dark green. See [15].

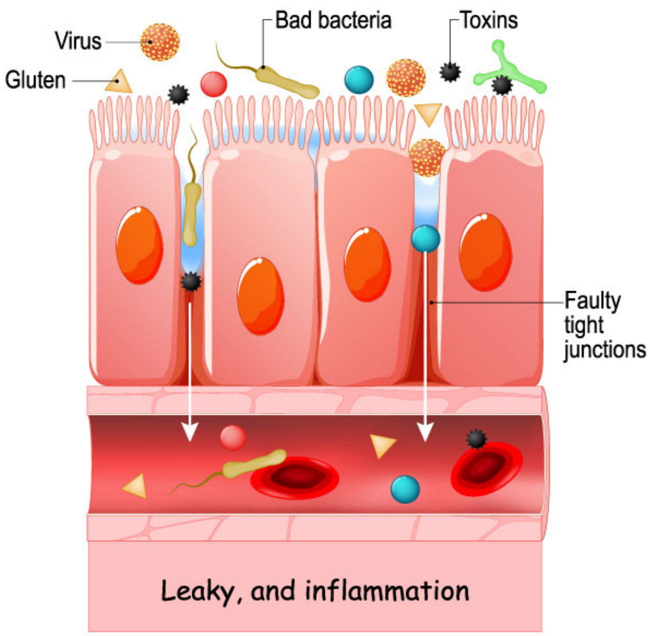


Fig 7. The term "leaky gut" describes damage to the gut lining due to various factors, leading to intestinal permeability. In this condition, bacteria, toxins, and even food particles begin to enter the bloodstream.

While a variety of gluten-free alternatives exist, they often fall short in terms of taste and texture. Gluten-free bread, for instance, can be dense, dry, and lacking in flavor. This is largely due to the absence of gluten, which provides elasticity and structure to dough. To compensate, manufacturers often use a combination of starches, fibers, and hydrocolloids, but these ingredients can impact the bread's overall quality.

To improve the quality of gluten-free bread, researchers are exploring several strategies:

Mimicking Gluten's Function: By carefully selecting and combining different ingredients, such as hydrocolloids, starches, and proteins, manufacturers can create doughs that mimic the properties of gluten-containing dough.

Enhancing Flavor and Aroma: The Maillard reaction, a chemical process that occurs during baking, contributes to the flavor and aroma of bread. By manipulating the ingredients and baking process, researchers can enhance the Maillard reaction in gluten-free bread.

Improving Texture: Enzymes, such as transglutaminase and proteases, can be used to modify the protein structure and improve the texture of gluten-free bread.

Leveraging Fermentation: Sourdough fermentation can enhance the flavor, aroma, and texture of gluten-free bread by introducing beneficial bacteria and yeast.

While gluten-free bread may not yet match the taste and texture of traditional wheat bread, ongoing research and innovation are bringing us closer to this goal. As scientists continue to delve deeper into the science of breadmaking, we can expect to see significant improvements in the quality of gluten-free products.

Is there a silver lining?

Overall, gluten-free bread is more expensive than traditional bread. However, the market for gluten-free products is steadily growing. Beyond human consumption, gluten finds applications in pet food. Additionally, it has non-edible uses, such as removing ink from waste paper, creating pressure-sensitive medical bandages and adhesives, solidifying waste oils, and forming biodegradable resins. Gluten films also protect food from moisture and bacteria. Therefore, contrary to some media portrayals, gluten is not inherently harmful.

Gluten, though discovered three hundred years ago, has only recently become a focal point of attention due to the growing awareness of various gluten-related disorders. Fortunately, we no longer live in a time devoid of gluten-free alternatives. Today, the market offers a plethora of such options, although there's still room for improvement in their taste. Nevertheless, the demand for gluten-free alternatives has opened up new business opportunities. So, cheer up your gluten-sensitive friends! It's not far-fetched to imagine a future where new wheat cultivars are developed, free from the toxic polypeptides found in gluten. Of course, achieving this milestone requires a deep understanding of protein folding, both experimentally and theoretically.

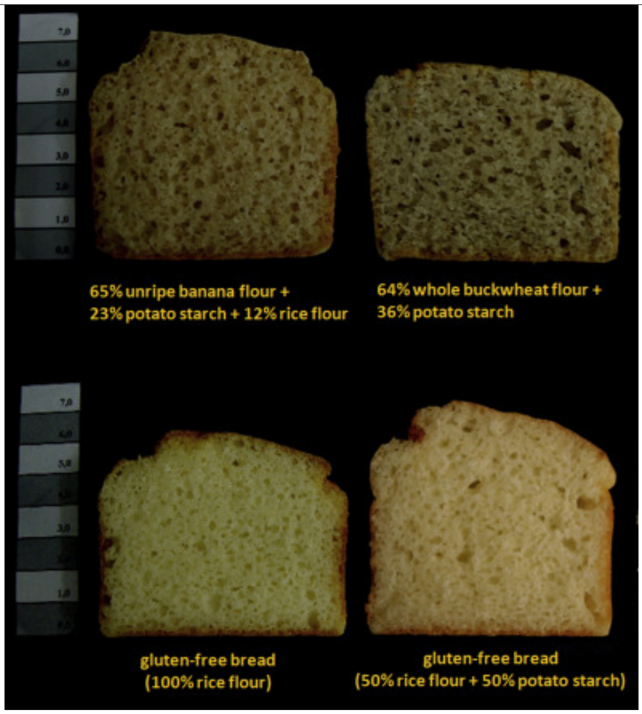


Fig 8. Appearances of central slices of optimized gluten-free bread formulations containing nutrient-dense alternative flours, and their comparison with white gluten-free and wheat-containing counterparts. See [22].

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Fig 9. Jacopo Bartolomeo Beccari, known as the discoverer of gluten in wheat flour.

Shrestha Chowdhury is currently working as a Senior Research Fellow in the Department of Chemical Sciences at IISER Kolkata and is about to wrap up her doctoral degree. Recently diagnosed with psoriasis, she got curious about gluten. Hence the article. Hope the readers enjoy it!

iGEM 2024 team of IISER Kolkata. From left to right: Shamba Chakraborty, Anushka Mishra, Sharanya Chatterjee, Ayantik Kundu, Utkarsh Aryan, Gitanjali Das, Smrutimayee Prusty, Fathima Anjum EC, Sampoorn Pandey, Divyanshu Kumar

Engineering Solutions for Foot Care: IISER-K's E coli-Powered Foot Insole Bags Gold at iGEM

Swarnendu Saha, Suman Haldar (IISER Kolkata)

The IISER Kolkata iGEM 2024 team addresses the widespread problem of foot infections by developing a self-sustaining, GMO-based insole that can both treat and prevent fungal growth. Using engineered E. coli to produce linalool, a natural antifungal and antibacterial compound found in lavender, the insole continuously protects against fungal and bacterial growth, reducing discomfort and leaving a refreshing scent. The team, through complex control systems, such as quorum sensing and cell cycle arrest, ensured the bacteria became effective with time. Their interdisciplinary project won a gold medal and special award nomination for Best Fashion and Cosmetics.

For IISER Kolkata's iGEM 2024 team, their journey began with a common but persistent issue—foot infections. Athlete's foot, diabetic ulcers, and other fungal infections cause discomfort, itching, and unpleasant odours for millions around the world. The team wondered whether biotechnology could offer a solution? Their answer was a **GMO-powered foot insole designed to treat and prevent foot fungal infections**. Their project stood out among global entries, earning the team a **gold medal and a nomination for the Best Fashion and Cosmetics Project category**. Through genetically modified organisms (GMOs), the project transforms everyday foot care into a scientific marvel. This interdisciplinary approach, typical of iGEM, integrates biology, chemistry, and mathematical modelling to address critical societal challenges like health and hygiene.

iGEM educates the workforce and leaders of the synthetic biology industry. The iGEM Foundation is an independent, non-profit organisation dedicated to advancing synthetic biology, fostering education and competition, and building an open, collaborative, and cooperative community. Synthetic biology often originates from simple, everyday problems, and iGEM's mission is to provide a platform for teams like IISER Kolkata to find innovative, impactful solutions.

Mentors always play a key role in projects like this, guiding young and enthusiastic students through complex challenges, ensuring that **interdisciplinary collaboration** leads to **innovative results**. This year, Prof. Supratim Dutta, Prof. Tapas Kumar Sengupta, Prof. Susmita Roy and Prof. Anindita Bhadra helped the students in refining their designs, offering crucial insights from their own expertise.

The Innovation: A GMO-Powered Foot Insole

At the heart of their idea lies **Escherichia coli** (E. coli) - **a genetically modified bacterium that produces linalool**, a fragrant monoterpene(compounds found in the essential oils extracted from many plants, including fruits, vegetables, spices and herbs). Found in lavender, linalool boasts antifungal, antibacterial, and pain-relieving properties, making it perfect for foot care applications. This naturally occurring compound isn't just about making your feet smell good—it actively combats the microbes responsible for common infections, while also reducing discomfort.

The engineered insole nurtures the growth of these bacteria, using a **multi-layered structure** for protection and functionality. A non-porous bottom layer ensures durability, while the bacteria thrive in a nutritive medium held in a biocompatible polymer. The semi-permeable upper layer allows the beneficial compounds to diffuse, reaching the foot while keeping the bacteria contained.

As **Prof. Tapas Kumar Sengupta** puts it, this system offers a unique advantage: it transforms foot care from something you have to do into something that happens naturally and continuously, all thanks to the insole. Importantly, teamwork among experts from various fields—biologists, engineers, and modellers—is essential for iGEM projects like this one, enabling the fusion of disciplines to create well-rounded, innovative solutions.

But why linalool, you might ask? **Its antifungal properties help fight infections such as athlete's foot, while its antibacterial effects ward off other common pathogens.** The analgesic and anti-inflammatory benefits reduce pain and swelling, providing relief from the discomfort often caused by these infections. Plus, its pleasant lavender-like scent adds a touch of freshness to the mix, eliminating foot odour—a common symptom of microbial infections.

However, it's not just about choosing the right compound. The real genius of the project is in how the bacteria are engineered to consistently produce linalool. This is where the magic of synthetic biology comes into play.

The Engineering: Using Synthetic Biology to Power the Insole

The team didn't just slap some bacteria onto an insole and call it a day. **They carefully designed a system where the bacteria could live and thrive, ensuring long-term production of linalool**. The main challenge they faced was controlling the bacterial growth to ensure that it continued

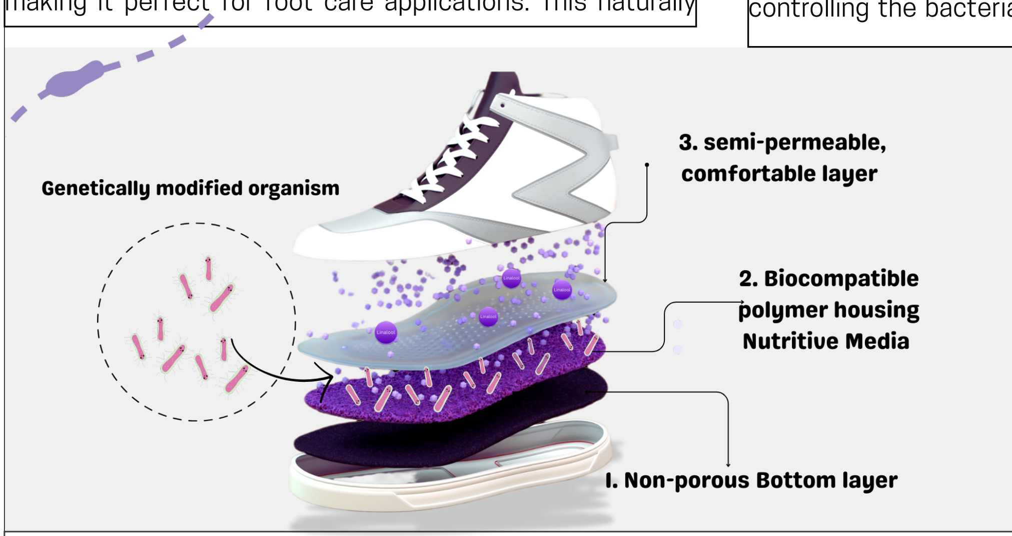


Fig 1. The GMO-powered foot insole is structured with multiple protective layers. A biocompatible polymer layer containing the GM bacteria sits at the core, providing nutrients for the bacteria. This polymer layer is sealed on the underside with a non-porous layer to prevent bacterial leakage, while a porous upper layer allows only the targeted volatile compounds to escape, keeping the bacteria contained within the insole. [IISER Kolkata iGEM 2024 Wiki]

Population Control Module: Ensures regulation of population

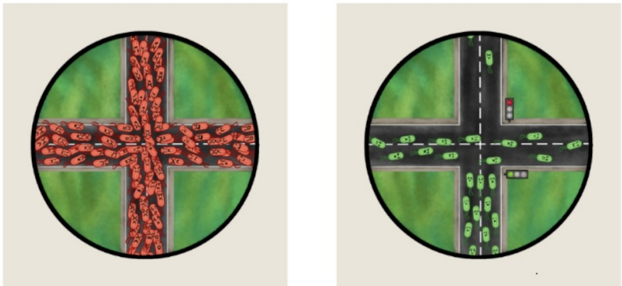


Fig 2. The system operates similarly to traffic control, managing bacterial "flow" to maintain efficient functioning. Bacteria can multiply as needed, but once the population hits an optimal level, the system temporarily "stops" further growth until it's necessary again. This method keeps the bacterial population balanced and efficient. [IISER Kolkata iGEM 2024 Wiki]

producing linalool without exhausting its resources or multiplying unchecked.

Lactobacillus rhamnosus is a well-established probiotic known for its safety and effectiveness in treatments for humans. It has gained recognition for its beneficial role in various therapeutic applications, making it a reliable choice in bioengineering projects aimed at improving health outcomes. One of its key advantages lies in its antifungal and antimicrobial properties, which complement the production of linalool—a compound with antibacterial and antifungal effects. Together, they create a robust defence against harmful microorganisms, enhancing the protective qualities of products in which they are incorporated.

Moreover, Lactobacillus rhamnosus is **compatible with the skin microbiome**, meaning it can **outcompete harmful pathogens without disrupting the natural microbial balance on the skin**. This compatibility is crucial, as it ensures that beneficial bacteria thrive, thereby supporting skin health rather than compromising it. Beyond its protective capabilities, Lactobacillus rhamnosus also offers **immunomodulatory potential**, aiding in **reducing inflammation** and **improving overall skin health**. This probiotic, therefore, provides a multifaceted approach to skin care, making it an invaluable asset in biotechnology applications focused on health, hygiene, and sustainability.

The solution was a combination of quorum sensing and cell cycle arrest (CCA). Quorum sensing is a **natural process where bacteria communicate and regulate their behaviour based on their population density**. This allows the team to control when and how much linalool is produced, ensuring that the bacteria don't consume all the nutrients too quickly or overpopulate, leading to their own demise.

The **cell cycle arrest mechanism** (CCA), powered by antisense RNA, regulates the growth of the bacterial colony. Essentially, the bacteria can "pause" their growth to focus on producing linalool, preventing them from growing too quickly and running out of resources. These two mechanisms, quorum sensing and CCA, work together to ensure the bacteria remain in a productive phase for longer, keeping the insole functional and effective over extended periods.

The complex interaction between bacterial growth, nutrient availability, and linalool production required detailed mathematical modelling. Using ordinary differential equations (ODEs), the team predicted how the bacteria would behave under different conditions. These equations helped them simulate population growth, nutrient consumption, and the timing of linalool release.

The **mathematical models were key to fine-tuning the design**. For instance, if the bacterial population grows too quickly, it could run out of nutrients, halting linalool production prematurely. By **adjusting the quorum sensing and CCA mechanisms**, the team was able to **predict and control the lifespan of the bacterial culture, ensuring sustained production of linalool without exhausting the insole's resources**. Mathematical modelling, alongside biology and outreach, plays an integral role in an iGEM project's success, contributing to the overall balance and precision of the design.

Safety First: Ensuring Biosecurity

The idea of putting genetically modified organisms (GMOs) into a consumer product naturally raises concerns about safety. The IISER Kolkata team tackled this issue head-on by incorporating several safety mechanisms. They used an **auxotrophic strain** of E. coli that requires specific nutrients

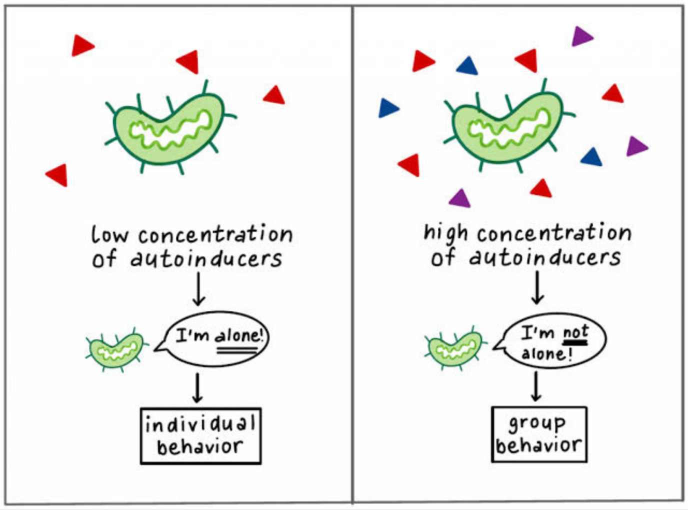


Fig 3. Live Application treatments often suffer from short activation periods, lowering effectiveness and requiring frequent reapplication. This system regulates GM bacteria to oscillate around a set population, enhancing linalool output and media conservation, extending product usability over time. [IISER Kolkata iGEM 2024 Wiki]

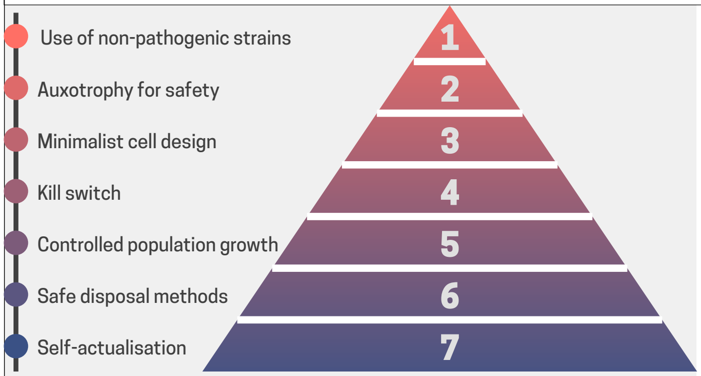


Fig 4. The team employed a large number of safety measures (see main text). These layered safety protocols guarantee that the microbial system is both efficient and safe for extended use in footbed applications, safeguarding both the user and the environment. [Wiki]

to survive—nutrients that are only provided within the insole's environment. By requiring these specific nutrients, the bacteria are confined to the footbed, preventing any unintended growth in uncontrolled areas. Additionally, the **bacteria are genetically streamlined**, containing only the essential components needed to produce beneficial compounds like linalool, reducing the risk of genetic interactions or unintended behaviours. This minimalist design reduces the likelihood of unpredictable outcomes, ensuring a safe and controlled microbial system.

Lactobacillus rhamnosus, the selected bacteria for the footbed, is a **non-pathogenic, safe probiotic commonly found in the human microbiome**, minimising health risks while performing its intended function. This strain has been carefully chosen for its safety profile, ensuring that it poses no threat to human health while fulfilling its role within the footbed. The footbed is **designed with a physical barrier to contain the bacteria and prevent unintended release into the environment**, adding an extra layer of safety. This barrier ensures that the microbial system remains confined and secure, further reducing any potential risks to the user or the surroundings.

To further enhance safety, the system includes a **kill switch** to deactivate the bacteria under certain conditions, such as exposure to the environment or the end of the product's lifespan. The kill switch provides a failsafe to ensure the bacteria are rendered inactive if needed, such as at the product's disposal or after use. **Population growth is regulated through quorum sensing**, controlling cell division and preventing overgrowth, while disposal protocols ensure any remaining bacteria are neutralized, preventing environmental contamination. These combined measures ensure the bacteria do not pose any lasting risk once the footbed is no longer in use.

Contribution to Synthetic Biology

The impact of this project goes beyond just foot care. The IISER Kolkata team has made significant advancements in using quorum sensing and CCA mechanisms to regulate bacterial production of bioactive compounds. By contributing new plasmid designs (the intentional engineering and modification of **plasmids**, which are small, circular pieces of DNA found in bacterial cells) and models for the continuous production of bio-manufactured molecules, they've provided valuable tools to the synthetic biology community.

Their approach to sustaining the production of a medicinal molecule like linalool can be adapted for other applications as well. This opens up new avenues for creating sustainable, bio manufactured products that could benefit a wide range of industries, from pharmaceuticals to agriculture.

In the long run, **iGEM teams that address real societal issues can have a lasting impact on improving the quality of life**. Such projects can pave the way for marketable products, especially with institutional support or links to industries. Teamwork, mentoring, and interdisciplinary collaboration are the cornerstones of such success stories.

Going Green: A Sustainable Solution

In a world where sustainability is more important than ever, the team's solution is a breath of fresh air. Unlike traditional foot care products, which often rely on synthetic chemicals and come with a high environmental cost, this insole uses naturally occurring biological processes to achieve the same goal.

Most foot creams and sprays are not only laden with chemicals, but they also require constant reapplication. They wash off easily, and many contain formaldehyde derivatives and other harmful substances. The team's insole, by contrast, offers a self-sustaining solution. The bacteria continuously produce linalool, providing long-term protection with minimal environmental impact. There's no need for large-scale manufacturing of chemical compounds

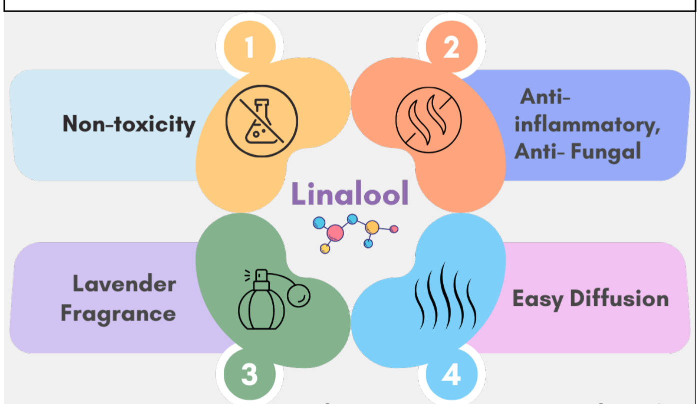


Fig 5. Linalool, a naturally fragrant monoterpene found in plants like lavender, offers a range of benefits ideal for foot care. It possesses strong antifungal and antibacterial properties that help combat harmful microbes responsible for infections. Linalool has pain-relieving qualities that can reduce discomfort and is known for its pleasant, soothing scent, which helps to eliminate unwanted odours.

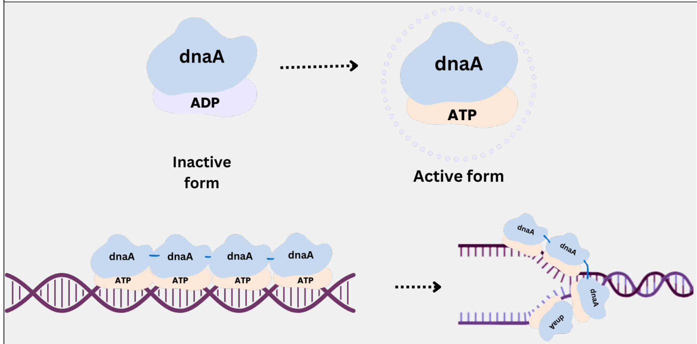


Fig 5. In order to limit bacterial population growth without stopping it indefinitely, the team used DnaA, a protein in bacteria, particularly E. coli, that plays a key role in initiating DNA replication. It binds to the origin of replication, called the oriC region, recognizing specific DNA sequences and unwinding the DNA to allow replication machinery to begin copying the bacterial genome. DnaA's activity is carefully regulated to ensure replication occurs only once per cell cycle, as over- or under-activation can lead to cell growth issues or genomic instability.

or complex supply chains, making this approach far more eco-friendly.

The beauty of this project lies in its **practicality**. Foot infections are a common problem, especially for athletes, soldiers, and people with diabetes. These individuals face higher risks of fungal infections, and traditional treatments can often fall short. By offering continuous protection through a simple insole, the team's product could make a huge difference. **The insole doesn't just treat infections after they occur—it helps prevent them from developing in the first place**. This proactive approach is a game-changer for foot care.

Bridge Between Academia and Industry

This project promises to revolutionise foot health for all our diabetic relatives suffering right now who require foot insoles to be at least a centimetre thick. While the current focus is on linalool production for foot care, the platform the team has developed has much broader applications. **The same technology of live application could be used to produce other medicinal compounds**, by modulating a specific gene of interest, opening up possibilities in fields like wound care, hospital infection prevention, and more.

For example, the team envisions creating wound dressings that continuously produce antimicrobial compounds, helping prevent infections in patients with open wounds and burns. Another possible pursuit could be production of room fragrance with population-regulated, live-application of bacteria, producing certain fragrant molecules. **The concept of in-situ production, where the compound is made directly at the site where it's needed, could revolutionise the way we approach medical treatment**.

The IISER Kolkata iGEM 2024 team has already started conversations with academic institutions and industry players to explore commercialising their product. While the project is still in its experimental phase, the team's long-term goal is to **develop a prototype that can be pitched to companies specialising in foot care and biotechnology**. They've also been actively engaged in outreach and collaboration within the iGEM community, sharing their designs, models, and insights to help others build on their work.

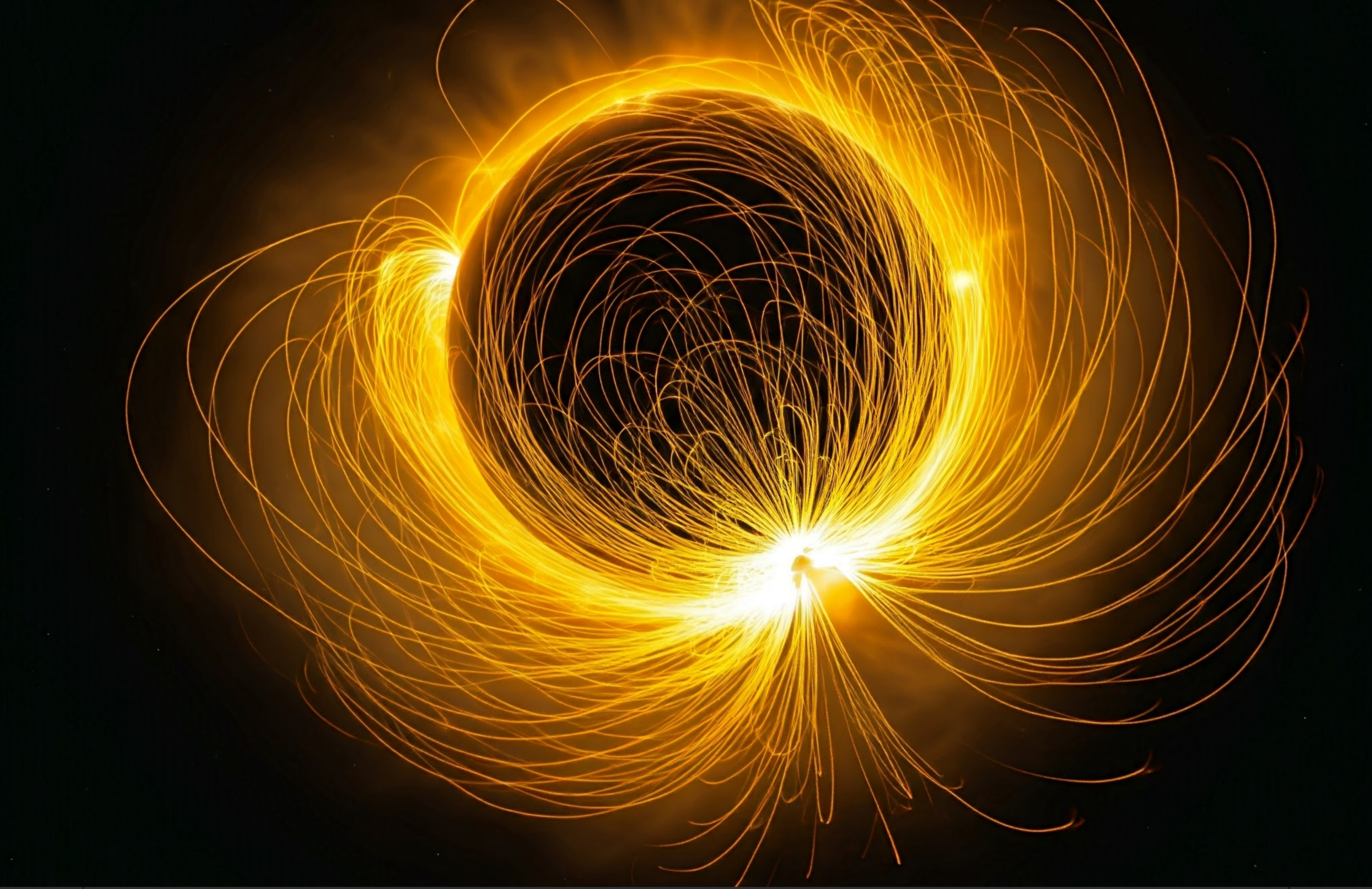
A Game-Changing Solution

IISER Kolkata's iGEM project is a testament to the power of synthetic biology, **representing a shift in how we approach healthcare and sustainability**. Returning from Paris after winning a gold medal, the team brought back more than just accolades; they demonstrated the potential for biotechnology to address real-world challenges. Their biologically powered foot insole offers continuous protection, eco-friendliness, and convenience, showcasing a sustainable, bio-based approach to healthcare. This innovation is not just a novel solution for foot infections—it's a glimpse into the future of biomanufacturing and sustainable healthcare, setting the stage for synthetic biology to change the world.

InScight heartily thanks the members of IISER Kolkata 2024 iGEM team and the principal investigators of the project for fruitful discussions and for their feedback on the article. InScight is also grateful to the team for allowing us generous use of figures and information from their wiki.

A fifth year BS-MS student of IISER Kolkata, **Swarnendu Saha** is a student working with Prof. Rajesh Kumble Nayak, He is a travel enthusiast who loves to travel anywhere below the sky.

Suman Halder is a second-year PhD student at IISER Kolkata, working under the guidance of Dr. Rumi De. He enjoys writing essays and poems, reading thrillers, photography, and listening to rock music. Currently, he is researching cell oscillations and migration



Insight Digest

In Insight Digest, we showcase simplified summaries of recent research articles, to give a feel for what's happening at the frontiers. This issue's focus is **physics**.

Mapping Strain in Laser-Written Diamond Waveguides Using Optically Detected Magnetic Resonance

M. Sahnawaz Alam et al., Phys. Rev. Applied 22, 024055 (2024)

Contributed by **M. Sahnawaz Alam (RWTH Aachen University, Germany)**

Keywords: *Color Centers, Diamond waveguides, Strain imaging, Quantum Sensing*

Color centers in diamond, such as the nitrogen-vacancy (NV) center—which consists of a nitrogen atom adjacent to a vacancy in the carbon lattice—are renowned for their exceptional quantum properties, making them ideal candidates for applications in nanoscale sensing and quantum information processing at room temperature. However, NV centers often suffer from low contrast in experiments, which hampers their performance and limits practical applications.

Integrating NV centers with laser-written optical waveguides enhances the coupling of light to these quantum systems, facilitating more efficient manipulation and readout of their states. This integration addresses the low-contrast issue by improving the interaction between NV centers and light. However, the process of laser writing photonic structures inherently introduces strain into the diamond lattice. This strain can alter the electronic and spin properties of the NV centers, affecting their performance and the fidelity of quantum operations. Until now, the full impact of this strain on defect centers has not been thoroughly understood.

In our combined experimental and theoretical study, we demonstrate that optically detected magnetic resonance (ODMR) spectroscopy—a technique commonly used to probe the spin states of NV centers—provides sufficient information to fully characterize the spatial distribution of strain within laser-written diamond waveguides. Remarkably, this characterization is possible even without the application of an external constant magnetic field.

Our findings present an accessible and non-invasive tool for mapping strain in diamond-based photonic devices. By utilizing ODMR spectroscopy, researchers can gain detailed insights into strain distributions, enabling the optimization of device fabrication processes and the improvement of quantum device performance. This advancement is a significant step forward in the development of diamond-based quantum technologies, potentially impacting a wide range of applications from high-precision sensing to quantum communication and computation.

Earth has its own electric field weaker than a pencil battery

Collinson, G.A., Glocer, A., Pfaff, R. et al., Nature 632, 1021–1025 (2024)

Contributed by **Chitradeep Saha (CESSI, IISER Kolkata)**

Keywords: *polar wind, electric field, ambipolarity*

Our planet Earth also has a global electric field – as fundamental as its gravity and magnetic fields. Researchers have successfully measured this electric field for the first time. The quest started over half a century ago when a steady stream of outgoing plasma particles was detected near the Earth''s poles. Theories have been proposed and refined over time to understand this peculiar phenomenon. Peculiar. Because the temperature of the outflowing plasma is too cold to evaporate due to solar radiation. Therefore, existing knowledge of global energy fields failed to explain it. Alternatively, the existence of an independent, electric field was hypothesized. However, more mature technology was required to make precise measurements and test the hypothesis. The research team flew a suborbital rocket through the arctic skies that touched the exosphere while sampling various ionospheric properties. The photoelectron spectrometer onboard detected a minute change in electric potential of 0.55 volts – less than that of a standard AA battery – across an altitude range of ~500 km, confirming the existence of such a global electric field. Due to an asymmetric gravitational pull on the lighter electrons and heavier ion cores, charge separation occurs in the atmosphere. The Coulombic force partially counteracts this charge separation; the associated electric field is ambipolar, as it works in both directions. The net effect of this global ambipolar field is to puff up the atmosphere, lifting some ions high enough to escape through the polar caps and giving rise to polar winds.

GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo during the Second Part of the Third Observing Run

R. Abbott et al., Phys. Rev. X 13, 041039 (2023)

Contributed by **Swarnendu Saha (Department of Physical Sciences, IISER Kolkata)**

Keywords: *Astrophysics, Gravitation, Black Hole Mrrger, LIGO*

This paper, "GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo during the Second Part of the Third Observing Run", is an excerpt from the third Gravitational Wave Transient Catalog. The report was published in December 2023 in the journal Physical Review X that reports on observation of gravitational waves by the LIGO, Virgo, and KAGRA for the second half of the period of the third observing run. The interval covered is from November 1, 2019, through March 27, 2020. Our very own Professor Rajesh Kumble Nayak has been a part of this team from IISER Kolkata.

The paper also lists 35 new gravitational-wave events detected during that period, all the result of a "compact binary coalescence" in which pairs of black holes or neutron stars orbit ever tighter until they eventually merge. This brings the number of gravitational-wave detections across three observation runs to 90. Most of the events in the catalog arise from the merger of black holes, which can be pretty large, but this observing run also marks the first definite identification of neutron star–black hole (NSBH) mergers. Curiously, however, no BNS mergers were confirmed during this period.

The researchers selected these signals with advanced algorithms and data calibration, estimating probabilities for each event to be of astrophysical rather than noise artifacts. As there is always some inevitable noise, the probability for these signals to be due to a non-astrophysical origin is estimated to be around 10-15%. All the data are made available in the public domain for use by the community through the Gravitational Wave Open Science Center. The expanding dataset from GWTC-3 gives unparalleled insight into the properties and behaviors of black holes and neutron stars, offering unique insights into the population in the universe and providing informative input into the theory governing their formation, structure, and evolution.

Strange Metal and Quantum Spin Liquid in Heavy-Fermion Material: An Array of Exotic Phases

Hengdi Zhao et al., Phys. Rev. Lett. 132, 226503 (2024)

Contributed by **Abhirup Mukherjee (IISER Kolkata)**

Keywords: *metal-insulator transition, quantum spin liquid, strange metal, spinon*

Strange metals and spin liquids constitute deviations from the "standard model" of condensed matter physics. For most of the twentieth century, metals were believed to be smoothly connected to non-interacting electrons at low-energies (the so-called Landau's Fermi liquid theory), and insulators and superconductors were believed to arise from spontaneous symmetry breaking (the ground state does not have all symmetries of the Hamiltonian). Violations of these ideas were observed in the 1980s, a notable example being the discovery of high-temperature superconductivity in copper oxide materials. The strange metal phase of the copper oxides, while being a metal, displayed a linear-in-temperature resistivity, in contrast to the quadratic-in-temperature resistivty of Landau Fermi liquids. Due to the large transition temperature of the material and the proximity to an electronic-correlation driven Mott insulator, Phillip Anderson hyppthesised that the ground state of the Mott insulator was close to a "spin liquid", where the system does not settle into any particular configuration (in contrast to the symmetry-broken insulators) but keeps shifting (in the sense of a quantum superposition) between various configurations.

While these exotic phases typically emerge in different materials, the authors of the present work have experimentally realised these exotic phases in crystals of the material $Ba_4 Nb_{1-x}Ru_{3+x}O_{12}$, where x is the hole-doping concentration. By tuning the doping concentration, the material undergoes transition from a heavy strange metal phase to a heavy Fermi liquid phase to finally a spin liquid phase. The "heaviness" arises from the fact that these are heavy-fermion materials in which the inter-electron interactions increase the "inertia" of the quasiparticles. Other results suggest that the excitations in all three phases are described by *spinons* - spin-1/2 charge-neutral objects. These spinons are fractionalised excitations (to see why, recall that flipping a spin from -1/2 to 1/2 creates a spin-1 excitation). At the heart of these exotic phenomenon in this material is the underlying triangular lattice that leads to geometric frustration (it is not simple to obtain an energy-minimising configuration of spins on this lattice) and the emergence of novel elementary excitations (the spinons). Such a material provides a wonderful platform to realise and study these highly-correlated phases of matter.

Geek & Seek

General Science Quiz

Test your scientific mettle with our 10 questions pop quiz.

Themed Crossword

This theme for this issue is **Quantum Physics**. Send us your crosswords if you want to be featured!

Linked List

Link each term with the next, and complete the science word chain!

General Science Quiz

Q1. This Nobel Prize-winning physicist has an element named after him. His wife, upon being shown the results of his experiment for the first time, said, 'I have seen my death!'. Who is the scientist?

(a) Wilhelm Roentgen
(b) Pierre Curie
(c) Henri Becquerel
(d) Enrico Fermi

Q2. *Dr Dilip Mahalanabis*, an Indian paediatrician, is famous for pioneering one of the most important medical advances of the 20th century that dramatically saved lives during the cholera outbreak in Bangladesh in 1971. What is this medical advancement?

(a) Vaxchora vaccine
(b) Oral rehydration solution (ORS)
(c) Zinc supplementation
(d) Ringer's lactate

Q3. This physician was one of the pioneers of plastic and dental surgery, and was one of the first to attribute malaria to mosquitoes. The *Royal Australasian College of Surgeons* at Melbourne has a statue in his honour. Who is he?

(a) Sushruta
(b) Hippocrates
(c) Herophilus
(d) Dioscorides

Q4. As part of the National Quantum Mission, this Indian research institute is leading the efforts to create a 100-qubit quantum computer, and recently completed end-to-end testing of a *6-qubit processor*, in collaboration with DRDO and TCS. Name the research institute.

(a) Indian Institute of Science Education and Research Pune
(b) Indian Institute of Science (IISc), Bengaluru
(c) Tata Institute of Fundamental Research (TIFR), Mumbai
(d) Raman Research Institute (RRI), Bengaluru

Q5. Diamond is traditionally known to reside at the top of *Mohs' scale* of mineral hardness since it can scratch all other minerals on the scale. However, scientists in modern years have discovered other materials that are in fact harder than diamond, and would go above diamond in a modern Mohs' scale. Name such a naturally-occuring mineral.

(a) Lonsdaleite
(b) Boron carbide
(c) Moissanite
(d) Cubic boron nitride

Q6. *In Nomine Terra Calens* is a music piece composed by Dr Lucy Jones by converting scientific data from the past 138 years regarding a major global issue into various musical notes. The musical piece was performed by Jones and the Los Angeles Baroque at the Los Angeles Natural History Museum in 2019. What global issue was being studied?

(a) Global warming
(b) Shortage of drinking water
(c) Depleting energy sources
(d) Increasing air pollution levels


Kamala Sohonie with her husband and children. See Q7. [Resonance Journal, 4, 21 (2016)]

Q7. *Kamala Sohonie* was the first Indian woman to be conferred the degree of PhD, for her ground-breaking work on the electron transport chain. However, she was initially refused admission to one of India's premier research institutes by the institute's director, simply because she was a woman! Who was the director?

(a) C V Raman
(b) Homi J Bhabha
(c) Shanti Swarup Bhatnagar
(d) Vikram Sarabhai

Q8. String theorists at IISc recently found a series representation of a certain irrational number, while studying quantum scattering of high-energy particles. *Ramanujan* has also worked on representations of this number. Which number are we talking about?

(a) ‘Pi’
(b) Euler’s number e
(c) The golden number
(d) Euler–Mascheroni constant

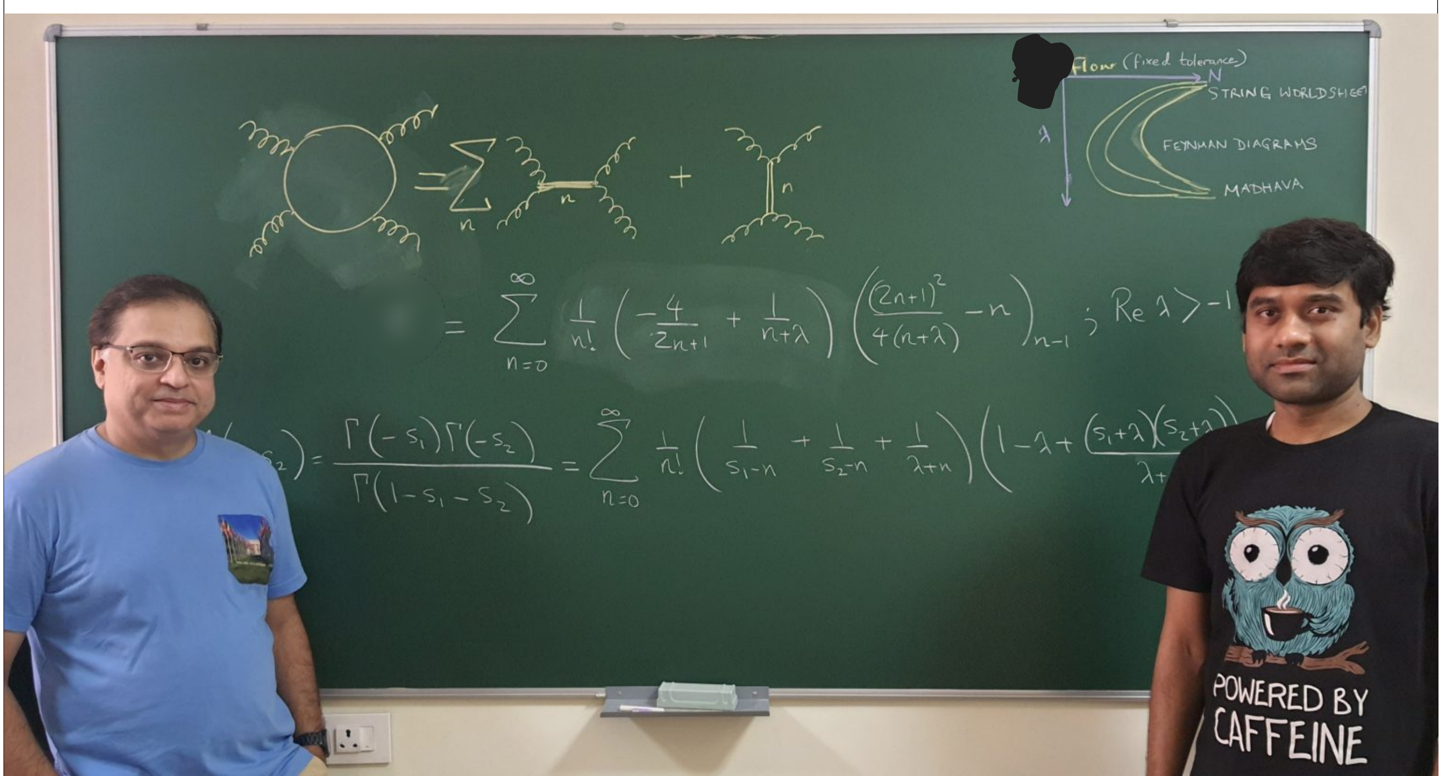
Q9. *Hennig Brand* was a German alchemist who, while searching for the 'philosopher’s stone,' discovered a new material that gave off a pale-green glow by concentrating boiled-down urine. What was this new element?

(a) Zinc sulphide
(b) Strontium aluminate
(c) Sulphate
(d) Phosphorus

Q10. This 20th century European mathematician, during a US citizenship test, claimed before Judge Phillip Forman that the US constitution had a loophole that could reverse democratic government itself. His theorems in mathematical logic are referred to by his name today. Who is he?

(a) André Weil
(b) David Hilbert
(c) Georg Cantor
(d) Kurt Gödel

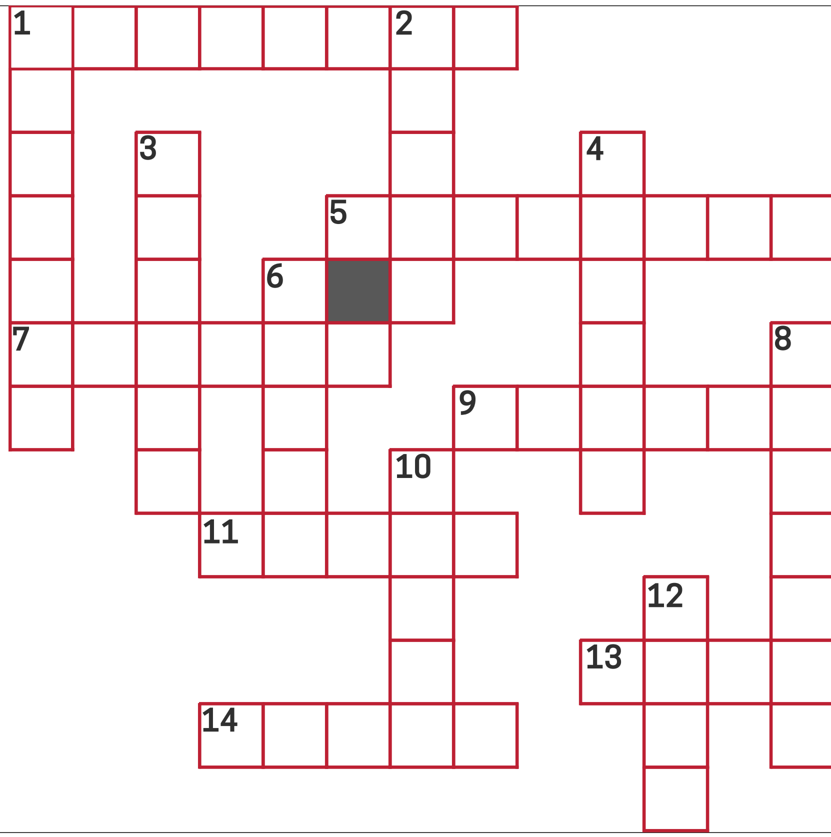
This issue's quiz is brought to you by Alekhya (IISER K) and Archita (HHU Düsseldorf). Answers are provided at the end of the issue.



Aninda Sinha (left) and Arnab Saha (right), scientists from IISc who recently came up with the series representation of a certain irrational number using Feynman diagrammatic expansions. See Q8. [IISc]

Themed Crossword

2025 will mark the 100th anniversary of Heisenberg's formulation of matrix mechanics and the foundation of quantum mechanics. This issues's crossword, based on **quantum physics**, is brought to you by Swarnendu and Abhirup (IISER Kolkata).



Across

1 (verb,)'Mix' two particles such that you cannot specify the state of one without specifying that of the other (8)
5 Lose quantum information by interacting with environment, typically irreversibly (8)
7 Pass through classically-forbidden region (6)
9 Quantised excitation of electromagnetic field (6)
11 English mathematician and physicist, used Lorentz invariance and quantum mechanics to predict antimatter (5)
13 Danish physicist, popularised the Copenhagen interpretation (4)
14 Two-level quantum system, unit of quantum information (5)

Down

1 American physicist, proposed the many-worlds interpretation of quantum mechanics in his doctoral dissertation (7)
2 Source of focused light that uses stimulated emission (5)
3 Unit of 'quantum angular momentum', also a physicist (6)
4 Bosonic excitation, quantised sound wave (6)
6 Italian Nobel laureate, created the first nuclear reactor, well-known for wielding a six-inch slide rule (5)
8 Adjective to describe a transformation that preserves norms of vectors (7)
10 Austrian physicist, the first to propose existence of neutrinos (5)
12 German physicist, postulated that squares of amplitudes are measurement probabilities (4)

Solution can be found at the end of the issue.

Linked List

Linked List is a general science-based word game. The rules are straightforward:

1. The goal is to guess eleven words that have been drawn from science.
2. The first word (the *seed*) will be provided to you, and hints and number of letters will be provided for the remaining words.
3. You are also informed that the first letter of any word is the last letter of the previous word. So the first letter of the second word will be the last letter of the seed word, the first letter of the third word is the last letter of the second word, and so on.
4. This property goes all the way, so that the last letter of the last (eleventh) word is also the first letter of the seed word.

Find all the words!

Today's seed: **MUTATION**

2.	Carrier of electrochemical impulses between brain and rest of the body (5)	N
3.	Oval-shaped figure with two lines of symmetry (7)	
4.	Energy measure combining internal energy and "pressure energy" (8)	
5.	Three feet or 36 inches (4)	
6.	Geological process by which sediments, soil, and rocks are deposited onto a landform or landmass	
7.	Elementary particle, cosmic ray component (8)	
8.	A process in which fluid moves through semipermeable membrane to seek equilibrium(7)	
9.	Sedimentary rock formed from the cementation of sand-sized mineral particles, used to build the Qutub Minar (9)	
10.	Inverse of log function (11)	
11.	Lightest metal, used in batteries (7)	M

Answers can be found at the end of the issue.

Do Contribute!

Contributions are welcome from students and faculty members across all academic institutions. The portals for submitting all kinds of content can be found on our website. More specific details regarding the content can also be found there, so please take a close look at the linked page if you are interested in contributing. For any queries, reach out to us at **scicomm@iiserkol.ac.in.**

Science Articles: We publish write-ups on interesting ideas in science, as long as the content is accessible to a broader audience and not just to the experts. Submit your articles here.

Short Summaries: In order to showcase the frontiers of research, we publish short summaries (350-400 words) of recently published science research articles. The summary should broadly lay out the questions being asked and the new results obtained. Submit your research stories here.

Quizzes and Games: We also feature science games such as crosswords, quizzes and word-link games. If you have content for these games or have new interesting games in mind, please pass them on to us via our email.

Interview Recommendations: If want us to interview specific scientific personalities or if you have an interview that you want to publish, please send us an email.

Submissions are accepted on a rolling basis, so send in your content whenever you are ready. Finally, but very importantly, we would love to hear any feedback that you might have about this endeavour, so please send us your comments at scicomm@iiserkol.ac.in.

The Team

We are currently looking to expand our team. If you are interested in what we do and are confident that you will be able to devote time to this, please reach out to us at scicomm@iiserkol.ac.in. We will be happy to discuss possible roles for you depending on your skills.

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Quiz Answers

1. Wilhelm Roentgen
2. Oral rehydration solution
3. Sushruta
4. Tata Institute of Fundamental Research (TIFR), Mumbai
5. Lonsdaleite
6. Global warming
7. C V Raman
8. Pi
9. Phosphorus
10. Kurt Gödel

Crossword Solution

Across: 1 Entangle, 5 Decohere, 7 Tunnel, 9 Photon, 11 Dirac, 13 Bohr, 14 Qubit.

Down: 1 Everett, 2 Laser, 3 Planck, 4 phonon, 6 Fermi, 8 Unitary, 10 Pauli, 12 Born.

Linked List Solution

1. Nerve
2. Ellipse
3. Enthalpy
4. Yard
5. Deposition
6. Neutrino
7. Osmosis
8. Sandstone
9. Exponential
10. Lithium