InScight

The IISER Kolkata Science Magazine

#4 | July 2025

THROUGH THE EYES OF THE FOUNDING DIRECTOR
Interview with Prof. Dattagupta

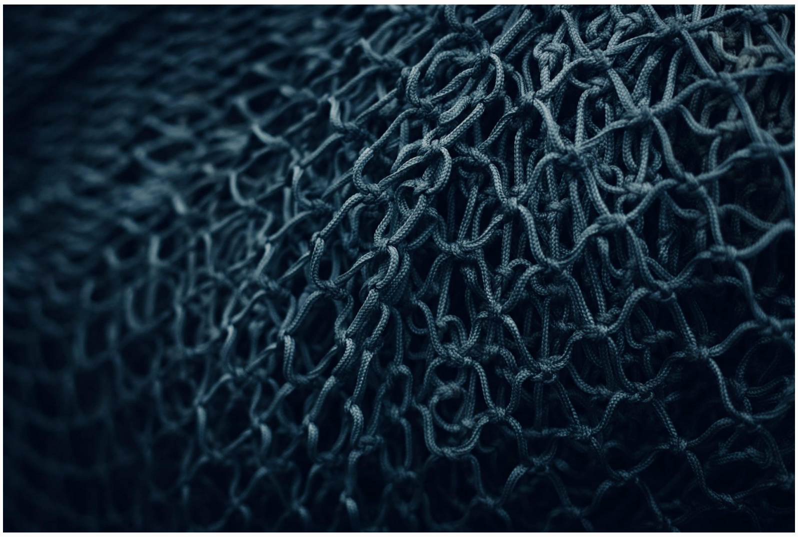
A CENTURY OF QUANTUM MECHANICS
From Paradoxes to Possibilities

THE QUEST FOR THE SEA'S BLUE
Comic on the Raman Effect

The Celebration of Science For A Better Future

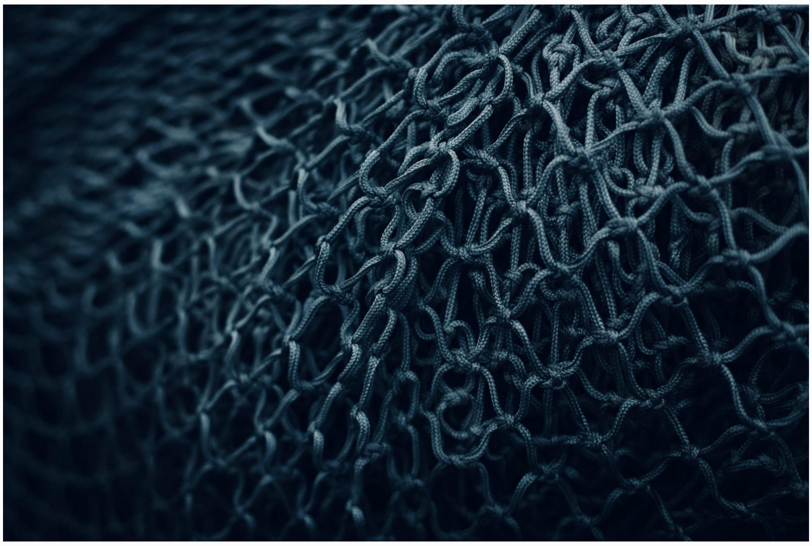
Foreword by Prof. Tapas Kumar Sengupta

Science is the celebration of unravelling the mysteries of our evolving universe. Unravelling the existence and functions of galaxies involved in formation of stars, planets and evolution of life itself on our beloved blue planet. Through observations, studies and discoveries of the true facts we practise science in our everyday life. Our scientific studies made us able to understand the importance of the ecosystem and its conservation, necessity of food production and storage, combating and preventing diseases and innovation of new, better and safer therapy, safer energy production and its sustainability, faster communication and making artificial intelligence as a new tool.



0 : Knots are hard to untie, making them robust. Sukalyan Deb's article explores how similar robustness emerges in properties of certain quantum systems.

As we cannot freeze any condition forever, contentious studies and scientific experimentations are required to understand the ever-changing ecosystem and need of our civilization and to come up with more and more innovations in order to address those changes to make our planet more habitable.



0 : Knots are hard to untie, making them robust. Sukalyan Deb's article explores how similar robustness emerges in properties of certain quantum systems.

For that, besides the traditional scientific studies and standard scientific research, out of the box thinking is required for seeding and cultivating young minds for innovations. Let *InScight* be the platform for the Insight of our future to seed, cultivate and nurture the open minds and unbound thoughts of the young scientists.

After the first release of *InScight* in the month of January in 2025, this journey is going on with a clear motivation and with fullest energy and enthusiasm to publish the fourth issue. My sincere thanks to the InScight team for having such an endeavour. Keep going, keep doing and thinking about science. Very best wishes to the team InScight.

A Word From The Editor

Hello Friends! Welcome to the fourth issue of InSight. As we celebrate the turning of another issue, I take this opportunity to thank you all who have stood with us, and helped us to continue this journey of InScight Magazine - The IISER Kolkata Science Magazine. Filled with vibrant stories and voices of our alumni, Professors, and guest scientists, this month, we have tried to add colour to the magazine and take the readers on a journey through the history of IISER Kolkata and also to newer domains of Science today.

As Prof. Ayan Banerjee has rightly mentioned, in his words, Science is a method and an attitude, and Prof. Tapas Kumar Sengupta, in his foreword to this issue of InScight Science, is the celebration of unravelling the mysteries of our evolving universe - it is our duty as scientists, who are funded by the tax paid by the commoners, to come out of the labs and take our research to the mass. InScight envisions bridging the gap between distance between the scientists and the masses in the upcoming days.

In this issue, we have featured our alumni from the Department of Physical Sciences - Dr. Rajarshi Bhattacharyya, who is currently working in Germany as a Cryogenic Systems Engineer at attocubes systems AG. We believe that his journey from a BSMS student at IISER to PhD scholar in Israel and finally now as a professional engineer in Germany would show you all a newer perspective of the higher education and job market after BSMS.

In the other two interviews, we have featured Prof. Sushanta Dattagupta - the founder director of IISER Kolkata, and Dr. Sanjit Mitra of IUCAA - a leading scientist of the LIGO-India project, and we hope the interview with them shall help you all in your journey forward.

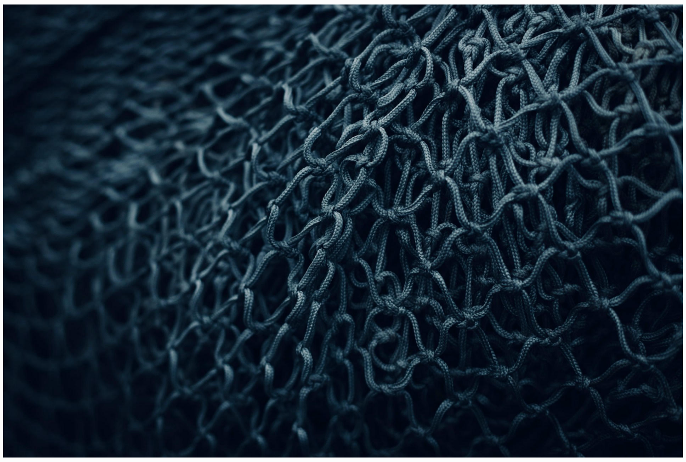
We have started a new section in the magazine, where we advertise academic internships, PhD positions, and Post-Doctoral applications, gathered by scraping the internet and email conversations. We believe that this section will help the students plan accordingly and in advance for their upcoming academic and scientific journey. Of course, we by ourselves cannot gather all the news that can be gathered, so we request all our readers to bring such information to our notice, so that we can better distributed the information.

We are planning on adding a new section to the magazine - write about your PhD thesis! The point is to discuss the story of your PhD thesis; the questions, the results and the philosophy of your approach, written so that students across the disciplines can understand and have a feel for it. We aim to tighten the research community of IISER Kolkata across disciplines, and who knows - you may find a newer possibility and a collaboration for your project too!

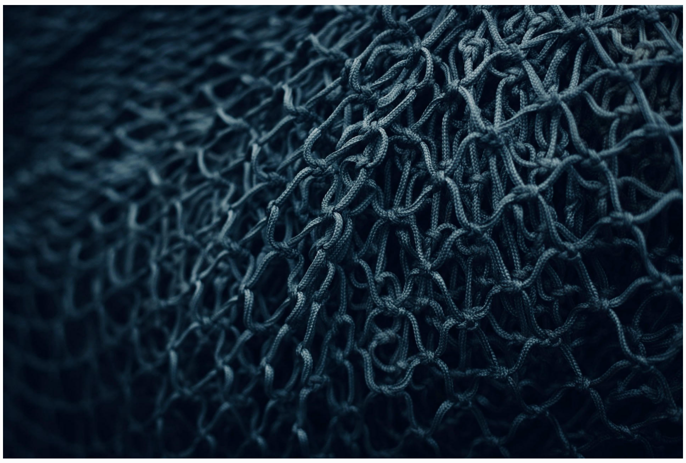
We are always looking for your contributions and feedback. Thank you for journeying with us. On behalf of the entire team, happy reading—and here's to building bridges, one insight at a time.

With warmth,

Swarnendu Saha,
Editor-in-chief,
InScight



Knots are hard to untie, making them robust. Sukalyan Deb's article explores how similar robustness emerges in properties of certain quantum systems.



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In This Issue

Academic Listings: Internships, PhDs, Post-docs

INTERNSHIPS

DoS/ISRO Internship & Student Project Trainee Schemes
⏰ **Deadline**: varied
📎 **Website**

Research Internship at OIST
⏰ **Deadline**: 15/10/25
📎 **Website**

Visiting Student Research Program at KAUST
⏰ **Deadline**: rolling
📎 **Website**

PHD POSITIONS

Max Planck Institute for Informatics - PhD Applications
⏰ **Deadline**: rolling
📎 **Website**

IMPRS – Solar System Science (Astrophysics) – Göttingen & Braunschweig
⏰ **Deadline**: 1/10/25
📎 **Website**

The International Max Planck Research School on Astrophysics at the Ludwig Maximilians University Munich
⏰ **Deadline**: 1/11/25
📎 **Website**

UC Berkeley's Physics Graduate Program
⏰ **Deadline**: 15/12/25
📎 **Website**

Arizona State University Physics PhD Admission
⏰ **Deadline**: 31/1/25
📎 **Website**

Univerity of Denver Physics - PHD
⏰ **Deadline**: 8/9/25
📎 **Website**

Curtin University, John de Laeter Centre PhD Scholarships
⏰ **Deadline**: 1/8/25
📎 **Website**

Graduate Research Assistantships (Ph.D.) in drought and dust flux, Northern Great Plains, U.S
⏰ **Deadline**: 14/8/2025
📎 **Website**

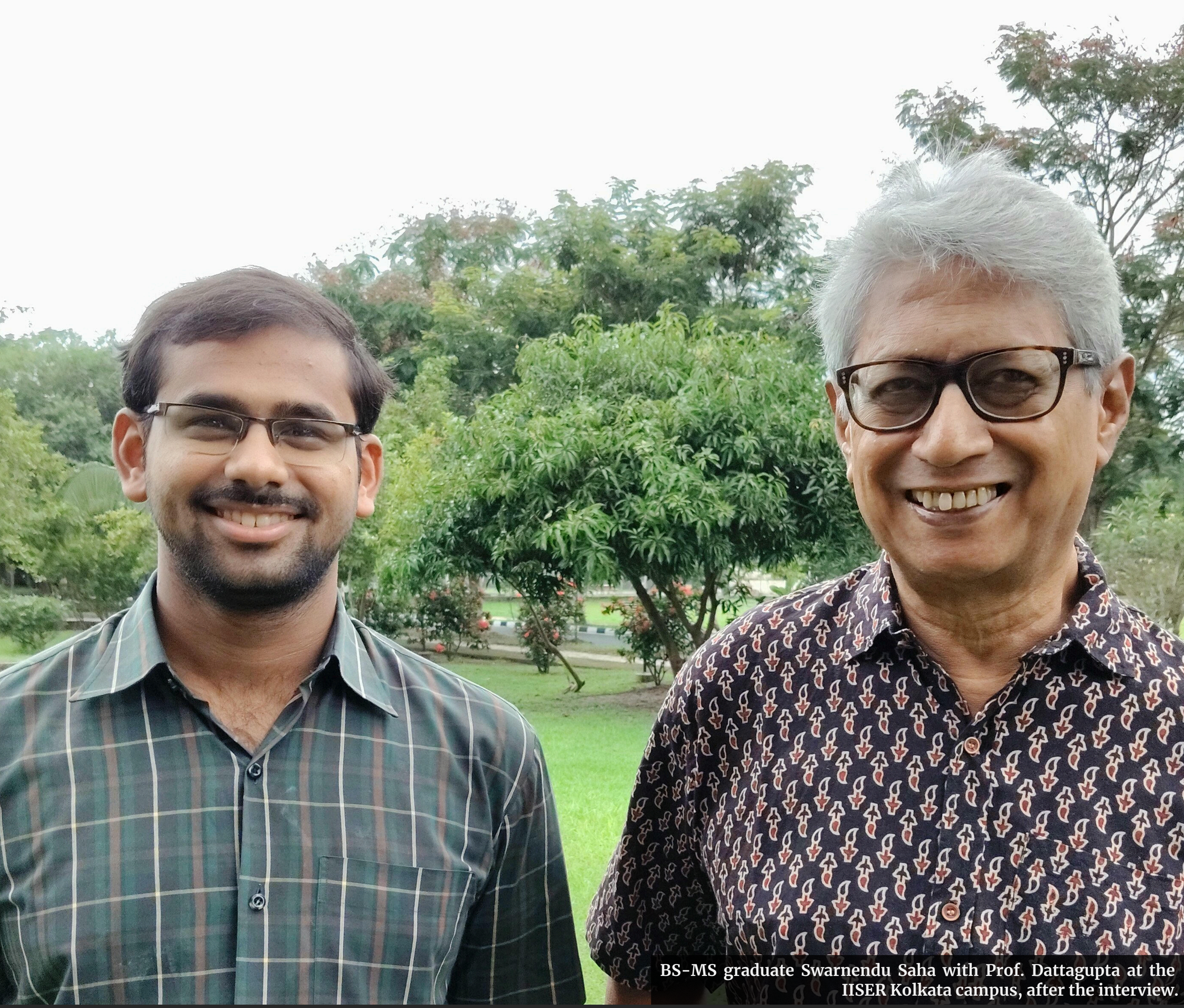
Exoplanet Characterisation Predictions via Gravitational Microlensing: Competition Funded PhD Project
⏰ **Deadline**: rolling
📎 **Website**

POSTDOCTORAL AND OTHER SHORT-TERM POSITIONS

Stanford Postdoctoral Recruitment Initiative in Sciences and Medicine
⏰ **Deadline**: 26/8/25
📎 **Website**

U.S. Naval Research Laboratory Post-Doctoral Fellow (Coastal / Sea Ice Remote Sensing)
⏰ **Deadline**: 8/8/25
📎 **Website**

North Arizona University Postdoctoral scientist position: Greenhouse gas emissions modeling and mapping	⏰ **Deadline**: 6/8/25 📎 **Website**
Marine Biomedical Postdoctoral Fellowship at Mote Marine Lab and Aquarium	⏰ **Deadline**: 14/8/2025 📎 **Website**
John S. Foster, Jr. Postdoctoral Fellowship and the Harold Brown Postdoctoral Fellowship	⏰ **Deadline**: 11/8/2025 📎 **Website**
Advanced Study Program (ASP) Postdoctoral Fellow I	⏰ **Deadline**: 8/8/2025 📎 **Website**
Postdoctoral Scholar in Oxygen Dynamics - Scripps Institution of Oceanography	⏰ **Deadline**: 15/8/2025 📎 **Website**
Project Associate, Studying protein folding and aggregation using computer simulations, IMSc (India)	⏰ **Deadline**: 31/07/2025 📎 **Website**



BS-MS graduate Swarnendu Saha with Prof. Dattagupta at the IISER Kolkata campus, after the interview.

Through The Eyes Of The Founding Director: Interview with Prof. Dattagupta

Swarnendu Saha (IISER Kolkata)

“You have to do what makes you happy, what brings you peace, and what makes you feel that you are your own person. You hold your own destiny in your hands.” says renowned condensed matter physicist Prof. Sushanta Dattagupta. As the founding Director of IISER Kolkata, he reflects on the interdisciplinary spirit of IISERs, critiques academic gatekeeping, and urges students to seek fulfillment over mere careers.

Also available online, at scicomm.iiserkol.ac.in

SS: Hello, sir. I am Swarnendu Saha from Team InScight and a BSMS student here. I welcome you to this interview session with InScight.

SDG: Thank you, Swarnendu.

SS: You were the founding director of IISER Kolkata and remain closely associated with it. Now, almost 16 years later, how do you see IISER Kolkata today? Has it stayed true to the original vision, or has the direction changed?

SDG: Thank you for having me. First, it's actually been 19 years - we started in July 2006. At that time, IISER Pune and IISER Kolkata were the first two IISERs. Pune had the advantage of being adjacent to NCL, which provided access to facilities like water, power, and even lab space, including for NMR. We, however, started with nothing. The government channeled our initial funding through IIT Kharagpur, which gave us space in its Salt Lake campus. That's where we began in July 2006. I was the only faculty member, and there was just one attendant - Ajay, who is still here.

To start teaching, we borrowed faculty from institutions like Calcutta University, Jadavpur University, IIT Kharagpur, Bose Institute, SN Bose Centre, and others. Recruitment had to begin from scratch. Once faculty were hired, we needed lab space, which we got at NITTTR Kolkata. So, between Salt Lake (IIT Kharagpur), and NITTTR, we began to grow. We also received faculty housing from NITTTR. By then, we had about 20–30 faculty members.

SS: Prof. Tapas Kumar Sengupta was among them, right?

SDG: Yes, in biology. In chemistry, we had Balaram Mukhopadhyay, Swadhin Mandal, Sanjio S. Zade. They were among the first recruits. In physics, we had mostly theorists at first; experimentalists joined later. In earth sciences, there were Somnath Dasgupta and Nibir Mondal, who had a lab at IIT Kharagpur. NITTTR provided some labs, but we needed our own campus. At that point, we approached the Ministry and the then Chief Minister, Shri Buddhadeb Bhattacharya. He said land in areas like Rajarhat or Newtown would cost around ₹20 crores per acre, with only 20 acres available - adding up to ₹400 crores, nearly all of our initial ₹500 crore seed funding (which increased soon after). It was financially not viable.

But I also believed in the historical precedent of institutions starting modestly - like IIT Kharagpur, which began in Hijli Jail, or IIT Kanpur, which dealt with dacoity issues early on. Great institutes don't need to be in cities; they can grow in rural settings too. Fortunately, through the Chief Minister's intervention, we received nearly 210 acres of land at Mohanpur for just one rupee - essentially free. But then, we were still grappling, because while the space was given, construction had to be done. And you might know that this area is very fertile, also it's very soft land, because the river was very close.

Then the river moved away a little bit towards Hongsheshwari Mandir and all that. So, because of the softness of the land, you know, we had to do the foundation and all that. We had a wall, but then we needed some building space. We wanted to move, because by that time, faculty recruitment had started. We ordered two NMR facilities, 400 megahertz and 500 megahertz, x-ray, basic rudimentary things for physics and chemistry experiments, and a small animal house for biology. So, we decided to shift. We shifted here, I think, on the National Science Day, which is 28 February of 2009. We had then Governor Gopalakrishna Gandhi come and inaugurate the Raman Building. We basically got, through the West Bengal government, some old dilapidated buildings, which are adjacent to this campus that we are in now, which are in what is called the old Haringhata area, adjacent to Vidhan Chandra Krishi Vidyalaya and the University of Animal and Fishery Sciences.

And so, we reconstructed those buildings, like one building became the AJC Bose building. Those buildings were already there but in rather dilapidated condition. They were basically just left there, lying there as parts of either Bidhan Chandra Krishi Vidyalaya or Animal and Fishery Sciences under the West Bengal government. And there were also many hostel buildings, we renovated all of them. The new hostel building was called APC Ray Hostel Building. Another new building was called JC Bose Building, which is very scenic, next to the canal. And we even had a hut there, where we could congregate after every seminar for tea.

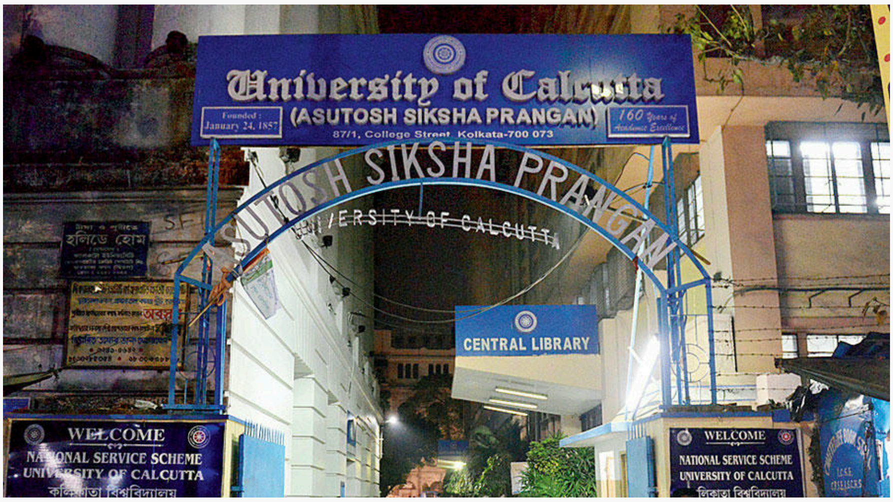


FIG 1: *Sushanta Dattagupta obtained his BSc. and MSc. degrees from the University of Calcutta in 1965 and 1967 respectively.*

So, it gave an impression of almost like Cambridge actually. This is a very, very green campus. So, what I was going to say earlier was this, because of the fertility of the land, this area is very green and you throw anything, it grows, you know. So, I'm just making a preamble to coming to the campus now. The JC Bose Building, the Raman Building, you know, had absorbed many experimental facilities. Like in the ground floor, we had the two NMR machines looked after by Swadhin Mandal. He had some glove boxes and also inorganic chemistry facilities. Balaram Mukhopadhyay had his lab on organic chemistry. Chiranjib Mitra had his PPMS (physical property measurement system) and MPMS (magnetic property measurement system) and also the other measurement system.

Bipul Pal had also, you know, an optical table and all that. So, the ground floor of the Raman Building was occupied like that. Soon, we started accommodating some environmental biology people there. And then the lady who shifted later on, moved to Bose Institute, Srimanti Sarkar. Then we moved to the first floor and other people also had labs there. So, most of the chemistry physics laboratories were there in the Raman Building. And then in the JC Bose Building, we started to have some labs on the ground floor. Prashant Upadhyay joined.

And then next to the JC Bose Building was the LEL Building, the old LEL. These names are all from the animal and fishery sciences or BCKV. We again reconstructed, remodeled it. And we started a new experiment of having some eight biology faculty members in the same area, sharing their common research facilities, like Jayasree Das Sarma, like Partho Protim Roy, like Shankar Maiti, like Chanchal Dasgupta, like Tapas Kumar Sengupta and so on. Then the theoretical physicists had their offices there. So, we soon became almost 50-60 faculty members.

But this campus was still being built. Now, as I said, this is already 2009. We have already spent three years of our time. And then in this campus area, there were a few buildings left over. They didn't demolish them. We also didn't want to demolish them. We reconstructed them. And now you can see them. Just behind the guest house is the Polymer Research Center. Priyadarshi is there and Raja Shanmugam is there. And then there's an Advanced Materials Laboratory, which is next door in the corner. Earlier, Sayan Bhattacharya was there, but he has moved out, I think. But then Soumyajit is there.

And then we created a seismic observatory towards gate number seven under Supriyo Mitra. It's still there. There's the equipment to check, because this is also an earthquake zone. And we wanted to connect to the Bakreswar Helium facility here. Because there's a correlation between earthquakes and the proliferation of Helium in Bakreswar.So, we want to study that. It's an inter-institutional program. And then there were two other buildings. One went to Radio Chemistry in Geology, Somnath Dasgupta and others, and the other to an environmental lab facility.

SS: Is this towards the Kalimandir?

SDG: Towards the Kalimandir, yes. So these five buildings were there. But then soon again, we were short of space. Architectural modeling was done on the campus. Your hostel buildings had started to come up, but we needed space for the faculty. So we created the prefabricated structure buildings. And your hospital facilities are there. Gautam Dev Mukherjee moved his high pressure laboratory there. Jayasree had her biology lab there. So things were moving and were increasing. I think by the time I left, it was in September 2011, we already had close to 80 faculty members.

And one thing I am very happy to tell you, that though by my narration, you would have got an understanding that we were working against many odds in terms of space, in terms of facilities, but let's say we were very productive at that time, if you look at our publication record during that time. So, I state that concrete alone does not make good research. I mean, good research has to be done by the will of the people and the extent to which they put their mind to it and having very competent faculty. Most of them came after postdoctoral experiences, either abroad or in India, mostly abroad, after their doctoral thesis. And so,

FIG 2 : *Sushanta Dattagupta carried out his doctoral research work at Brookhaven National Laboratory between 1969 and 1973, under Martin Blume.*

we had a very good set of faculty members. And J.C. Bose had two huge lecture hall auditoriums. I mean, each could hold at least 100 students. At that time, our intake was increasing. So, in the first year in the B.S.- M.S. program, the student intake was about 40, then it increased up to 100 maybe. And so, but then, as I said that the construction started and it was time for me to leave. Now you ask me, how do I feel after coming back? I feel very gratified.

I feel very happy that we chose this campus for one rupee, as I said. And it's a beautiful campus. It's very green, as you can see, with lots of trees, lots of flowers. And the swimming pool here, there are many sports facilities. And of course, the laboratory facilities are there. And so, facility wise, one cannot grumble, one cannot complain. It's sort of very gratifying that we moved here, especially also, see, as I said, it's less than 20 years. But maybe because the All-India Institute of Medical Sciences has come up, the roads have improved enormously. And by the end of 20 years, I think it will take you less than an hour to get here from the airport. So, if you compare, let's say, with Indian Institute of Science, and the time of journey it takes from the airport to Indian Institute of Science, that's actually much more than what it would be here in just about a year's time after the Kalyani Expressway is built up. And if they can solve the National Highway 34 problem near the Amdanga area, then going to the airport will not take you more than an hour.

And the proximity of Kalyani University, which is a very good state university nearby, and then the WBUT, the West Bengal University of Technology just has got a new name now, Maulana Abul Kalam Azad University of Technology, which has come near the campus. Then Netaji Subhash University is supposed to come. And with the Old River Research Institute here, we had a kind of a hub of education, which was the original vision that I shared with Buddhadev Babu when we got land here. So, it's very gratifying for me to come back and interact with students here and see how the campus has come up.

SS: After leaving IISER Kolkata, you've been associated with Visva-Bharati University. How would you describe the difference between the university system - particularly Visva-Bharati - and an institution like IISER Kolkata?

SDG: There's a big difference. A university system like Visva-Bharati caters to all disciplines - not just science. In Visva-Bharati, the two most prominent departments are Kala Bhavana (Fine Arts) and Sangit Bhavana (Music). Another significant distinction is that Visva-Bharati integrates schooling into its system, a legacy from Rabindranath Tagore. It has pathshalas - like Ananda Pathshala, Santosh Pathshala, and schools like Patha Bhavana and Siksha Satra in Sriniketan. This integration of primary and secondary education within a university system is quite unique in India.

Furthermore, Visva-Bharati offers philosophy and comparative religion, various languages (including Chinese, Japanese, Arabic, Farsi, Indo-Tibetan Studies), and also runs a massive rural reconstruction program called Palli Sangathan in Sriniketan. There's Siksha Bhavana for science, Vidya Bhavana for humanities, and Bhasha Bhavana for languages. By contrast, IISER is the Indian Institute of Science Education and Research - it's purely focused on basic science education and research.

SS: And how do the IISERs compare with the IITs?

SDG: IISER is also very different from the IIT system, which primarily caters to engineering and applied sciences. Back then, we observed a trend - bright students were moving away from basic sciences, often opting for engineering through IITs or, later, NITs. Our aim with IISER was to retain scientific talent in India and in basic science, specifically. We wanted to make science education attractive and integrated, so that students didn't feel the need to leave it behind after school.

SS: How did that influence the conception of the BS-MS program of the IISERs?

SDG: That's a great question. You see, in our time, we had 11 years of schooling followed by 3 years of B.Sc., totaling 14 years before entering M.Sc. Higher secondary ended at class 11 back then. For your generation, it's 12 years now. But here's the issue: much of what was earlier taught in first-year B.Sc. got pushed into the last two years of school, syllabus-wise. But we didn't have enough qualified teachers in the school system to handle advanced science topics effectively. So. what happened was repetition - the same things taught again in B.Sc., which affected depth. Now it's 12 + 3, totaling 15 years, but content-wise it's scattered and not necessarily deeper.

SS: So how did IISER resolve that?

SDG: We felt that the conventional 3-year B.Sc. plus the 2-year M.Sc. (3+2) model wasn't ideal. Everything could be covered in 4 years, and we wanted students to experience research. So, we designed a 5-year Integrated B.Sc.-M.Sc. program, where the final year would be research-focused, like an M.Sc. by thesis. This also helped phase out the

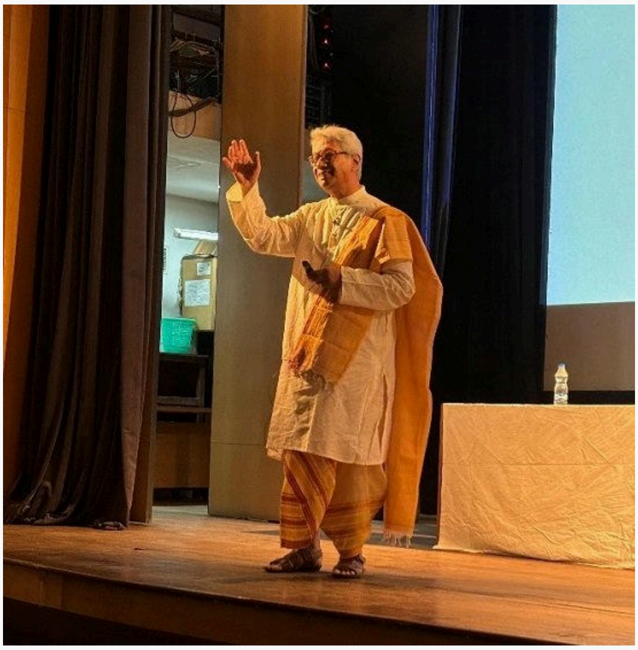


FIG 3 : *Prof. Dattagupta delivering the Annual Oration 2025 of the West Bengal Academy of Science & Technology. Prof Dattagupta talked about the historic and scientific significance of the seminal letter sent by Indian physicist Satyendra Nath Bose to Albert Einstein in 1924.*

old M.Phil. system. By the end of five years, students like you would not only have had a robust science education but also gained research experience, maybe even a publication. From the third year onwards, we encouraged research projects - both within India and abroad.

SS: That must be quite different from a traditional university model.

SDG: Absolutely. Universities like Visva-Bharati follow a more segmented discipline structure, whereas IISER promotes interdisciplinary science from day one. In the first two years at IISER, students were taught all major science subjects - physics, chemistry, biology, mathematics, and even computer science and earth science. The idea was to broaden scientific thinking before specialization.

In fact, initially, we even considered admitting only those students who had studied mathematics in school, to ensure a stronger foundation across the sciences. Students without mathematics were not encouraged to join initially. I don't know now what's happening. But there were some students who never had biology. But there are instances here where a student after doing biology in the first two years had got shifted or drifted to biology.

SS: I actually know of two such instances. One of them is a member of InScight, she's an alumnus now. She didn't have biology in 11th and 12th and didn't want to do it. She studied biology in the first two years because it was compulsory, but she ended up obtaining an MS in biology.

SDG: Ujani was in the first batch and she's another example of that, had a PhD in biology from Cornell and she is now in the faculty somewhere in biology. So, here are instances of that also. I'm very happy about that kind of interdisciplinary approach that we could instill in the students there and you are now saying that that has continued which is a very gratifying thing which is one of the aims and objectives of IISER.

By the way, life science started as an interdisciplinary subject - we branched off into different departments unfortunately, but it is very interdisciplinary and especially these days, when focus is very much on biological systems and material systems, you need interdisciplinary approaches of mathematics, chemistry and physics. So that way we feel that IISER was a very good experiment. Anyway, Visva-Bharati is another model.

Even within the university system Visva-Bharati from the Tagorean idea is a very different kind of a model. It's a unique model. I've already mentioned about the fact that the schools were part and parcel, the schools were imbibed within the university system. That's very different from other central universities like let's say JNU or Hyderabad University where I have served also. So that way, I hope I have answered your question about the difference between Visva-Bharati and IISER. Both are two different, both are very good experiences.

SS: Do you see yourself more as a scientist or as a teacher?

SDG: I would say teacher and a researcher, in that order. Because that's what I enjoy doing - teaching with research. I think teaching and research are two sides of the same coin. One cannot do without the other and in fact through classroom activities you get many new ideas of research also.

I can give you many examples from the history of development of physics where such things have happened. Because research is something that lies within yourself and maybe with some collaboration with some other colleagues but when you teach, you interface with a large number of students, you make eye contact, you sit with them over tea and then discuss even outside classes. So that's the part I enjoy most.

FIG 4 : *After leaving Carnegie-Mellon University, Sushanta Dattagupta worked as a post-doctoral researcher at University of Albera in Canada for a year.*

There can be, I believe in IISER also, there can be instances, there can be some people who are great teachers but research-wise they may not be the first options for the students. Similarly, there can be people who are doing fantastic research if you join them, it's a different ballgame but in classrooms they might not be the best teachers chosen for. So, my philosophy is that you have to be both if you want to be in IISER. If you only want to do research and write papers then you can be in a research laboratory. There are many CSIR labs, DST labs etc. – Tata Institute, where you don't have to do much teaching.

Your primary condition of even employment is that you're here to train students through teaching. At the same time, you also have to do research. So, I think that if your focus is only on research then IISER is not your place. If your focus is only on teaching also and not writing anything or doing much research then you're also a misfit here. So, you have to have a combination of both and this is the model I personally like very much. Even at this age I'm still productive in research. I write five to six papers a year in international journals. I even wrote some single author papers in the last three or four years in the physical review. Therefore, that part is there.

At the same time I feel that I must be able to translate my even physical review level research into a classroom teaching either for MSc students or even PhD students and even go to undergraduate level because that's the hardest part to teach because when you come fresh from school and your mind is keen to get into new ideas, stir up the class with questions and so that is also something I enjoy very much.

SS: One of the goals of the IISER system was to retain bright minds in basic sciences. Can you comment on how studying basic science actually helps students in their career? Students like me who have obtained their BS-MS degree and want to pursue academia have to constantly worry about certain questions: What is the employment status after BS-MS? How about after a PhD? Some people say that basic science is saturated.

Others say that while an engineer will always find employment, a student of science has to wait until they become a scientist in order to get a proper job - and even that is on God's grace. What's your opinion on this?

SDG: Okay, I appreciate the question. Let me say this first - You have to do what makes you happy, what brings you peace, and what makes you feel that you are your own person. You hold your own destiny in your hands. In a government system or industrial job, you might often be working to fulfill someone else's vision, climbing hierarchies, fulfilling institutional mandates. But one of the main reasons many of us chose academia is because we value academic freedom. While I admit that this freedom is slowly eroding, it still exists. So, first - do what makes you happy, not what others expect of you.

Secondly, let me talk about the societal aspect. Recently, I was teaching as a guest teacher in a school in Durgapur. The students were bright, and I enjoyed the interaction. But soon they began opening up. They told me horror stories - from class 5 or 6 onwards, they are pushed into private tuitions and coaching classes. It's quite traumatic. This is a new phenomenon, especially in townships like Durgapur, Jamshedpur, Rourkela. Parents are often part of nuclear families, and in the evenings, they have nothing else but to focus on but their children's academic performance. It's led to a system where coaching culture has become the new normal. Places like Kota have institutionalized this pressure.

This - what you're describing - is not just about science vs. engineering. It's about a deep-rooted societal insecurity: "What will my son or daughter do?", "Will they earn enough?", "Can they support us?". And there's a

FIG 5 : *From 1981 to 1986, Sushanta Dattagupta taught as a Reader at the School of Physics in University of Hyderabad.*

gender bias too - people often think, “My son will support the family; my daughter will get married.” These are toxic ideas, but they’re still very much present. So, if students fall victim to these insecurities, it’s a problem. And sadly, this insecurity is pervasive in middle-class India today.

SS: It is often said that it is easier to get a job in engineering that in science. What do you think of that?

SDG: Let me give you a counterexample. Take Prasanta Chandra Mahalanobis, who started the Indian Statistical Institute (ISI). They run a B.Stat and M.Stat program that is phenomenal. If a student from ISI combines that with even basic business knowledge, they might end up earning more than an average IIT graduate. People just don’t know about these opportunities. Or take mathematics - people think there’s no future in it. But if you study math seriously, you can go into economics, data science, AI, finance, or modelling. You can enter banking, research, analytics, and so many other fields. So this idea that only engineering gives jobs is deeply flawed. There are plenty of opportunities in science - you just have to know how to navigate them.

Bottom line: this belief comes from middle-class insecurity, not from reality. That’s why, Swarnendu, the very fact that you’ve left home, stayed in a hostel, and are thinking independently is already a big step. Now is the time to free yourself from societal pressure and follow what you truly love.

SS: That is certainly encouraging, but the issue of funding remains, especially for those who are not yet in institutionalized research.

SDG: I agree that there are irritating issues. I believe that Bengal doesn’t have too many possibilities today and people want to leave, people find things elsewhere. Yet Bengalis, I know, don’t want to leave this state. The cultural bonds are so strong. So, there’s a dichotomy here and you’re caught in that.

I agree with that. But earlier, you know, we went abroad even for graduate school etc. leaving our family. They were crying and all that sort of thing. But having done that, you feel happy. The world is becoming smaller and there are many possibilities. So, think of those possibilities. Don’t feel that you have to be cocooned in Bengal, as a Bengali I’m saying.

And if you don’t have that feeling, then you will find that there are many possibilities. At the same time, it is possible that today’s climate is not really healthy for science. This is something that we don’t want to get into in this discussion in detail. This is my feeling But what can you do? It is not in your hand. You can, of course, have a certain hand that you have voting power. But other than that, you have very limited ability to change the system. But nobody else can change you.

SS: Do you believe in the brain drain concept?

SDG: I don’t believe in it because the world is one world. This did not happen in our time. Today there are a lot of students going to Korea, and a lot of students going to Singapore, Malaysia. This didn’t happen during our time. So there are possibilities elsewhere, right? Israel, well, of course, Israel is now at war. But I’m saying many students are going to Israel, Weizmann Institute and other places.

So that didn’t happen during our time. During our time, it was only the UK and America. Students are now going to Germany, France, and Russia. So I think things are changing also. So now brain drain, you’re talking about, possibly there is a brain drain outside, away from Bengal. But I’m hopeful that things will change.

SS: Well, the issue often is that people go elsewhere because there aren’t too many quality opportunities here. And very often, if such people become successful outside, they do not feel the need to come back to the country. It almost feels like had they had opportunities to become succesful here itself, it would be a gain for this country as well.

SDG: Yeah, one thing I feel is Swarnendu, I think institutes like this should also be international. There should be students not just from all parts of India but also from

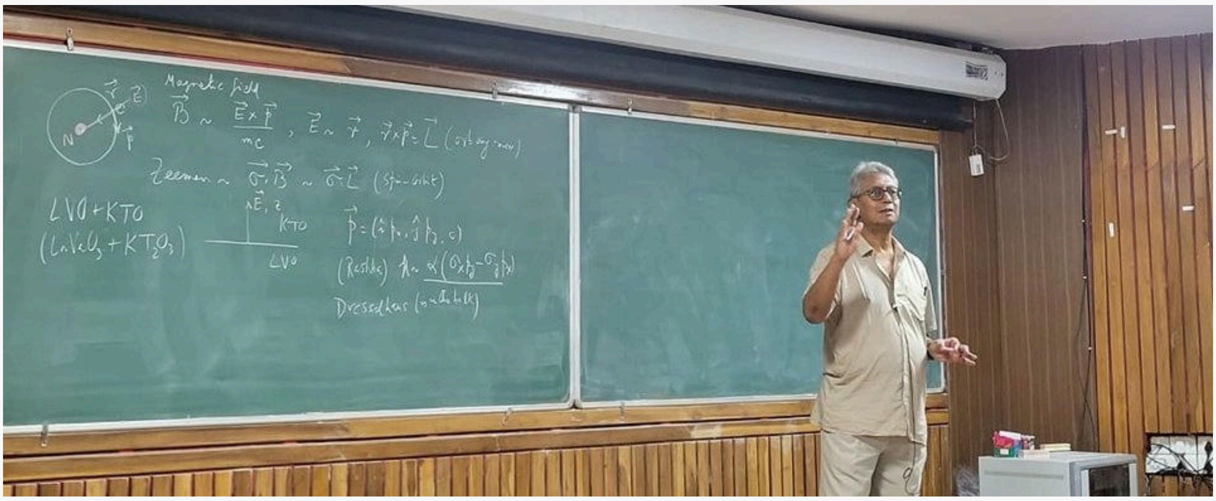


FIG 6 : *Sushanta Dattagupta delivering a series of lectures at the Indian Institute of Science Education and Research (IISER) Kolkata. He served as the founding director of IISER Kolkata from 2006 to 2011.*

outside. This is the strength of the Western universities like Oxford, Cambridge or American universities. Vast number of students come from outside. So you also have a cultural mix. You should not be just soaked into one culture and so if you are very multidimensional, then maybe such concerns should be little less, what you are talking about.

SS: But in India, everyone who has to join higher education, masters or PhD in a good place, as far as science is concerned, you have to clear JEST or JGEEBILS, NET, GATE and those are the only pathways you can achieve that. In international universities, you can just mail them or apply in a portal and if there is a possibility, they reply back to you. That doesn't happen in India.

SDG: So Swarnendu, if you ask me as a private person, I do not believe in all this NET, GET etc. You know that I served Visva-Bharati. Rabindranath Tagore didn't go to school. Einstein didn't have a very fantastic record in schooling. So, these are mechanical things. Perhaps they came in because they had to uniformize or whatever, a PhD from one state was not the same as a PhD from another state. Traditionally in Bengal, University of Calcutta, not in your time maybe, but in our time, they were very conservative about giving marks.

So even 65% in physics honours was considered to be very good, not today maybe, but that is not the case let's say in another university which I'll not name. So maybe they had to uniformize, but I don't believe in these things. So, I think these are all mechanical things and really motivated students may be deterred from such mechanical things.

On a given day, you may not do well in a NET exam or GATE, but you are good. So why should the system lose you? So as a teacher, I would like to support such students, but as a system it's very difficult. So, I agree with you that when you are writing to professors abroad, they don't ask you whether you have cleared your NET, GATE and all that.

SS: They only take interviews if they have a position and they try to understand if I can do it. If not, I know it or not. If I am able to do it, I think that should be adequate. If the teacher wants it, you want the teacher, the place administrator wants you and it's done.

SDG: Yes, yes and I think that's the healthy system. We actually have got into an unhealthy system, very mechanical. I will give you an example.

Since you mentioned Visva-Bharati, have you heard of Ram Kinkar Baij? He was a sculptor. He's from Bankura, completely supposedly illiterate. Could he have become a professor in Visva Bharati by today's standards? He had not cleared NET. He used to stay in his own world, stay in his own fashion. He was a professor. Konika Bandyopadhyay was a professor. Did Konika Bandyopadhyay clear NET examination? So why do you have such things? J.C. Bose did not have to clear NET examination. By the way, they were all part of the teaching departments.

You were asking earlier about teaching and research. The fact that S. N. Bose could do this problem of how to count and have a new kind of statistics by saying that particles are indistinguishable, that happened because students were asking him, barraging him with questions. "Sir, this derivation of Planck law radiation is not very satisfactory, you know, you please explain." That is what drove him there. To answer the question in the class.

It was not just in Dhaka in 1924 when he wrote that letter to Einstein, but it started happening from 1920-21 onwards in University of Calcutta when he was teaching mathematics here. So it is because of the students asking him questions. The researcher J.C. Bose was teaching in Presidency College. So, examples galore where teaching and research in combination have produced this.

Here, after independence, we have separated our research institutions from the university system. Has that been good for us? We keep on asking why there are no Nobel Prizes from here? The answer is obvious, I think.

SS: On to my next question. For the last several months, many international opportunities have become blocked. The US appears cutoff. UK says we don't have funding. many countries are at war. In this scenario, what is your suggestion? How should today's students make progress? Is doing a PhD in

FIG 7: *Profs. Bernard C. Patten, Brian D. Fath, Sushanta Dattagupta, and Sudhendu Mandal during the inaugural functions of the International Conference on Environmental Biology and Ecologiacl Modelling, Visva-Bharati University, Santiniketan, India (Photo credit to Jana Debaldev).*

India a good choice? More specifically, how much of a difference does getting a degree from a good Western University make versus getting the degree from a good place in India?

SDG: Let me answer the last part first. There are many counterexamples of students, who have done PhDs in our country, have done exceedingly well internationally also. I can give you some names also. So, I think again that distinction is immaterial. The first part is difficult for me to answer. Let me tell you my own experience with my two daughters.

My elder daughter Shahana, after schooling, did architecture from Delhi School of Planning and Architecture. Then she had some higher degrees in the U.S. and also she was working for a company. So, as an architect, she would have done very well.

She is very, very creative. She is very strong in mathematics also. But today, she is completely into Dhrupad music. So, one may think, ah, she has wasted her career. She could have become a great architect, but she is in Dhrupad. I don't think like that - she is personally very happy with music – she has innumerable mentees all over the world - and I am extremely happy for her.

My younger daughter Sharmishtha did chemistry from St. Stephen's College, Delhi. And then did an M.Tech program from IIT Bombay in biotechnology. Then did a PhD in deep sea biology in Pennsylvania State University. Eventually had a position, faculty position, in geobiology in the Courant Center of Excellence in Geo-biology in Gottingen University. But she gave up everything and she is now a life's coach.

What is that? Basically, she talks to people about happiness in life, going mountaineering, going to yoga, going to, you know, practising spiritualism and traditional knowledge, ecology and all that. And she lives mostly in India, in Himachal now. And also works with Adivasi women near Shantiniketan in Bolpur, where I stay.

FIG 8 : *At the release of a book on the doyen of Rabindrasangeet: Shailajaranjan Majumdar, on his 125th birth anniversary, at the Lipika auditorium of Visva-Bharati. Standing by his side is Dr. Shruti Bandyopadhyay, Principal, Sangit Bhavana.*

SS: And that's very fulfilling for you, I guess.

SDG: Fulfilling for her also. So, what more does one want in life, I am saying. She drives all the way in her Alto Maruti car, all the way from Himachal to Shantiniketan, Bolpur, where I stay in the house designed by Shahana, who is an architect. So, they are not in any kind of traditional mold anymore. This is very different from our days. Since you are asking me, it is a very difficult question to answer now.

Because in our days we came from middle class families - one track minded. You have to do physics, then you have to do this, do PhD, do post-doc, then see where you get the faculty position. So, these kids are now able to do many other things. So, Swarnendu, the reason it is difficult is that our days and your days are very different now. So, we should not bias you from our kinds of experiences. And we should also adapt to your needs.

The fact that you are happy with doing what you are doing is the most important. Gone are the days where you would stay at home, looking after parents in the old days, etc. But, you know, that also made parents dependent, your dependent, and your freedom curtailed. But now, even staying away, you can do a lot for your parents. I don't think that that concern is not there anymore because connectivity has also increased, you know. You can travel much faster today compared to our days. First time I went inside a plane was when I went to the US for my PhD studies. But these days, you guys are travelling all the time.

SS: This question is not to the researcher Sushanta Dattagupta, but primarily to the teacher Sushanta Dattagupta and the person Sushanta Dattagupta. Do you feel today's students have forgotten to talk, have forgotten the meaning of friendship. Today's students, though more alert, frequently fall prey to substance abuse.

After graduating, they forget the friends they made there. It feels like we talk only when we absolutely need to, and not for the sake of relationships. Even though many of my school friends are in Kolkata, we rarely meet. Do you have any comments on this trend?

SDG: I think this is not a good trend. In fact, when COVID happened, we went into a system of virtual classes. I think that's disastrous. Unless you have eye contact with the teacher, and also reversely with the students by the teacher, it's not a very effective communication. That's number one. So, what you are saying is that today, most of the time, with earplugs, listening to mobile phones, maybe some music, some recording, you have very little time for even Adda, as you mentioned.

SS: We all have problems - academic problems, financial problems, problems at home, etc. But we don't have close friends to talk to about them. It seems like people are insecure about opening up in front of others about their vulnerabilities. How does one cope with that?

SDG: I don't really know. One thing is sports facilities. Like, you know, if you are feeling bored, go play basketball. Go play volleyball. Chat with the guys. This campus is fantastic for that. Go and have a swim. Do that. Or go cycling in the campus. Watch the birds. Watch the many varieties of flowers here, nature. Getting hooked on the mobile phone is a scourge, I think.

SS: How are Tagore's works related to science?

SDG: Fantastic. A lot of people don't know that Tagore was very interested in mathematics. His eldest brother more so.

SS: Are you talking about Dwijendranath?

SDG: Yes. He was very good at maths. And he was the one who was a nature lover. Birds and all that. So, he imbibed that. Tagore actually got a lot of things from his brothers and combined them into the genius that he was.

The first article that Rabindranath published in Tattvabodhini Patrika at the age of 12 was on astronomy. So, then, you know, Tagore is quite interesting. Tagore was a great friend of J.C. Bose. Around 1900, they were writing lots of letters. Bose Institute has come up with two volumes. In which these letters are there. But, if you look at them, Tagore was trying to understand what Bose was doing. And, Bose was actually propagating Tagore's works in the western world also. Translating them into English.

So, science was very much in Tagore's mind. Eventually, he went and met Einstein. Five times. Between 1926 and 1930. Then, Heisenberg came in 1929 to Jorasanko to have tea with him. He went to Darjeeling on the way. He stopped by and had tea with Tagore. And, he wanted to understand about Upanishad and the idea of how you learn things from nature. And, the fact that Upanishad, this is what he says to J.C. Bose. Upanishad taught us that everything, even which you think is immobile, actually vibrates with life. He basically talked about atoms and molecules, even in trees and even in concrete. And so, Heisenberg writes about that to his daughter. Then, Sommerfeld went to Shantiniketan in 1928.

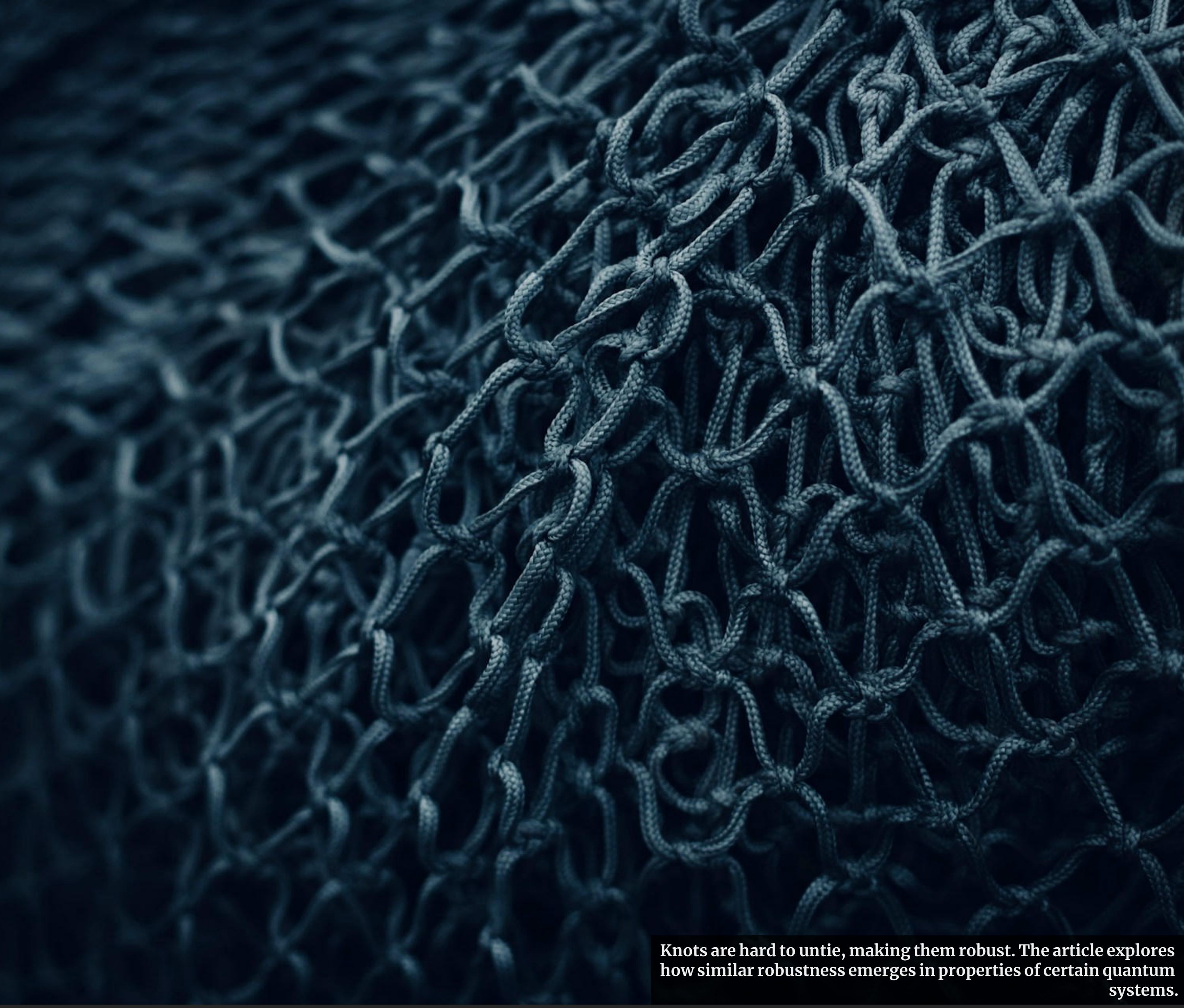
It is Sommerfeld who during Tagore's visit to Germany introduced Meghnad Saha to Tagore. Tagore talks about Meghnad Saha's work in Bishwa Parichay, which he wrote between 1934 and 1937. Bishwa Parichay has various sections - full of various scientific concepts and much of it has to do with radiation and *Alo* (light). And what is the meaning of *Alo*? And *Alo*, as you know, is a basic aspect of science. So, Tagore, I think, had a scientific mind. It's just that he is a great philosopher.

SS: It has been very nice talking to you, sir. One last question, what is your advice to the students, and maybe particularly to the outgoing students?

SDG: Be happy, be on your own and be responsible to your surroundings. Worry about the fact that we have done big damage to ecology in the name of development. If you look after your health and look after your health means that you have to do physical exercise and look after your diet and also be happy. So, mental peace is the most important thing in life and that is what you should have. And finally, as you said, and I'm unhappy to hear this, you must have a lot of friends and have a lot of *Adda*.

SS: Thank you, sir.

FIG 9 : *In 2011, Sushanta Dattagupta was appointed as the Vice-chancellor of Visva-Bharati university. He served in that role till 2016.*



Knots are hard to untie, making them robust. The article explores how similar robustness emerges in properties of certain quantum systems.

Topology in Action: From Doughnuts to Quantum Devices

Sukalyan Deb (Department of Physical Sciences, IISER Kolkata)

Topology focuses on the global properties of systems, ignoring precise details like size or angles. This article explores its origins in Euler's *Seven Bridges of Königsberg* problem, and trace its profound impact in condensed matter physics from the quantum Hall effect to topological insulators and quantum computation.

Also available online, at scicomm.iiserkol.ac.in

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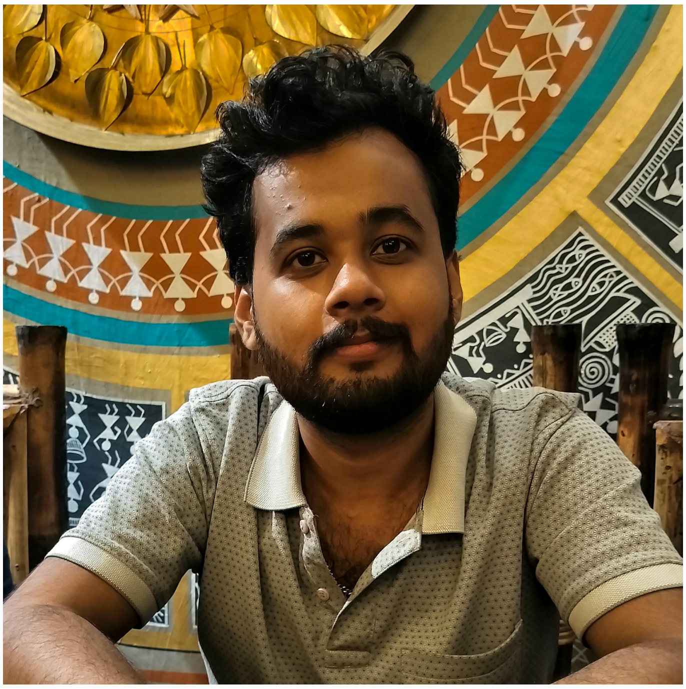
Jun 06, 2025

CATEGORY
Physics

***Sukalyan Deb** is a PhD scholar in the Department of Physical Sciences in IISER Kolkata, currently working in theoretical physics, focusing on strongly correlated systems.*



Mathematics has long served as the language of physics, helping us express and understand the laws of nature. From Newton's second law, which led to the development of calculus, to Schrödinger's equation in quantum mechanics, math enables us to model how the universe behaves. More abstract tools like group theory allow us to classify phases of matter by their symmetries - or more interestingly, by how those symmetries are broken.

But there's another powerful branch of mathematics that's become essential in modern physics, especially in studies of condensed matter systems: **topology**.

Topology studies the properties of spaces preserved under **continuous deformations** - stretching, bending, or twisting - without tearing or gluing. Imagine a rubber sheet: you can stretch or compress it into various forms, but as long as you don't puncture it or attach new parts, the sheet remains topologically the same. These types of deformations, where the object is smoothly transformed without cutting or gluing, are called continuous deformations.

This is the key difference between topology and geometry. Geometry is concerned with precise measurements: angles, lengths, and areas. Two geometric shapes are considered different if those measurements differ. In contrast, topology focuses on the more abstract, structural aspects of a shape - **how it's connected**, how many holes it has, whether it's bounded or unbounded. In a topological sense, a coffee mug and a doughnut (torus) are the same because **each has one hole**; their detailed shapes and sizes are irrelevant (Fig 1).

How to quantify topology: Topological invariants

One of the oldest and simplest tools in topology is the **Euler characteristic**, a number associated with a geometric object. For a polyhedron, it's defined as

$$\chi = V - E + F$$

where V is the number of vertices, E the number of edges, and F the number of faces. Take a tetrahedron: it has 4 vertices, 6 edges, and 4 faces. Plugging these into the formula gives

$$\chi = 4 - 6 + 4 = 2$$

. A cube has 8 vertices, 12 edges, and 6 faces, giving

$$\chi = 8 - 12 + 6 = 2$$

again. In fact, for any convex polyhedron, this number is always 2. This is no coincidence - these shapes all share the same underlying topology: **they are topologically equivalent to a sphere**.

What makes the Euler characteristic especially important is that it is a **topological invariant** - a quantity that remains unchanged under continuous deformations. So if you smoothly stretch or bend a cube into a sphere, its Euler characteristic stays the same. But if you punch a hole through the object, turning it into something like a torus (a doughnut shape), the Euler characteristic changes. For a torus, $\chi = 0$. That difference tells us the two shapes are topologically distinct-they belong to different "families" of spaces (Fig 2).

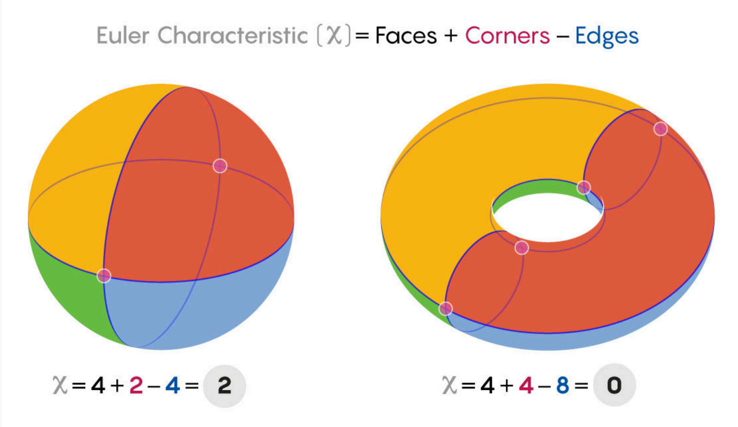


FIG 2: *The Euler characteristic is an example of a topological invariant that distinguishes between objects with different topologies (sphere and torus in the figure). The sphere (left) can be divided into four regions (differently coloured). This creates four faces F (red, orange, green and yellow), four edges E (blue lines that separate at least two distinct faces) and two vertices/corners V (where at least two edges meet). The Euler characteristic then works out to be* $\chi = F - E + V = 2$. *In the same way, the torus divides into four regions but the presence of the internal hole means there are 8 edges and 4 verticles, leading to* $\chi = 4 - 8 + 4 = 0$. *[Credit: Quanta Magazine 2020]*

Topological invariants like the Euler characteristic allow mathematicians and physicists to **classify shapes and spaces** in a way that's robust against local disturbances. Rather than tracking every detail, we focus on what truly matters: how the space is connected, how many holes or boundaries it has, and how it behaves as a whole.

The Problem of the Seven Bridges of Königsberg

Looking back through history, we find that topology originated from a mathematical problem posed by Euler in 1736 [1]. This problem, known as the **Seven Bridges of Königsberg**, holds historical significance. The problem is rooted in the unique geographical layout of the 18th-century city of Königsberg, then part of Prussia (now Kaliningrad, Russia). Situated along the Pregel River (now known as the Pregolya), the city encompassed two large islands-Kneiphof and Lomse-formed by the river's branching channels. These islands were connected to each other and to the mainland by a total of seven bridges, creating a complex network of crossings (shown in Fig. 3) . This configuration led to a natural curiosity among the city's inhabitants: **is it possible to devise a walk through**

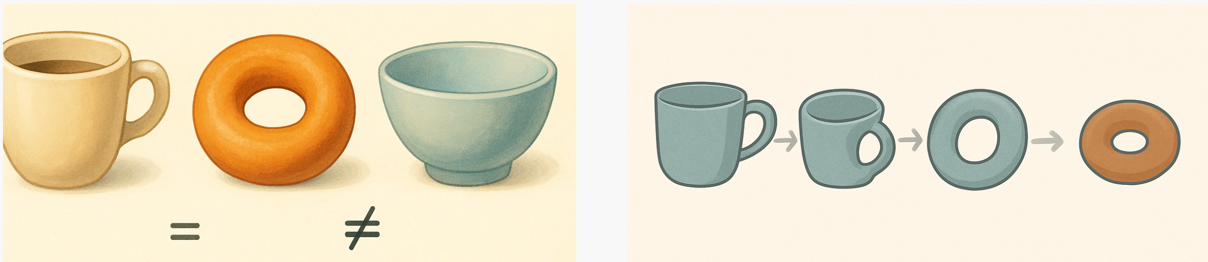


FIG 1 : Left: *A cup (with a handle) is topologically the same as a doughnut but topologically inequivalent to a bowl. This is because while a coffee cup and a doughnut both have the same number of holes (1), a bowl has no holes. Right: Shows pictorially why the cup is equivalent to a doughnut. Starting from the cup, one can gradually make continuous deformations (changes that do not introduce or remove holes into the system) and eventually form a doughnut. Because one can be transformed into the other through continuous deformations, we say that the objects are topologically equivalent.*

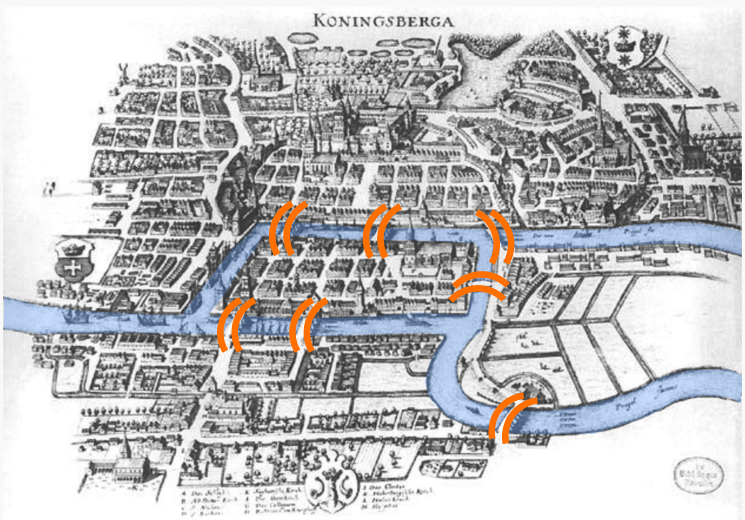


FIG 3: *A stylized historical map of Königsberg, where seven bridges (orange marks) connected four different parts of the city separated by the river Pregel (blue). This setup posed a famous problem: is it possible to walk through the city crossing each bridge exactly once? Euler's resolution of this question in 1736 marked the birth of graph theory and laid the foundations for modern topology.*

the city that crosses each bridge exactly once without retracing any steps?.

At first glance, this seems like a challenge of planning or persistence. One might start at one part of the city-say, on one of the islands-and attempt a path that carefully crosses each bridge without retracing any steps. Maybe try crossing to the northern bank, then loop through the western side, come back to the island, and finish on the southern bank. **But no matter how carefully you plan, you'll find yourself stuck: either forced to cross a bridge you've already used, or stranded with no remaining bridge to exit from.**

People naturally attempted many such trial-and-error strategies. Some tried drawing the path, others tried tracing routes on a map. Yet none succeeded.

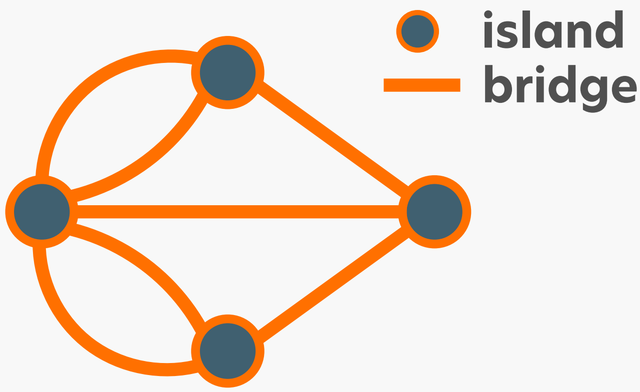


FIG 4 : *Abstracted graphical form of the Seven bridges problem. The blue circles represent landmasses while the connecting orange lines represent bridges. Euler noted that the original problem was equivalent to figuring out whether one can construct a path along the graph that traverses every edge exactly once while passing through every node.*

Euler's solution and the birth of topology

In order to tackle the problem, Euler performed an **abstraction** on it - he removed all irrelevant features and information (such as the lengths of bridges and sizes of landmasses) and retained only the necessary components. He realised that each land mass can be simplified by representing it as a node (gray points in Fig. 4), and the seven bridges can be viewed as connecting edges between these nodes (orange lines in Fig. 4). In modern mathematics, this is called a **graph**.

Note that the initial problem that was posed was to figure out if it's possible to traverse all bridges exactly once, without retracing steps. **Euler noted that this problem is equivalent to figuring out whether one can construct a path along the graph that traverses every edge exactly once while passing through every node**. In order to do this, certain constraints must be obeyed by the path. The starting and ending nodes (which correspond to the landmasses you start from and end at) must have at least one edge attached to them (you must have a bridge to move out of the starting landmass and a bridge to move into the final landmass). The other nodes must have an even number of edges connected to them, because if you enter a landmass using a bridge, you must exit it using a different bridge (retracing steps is not allowed).

In mathematical terms, if a non-terminal node is traversed n times, it must therefore be attached to $2n$ number of distinct edges (if you pass through a landmass 2 times, you must have 4 distinct bridges connecting it, otherwise you will retrace your steps at some point). Since only two nodes can be the terminal nodes, we have the constraint that at most two nodes in our graph can have an odd number of nodes; all other nodes must have an even number of nodes. **This means that in order for a solution to exist, at most two of the landmasses can have an odd number of bridges attached to it, the rest of the regions must have an even number of bridges.** In the specific graph problem we are encountering (Fig 4), we see that all the nodes in fact have an odd number of edges attached, thereby showing that no path with the specified requirements can be constructed for the Königsberg problem.

Note that the solution of the problem **required no knowledge of the shape and size** of the landmasses or the lengths of the bridges; the only relevant details were the **connections among the nodes**. In fact, distorting the size and shapes of the nodes or displacing the nodes by small distances does not alter the solution in any way. The solution is therefore **impervious to continuous deformations**, and is dictated purely by the topology of the graph. In this way, the Königsberg bridge problem also led to the birth of topology as a new field of mathematics.

Topology in action: The quantum hall effect

Topology is not just a fancy mathematical construct-it plays a profound role in modern physics, particularly in understanding exotic phases of matter. A classic example is the **quantum Hall effect**. This is a juiced-up version of the classical Hall effect [2] in which a perpendicular magnetic field applied on a current deflects the electrons perpendicular to the current in the plane perpendicular to the field, and makes them accumulate on the boundaries, due to which an electric voltage (Hall voltage, V_H) develops in the same direction. The Hall resistance R_H, defined as the ratio of Hall voltage to longitudinal current (I),

$$R_H = \frac{V_H}{I} \quad ,$$

increases linearly with magnetic field in the classical case:

$$R_H(\text{classical}) \propto B \quad .$$

However, in a two-dimensional system with a bit of disorder (e.g., impurities or imperfections in the material) - such as a thin film of semiconductor subjected to very high **magnetic fields** and very low temperatures, the Hall resistance no longer follows a smooth linear trend. Instead, it exhibits a series of **quantized, precise plateaus** - meaning the Hall resistance takes on discrete values, each corresponding to a specific fraction involving fundamental constants (Fig 5):

$$R_H(\text{quantum}) \propto \frac{1}{n}\frac{h}{e^2}, n = 1, 2, ...$$

where h and e are the Plancks constant and charge of electron. This is the quantum hall effect [3]. Its most remarkable feature is the **robustness of these plateaus**:

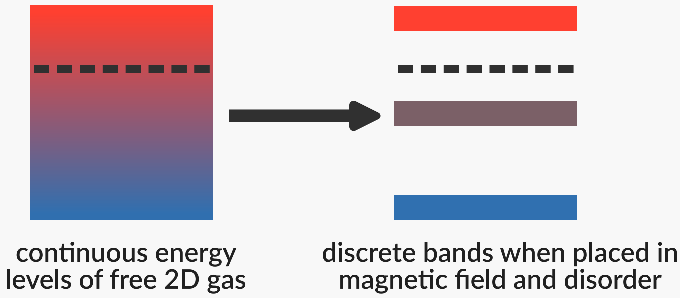


FIG 6: *Evolution of electronic energy levels under the influence of a magnetic field. In the absence of a magnetic field (left), energy levels of a free-electron gas are continuous. Under strong magnetic fields and disorder (right), the energy levels split into discrete Landau levels, with each level broadened into a band by impurities. The emergence of localized and extended states within these broadened bands is key to the quantized behavior of the quantum Hall effect.*

they are unaffected by imperfections in the material, such as impurities or small variations in geometry. This stability is a hallmark of topological phases of matter [4].

A peculiar property of magnetic fields is that they have a strong directionality – they **localise electrons** in one direction and force them to move in another direction. This localisation has a severe effect on the energy levels of the 2D electrons. In the absence of magnetic fields and any impurities (disorder), the energy levels vary smoothly (left, Fig 6);

$$E(B=0) \propto p^2 \quad ;$$

adding impurities and turning on a perpendicular magnetic field makes these levels bunch up into **discrete bands called Landau levels** (Fig 6):

$$E(B \neq 0) \propto n + \frac{1}{2} \quad , n = 1, 2 ...$$

Each value of n represents a distinct Landau level. Each Landau level is macroscopically **degenerate**, consisting of a huge number of electronic states at the same energy. These degenerate states in each Landau level are spatially distributed along the transverse (Hall) direction, each state **localised** (cannot travel too far) at various positions [5], but are **extended** (can travel from one end to the other end) in the longitudinal direction.

Origin of quantisation: Chiral edge states

It's important to note that **disorder** plays a crucial role in enabling the quantized Hall plateaus. By localizing most bulk states in between Landau levels, disorder prevents small changes in electron density from altering the number of conducting channels. This makes the quantization **experimentally robust**.

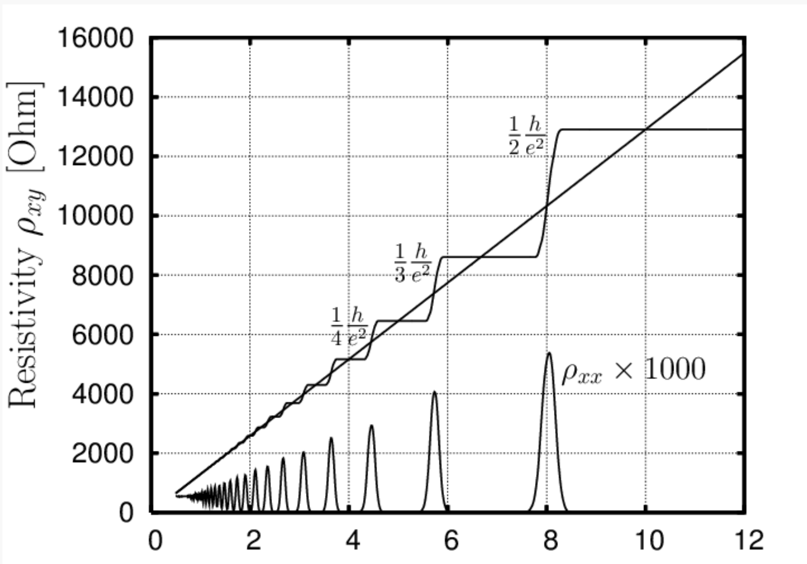


FIG 5: *Comparison of Hall resistance behavior in different regimes. In classical systems (solid straight line), the Hall resistivity increases linearly with the magnetic field. In contrast, under strong magnetic fields and low temperatures, the system enters the quantum Hall regime, where the Hall resistivity forms sharply defined plateaus at quantized values. These plateaus are robust against disorder and signal topological protection.*

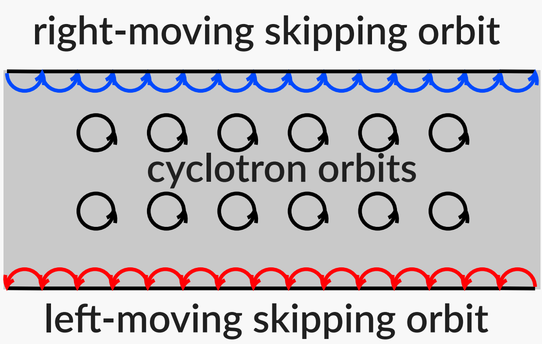


FIG 7: *Depiction of chiral edge states in a two-dimensional electron system under a strong perpendicular magnetic field. In the bulk, electrons follow closed cyclotron orbits and remain localized. Near the boundary, these orbits are interrupted, creating skipping trajectories that propagate in one direction along the edge. These unidirectional states are topologically protected and form the basis of dissipationless edge transport in the quantum Hall effect.*

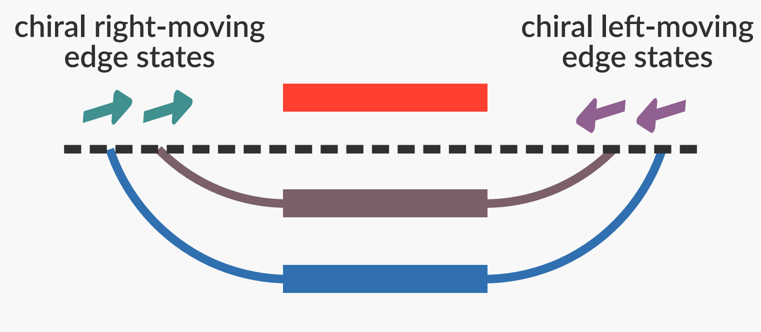


FIG 8: *A schematic showing how edge states emerge from Landau levels and contribute to quantized Hall conductance. The dashed line represents the chemical potential. Each filled Landau level below the chemical potential contributes one chiral edge channel (right-moving on one edge and left-moving on the other edge), leading to a quantized Hall current. Because the number of filled levels changes only when the chemical potential crosses a Landau level, the Hall conductance remains constant over a range of energies, resulting in quantized plateaus.*

We will now figure out how topological considerations play into the robustness of the quantum hall resistivity plateaus, using a semiclassical picture. As mentioned in the previous section, each Landau level has multiple states with the same energy but placed at various positions along the localised direction. Away from the edges of the sample, the electrons in these states **circulate in closed cyclotron orbits** due to the magnetic field and do not contribute to any conduction mechanism. What happens when we consider states that are very close to the boundary, at a distance less than the radius of the cyclotron orbits? This is shown in the blue and red trajectories of Fig 7 - under the influence of the magnetic field, electrons try to exit the sample but of course cannot, and they reflect off the edge, **forming skipping orbits**. These states therefore extend along the length of the sample, and are **not localised** [6].

The important point is that the directionality of the magnetic field forces these delocalised skipping orbits to move in a certain direction - rightwards on the top edge and leftwards on the bottom edge, as shown in Fig 7. **There cannot be any left(right)-moving states on the upper(lower) edge**. Such states that move only left or right are called **chiral states**, and are generated because of the strong magnetic field [3]. More precisely, such chiral edge states result from the **time-reversal symmetry-breaking** nature of the magnetic field. A video of a time-reversal symmetric system looks the same if the video is played backwards. The magnetic field makes this impossible, because it separates the left and right-going states and places them on different edges - playing the video backwards would lead to a switch in the behaviour of the two edges. This separation also makes them robust - an electron travelling along an edge (as mentioned in the previous paragraph, the edge states are delocalised and can therefore carry current) **cannot stray from its path without expending a large energy cost**. To do so, it must "jump" to the other edge state (which is of similar energy), but since these states are **widely separated in real space** (they lie on opposite edges), such processes are effectively impossible.

How does the presence of chiral edge states explain the quantisation of resistivity in the plateaus? Given that each Landau level contributes one pair of **robust delocalised current-carrying** edge states moving in opposite directions on the opposite edges of the sample, applying a hall voltage difference between the left and right states leads to a net current I flowing along the edge of each Landau level. Because of the presence of energy gaps between the Landau levels, the number of Landau levels that are occupied (below the dashed line in Fig 8) **cannot change continuously, but can only increase by one each time the dashed line passes through the center of a Landau level**. If the number of Landau levels below the dashed line is n, there are n such edge states that have electrons in them and hence contribute a current nI. The Hall resistance is the total Hall current divided by the Hall voltage V, which comes out to be nI/V, which is clearly quantised through the integer n.

What's the topological invariant?

What is the role of topology in all of this? The quantisation arises owing to the robustness of two aspects:

- robustness of the gaps in the Landau level which ensures the number of edge states do not change smoothly but rather in discrete steps, and
- robustness of the chiral edge states that can carry the Hall current.

Both of these are consequences of the non-zero magnetic field, which sets the topology of the wavefunctions (the separation of left and right moving states at the two edges). The topology remains undisturbed under small deformations (such as changing, by small amounts, the magnetic field, size of the sample, the temperature or the disorder), and can only change under large deformations (such as switching off the magnetic field entirely or drastically reducing the system size).

Similar to the Euler characteristic which acted as a topological invariant for polyhedrons, **is there again an**

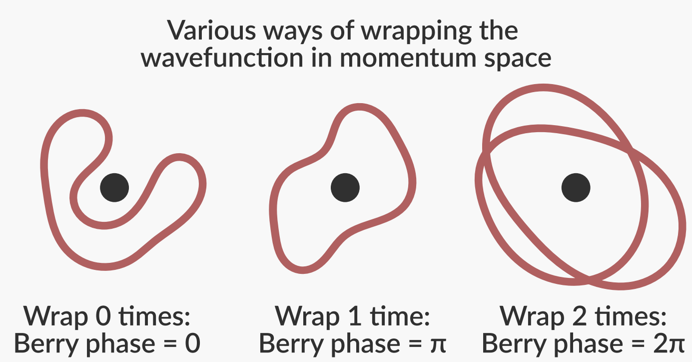


FIG 9: *Visual representation of the geometric phase (Berry phase) acquired by a quantum wavefunction as its momentum traces a closed loop in momentum space. The central point represents a singularity in momentum space created by the magnetic field. The number of times the wavefunction's path wraps around this singularity determines the accumulated Berry phase - 0, π, or 2π in the examples shown. The total winding over the Brillouin zone gives an integer topological invariant known as the Chern number, which dictates quantized physical observables like the Hall conductance.*

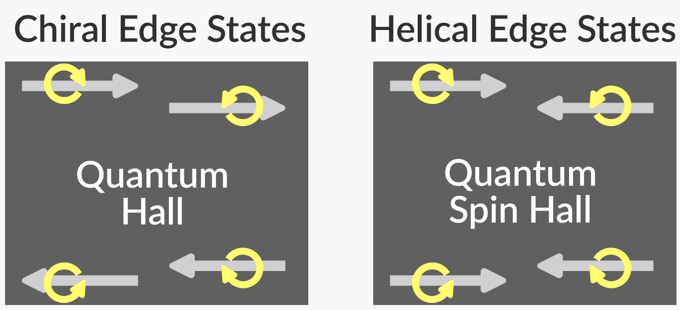


FIG 10: *Comparison of the edge state structures in two topological systems. Left: In the quantum Hall effect, chiral edge states carry charge in a single direction along each edge, determined by the magnetic field. All current flows unidirectionally on a given edge, and backscattering is suppressed by spatial separation. Right: In the quantum spin Hall effect, helical edge states consist of counter-propagating modes with opposite spins on each edge. These states are protected by time-reversal symmetry and immune to backscattering from non-magnetic impurities, enabling dissipationless spin-polarised transport.*

invariant in this context that sets the topology of the wavefunction? In quantum mechanics, the state of an electron moving with a certain momentum is described by a **wavefunction** with a phase. As the momentum $\boldsymbol{k}$ changes, this phase can twist and evolve, and is captured by something called the **Berry curvature** $\Omega(\boldsymbol{k})$. But what does the Berry curvature have to do with the Hall conductivity? Well, it turns out that the Hall conductivity in two dimensions can be expressed as **the integral, in momentum space, of the Berry curvature** of the wavefunction - the more the wavefunction "curves" in momentum space, the more is the conductivity. [7]

What does this have to do with topological quantisation? It can be shown that the integral of the Berry curvature is **always an integer multiple** of 2π:

$$\iint_{\text{MS}} \Omega(\boldsymbol{k})\, \mathrm{d}\boldsymbol{k} = 2\pi C, \quad C \in \mathbb{Z} \quad ,$$

where the integral is over momentum spac (MS), $\mathrm{d}\boldsymbol{k}$ represents the differential area in momentum space and $\Omega(\boldsymbol{k})$ is the Berry curvature at any point, acting as the integrand. **The quantised nature is reflected in the fact that C (on the right hand side of the equation) is necessarily an integer**. This is analogous to the way the total curvature of a closed curve in 2D geometry - say, walking around a point - always adds up to an integer multiple of 2π, depending on how many times the path winds around that point (Fig 9). Similarly, the Berry curvature accumulates in momentum space, and its total integral - the **Chern number (C) - counts how many times the quantum wavefunction twists or "wraps" around the space of momenta**. This argument therefore links the Hall conductivity to the Chern number:

$$\sigma_H = C\frac{e^2}{h}$$

The Chern number is a **topological invariant**; it is insensitive to local details of the wavefunction and only depends on how many times the wavefunction wraps around in momentum space. This topological nature of the Chern number explains the robustness of the Hall conductivity: **it cannot change gradually as experimental conditions are tweaked**. Instead, it only jumps when the system undergoes a true topological transition - such as when the chemical potential crosses a Landau level and a new chiral edge state emerges. This is why the plateaus are sharp and stable: **they reflect changes in an integer-valued invariant that counts how the wavefunction "winds" in momentum space** [8].

Beyond quantum hall: Topological insulators

While the quantum Hall effect relies on the breaking of time-reversal symmetry (TRS) to generate its chiral edge states and quantized conductance, physicists have discovered materials, referred to as **topological insulators** [9], that can support topologically-protected edge states even in the **absence of any external magnetic field**. Instead of a magnetic field, these materials require **strong spin-orbit coupling** (SOC) - an effect where an electron's motion through the crystal lattice is intimately linked to its intrinsic angular momentum (spin). In fact, SOC acts like an internal, spin-dependent magnetic field, but one that **does not break TRS**. The presence of SOC gives rise to **helical edge states**: at each edge, electrons of opposite spin travel in opposite directions. This mechanism filters out spin-up and spin-down electrons into opposite directions at the edges, forming spin-polarized, counter-propagating states at each edge - a hallmark of the **quantum spin Hall effect** (Fig 10).

Importantly, due to TRS, **backscattering between the opposite spin states at each edge is prohibited**; such a scattering process is not allowed by the symmetry. This makes these edge channels robust against non-magnetic disorder (magnetic disorder will allow scattering between the opposite spin channels at each edge). The edges of a topological insulator exhibit **perfect transport**, meaning no energy is lost as heat, and the number of conducting pathways can be tuned. Though measuring spin currents is more subtle than charge currents, advanced experimental techniques have made such measurements possible, confirming the presence of spin transport along the edges.

Topology meets technology: The promise of topological qubits

A natural question arises: why should we care about the topological properties of quantum systems? One compelling answer lies in **quantum computing**!

Quantum computers leverage the unique property of quantum particles to exist in multiple states simultaneously (**superposition**) to store information in qubits. This enables them to solve problems **exponentially faster** than classical computers, which rely on classical bits (which are either 0 or 1). The main challenge in this approach is that qubits are **extremely fragile** - tiny interactions with the environment can decohere the information, leading to errors in computation.

Topological quantum computation addresses this by using topological qubits that encode information not in the precise configuration of a system, but in its topological properties - features that are preserved under continuous deformation [10]. One approach towards this is by using **anyons** - exotic emergent particles that appear in two dimensions. The collective quantum state of such systems depends on **global properties** such as the winding pattern of the anyons around each other (a process known as braiding), and is independent of the precise geometric or local details [11]. This topological nature of the quantum state makes the system inherently robust against local disturbances or errors, providing a promising foundation for **fault-tolerant quantum computation** [12].

Several platforms are being explored to realize these ideas, including systems based on **Majorana modes** [13]. Recently, Microsoft published a study in Nature that carries out measurements on a topological superconductor [14] (Fig 11). In **topological superconductors**, it is theorised that the lowest-energy excitation corresponds to a single electron being nonlocally stored between two spatially separated Majorana modes. Microsoft's results show evidence for an extra electron occupying a low-energy bound state, consistent with theoretical predictions for a Majorana mode. While the report is not unequivocal in the demonstration of the topological Majorana modes and does not rule out non-topological explanations, it highly constrains such non-topological states and advances the field of topological computation in a concrete way by demonstrating that such measurements are certainly consistent with topological computation.

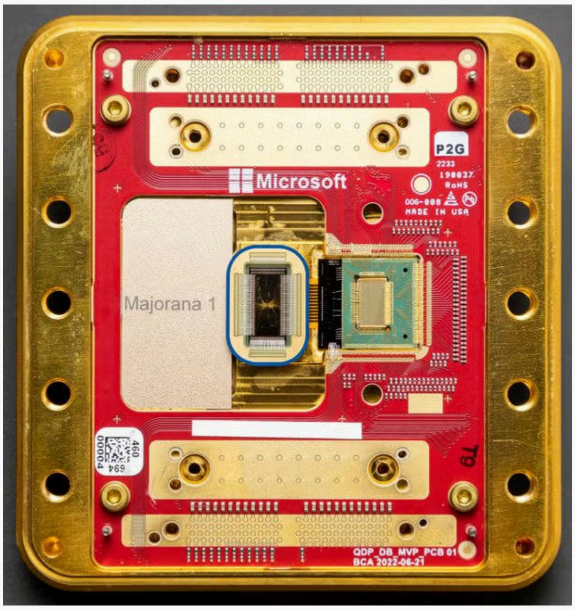


FIG 11 : *Microsoft's "Majorana 1" chip, an experimental platform designed to probe topological superconductivity. The chip architecture supports bound states consistent with spatially separated Majorana modes, which could serve as building blocks for topological qubits. This marks a major step toward realizing fault-tolerant quantum computation grounded in the topological robustness of quantum states where information is stored not in physical configurations, but in the winding and braiding of emergent excitations.*

While the full experimental verification of Majorana-based qubits remains an ongoing challenge - previous claims have been met with skepticism and rigorous scrutiny - Microsoft's results are a tangible step forward in the quest to harness topological phases of matter for real-world quantum computing. If successful, it would validate years of theoretical predictions and could signal a turning point where topology moves from abstract mathematics into the heart of practical, next-generation technologies.

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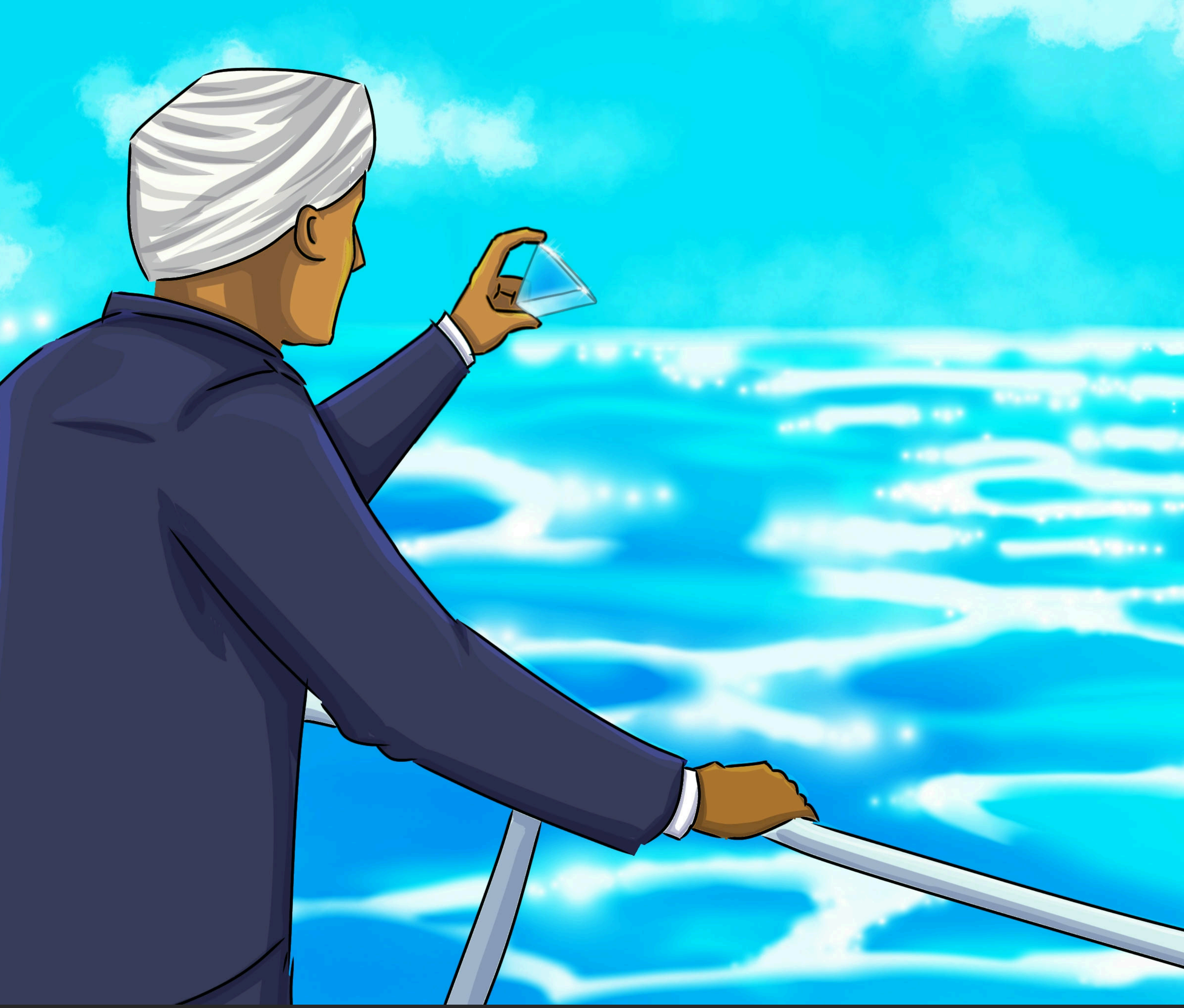


The Quest For The Sea's Blue: The Discovery of the Raman Effect

Shreya Ganguly (IISER Kolkata)

Dicover how a simple question - why does the sea look blue - led to one of the most groundbreaking discoveries in physics. This engaging **science comic** traces C. V. Raman's journey to uncover the phenomenon that now bears his name.

Shreya Ganguly *is a student of 22MS batch pursuing a physics major at IISER Kolkata. A habitual explorer and art-lover, she likes drawing, dancing and trying out her hand at graphic design and video editing - when she isn't drowning in coursework, that is.*

A QUEST FOR THE SEA'S BLUE

THE DISCOVERY OF THE RAMAN EFFECT

WHY DOES THE SEA LOOK BLUE? A YOUNG INDIAN PHYSICIST'S PURSUIT OF THIS ONE ANSWER WOULD SPIRAL INTO SOMETHING FAR GREATER - A DISCOVERY THAT WOULD GO ON TO LAY THE FOUNDATION FOR ALL MODERN DEVELOPMENTS IN MOLECULAR STUDIES AND SPECTROSCOPY.

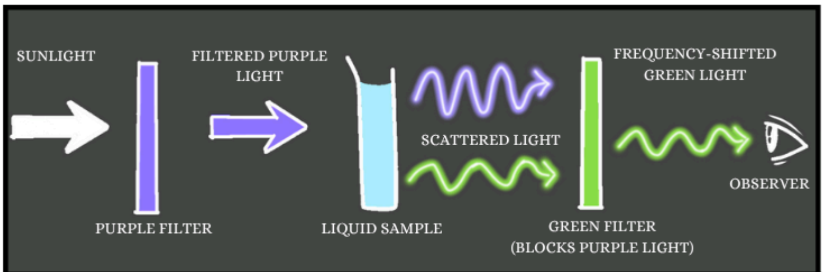
THIS IS THE STORY OF SIR CHANDRASEKHARA VENKATA RAMAN, AND THE GROUND-BREAKING DISCOVERY THAT CAME TO BEAR HIS NAME - THE RAMAN EFFECT.

BORN IN TRICHINOPOLY IN 1888, RAMAN CAME TO CALCUTTA IN 1907 TO JOIN THE INDIAN FINANCE SERVICES, LATER LEAVING TO JOIN RAJABAZAR SCIENCE COLLEGE AS PALIT PROFESSOR OF PHYSICS. ALL THE WHILE, HE CONTINUED HIS EXPERIMENTAL RESEARCH IN ACOUSTICS AND OPTICS AT THE INDIAN ASSOCIATION FOR THE CULTIVATION OF SCIENCES, CALCUTTA, FROM 1907 TILL 1933.

IT WAS 1921 - RAMAN WAS ON HIS WAY BACK FROM THE CONGRESS OF UNIVERSITIES OF THE BRITISH EMPIRE, OXFORD, ABOARD THE S.S. NARKUNDA.
HE NOTICED THE VIBRANT BLUE OPALESCENCE OF THE MEDITERRANEAN SEA AND BEGAN PONDERING - WHAT GAVE THE SEA ITS STRIKING HUE?

HE WAS NOT CONVINCED THAT THE BLUE WAS SIMPLY A REFLECTION OF THE SKY, WHICH WAS THE PREVAILING EXPLANATION BY LORD RAYLEIGH AT THE TIME.

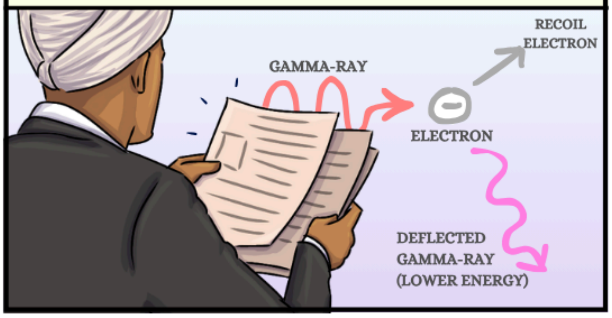
LIKE THE TRUE EXPERIMENTALIST THAT HE WAS, RAMAN PULLED OUT A POLARIZING NICOL PRISM FROM HIS POCKET.
QUENCHING THE REFLECTED LIGHT FROM THE SKY, HE NOTED THAT THE SEA'S BLUE HUE WAS UNATTENUATED - THE BLUE COLOUR WAS NOT MERELY A REFLECTION!
HE HAD A CONVICTION THAT WATER MOLECULES COULD SCATTER LIGHT, JUST AS AIR MOLECULES DID.
AS SOON AS THE SHIP REACHED BOMBAY, HE SENT A LETTER TO NATURE.

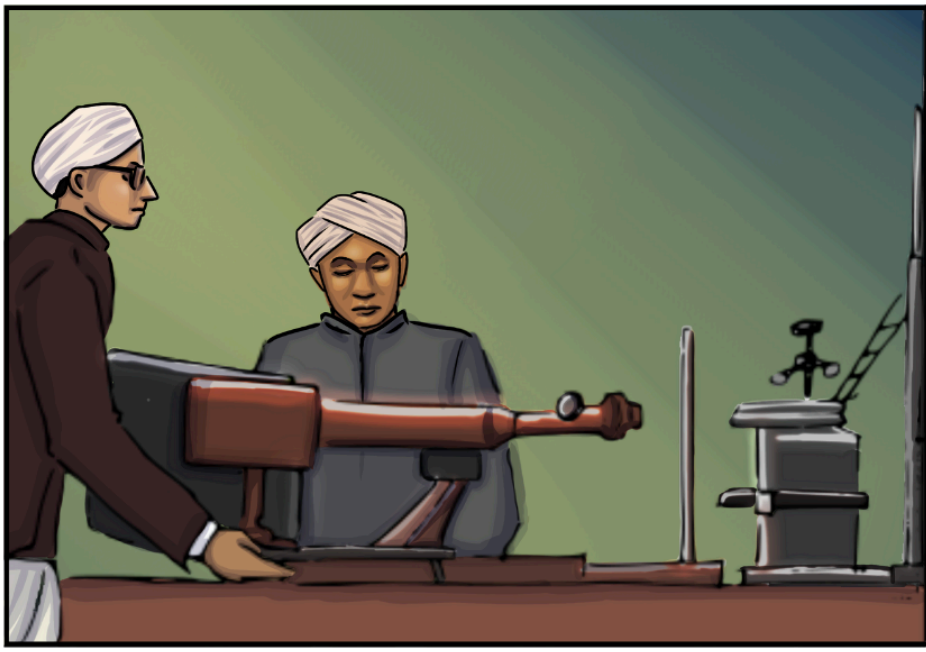


RAMAN'S RESEARCH GROUP AT IACS NOW EMBARKED UPON STUDYING LIGHT SCATTERING IN LIQUIDS.
THEIR SETUP WAS SIMPLE. LIGHT FROM A SOURCE - INITIALLY PLAIN SUNLIGHT, AND THEN SUNLIGHT CONCENTRATED USING A REFRACTING TELESCOPE - WAS PASSED THROUGH A COLOURED FILTER AND THEN MADE TO SCATTER OFF A LIQUID SAMPLE. OBSERVATIONS ON THE SCATTERED LIGHT WERE ALL CARRIED OUT BY EYE.

THEY TESTED OVER 60 DIFFERENT LIQUIDS AS WELL AS SOME SOLIDS, AND OBSERVED THE SAME WEAK, BUT UNDENIABLE EFFECT – THERE WAS A SHIFT IN THE COLOUR OF SOME OF THE SCATTERED LIGHT.

RAMAN'S COLLEAGUES INITIALLY DISMISSED THE PHENOMENON AS A FAINT TRACE OF FLUORESCENCE. HE, HOWEVER, HAD A DIFFERENT HUNCH.
IN 1922, ARTHUR HOLLY COMPTON HAD DISCOVERED THE "COMPTON EFFECT" - INELASTIC SCATTERING OF X-RAYS BY ELECTRONS. RAMAN SUSPECTED THAT SOME SIMILAR OCCURRENCE IN VISIBLE LIGHT MIGHT BE AT PLAY HERE, UNDERLYING THEIR STRANGE OBSERVATION.



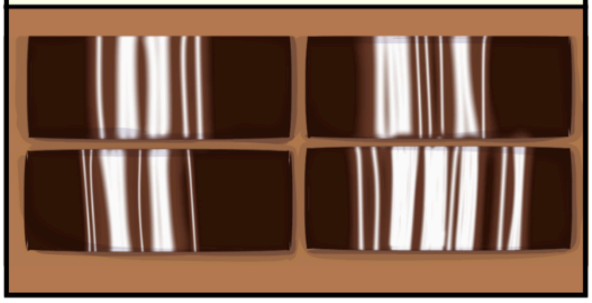


ALTHOUGH THE THEORETICAL IDEAS WERE STILL FUZZY, THE EVIDENCE FOR LIGHT SCATTERING IN BOTH LIQUIDS AND SOLIDS WAS CLEAR BY NOW.
RAMAN AND HIS COLLEAGUE K.S. KRISHNAN NOW SET OUT TO RIGOROUSLY VALIDATE THE FREQUENCY SHIFT THEY HAD OBSERVED, USING A HANDHELD POCKET SPECTROSCOPE.

FINALLY, THEY IMPORTED AND SET UP A QUARTZ SPECTROGRAPH, WITH WHICH THEY COULD CAPTURE THE SPECTRUM OF THE SCATTERED LIGHT, USING A MERCURY ARC LAMP AS THEIR LIGHT SOURCE.
RAMAN IS SAID TO HAVE REMARKED REGARDING THE SPECTROGRAPH, "WITH THIS, I BELIEVE I CAN GET A NOBEL PRIZE FOR INDIA."

SURE ENOUGH, THE PHOTOGRAPHIC PLATES FROM THE SPECTROGRAPH SHOWED FAINT, BUT DISTINCT, EMISSION LINES ON EITHER SIDE OF THE ELASTICALLY SCATTERED RAYLEIGH LINES.

FINALLY, ON FEBRUARY 28, 1928, THEY OBSERVED THAT THE SCATTERED LIGHT WAS POLARIZED, DISTINGUISHING THE OBSERVED EFFECT FROM FLUORESCENCE WITH CERTAINTY.
RAMAN'S SUSPICIONS WERE PROVEN TRUE - THIS WAS INDEED A NEW PHENOMENON, INELASTIC SCATTERING OF VISIBLE LIGHT!



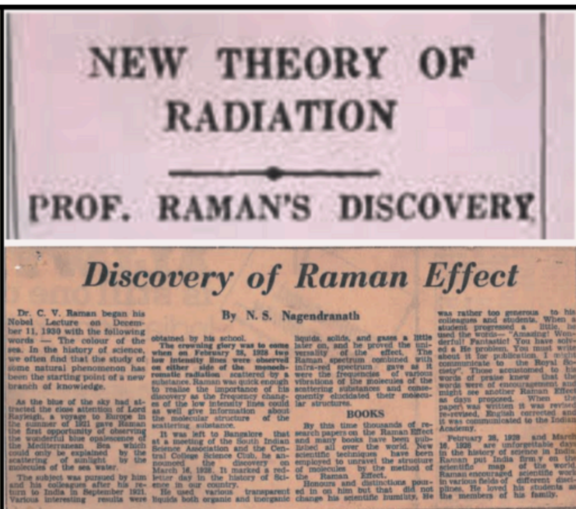
RAMAN AND KRISHNAN SENT OFF A SHORT PAPER TO NATURE, TITLED "A NEW TYPE OF SECONDARY RADIATION", BRIEFING THEIR RESULTS AND THE NEW DISCOVERY. IT WAS PUBLISHED ON MARCH 31, 1928.

RAMAN FIRST PRESENTED THEIR QUANTITATIVE MEASUREMENTS ON MARCH 16, IN HIS LECTURE TO THE SOUTH INDIAN SCIENCE ASSOCIATION. THE RESULTS, INCLUDING THE SPECTRAL DATA, WERE DETAILED IN RAMAN'S PAPER IN THE INDIAN JOURNAL OF PHYSICS, PUBLISHED IN APRIL 1928.

THE NEWS OF RAMAN'S DISCOVERY SENT WAVES THROUGH THE PHYSICS COMMUNITY. PHYSICISTS RECOGNIZED ITS SIGNIFICANCE IN THE ERSTWHILE NEWLY-DEVELOPING QUANTUM THEORY OF LIGHT. SEVERAL SCIENTISTS REPRODUCED AND STUDIED "THE RAMAN EFFECT" IN THE FOLLOWING YEARS.

IN RUSSIA, MANDELSTAM AND LANDSBERG HAD ALSO INDEPENDENTLY FOUND THE SAME EFFECT IN QUARTZ CRYSTALS AROUND THE SAME TIME, BUT THEIR WORK WAS PUBLISHED LATER, IN JULY 1928.

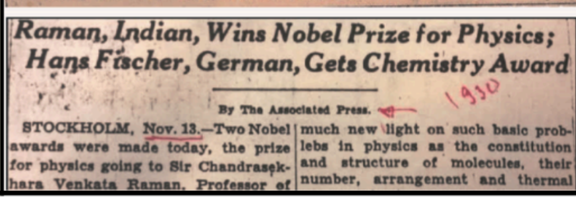
FINALLY, IN 1930, SIR C.V. RAMAN WON THE NOBEL PRIZE IN PHYSICS - THE FIRST NON-WHITE SCIENTIST, AND SO FAR THE ONLY INDIAN SCIENTIST, TO EVER HAVE WON A NOBEL FOR A SCIENTIFIC DISCOVERY.


NEW THEORY OF RADIATION

PROF. RAMAN'S DISCOVERY

Discovery of Raman Effect

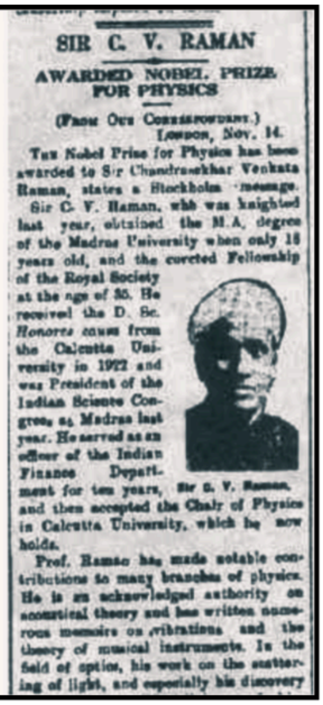
By N. S. Nagendranath


Raman, Indian, Wins Nobel Prize for Physics; Hans Fischer, German, Gets Chemistry Award

By The Associated Press.

1930

STOCKHOLM, Nov. 13.—Two Nobel awards were made today, the prize for physics going to Sir Chandrasek-hara Venkata Raman, Professor of much new light on such basic prob-lebs in physics as the constitution and structure of molecules, their number, arrangement and thermal


SIR C. V. RAMAN

AWARDED NOBEL PRIZE FOR PHYSICS

(From Our Correspondent.)
London, Nov. 14.

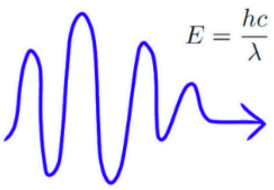
The Nobel Prize for Physics has been awarded to Sir Chandrasekhar Venkata Raman, states a Stockholm message.

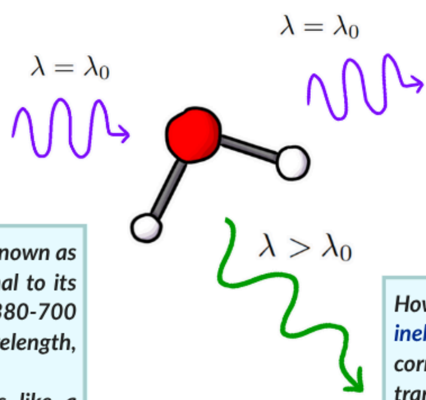
Sir C. V. Raman, who was knighted last year, obtained the M.A. degree of the Madras University when only 18 years old, and the coveted Fellowship of the Royal Society at the age of 35. He received the D. Sc. Honoris causa from the Calcutta University in 1922 and was President of the Indian Science Congress at Madras last year. He served as an officer of the Indian Finance Department for ten years, and then accepted the Chair of Physics in Calcutta University, which he now holds.

Sir C. V. Raman.

Prof. Raman has made notable contributions to many branches of physics. He is an acknowledged authority on acoustical theory and has written numerous memoirs on vibrations and the theory of musical instruments. In the field of optics, his work on the scattering of light, and especially his discovery

WHAT IS THE RAMAN EFFECT - AND WHY IS IT SO SIGNIFICANT?

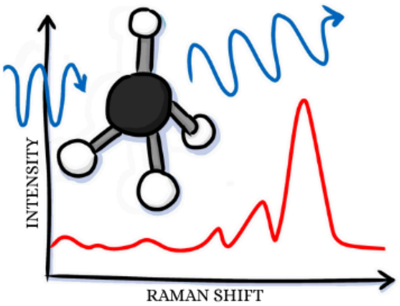




Light travels in the form of discrete wave-packets known as photons. A photon's energy is inversely proportional to its wavelength. The colour of visible light (380-700 nanometres) is determined by its frequency or wavelength, and thus directly by its energy.
When light is incident upon matter, it behaves like a stream of particles. Upon striking a molecule, photons interact with it and get deflected at different angles. This is the phenomenon of scattering.

Most of these scattering events are elastic - the collisions do not result in any transfer of energy between the photon and the molecule.
The deflected photon has the same frequency as the incident state, hence the scattered light has the same colour.
This is known as Rayleigh scattering.

However, a small fraction of these collisions are inelastic, i.e. they result in energy transfer - corresponding to rotational and vibrational transitions in the molecule.
Thus, some photons are deflected with a higher or lower energy, giving a different colour to a fraction of the scattered light. This is the phenomenon of Raman scattering, or the Raman effect.
This was why, in Raman's early light-scattering experiments on liquids, a part of the purple filtered sunlight was scattered as green.



The discovery of the Raman effect provided experimental support for the theory of discrete light quanta, as well as for quantum transitions between molecular energy levels. The theoretical implication was profound - the Raman shifts in light scattered from a molecule were a direct imprint of its vibrational energy levels.

The Raman shift plotted against intensity of the scattered light is known as the Raman spectrum. The Raman spectrum is unique for a given kind of molecule, which is why it is known as a "molecular fingerprint".

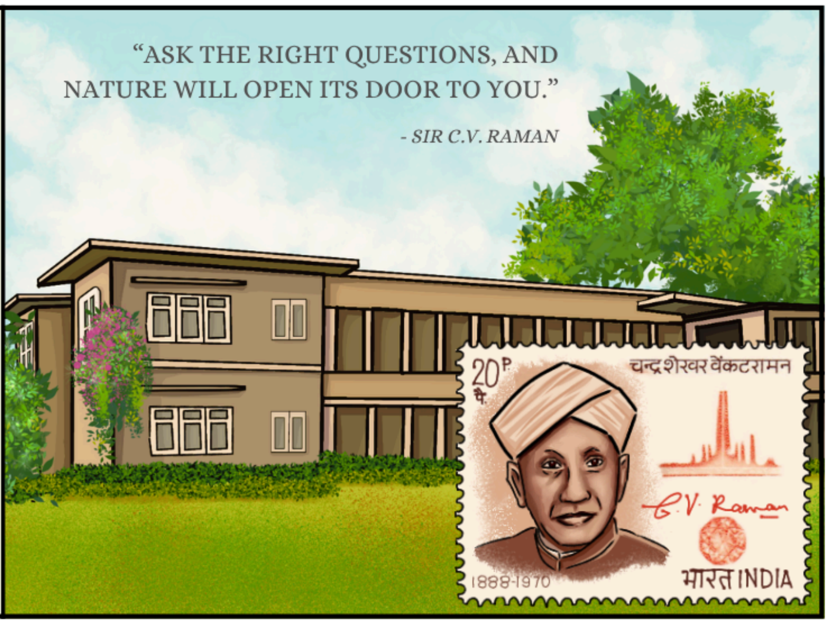
With the invention of the laser as a coherent monochromatic light source in the 1960s, the Raman spectra of molecules could now be captured and studied in high resolution, providing the first impetus to the development of Raman spectroscopy. Analysis of the Raman spectra allowed for characterisation of substances based on their "molecular fingerprint", and thus detection of their chemical composition.

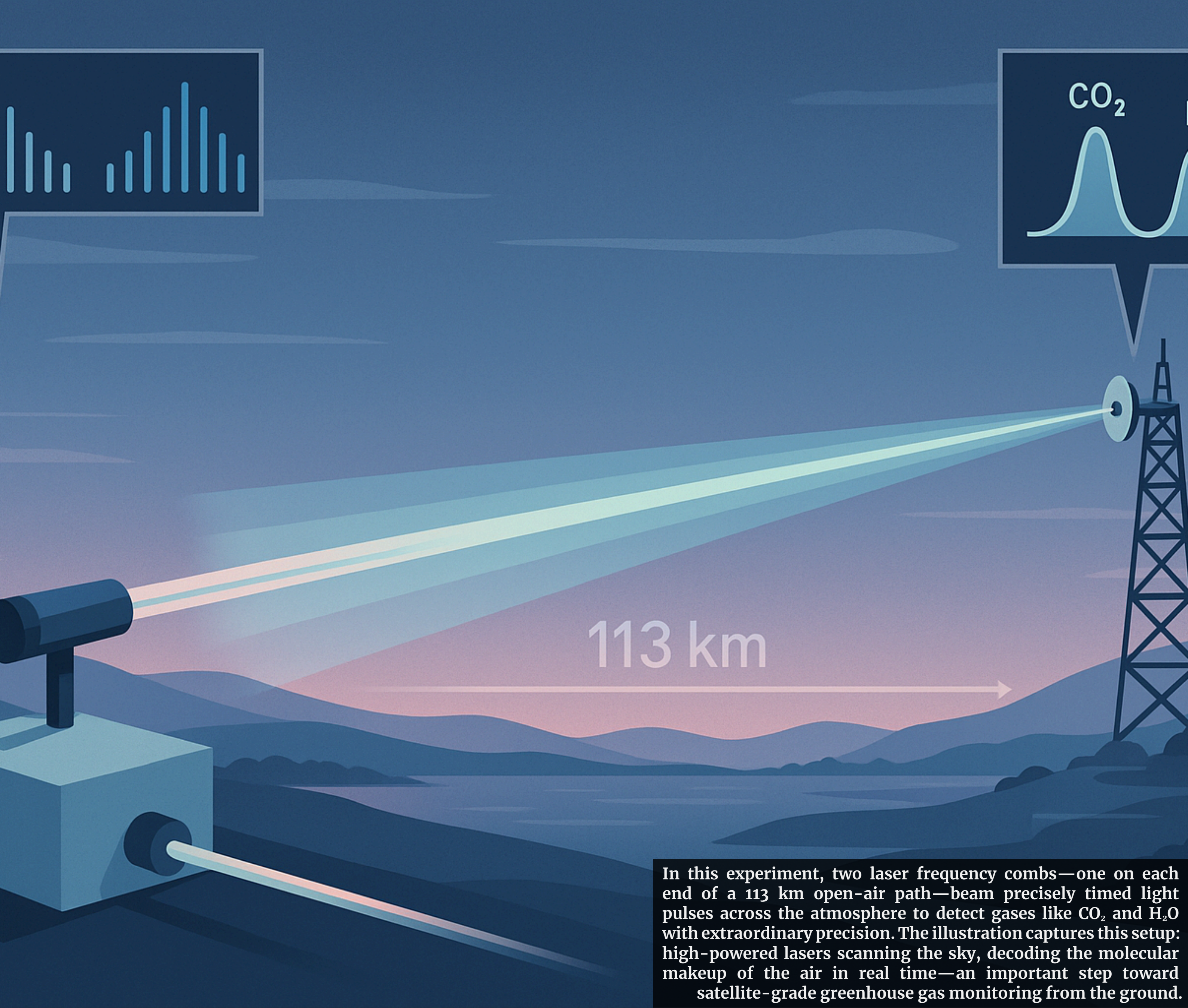
Today, this principle finds application in technologies like Raman spectroscopes, confocal Raman microscopes, Raman scanners, etc. which are widely used for a multitude of detection, identification and characterisation purposes across diverse fields, ranging from healthcare, to forensics, to industrial chemistry, to materials science research.

RAMAN RECEIVED SEVERAL MORE HONOURS FOR HIS CONTRIBUTIONS TO PHYSICAL SCIENCE, INCLUDING THE KNIGHTHOOD FROM THE BRITISH EMPIRE IN 1929, AND THE BHARAT RATNA IN 1954.

HE BECAME THE FIRST INDIAN DIRECTOR OF THE INDIAN INSTITUTE OF SCIENCE, BANGALORE, SERVING FROM 1933 TILL 1948, AFTER WHICH HE WENT ON TO ESTABLISH THE RAMAN RESEARCH INSTITUTE IN THE SAME CITY, WHERE HE CONTINUED HIS SCIENTIFIC WORK TILL THE END OF HIS LIFE.

TO COMMEMORATE RAMAN'S DISCOVERY, 28TH FEBRUARY IS OBSERVED AS NATIONAL SCIENCE DAY IN INDIA EVERY YEAR. ALMOST A CENTURY ON, SIR C.V. RAMAN'S LEGACY REMAINS A BEACON OF SCIENTIFIC CURIOSITY AND EXCELLENCE, INSPIRING GENERATIONS OF SCIENTIFIC MINDS TILL DATE.





In this experiment, two laser frequency combs—one on each end of a 113 km open-air path—beam precisely timed light pulses across the atmosphere to detect gases like CO_2 and H_2O with extraordinary precision. The illustration captures this setup: high-powered lasers scanning the sky, decoding the molecular makeup of the air in real time—an important step toward satellite-grade greenhouse gas monitoring from the ground.

Insight Digest

Fresh highlights from the frontiers of science

Debanuj Chatterjee Fast and precise atmospheric sensing over 100 km open path

Chitradeep Saha Tree rings unlock the sun's age old secrets

Madhura Narayan Joshi How does Antarctic sea ice and circulation change fate of global CO_2 levels

Swarnendu Saha Old carbon routed from land to the atmosphere by global river systems

Also available online, at scicomm.iiserkol.ac.in

Fast and precise atmospheric sensing over 100 km open path

Han, JJ., Zhong, W., Zhao, RC. et al. Nat. Photon. 18, 1195–1202 (2024)

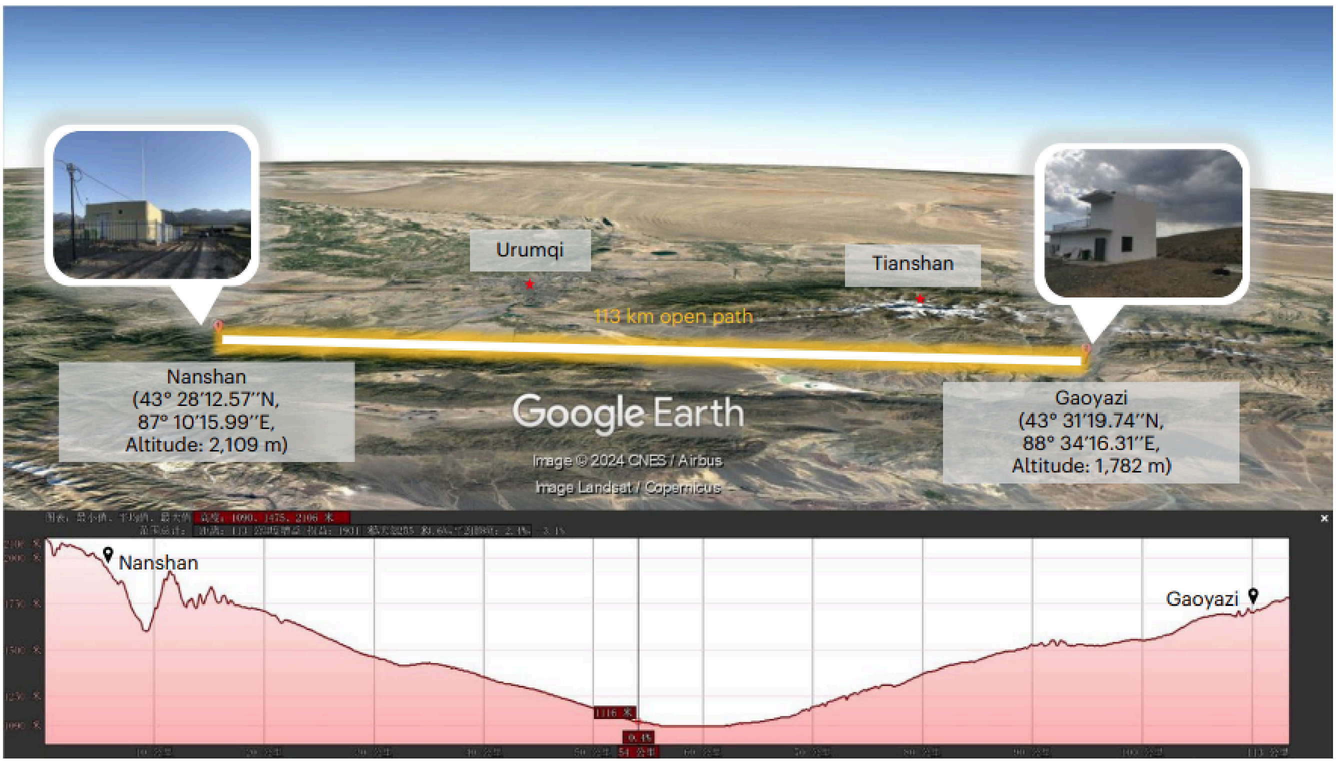
Contributed by **Debanuj Chatterjee (University of Lille, France)**

Dual comb spectroscopy (DCS) is a powerful optical sensing technique that leverages two laser frequency combs, to measure gas absorption with high speed and sensitivity. By precisely determining the absorption frequencies of the sample, across a broad spectral range, DCS can detect trace gases like carbon dioxide (CO_2) and water vapor (H_2O) in the atmosphere with sub-ppm precision. This makes it ideal for applications in climate science, especially relevant for air quality monitoring, greenhouse gas emissions tracking, etc.

Traditionally, the reach of DCS when performed in open path has been limited to distances under 20 km due to significant signal loss and technical constraints, such as the need for highly reflective mirrors, high atmospheric turbulence, etc. However, last year, in a landmark advancement, researchers from the University of Science and Technology of China have now extended DCS to a staggering 113 km open-air horizontal path; nearly six times longer than previous records.

To achieve this, the team utilized a novel bistatic configuration, placing one frequency comb at each end of the path and transmitting light bidirectionally through the atmosphere without the need for reflectors. Each comb was synchronized to a rubidium atomic clock, acting as a local timing reference. The system incorporated high-power (1 W) optical frequency combs stable telescopes, and real-time data acquisition to overcome atmospheric turbulence and extreme signal attenuation, going up to 83 dB.The experiment conducted between two mountain sites in the Xinjiang provice of China, viz. Nanshan and Gaoyazi, successfully measured absorption spectra of CO_2 and H_2O over a 7 nm bandwidth and a frequency accuracy of 10 kHz. The system achieved CO_2 detection sensitivities better than 2 ppm in just 5 minutes and below 0.6 ppm in 36 minutes; a remarkable performance for such a long-range setup.

This breakthrough not only validates DCS for ultra-long-range sensing but also opens a plethora of possibilities for a diverse set of technological advancements. A curious reader would ask, if one can perform DCS over 100 km path in the turbulent atmosphere, why not shoot it towards the sky? Can the dual comb reach the ionosphere (50 km) and get reflected with only the radio wave content? Can it lay the foundation for future satellite-ground dual comb links? Can it perform high-precision monitoring of greenhouse gases from geostationary orbits? I leave the numerous possibilities to the fancy of



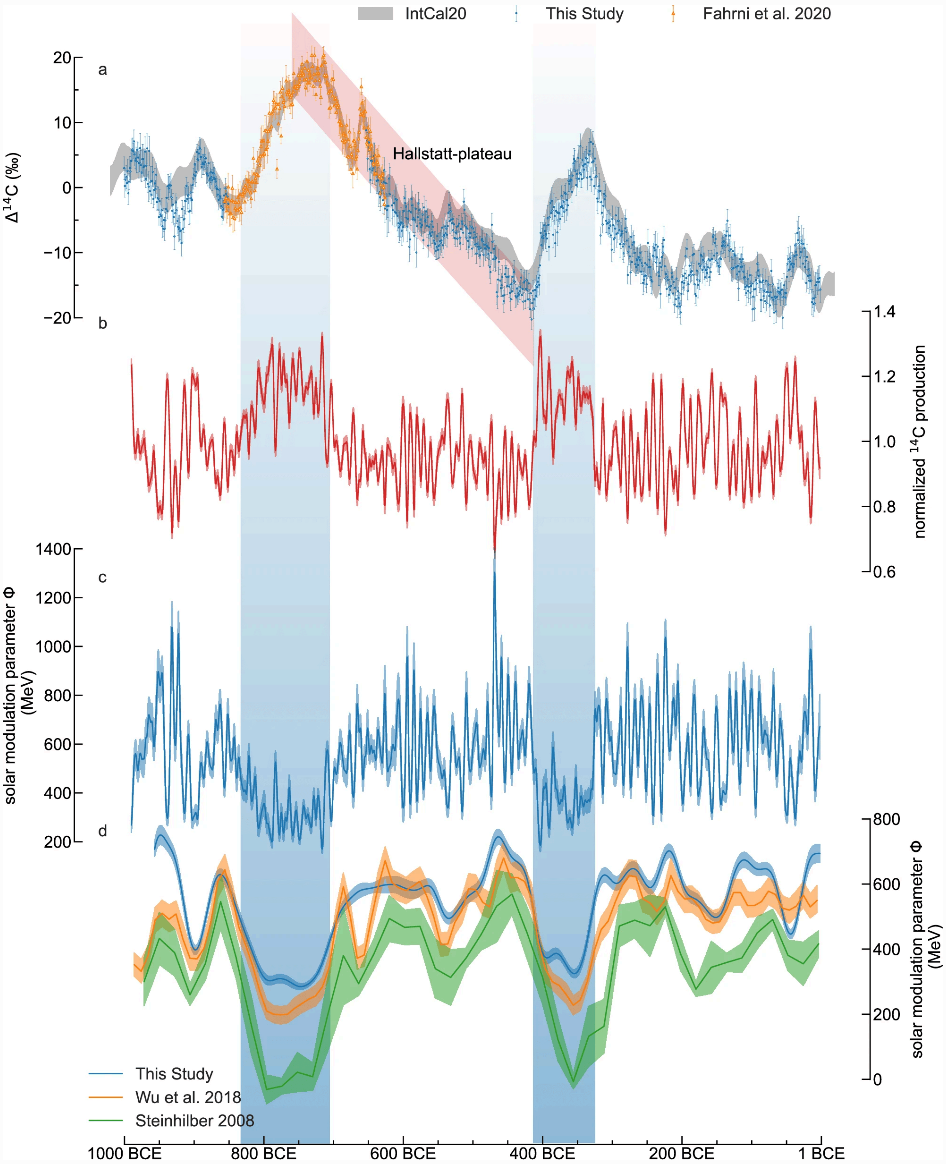
Google Earth view of the DCS path of 113 km running from Nanshan to Gaoyazi in China.

Tree rings unlock the sun's age old secrets

Brehm, N., Pearson, C.L., Christl, M. et al. Nat Commun 16, 406 (2025)

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

The oldest telescopic observation of the sun is only four centuries old. Thanks to nature's silent archivists, it is possible to unveil how this star behaved multiple millennia ago. Tree rings are one such natural reservoir that keeps a record of the time. Cosmogenic isotope contents in old tree rings carry imprints of the terrestrial climate, which in turn is modulated by the sun's magnetic activity. A more magnetically active sun sweeps away galactic cosmic rays more vigorously. As a consequence, the production rate of radioactive isotopes in the earth's atmosphere goes down. This results in a reduced amount of Carbon-14 deposition in the tree rings during the period of enhanced solar activity, and vice-versa. Recently, scientists have used precise dendrochronological techniques to retrieve the sun's magnetic behaviour during the first millennium BCE with an unprecedented resolution of annual time scale. They have successfully detected a strong decennial timescale signal in the isotope data, as expected from current understanding of the solar cycles. Besides, their analysis hints towards possible occurrences of two solar grand minimum episodes during this period. Solar grand minima are phases of prolonged magnetic quiescence on the sun. These findings have implications for a better understanding of solar-stellar magnetism.



A plot showing the variation of Carbon 14 production rate (top two panels), and solar modulation potential – a measure of solar magnetic activity (bottom two panels) during 1000-1 BCE. Vertical shaded regions depict the two solar grand minima events. Notably, Carbon 14 production goes up during the reduced solar activity phases, and vice-versa.

How does Antarctic sea ice and circulation change fate of global CO_2 levels

R. Ferrari, M.F. Jansen, J.F. Adkins, A. Burke, A.L. Stewart, & A.F. Thompson, Antarctic sea ice control on ocean circulation in present and glacial climates, Proc. Natl. Acad. Sci. U.S.A. 111 (24) 8753-8758 (2014)

Contributed by **Madhura Narayan Joshi (22MS, IISER Kolkata)**

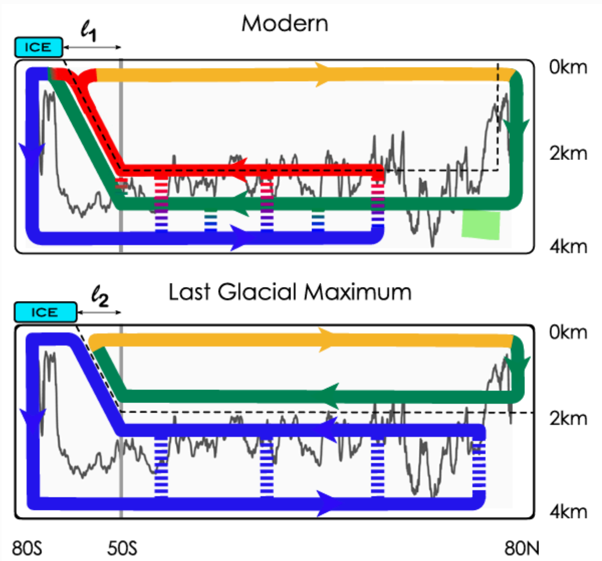
One of the key indicators of climate change is global warming — often discussed in academic circles and increasingly felt in daily life. A major driver of this warming is the rising concentration of atmospheric CO_2 over recent decades. Oceans, which store about 90% of Earth's carbon (combined oceanic, atmospheric, and terrestrial), play a vital role in regulating the carbon cycle and influencing climate.

During the Last Glacial Maximum (LGM), around 25,000 to 20,000 years ago, Earth's surface was 3–6 °C colder, atmospheric CO_2 levels were 80–90 ppm lower, and vast ice sheets and sea ice covered the poles. Unlike the modern ocean, where Arctic-origin waters dominate and Antarctic waters occupy depths below 4 km, LGM oceans were filled with Antarctic-sourced waters up to 2 km, compressing northern water masses into shallower layers. This reorganization of deep water circulation reduced CO_2 escape from the ocean surface and drew down atmospheric concentrations by 10–20 ppm.

Previously, these shifts were seen as a sum of individual physical changes — altered currents, increased layering, and less CO_2 outgassing from the Southern Ocean. Several mechanisms contributed: an equatorward shift of the Southern Hemisphere westerlies weakened upwelling of deeper water, increased stratification acted like a lid on carbon venting, expanded sea ice reduced air-sea exchange, and reduced mixing between northern and southern waters limited carbon leakage.

Overturning circulation is a large-scale movement of ocean water where warmer, lighter surface waters move toward the poles, cool, and sink to form deep currents that eventually return to the surface. This circulation is driven by two main factors: flow along isopycnals (surfaces of equal density) and surface buoyancy flux — which reflects whether water in a region is becoming lighter (due to warming or precipitation) or denser (due to cooling, brine rejection, or evaporation). These isopycnals slope steeply at high latitudes, and a key one the 27.9 kg/m^3 isopycnal which separates the shallow and deep overturning branches in the Southern Ocean.

In today's climate, the sea ice edge stays close to Antarctica, and the isopycnal plunges below 2 km before reaching ocean basins. There, it intersects topography like ridges and seamounts, enhancing mixing and connecting the two branches into a single, figure-eight-like circulation. However, during the LGM, the summer sea ice line shifted northward by about 500 km. The isopycnal followed, shoaling above 2 km and avoiding major topography. Without significant mixing, the circulation split into two separate loops: deep Antarctic



Schematic of overturning circulation in modern(upper) and LGM(lower) highlighting change through time. The blue ribbon is indicative of Antarctic bottom water, green indicate North Atlantic deep water, red indicates Indian and Pacific ocean deep waters and orange indicates Antarctic intermediate waters. The black dashed line is an isopycnal which separates two branches of circulation in Southern Ocean. ℓ1 is the distance between the northernmost latitude reached by the ACC, indicated by a solid gray line, and the quasi-permanent sea ice line. The ragged gray line is the crest of the main bathymetric features of the Pacific and Indian ocean basins: mixing is enhanced below this line. The extent of the quasi-permanent sea ice line has shifted equatorward compared with modern climate ðℓ2 < ℓ1Þ. Mixing-driven upwelling of abyssal waters is confined below 2 km and it cannot lift waters high enough to upwell north of the ice line. As a result the abyssal overturning circulation closes on itself, leaving above a small overturning cell of North Atlantic waters.

Old carbon routed from land to the atmosphere by global river systems

Dean, J.F., Coxon, G., Zheng, Y. et al. Old carbon routed from land to the atmosphere by global river systems. Nature 642, 105–111 (2025)

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

We usually think of rivers as part of the modern carbon cycle — transporting carbon that plants have recently absorbed from the atmosphere. But this new study reveals that rivers also act as a hidden highway, carrying very old carbon — hundreds to thousands of years old — from land into the air.

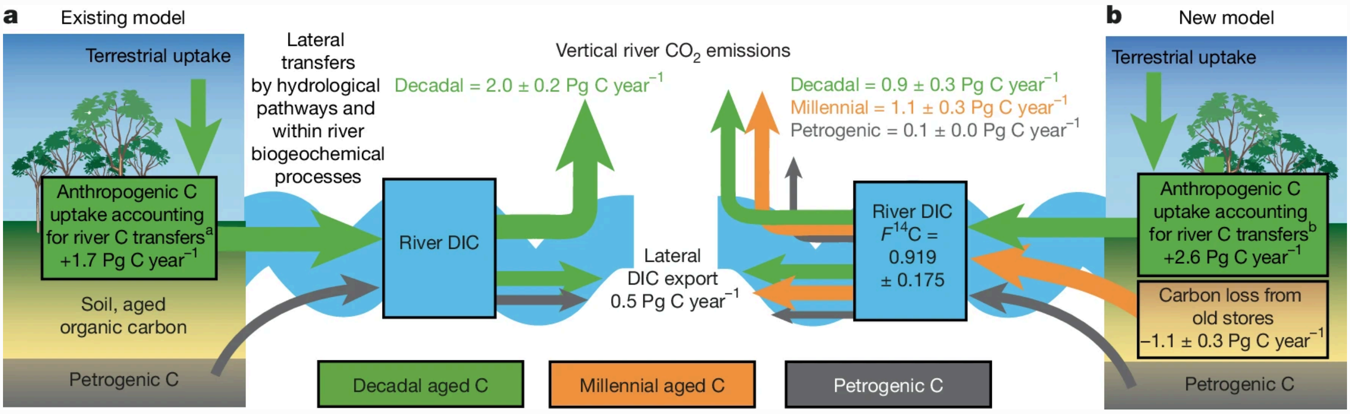
Scientists examined over 1,100 samples from rivers all over the world, looking at the type of carbon gases (CO_2 and CH_4) being released into the air. By measuring radiocarbon (a kind of natural carbon dating), they could determine how "old" the carbon was. Surprisingly, nearly 60% of river CO_2 emissions were found to come from millennia-old carbon, not recent plant activity.

This "old" carbon comes from deep in the soil, sediments, and even from ancient rocks. Rain and groundwater erode and carry this carbon into rivers, which then release it into the atmosphere. The amount of old carbon released — around 1.2 billion tons per year — is nearly as much as all the carbon plants worldwide absorb from the atmosphere in a year.

Different factors affect how much old carbon a river releases. Rivers in areas with sedimentary rocks, like limestone, or those in high mountain regions, were more likely to release older carbon. Large rivers also showed older carbon emissions, which challenges the common belief that only small rivers are affected by old carbon sources.

These findings mean that current climate models and carbon budgets may be underestimating how much ancient carbon is being released. Old carbon, once locked in the earth, is now entering the modern carbon cycle — potentially speeding up climate change.

This study suggests we need to rethink how rivers fit into the global carbon puzzle. Rivers are not just channels for young, fresh carbon. They are also leaks for ancient carbon stores, and this has major implications for how we understand and manage Earth's carbon balance.



a) In the earlier model, it was believed that river carbon dioxide (CO_2) was mainly released from young, fast-cycling carbon — recently captured by plants (referred to as decadal-aged, shown in green). A smaller portion was considered to come from rocks (petrogenic carbon, shown in grey). Based on this understanding, it was estimated that about 1.7 billion tons of human-caused CO_2 per year was being absorbed and stored in forests and soils. b) In the revised model, new measurements of carbon age in rivers (using radiocarbon data) revealed that much of the CO_2 released by rivers is from older sources — carbon stored for thousands of years. This old carbon is believed to be released from deeper soils and weathered rocks. As a result, it is now recognized that rivers act as a pathway through which ancient carbon is lost from the land to the atmosphere. This finding requires a change in how Earth's carbon storage is understood and how human CO_2 emissions are tracked.

This issue's crossword is drawn from Chemistry.

Science Games

Questions drawn from ideas of general science.
Science Quiz

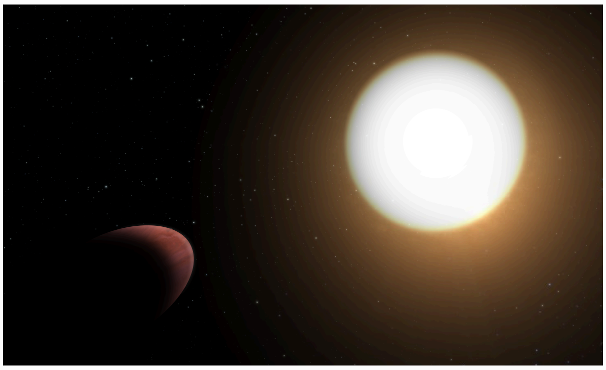
The theme for this issue is Chemistry.
Themed Crossword

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

General Science Quiz

Q1. NASA's James Webb Space Telescope recently detected several unexpected molecules — including one never before observed in any planetary atmosphere — in the scorching skies of a tidally locked gas giant exoplanet. This planet is approximately 1.2 times the mass of Jupiter and completes an orbit around its star every 30.5 hours. **Which exoplanet is it?**

I. Kepler-186f
II. WASP-121b
III. TRAPPIST-1d
IV. HD 209458b



Q2. This amino acid, found in certain foods and produced by the human body, has been shown in animal studies to slow signs of aging and extend lifespan when taken as a supplement. However, recent research is questioning this by examining its levels in people, monkeys, and mice across different ages. **Can you name this amino acid?**

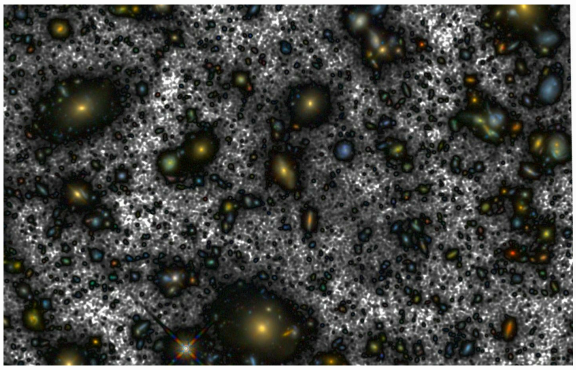
I. Glycine
II. Taurine
III. Lysine
IV. Tryptophan

Q3. For years, scientists believed the mysterious dark streaks running down cliffs and crater walls on Mars were caused by flowing water. However, a recent AI-powered study published in *Nature Communications* suggests a new explanation. **What is now believed to be the more likely cause of these long, dark features that stretch for hundreds of meters down Martian slopes?**

I. Lava flows from ancient volcanoes
II. Subsurface ice melting
III. Movement of wind and dust
IV. Seepage of salty brine

Q4. Fossilized bones of an extinct human ancestor were recently discovered on the seafloor of the Madura Strait in Indonesia. These remains reveal a previously unknown population that hunted large animals and may have interacted culturally with other human species nearly 140,000 years ago. **Which species was this?**

I. Neanderthal (Homo neanderthalensis)
II. Denisovan
III. Homo habilis
IV. Homo erectus



Q5. This is one of the most iconic deep-space images ever captured, and reveals thousands of galaxies, some dating back to less than a billion years after the Big Bang. **Which space telescope took this photograph?**

I. James Webb Space Telescope
II. Spitzer Space Telescope
III. Chandra X-ray Observatory
IV. Hubble Space Telescope

Q6. Which hospital superbug — known for causing deadly infections — was recently discovered to survive by breaking down and consuming biodegradable medical plastics such as sutures and implants?

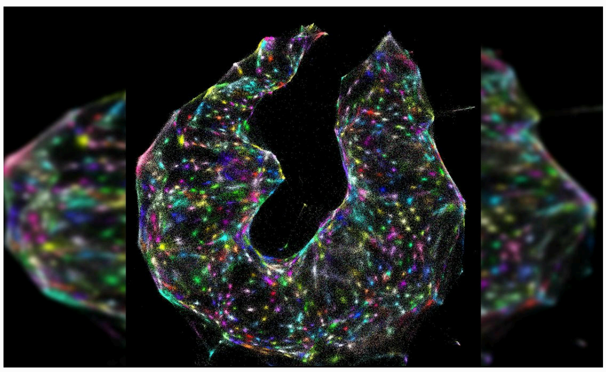
I. Escherichia coli
II. Staphylococcus aureus
III. Pseudomonas aeruginosa
IV. Clostridium difficile

Q7. Jayant Vishnu Narlikar, a pioneering Indian astrophysicist, collaborated with a prominent British cosmologist to develop a theory that challenged the conventional Big Bang model. Their theory incorporated continuous matter creation, avoided a singular beginning of time, and was based on Mach's Principle, introducing a scalar field responsible for spontaneously generating matter. **What was the name of this cosmological theory?**

I. A model featuring inflation and quantum fluctuations that seeded cosmic structure
II. A steady-state theory with continuous matter creation via a scalar creation field
III. A universe governed only by general relativity and cold dark matter, beginning with a singularity
IV. A cyclic model involving repeated big bangs and big crunches

Q8. This renowned string theorist was one of the first recipients of the Breakthrough Prize in Fundamental Physics, for "opening the path to the realization that all string theories are different limits of the same underlying theory." He has made advancements in calculation of black hole entropy from first principles. **What's his name?**

I. Stephen Hawking
II. Ashoke Sen
III. Juan Maldacena
IV. Edward Witten



Q9. The image shows a revolutionary genetic imaging technique that maps DNA and RNA distribution inside living cells with unprecedented detail. themselves, it does not use traditional optics or lenses, instead reconstructing spatial information from genetic sequences alone. **What is this technique called?**

I. Cryo-electron microscopy
II. Fluorescence in situ hybridization (FISH)
III. DNA microscopy
IV. Optical coherence tomography

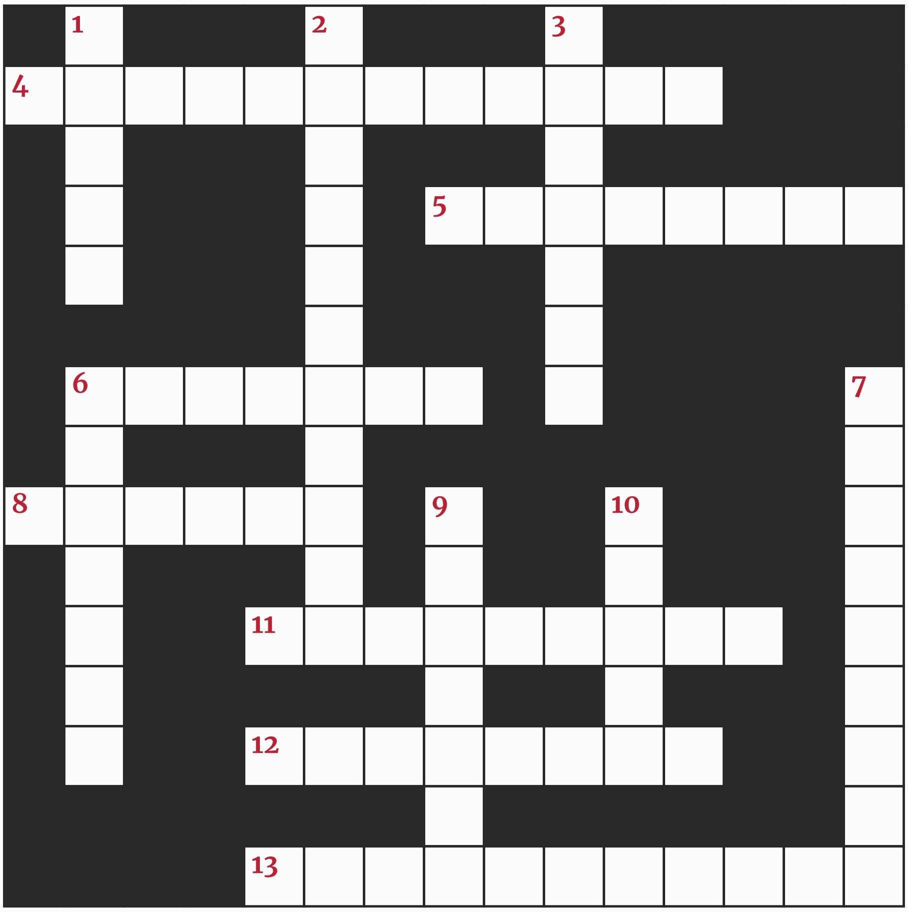
Q10. The surreal landscape in the image is marked by vivid green, yellow, and orange colors, caused by acidic, mineral-rich brine bubbling from hydrothermal pools. Despite their colorful appearance, some of these pools are completely devoid of life, making them among the harshest environments on Earth. **Which location is this?**

I. Yellowstone Caldera, USA
II. Danakil Depression, Eritrea
III. Mount Erebus, Antarctica
IV. Dallol, Northern Ethiopia

Answers can be found at the end of the issue. For an interactive version of the quiz, check out our ***website***

Themed Crossword

This issue's crossword is drawn from **chemistry**.



Across

4. Using electricity to split compounds into elements or simpler compounds (12)
5. Speeds up a chemical reaction without being consumed, crucial in oil refining (8)
6. Pioneer in quantum chemistry and molecular biology; explained nature of chemical bonding, won Chemistry and Peace Nobel Prizes (7)
8. Ionized, high-energy state of matter with free electrons (6)
11. Created the first widely accepted periodic table by organizing elements by atomic mass, predicted new elements (9)
12. Breaking large hydrocarbons into smaller ones (e.g., in fuel refining) (8)
13. Transition from a solid to a gas without becoming a liquid, like dry ice into vapor (11)

Down

1. Mixture of metals and/or non-metals to create materials with improved properties (5)
2. A solid that forms and separates from a liquid during a chemical reaction; often seen in cloudiness or as solids in test tubes (11)
3. Atoms of same element with different neutron numbers; used in radiology or carbon dating (7)
6. Large molecules of repeating units, like in plastics or DNA (7)
7. Process by which particles spread out from high concentration to low concentration (9)
9. Highly reactive molecule or atom with an unpaired electron (7)
10. Trade name for refrigerant gases; damaging to the ozone layer (5)

Solution can be found at the end of the issue. For an interactive version of the crossword, check out our website.

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: **TURBULENCE**

1. A community of organisms interacting with their environment through energy flow and nutrient cycling. (9)
   E _ _ _ _ _ _ _ _
2. All chemical reactions in an organism that produce energy from food and build or break down molecules. (10)
   _ _ _ _ _ _ _ _ _ _
3. A permanent change in DNA sequence that can alter traits or cause genetic disorders. (8)
   _ _ _ _ _ _ _ _
4. The kidney's functional unit that filters blood, reabsorbs useful substances and forms urine. (7)
   _ _ _ _ _ _ _
5. A DNA/RNA building block made of a sugar, phosphate group and nitrogen base. (10)
   _ _ _ _ _ _ _ _ _ _
6. The physical process of water changing into vapor, often driven by heat, as part of the water cycle. (11)
   _ _ _ _ _ _ _ _ _ _ _
7. A nearly massless, chargeless particle from nuclear reactions that rarely interacts with matter. (8)
   _ _ _ _ _ _ _ _
8. The gravitational path followed by a celestial body around another object. (5)
   _ _ _ _ _
9. Related to movement of Earth's lithospheric plates, causing quakes and mountain formation. (8)
   _ _ _ _ _ _ _ _
10. A substance that speeds up a chemical reaction without being consumed. (8)
    _ _ _ _ _ _ _ T

*Solution can be found at the end of the issue. For an interactive version of this game, check out our **website**.*

Join the Conversation

Contribute

Contributions are welcome from students and faculty members across all academic institutions, on a rolling basis. Submission portals for all types of content can be found on our website. More detailed guidelines are also available there, so please refer to the linked page if you're interested in contributing. For any queries, feel free to contact us at *scicomm@iiserkol.ac.in*.

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To showcase cutting-edge research, we publish short summaries (350–400 words) of recently published scientific papers. The summary should broadly outline the research questions and highlight the key findings.. Submit your research stories **here**.

Interview Recommendations

If you would like us to interview a particular scientific personality, or if you have an interview you'd like us to consider for publication, please reach out to us at *scicomm@iiserkol.ac.in*.

More 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*.

Join our 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.

The Last Page

Crossword

Across

4. ELECTROLYSIS
5. CATALYST
6. PAULING
8. PLASMA
11. MENDELEEV
12. CRACKING
13. SUBLIMATION

Down

1. ALLOY
2. PRECIPITATE
3. ISOTOPE
6. POLYMER
7. DIFFUSION
9. RADICAL
10. FREON

Quiz

1. WASP-121b
2. Taurine
3. Movement of wind and dust
4. Homo erectus
5. Hubble Space Telescope
6. Pseudomonas aeruginosa
7. A steady-state theory with continuous matter creation via a scalar creation field
8. Ashoke Sen
9. DNA microscopy
10. Dallol, Northern Ethiopia

Linked List

1. ECOSYSTEM
2. METABOLISM
3. MUTATION
4. NEPHRON
5. NUCLEOTIDE
6. EVAPORATION
7. NEUTRINO
8. ORBIT
9. TECTONIC
10. CATALYST

You made it to the end! While we cook up the next issue, here's a random photo dump.

Tradition and Modernity

A Dazzling Fusion of Culture and Creativity - IISER Kolkata's Fashion Show Celebrates Bold Expression and Timeless Aesthetics. *Credit: Jibitesh Das*

Germination

On the occasion the *20th Institute Foundation Day* and the Open House event with science exhibition organized was attended by more than 1000 students from neighbouring schools with lots of excitement. *Credit: IISER Kolkata*

The Prisoner of Conscience

A still from the IICM 2024 stage act. *Credit: Swarnendu*