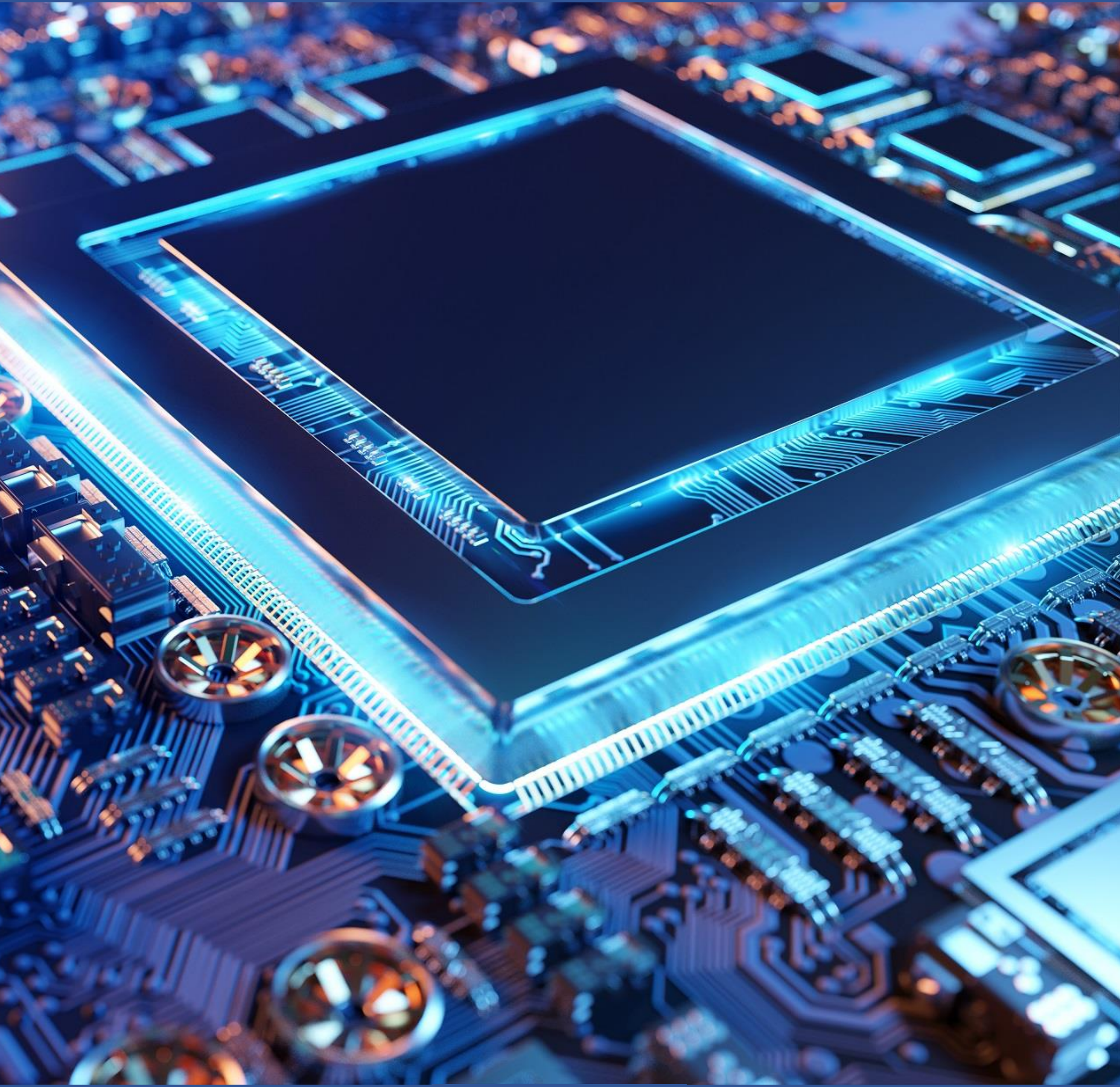
PHYSICS NEWSLETTER

SPRING 2023



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Cover image: Planqc's computer will be integrated into DLR's quantum computing stack. Credit: sdecoret via Shutterstock

LETTER FROM THE HEAD

I very happy with the initiative taken by the students of the department to highlight the activities of the department, especially the cutting-edge research activities. During the past ten years, a number of very active researchers joined the department and the research profile of the department has experienced an exponential growth with the younger faculty leading the way in quite a few fields. Of course, this strong growth would not have been possible without the active and enthusiastic participation of doctoral, masters and bachelors students.

It is heartening to see the interest evinced by the masters and bachelors students in the research being done in the department.

I wish all the best for this first effort in bringing out the newsletter and fervently hope that it will be a regular feature of our departmental calendar.

Best Wishes,
S. Uma Shankar

Head
Physics Department
IIT Bombay

WELCOME MESSAGE

Hello everyone.

The Physics department is one of the oldest departments in IIT Bombay; it started with the establishment of IIT Bombay itself. It feels that our physics department follows the Indian philosophy of unity in diversity. We have very brilliant minds who come from different cultures.

The last two years were very unpredictable and challenging. But we won the war and once again met in 2022.

As we have many creative minds, we decided to make a magazine that compiles the exciting interviews of some of our faculty, student section, and views of professors and doctoral students on current research in different subject areas. Last year Nobel Prize was awarded to *Alain Aspect, John Clauser and Anton Zeilinger and we* know the Indian government is also making an effort to enhance research in quantum computing; the focus area of this year's department magazine is quantum computing. I thank all faculties, all students, and our editorial team, without whom this newsletter would have been impossible.

Regards,

Abhinav Agarwal

General Secretary
Physics Department
IIT Bombay

EDITOR'S NOTE

Dear readers

I am pleased to unveil the spring 2023 edition of our physics department newsletter. After three years of the pandemic-induced communication void, this release marks a triumphant return.

As a lover of writing and physics, I was irresistibly drawn to being a part of the editorial board. It has been an exhilarating journey, from delving into people's research to leading and working in a team and creating a final piece that narrates the dynamic essence of our department. My team has been the very spine of this endeavor, carrying a sparkle in their eyes and an array of ingenious ideas in their tote bags during every meeting. Together, we have learned to be patient and innovative throughout the process of planning, researching, drafting, reviewing, and editing. I want to extend my heartfelt gratitude to everyone who contributed and supported the making of this newsletter.

This issue of the newsletter features articles centered around the theme of quantum computing and the experience of Professor Archana Pai, as a pioneering women researcher in her field. Moreover, we celebrate the incredible journey of our beloved Professor Urjit Yajnik, a faculty member in our department since 1996. He would leave the institute this term to embark on his next voyage. And for those seeking to be challenged, we've included a "Fun with Physics" section.

In conclusion, I hope you thoroughly enjoy reading this newsletter edition. My greatest hope is that, somewhere between the lines, you discover something valuable to carry with you on your scientific journey.

With warm regards,

Riya Verma

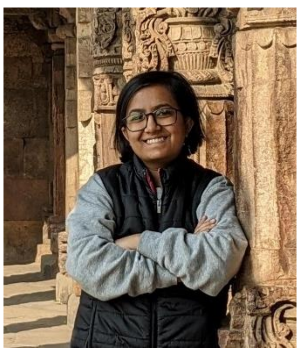
Editorial Secretary

Physics Department

IIT Bombay

THE EDITORIAL TEAM

RIYA VERMA | M.Sc. PHYSICS 2021-23
EDITORIAL SECRETARY



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SATYAM TIWARI | M.Sc. PHYSICS 2022-24
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SOHAM MITRA | M.Sc. PHYSICS 2022-24
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EDITOR

QUANTUM COMPUTING

INTRODUCTION AND RESEARCH PROSPECTS

PHOTOGRAPH: BARTLOMIEJ WROBLEWSKI/GETTY IMAGES

Introduction

Quantum computing is a rapidly emerging field of research in Physics and Computer Science. It harnesses the laws of Quantum Mechanics and applies them to solve computations that are too complex for any classical computer to solve. Physicists and Mathematicians use computers to solve complex mathematical equations that model a system, run simulations of chaotic physical systems to understand them better and, sometimes, click an image of a black hole. But as science progresses and we dive deeper into the mysteries of nature, the problems become too complex for classical computers to solve and simulate. This occurs when the poor classical computer is asked to solve a problem in which the Algorithm's complexity is too high, i.e., when too many variables interact in different kinds of complicated ways. Say, simulating a multi-electron atom or the behavior of individual atoms in a large organic molecule. One of the significant applications of Quantum Computing is to simulate these complex systems. Currently, quantum computers are far from being useful in any way. Worldwide, research in quantum computing is significantly focused on making quantum computers usable for humans to solve these problems. Mind you; quantum computers will never wholly replace classical computers.

There are situations where a classical supercomputer may outshine the quantum computer, like sorting through massive databases. Part of this research is figuring out quantum algorithms for different problems.

Quantum Algorithms

Quantum Algorithms are what make quantum computers faster. Quantum Computers work on qubits. For the unaware, qubits are superpositions of well-known classical bits 0 and 1. We can create qubits from photons, electrons or any quantum particle. The power of qubits is that N qubits can store information of as many as 2^N classical bits. This gives quantum computers a massive advantage over classical computers in complex calculations. The subtlety is that time of individual operation is generally higher in quantum computers, but the fact that quantum algorithms decrease the number of operations exponentially as compared to a classical computer is what gives them an advantage. Currently, Quantum Algorithms are known only for specific problems. Therefore, it is also an active research field in mathematics to figure out more of these algorithms for different problems.

Fault-Tolerance

The key is to develop Quantum Algorithms in which the result is deterministic. For example, Shor's Algorithm for factorization and Grover's Algorithm for unstructured search. These algorithms were designed assuming we have a perfect fault tolerance quantum computer.

Fault-Tolerance is the process of working of a system properly despite the occurrence of failures in the system. But current quantum computers are far from perfect fault tolerance. Quantum computing requires the maintenance of a complex quantum state of entangled qubits. The algorithms encode the problem we are trying to solve on the quantum state and then manipulate that state to arrive at a solution. Maintenance of such a quantum state requires isolation from the environment. Quantum particles used for qubits are supercooled to extremely low temperatures and are isolated to preserve the entangled state. Isolation is important because these entangled quantum states are highly sensitive to perturbations, noise and environmental effects. This sensitivity only increases with the addition of more qubits. This makes fault tolerance an important research topic in quantum computing, how you go from a few qubits to millions of qubits.

Quantum Cryptography

But, as quantum computers become more advanced, they can become a possible threat to the current internet cryptography. Shor's Algorithm allows us to find prime factors of huge numbers much faster than a classical computer. This is problematic because prime factorization is the basis of much of internet cryptography, the RSA protocol. The two parties must share a cryptographic key to send encrypted information from one party to another. The ideal and most secure way would be for the two parties to share a private key to decrypt the encrypted data. But this will be impractical in most cases of data exchange on the internet. Hence, we use public keys in the RSA protocol, which is generated by multiplying two prime numbers, one much larger than the other. The public key can be used to encrypt a message by special one-way mathematical functions. One-way mathematical functions are those that are easier to solve in one direction than the other. Prime Factorization is one such example, as it is easy to generate a large number knowing its prime factors than prime factorizing a large number. Such messages can be decrypted only by the prime factors of the public key. This method is secure as long as we are in the domain of classical computers, which cannot find prime factors of large numbers in small durations of time. But, with the advancements in capabilities of quantum computers, through Shor's Algorithm, they can easily and quickly factorize prime numbers, in this case, the public key and break the cryptography of the RSA Protocol. This makes developments in Quantum Cryptography in parallel to Quantum Computing important.

Quantum Key Distribution

Quantum Key Distribution is a developing scheme in Quantum Cryptography with the potential to provide unbreakable security. QKD enables the generation of a shared private key which can be used with the current encryption algorithms. The unique and defining property of QKD is that it allows the communicating parties to detect if a third party is trying to eavesdrop on the communication by gaining knowledge of the private key. QKD is better than a classical encryption protocol because it is based on fundamental principles in Quantum Mechanics like the Heisenberg Uncertainty Principle and concepts like Quantum Entanglement, whereas the classical protocols are based on computational difficulty. Two major categories of QKD protocols are Prepare and Measure Protocols and Entanglement Protocols. Examples are BB84 Protocol by Charles H. Bennett and Gilles Brassard, and E91 protocol by Artur Ekert respectively.

Current Quantum Computers, which work only on a few qubits, cannot factorize large prime numbers used in the RSA Protocol. The rapidly developing field of Quantum Computing has the potential to revolutionize our understanding of the universe through its applications in research in subjects like Physics and Mathematics, but it can also be used in unethical practices like breaking through classical encryptions used in the security of credit card transactions, email communications etc. Therefore, Quantum Computing requires Quantum Cryptography. With upcoming developments in Quantum Computing and Quantum Cryptography, we look forward to a future where we can solve problems previously unsolvable and attain unbreakable security in the online world. Quantum Computing is still a very young field with massive future research prospects.

Mehul Goyal (B.Tech. EP 1st year)

Quantum Mechanics, from the get-go has revolutionized technology. Lasers, masers, LEDs all heralded from revolutions sparked by quantum mechanics. So were harnessing nuclear energy, solar energy etc. It also brought a revolution in the field of computation through the creation of semiconductors and, subsequently semiconductor devices. Now, we carry small computers in our pockets and wear them on our wrists.

Now, the exploitation of peculiarities of quantum mechanics which makes it so intuitively different from our macro world, led to the development of quantum computers and the entire field of quantum information theories. This ushered in a completely new field of computation and will, perhaps, revolutionize the way computers are used. However, there has always been a question on the validity of these very concepts of QM-like entanglement, which required resolution.

So, what is the problem?

In classical physics, whose basic assumptions of observations arise from our macro world experiences, the physical properties of an object have an existence independent of observation. The act of observation cannot affect the actual tangible attributes of the object. But in QM, things are different: this very act of measuring properties (like position or velocity) of an object can change it. Here, the physical properties and the properties of measurement are intertwined affecting each other. QM only gives a solution to the problem of how these properties are related for a given system in terms of probabilities and not their actual instantaneous values.

Many physicists rejected this new view of Nature. The most prominent objector was Albert Einstein. In the famous ‘EPR paper’, co-authored with Nathan Rosen and Boris Podolsky, Einstein proposed a thought experiment which, he believed, demonstrated that quantum mechanics is not a complete theory of Nature. They argued that there must be some quantities (called hidden variables) which are not yet known that can, with certainty, tell what will be the result of a measurement on a given system at any given point of time or space. This aimed to show QM is incomplete.

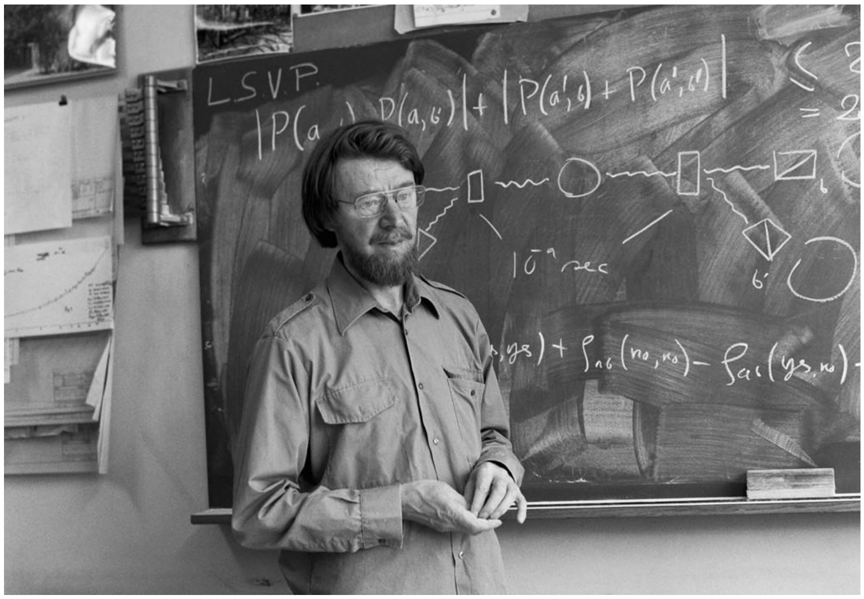
First, let us understand a simple system: the entangled state of two spin particles, called a spin singlet, is given by

$$|\psi\rangle = \frac{|01\rangle - |10\rangle}{2}$$

where the first components are the spin states of one particle and second ones are that of the other. Now according to QM, if the first particle gives a result of +1 (-1) spin along $\boldsymbol{u}$ axis (having a 50% probability for each), then the second will have a value of -1 (+1) spin along $\boldsymbol{u}$ (now each have a 100% probability for each knowing the 1st result). Measuring the first, apparently somehow, transports the information to the other particle as to what value it must measure to. This happens irrespective of distance, measuring the spin of one particle along any axis, completely determines the spin of the other.

Thus, QM only tells the probability of getting the values of the spin of the two particles without telling anything about the information conveyed from one particle to the other about fixing their probabilities. EPR argues that there must be something, some mechanism that must be responsible for this phenomenon. Mathematically expressing the EPR arguments leads to a set of inequalities called Bell inequalities (first proposed by John Stewart Bell in 1964) about the expectation values of this kind of above-mentioned experiments. Violation proves that there is no hidden variable, and if validated, then it shows the quantum theory is somehow incomplete.

The above propositions result in asking whether nature is realist, i.e. physical properties that exist irrespective of any kind of observations, and asking whether nature is local, i.e. systems only sufficiently nearby connected. There must be some kind of tangible interaction between the particles for one to affect the other. Thus, the very fundamental results that QM generates were questioned. The lack of Local Realism in QM shows that a single quantum mechanical bit of information, a qubit, cannot always be localized in a space-time box. This fact provides the fundamental basis of quantum information theory and quantum cryptography. However, this required some kind of experimental verification. This would set a solid foundation for quantum computation which heavily relies on entanglement as described above.



John Stewart Bell

Nobel Prize Work

First of these verifications came in 1972, with the work of John Clauser with graduate student Stuart Freedman at Berkeley. They measured the linear polarization correlation of the photons emitted in an atomic cascade of calcium. They proved that the restrictions imposed by Bell's inequalities on this correlation are violated and are in accordance with quantum mechanical predictions.

> *"Our data, in agreement with quantum mechanics, violate these restrictions to high statistical accuracy, thus providing strong evidence against local hidden-variable theories."*

John Clauser

Even before performing any experiment, Clauser, still a graduate student at Columbia University, along with Michael Horne, Abner Shimony, and Richard Holt, in 1969, modified the Bell's inequalities into a very specific experimental prediction called the Clauser–Horne–Shimony–Holt (CHSH) inequality. He also founded a more generalized version of the Bell inequality known as the Clauser–Horne (CH) inequality which can be applied to an experimental setting. Later, In 1976, he also proved the violation of the CH inequality in a separate and more refined experiment.

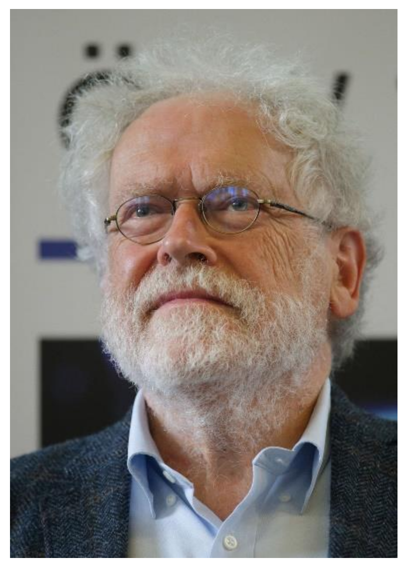
Many different experiments have been carried out since the Clauser-Freedman experiment to prove that the hidden variable theory is wrong. They came to be known as Bell tests. Among these, two very important experiments were conducted by Alain Aspect of France and Anton Zeilinger of Austria.

Alain Aspect

At first, it was Alain Aspect in 1982. He performed multiple experiments at the École supérieure d'optique in Orsay between 1980 and 1982 to prove the correlation between entangled photons beyond the restrictions of Bell inequality. His most complex experiment was performed in 1982 and is closely related to the original ideas of Bell in proving that there is no local realism in nature. Although his experiment may have had potential flaws known as detection loopholes, it laid the groundwork for future experiments.

Then came the very famous experiments of Zellinger. In 1997–1998, Anton Zeilinger conducted groundbreaking experiments using entangled light particles: the photons. It was the first time that the condition of locality was fully enforced in Bell's test. Here, two observers were spatially separated by $400\ m$ across the Innsbruck University science campus. The individual measurement interval was shorter than $1.3\ \mu s$, the time for direct communication at the speed of light. Their results confirmed the theoretical predictions of QM and hence, also showed that information can be transmitted faster than light. This formed one of the primary motivations of the quantum communication system.

Zeilinger co-invented a non-statistical version of Bell's theorem for three entangled particles -- called GHZ states. This was the first multi-particle entanglement. He later expanded the quantum communication experiments expanding the spatial range from across the river Danube to over 144 km between La Palma and Tenerife in the Canary Islands in 2007. This experiment became a benchmark for all similar future communication techniques.



Anton Zeilinger

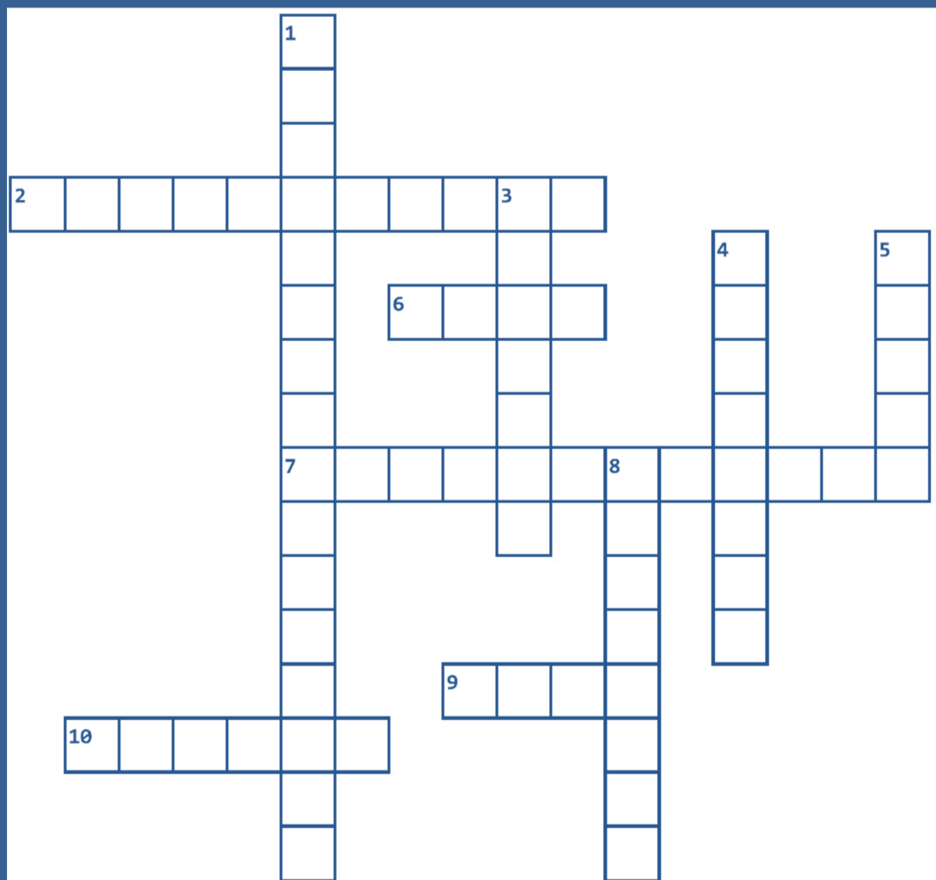
As stated in the 2022 Nobel Prize statement, the trio got the coveted prize *"for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science."* Their experimental findings will have long-lasting effects on quantum computing and communication. It gives a very solid bedrock on which the very basic postulates and their results of quantum mechanics stand, showing how mysteriously elegant the theory is. Einstein may have been wrong about QM, but his objections led to some of the biggest discoveries about the peculiarities of nature, on how strangely beautiful it is contrary to the human mind and its intuitions. And one day, for sure, these theories and experiments will truly usher a new revolution of technology and science as classical computers did in the 20th century.

Soham Mitra (M.Sc. Physics 1st year)

FUN WITH PHYSICS

QUANTUM CROSSWORD

Now, let's test your knowledge of the world of quantum computers and information. The answers can be found at the end of the magazine.



Down---

1. A hypothetical theory where the choice of measurement is determined by the system being measured.

3. The impossible process that takes an arbitrary, unknown quantum state and makes an exact copy without altering the original state in any way.

4. The gate that makes a one-qubit rotation, mapping the qubit-basis states to two superposition states with equal weight of the computational basis states.

5. The basic unit of information in quantum computing.

8. The principle that states, an object is influenced directly only by its immediate surroundings.

Across---

2. The greatest challenge involved with constructing quantum computers is minimizing quantum -----------.

6. ----'s algorithm is a quantum computer algorithm for finding the prime factors of an integer.

7. The phenomenon of particles' quantum state being dependent on each other.

9. The ----'s inequality, derived from basic assumptions that apply to all classical situations, is violated by quantum theory.

10. The quantum gate equivalent of the NOT gate for classical computers.

WOMEN IN SCIENCE

A TALK WITH PROFESSOR ARCHANA

Professor Archana Pai

Can you tell us about your childhood? What sparked your interest in science? Did you have any role models growing up?

Growing up I do not remember having any role models, it was just that I got interested in science. As a child I used to like Mathematics more, then I learned about the motion of planets and how the eclipses and seasons happen, which really fascinated me. In college I joined an astronomy club called Khagol Mandal. We used to go for night sky watching near Karjat, as the night passed, we could see different constellations rising and falling, the Milky Way at that time was quite visible with naked eyes too, it was a beautiful sky. I got really interested in this, so I chose Physics instead of Mathematics.

How did you choose gravitational wave astronomy?

At that time, nothing much was happening in the gravitational wave astronomy as the detectors were just getting constructed. I joined IUCAA's PhD program which involved a year-long course work and mini-projects; then we had to figure out who all are offering PhD, talk to them, try to understand their projects and then decide.

During my coursework I liked General Relativity a lot, it was something new and at that time Prof. Sanjeev Dhurandhar was offering projects in this field. I really liked his working style, and his work involved more applied mathematics so I chose him and all this directed me to do gravitational wave physics and astronomy.

> *"Enjoy what you do, enjoy the journey, that is important."*

Can you tell us how your research evolved from your PhD days to what you do now?

It is a long journey. I began my Ph.D. in 1996. At that time there were no interferometers, and people were skeptical if we would ever detect gravitational waves. The kind of problems my supervisor used to work on were pretty ahead in time. He gave me a problem on detecting gravitational waves with many interferometers, it was a multi-dimensional optimization problem, and as it involved mathematical formalism, I started working on it without worrying whether gravitational waves will ever be detected. I think nowadays not many students do this. That was the first work in the field on coherent detection of gravitational waves with multi-detectors.

After PhD, I did 3 postdocs, the first one at the Observatory of Nice in southern France near Italy. Here, a very big group was developing a laser for the French-Italian Virgo detector which worked closely with LIGO. At the onset of 2002, I was present during the assembly of the central interferometer. The Virgo interferometer consists of a 3- kilometer-long arm, and its initial design process requires the alignment of the central section, which consists of a laser and a beam splitter. In this process, a lot of noises interfered with the detector, and they needed ideas and input from people who worked with the data to understand these noises, my role involved precisely that.

For my second postdoctoral position, I went to the University of Rome, in Italy. While there, I joined a group that was working on resonant bar detectors, these were one of the first ideas for detecting gravitational waves. Essentially, these detectors are made up of metal bars. When a gravitational wave passes through them and matches the resonant frequency of the metal bar, the bar will vibrate at its resonant frequency. We measure this vibration and try to determine where the wave came from. At the time, there were two resonant bars (EXPLORER-Nautilus) being used - one in the outskirts of Rome and the other at CERN - and we were trying to collect data from both.

When I joined in 2003, they were planning to upgrade those resonant bars and take the data. So, I worked both with the resonant bar group and also in Virgo, I was also working with some people in Virgo. All through my postdoc phase I got quite a lot of freedom to work on whatever I wanted to do, not everybody gets that. It can work in either way because nobody will give you any problem to work on. But if one has ideas, then one can do quite well. I was quite happy because I could work with a lot of people.

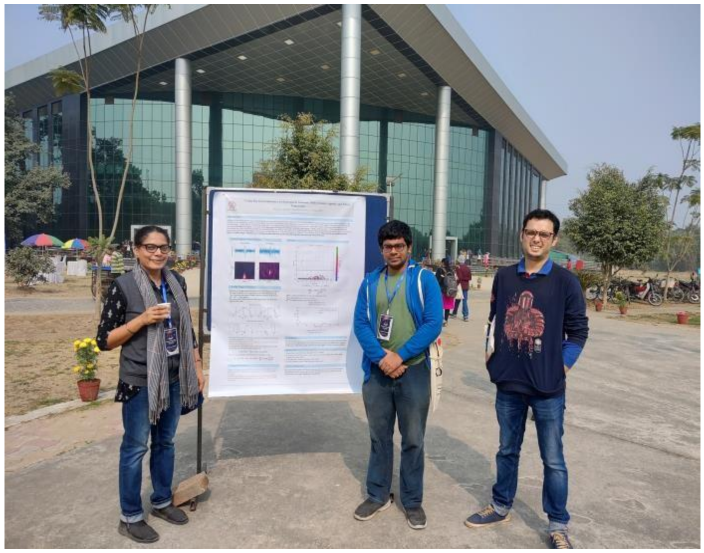
In the third postdoc, I worked at the Max Planck Institute of Gravitational Physics (Albert Einstein Institute) in Potsdam, Germany. There I worked with a group who were developing various algorithms for detecting gravitational waves using LIGO. In addition, there was another group working on space detectors located at its sister institute in Hanover, Germany. This group was responsible for making the laser used by LIGO and was focused on experimental work. During my time in Max Planck, I collaborated with different people to design advanced configurations of detectors, which was mostly theoretical work. We designed a table-top gravitational wave detector. While my work during my postdocs was diverse, it was great to meet and collaborate with a variety of people and work in different gravitational wave detector groups.

Then in 2009 I moved back to India and joined IISER Trivandrum. The institute was very young, only in its second year, and we were in the process of building it. As one of the first faculties there, we had to design curriculum, courses, which was a very different and new experience for me.

What was your reaction to the first observation of detection of GW?

Most of us were quite surprised, we did not really expect that. Whenever we designed algorithms in those days, we never assumed stellar mass black holes could be above 25 solar masses. Because in conventional X-ray astronomy the BH mass observed was never above 20-25 solar masses. Based on the amount of X-rays, one can estimate the mass of the central black hole, by drawing indirect inference. The first gravitational wave event detected was massive, with a total mass of 65 solar masses, which was surprising. After checks, it was confirmed, and it was a pleasant surprise. Indeed, it took us quite some time to realize that we had detected gravitational waves, people initially did not believe it. The event is now termed as GW150914. Maintaining secrecy is essential when working in a collaboration, and it was a challenging task back then, GW were detected on 14th September, 2015 but the discovery of the event was announced on 11th February, 2016.

In the LIGO collaboration, many groups focused on different research activities are set-up. A small group of people decides the scientific study to be done with the data, and different groups do different things. When a collaboration paper needs to be written then a paper writing team of experts is formed, and those working on the studies communicate with them to provide necessary information for the paper. I think it was quite a unique experience.



With her PhD students in IAGRG 2022 Conference at IISER Kolkata

There exists a problem of leaky pipeline in STEM fields, as we go higher and higher in academia the number of women keeps reducing. What kept you driven and encouraged to stay in academia?

I consider myself lucky to have had no pressure during my PhD and when I met my partner, Shankaranarayanan, it made life simpler. Though we faced some issues due to being from different states, things turned out fine. We had a son while doing postdoc, which is a time when women often take a break.

However, I was in my third postdoc. I had already started applying for jobs just after our son was born, so even though the break happened it did not impact much. But it was a tough period as I was looking for jobs in a field where there was a lot of skepticism. We were also searching for two jobs at the same place and same city, which made things tougher. IISER Trivandrum was just coming up. It was very young and wanted to hire initial faculties. We were quite happy to go there. Nowadays, a lot of young people do not want to go to new places. But we did not put that constraint. We just wanted to go back to India, stay in academia and work in the same city. I think these constraints are also another factor of this leaky pipeline. Because many times people want to go to a certain place. And then one person will get a job and the second will not and most of the time, it's the woman who ends up giving up on her career.

Physics is a field with very less percentage of women, how was your journey becoming a researcher in field with a gender imbalance?

I never faced a problem with gender imbalance in my academic journey, even though there were very few women in my astronomy club or BSc classes. I grew up in Bombay and was used to moving around a lot, so I never really felt like it was an issue. In

“Unfortunately, there are lot of stereotypes in our society regarding women. But my mother was a great influence on me, she always encouraged me to focus on studying further.”

fact, when I joined IUCAA, Pune for my PhD, I was the first girl PhD student, and there were no women faculty members at that time. I did occasionally feel lonely or isolated, but being brought up in a metro city, I was never scared to go anywhere. I would just go to the city and roam around with friends.

When I moved abroad, I found that people were freer and didn't have the same gender bias as in India, so it was easier to mix with both men and women.

Unfortunately, there are a lot of stereotypes in our society regarding women, but my mother had a great influence on me. In fact, she never taught me cooking or do household chores. She encouraged me to focus on my studies and career. Overall, I feel that it is important to break down gender stereotypes and encourage women to pursue their interests without any biases.

There must have been several ups and downs in your journey. Can you share a memory of a major setback and a moment of personal fulfilment that have had the most impact on you?

Yeah, life has its ups and downs, there is one experience in particular that comes to mind. Back in school, I was in Marathi medium, which was the language of instruction for science and math until 10th grade. After 10th, I joined Ruparel College, where I was surrounded by some incredibly bright students, many of whom went on to become JEE toppers. It was a challenging environment, but also very motivating. But the main challenge was the language. All the classes were taught in English, and I had to learn all of the new terminology in English. It was a difficult transition, and as a result my grades suffered. I struggled with organic chemistry and even thought I might fail in the subject. By that time, I developed interest in astronomy and decided not to compete in 12th. Despite facing a lot of pressure from family, I decided to continue BSc at the same college.

I learned that it is important not to get carried away with what your peers are doing, but to follow your own path and take breaks when you need them. You cannot continuously push yourself to the limit without consequences. It is all about finding balance and planning accordingly.

So, while I faced some challenges along the way, I never gave up. I took things one step at a time and eventually found my way. And that is the key: even when life throws you a curveball, you can always find a way to keep moving forward.

Nowadays what gives me a fulfilling feeling is when I finish any work, write papers with my students, when I graduate PhD students. I still remember that feeling of satisfaction when my first Ph.D. student M. K. Haris graduated in 2016. The recent achievement of our group was our leading contribution in the first IMBH merger event in the year 2019.

Is there any advice that you would like to give to women students, and to all students in general?

To all women students, once they decide what they want to do then they should try to follow it convincing whatever comes in their way. To students in general don't look for quick success. You must put in your hard work, there must be persistence. Quick success does not last for long; it's not something which you can really cherish. Do something which will stay with you for a long time. For that, you must spend a lot of time with it. Like Einstein said, "It's not that I'm so smart, it's just that I stay with problems longer." Enjoy what you do, enjoy the journey, that is important.

Prof. Archana Pai has been a gravitational wave researcher for more than two decades. She pursued her masters in Physics from IIT Bombay and Ph.D. from IUCAA, Pune in detection of gravitational waves through multiple detectors. Her current research involves detection of intermediate mass black holes (IMBHs), developing algorithms for short duration gravitational wave transients using time domain, time-frequency domain or/and using machine learning techniques, multi-messenger astronomy. She is also the chair of the LIGO India Scientific Collaboration. Her group was involved in the detection of the first IMBH event in the gravitational wave window.

Interview by Riya Verma (M.Sc. Physics 2nd year).

TALE OF A PHYSICIST

PROFESSOR URJIT YAJNIK

What sparked your interest in Physics? Where did it all begin?

My interest in Physics began in the 8th standard. There was an article on Bhabha Atomic Research Centre in the Newspaper. My father worked in Law, but he always felt that Science was more exciting. So, after reading the article, he encouraged me to read about Nuclear Power and Nuclear Energy, and that is where it all began.

My uncle was also a professor of Physics at IIT Kharagpur and was a role model for me.

Who were your favourite Physics authors?

Resnick and Halliday. I used to work through all the problems in the book. Besides this, two other books which influenced me a lot were Tracking Down Particles by RD Hill and a book on differential geometry by NJ Hicks.

Have you ever thought about writing a book?

As far as Physics Books are concerned, I have some lecture notes which got published. But writing a longer book was a big dilemma when I started my career because one option was that you write a very routine book which gets prescribed in some courses. Still, if you tried to write something innovative and ambitious, there was no market in India, and foreign publishers did not consider Indian authors for publishing easily. So I decided to focus on my research. I can think of writing a book that rephrases Weinberg's book on Quantum Field Theory.

How was your experience in IITs? You were away from home for the first time, so how did you cope with the difference between studies at IIT and School?


Professor Urjit Yajnik

It was my first time away from home. Once I came here, it was not very difficult to get used to it. I had excellent teachers in school. Jai Hind College also had outstanding professors. In IIT, the teaching was in-depth, and we had a robust set of teachers. IITs were started with MIT as a guideline. This free-thinking and active problem-solving were very much part of the paradigm when I joined, and most teachers were oriented towards that. We used to have these quizzes and exams, which were all just problem-solving, and I remember enjoying them a lot.

After your MSc, why did you choose the University of Texas, and How was the transition to PhD?

Initially, I wanted to pursue nuclear physics at BARC. My friends encouraged me to give the GRE and explore scholarships. Hearing about my seniors' experiences at UT Austin and the presence of researchers like John Wheeler in Quantum Gravity motivated me to apply, and I was accepted. With the help of a cousin in Dallas, I could adapt to life in America.

Upon arriving in Austin, I realized that particle physics had undergone a complete change in the last 10 -15 years, which I was unaware of. That is what Weinberg's Nobel Prize was on. I felt lost out a little because I was focusing too much on Quantum Gravity.

Were you also involved with the experimental side of Particle Physics?

I had some exposure to the experimental side at the Tokamak Lab. So, in the 60s, particle physics was much closer to experiments. But during the next decade, the mathematical methods grew exponentially. Supersymmetry, Supergravity, all of these proposals and String

Theory started off. These mathematical theories were reigning supreme when I began my research. My PhD Advisor George Sudarshan was also mathematically oriented, so I had good exposure to mathematical and theoretical techniques.

What convinced you to go into an academic career in Physics?

I was told by everybody, including my uncle and my professors, that there were no jobs in Theoretical Physics. I had excellent grades and could have easily switched to Electrical Engineering. I talked to a student who had switched from Mathematics to Electrical Engineering, who convinced me to make the switch by telling me about all kinds of exciting things going on in Electrical Engineering. But by the time I reached my room, I had decided not to! Even in Texas, Supergravity was going on, which was far more interesting to me. Austin had great minds like Weinberg and Ilya Prigogine, who had won Nobel Prizes, Wheeler and Sudarshan. So it was a very exciting place, and Prigogine brought the Solvay Conference to Austin, where it was the first time being held outside Europe. It was a very exciting time for Physics as well.

Did you get a chance to meet Feynman?

Feynman and I never met. Although, I believe he did come to our department once. But some of these things were kept secret because he is a celebrity. Somebody told us that Feynman was working down two days ago. There was a five-hour meeting, and he flew in and flew out.

Knowing that India lags behind the rest of the world, especially back in the 80s, when India was not really this far as it is today, why did you come back after your postdoc?

Before I left, I was set on the fact that I was going to come back and work here. Even while I was there, I was always oriented towards coming back. My goal of being in India was to be of help to Indian society.

Do you think it was a good decision to come back?

Definitely. Because I personally find greater satisfaction in being in India and teaching Indian students. My original idea was also to directly engage with education sectors.

As I said, because I didn't have any idea about what happened in the field of theoretical physics, I had thought that I would learn the trade and then do social service on the side while I did some kind of academic job. But then I realized that this was not possible, you cannot do two things. It is a full-time job.

So, I came back, and I had to make a decision: whether to go into the social sector or not. I had a great temptation for both kinds of activities. I decided that the level of things I had learned from people like Weinberg, Sudarshan and Wheeler, just bringing those to the science students here, was itself a great social service. Because there were lots of people who would be capable of serving at the high school level and school level. But the number of people who would be able to deliver at this level was very small. I was privileged to be one of the small numbers who could do it. So, I thought that it was best to do justice to that and stay with that. I also get the vibes in return for doing that, so I enjoy being in India.

How was your transition from being a student to a researcher to a professor?

It was a big jolt. By the time of my second or third year in Texas, I found that the research field is a completely different story. It's not just a slow gentleman's philosophical activity. It is a very feverish kind of activity which we could see from how Weinberg taught courses. He was teaching quantum field theory, and just the intensity of his teaching and all of that made clear that this is no past-time field. Philosophy is really hard work and hard labour.

I basically continued with that mindset, but I wanted to strike out on my own. I was trying to find things that I wanted to solve. Just as Sudarshan said that we work in physics because something about it bothers us. I wanted to remain focused on the things that would bother me and continue to work on them rather than just do other things. I had to develop an orientation towards doing that. It took me a long time to see where my drawbacks were, what I had to correct and so on.

And then, I got into teaching, which I enjoyed. But in my first few years, I tried to be impromptu in teaching, which may not have helped students. I would give the lectures, and everything would crystallise during the lecture. I would write down the notes afterwards, which were better than what I had done in the class, but that is not how it works. I later realised that somehow you deliver your best, when there is a live audience in front of you. But that is not very good for the live audience because you are actually improvising in front of them. I learned how to get notes ready before the lecture. So, then that improved things quite a lot.

Another thing I learned was to keep writing down on the blackboard because it's a very conceptual subject. You explain many things, and they evaporate because people are listening to you. They may think they understood, but 10 minutes later, it's gone because there is an inflow of so many things. It is better to write down the more important things, even if it requires writing a lot of English on the board. I tend to write them down so they are etched down there with markers. So, when people read the notes later, at least they can pick up from there.

Throughout your journey, how did you decide which physics problem you had to spend more time and were you ever frustrated solving a problem?

There are many times that you find that you started off something and it doesn't work, so you change the problem. Interestingly, I made two major switches in my career. One was that I did this work with grand unified theory in cosmology for my PhD. Then I got a post-doc in TIFR with a good friend of mine called T. Padmanabhan. Professor Narlikar was the head of that group. I thought that to match Paddy's interest, I would start working in curved space-time, which is also sort of allied with gravity and quantum field theory.

I worked out a problem in that which kind of fell flat. There was something wrong with that calculation, which, incidentally, nobody has told me to date. I've spoken to many experts, but I had very strong referee responses that said, no, this cannot be produced. So, I wasted about 3-4 years on this problem. It is still languishing. I managed to publish the summary of that result. Then I switched back to doing these unified theories and cosmology. I got into baryogenesis.

I was driven by what are called topological solutions that occur because of the gauge field structure of the ground unified theories. I have some old maintained fascination for these topological solutions rather than the perturbative calculations. That went on for about a decade. By the late 90s, I had to decide what to do next. I wrote an email to Weinberg asking: what does he think are interesting directions?

Weinberg characteristically gave a one-line reply that said here, "Dr Yagnik. If I knew of an interesting problem, I should rather assign it to a PhD student here." Now I was on my own, I had to fend for myself. I wrote to him more specifically, “There was a problem in QCD called hard thermal loops which required some topological methods, and the other was supersymmetric model buildings. Can I ask you specifically which of these two directions you think would be interesting?" He said the supersymmetric grand unification. That's what I did for the next decade.

From life at IIT over the decades, how have things changed?

My time at IIT is nicely split into three decades. The first decade is the 90s, the second decade is the Y2K, up to 2012, and the third decade is 2012 to now. Each decade had its own

> *“My advice is to pitch yourself to do your best and go to best possible place. Your contribution will ultimately be towards science.”*

characteristics and large changes that happened in a year during those years.

In the first year when I joined, there was one telephone line in the department head office. If you wanted to make a call, you had to fill out a form that included the call start time and end time. There was this one phone, and suddenly, within the year I joined, 15 phones came to the department. The department had about 30 professors at that time. So all the senior-most professors got an intercom.

There were these close by offices. The person told me to feel free to use their phone and to give the number to anyone else who would call me. Then we started buying computers for research use. There was one computer in the department. Prof. Dipan Ghosh made me buy the second one. I was one of the early purchasers of a very high-end called 286. 286 was the first intel chip. By 1995, it was 586. It was called the Pentium. The 286 was a big deal at that time. It cost 3 lakh rupees to buy that computer. Prof. Dipan Ghosh set up a computer with some 10 or 15 computers for us. In the early days, we used to go with little discs to the computer centre. You booted things from your disc, read the email and then downloaded your message on that disc. There was one server and terminal, and so on.

These were the old days. Things suddenly began to change after the mid-90s. But they took quite some time to reach the IIT system. The big change that happened after the Y2K was that a lot of students started going into mathematics and computer programming because of the Y2K Physics was the third fallback.

And so, they kind of got trapped into physics if they didn't get the computer job. We suddenly started getting better students. In the mid-90s, there was one year, when we had four PhD applicants, out of which we could shortlist only two, they were called, and neither of them showed up for the interview.

From that point onwards, we had something like 50 students who applied, we shortlisted 15 and then 10 appeared for the interview, things like this. Things were looking up by then. Now the numbers are in the hundreds.

Also, one major thing that happened was why was the time that the older IITians reached the peak of their careers in California.

The batch had completed 25 years. People had passed out in 1975 and had made enough, made big careers in California. They got together and made a big donation. That was the big launch for IIT to alumni relations. Exactly at that time, we got a new director, Professor Ashok Mishra from IIT Delhi, who was a chemical engineer and a very forward-looking director who could interface with alumni on their own terms. He projected a positive image of how IIT will do things, not in a *sarkari* way, but in mission mode. Ashok convinced people that IIT Bombay would be a good destination for their donations and funds.

He also began to invite foreign dignitaries. He was deeply interested in science in general. In the year 2000, we had an International Strings Superstrings meeting in TIFR. Witten, Stephen, Hawking. David Gross. All these people had come to that meeting, and there was one afternoon of colloquia by three of the leading people, including Witten.

And from the Institute, I booked a car to go to attend that and guess who was the only other person who had also booked the car. It was Mr. Ashok Mishra. We rode that car together, really interested in science and all the modern development. He invited David Gross here. And later, in 2007, which was our golden jubilee, he said that “Everyone, invite the top people from your field, Nobel or not”. During that time, there was a mathematician who worked extensively in string theory. I invited him, and he showed up. I wrote to Weinberg also, but Weinberg said he didn’t like long flights. The whole atmosphere, academically and in terms of resources and facilities, really looked up after the year 2000, we even got funding for the gymkhana.

And in 2008, we were invited to set up IIT Gandhinagar, so Ashok Mishra sent me because I am Gujarati. So, I went there for a year and a half, I got the Institute going, I landed there like a commander, of course, new acquired, everything that is needed. We had great support from the local college there. We were given a college to start it off, and then the campus came up later, Accommodation for faculty for students, the classroom, and the best facilities. Everything I got set up over there. It was a very good experience.

Ashok Mishra's style of managing the Institute constituted of always looking forward to generating more fun and creating new programs and new research fields. Bioscience, bioengineering and environmental science. We also grew our Industrial Design Centre.

In all the directions, there were a lot of improvements. The 2000s was when we were really ramping up. I ended up working with Ashok quite a lot because the first three years when he joined, I was the chairman of cultural affairs. We were inviting musicians doing this, that music dance, everything and Mood Indigo.

And somehow, we didn't feel the money crunch that much anymore, all through the 90s, it was like we were straining to have funding just even to maintain things to keep up to buy this. Even the smallest things, everything was a big struggle. But after 2007, suddenly, most of those things were gone, and we also began to get regular funding for foreign travel.

How was your experience as the dean of student affairs?

Our biggest inability was to shower up hostel infrastructure, constructing buildings is an intensive and time-consuming process, and we could not match the increasing rate of the number of students on the campus. It was a great time. Otherwise, one of my major contributions was setting up a mental wellness center for students. In the past, students used to have informal attachments with the faculty guide, but with a bigger system and modern research demands, there's no time for this. Many students required somebody to help them, so there was a need for a professional system.

We supervised and gave utmost support to big festivals like Mood Indigo, and Techfest. There were vertical bodies like a general secretary for cultural activities, sports and academics but none for Science and Technology related, so we started the Tinkerer's Lab and established the Science and Technology Activity Body (STAB) and General Secretary of Technology. The idea was that people would work out on their own, so with great zeal, lots of persuasion and campaigning, the Tinkerer's Lab was settled-right at the end of the corridor, now it has expanded its scale. But it was impressive enough that the then HRD minister said every IIT should have a Tinkerer's lab.

Then, I got to entertain Ratan Tata, Dr Abdul Kalam, and Sachin Tendulkar. We hosted the 50th inter IIT sports, the new gymkhana building with tennis and squash and a big gym was also built in my time. Our dean of infrastructure at that time was Venkat Raman, they did a great job specifying the full details.

Research in Western countries is very advanced compared to India. What advice would you give to our generation for higher education?

My advice is to go to the best place possible, India or abroad. Although I came back with a lot of conviction and zeal, I never told the students to come back and to go where they would professionally do their best. All my students went abroad. I went abroad with the specific orientation that I wanted to return to India. I chose my research problems so that I could continue in India. Even though I was interested in experimental physics, I didn't join it because I knew experimental physics would be difficult here. I picked up topics I thought would be of interest to the Indian circuit. I encouraged students to think that they are suited for the best possible system that is American, European, or whatever, then they can always make a choice later but never pre-decide. So let the professional considerations alone drive how you make your choices.

It will still serve the country because you are still ultimately tied to India, or you will return to India before your development and experience and give back to India like Prof. Govind Swaroop, who did a PhD at Stanford and set up the Giant Meter wave Radio Telescope in India. Pitch yourself to do your best professionally and go to the best possible professional place, your contribution will ultimately be towards science.

What is your philosophy of life?

During my time at IIT Bombay, I took courses on Indian and contemporary Western philosophy, which had a profound impact on me, especially in the area of Buddhism. The balance between intuition and reason in Buddhism resonated with me. Later, while studying in Texas, I spent much of my free time reading philosophy and literature. My philosophy centers around finding a balance between intuition and reason and acknowledging that what works for one person might not work for another. I also believe that there's no one-size-fits-all solution to problems. Ultimately, what works for an individual is what's best for them, regardless of whether it can be scientifically explained or not.

Do you have other interests besides academics?

During my time in Texas, I played squash and tennis with friends but found squash to be a better option as it could be played alone. I also developed an interest in Western classical music and learned about its history and major composers. My exposure to Indian music began in school, and later, I studied music with teachers in Bangalore. Bhimsen Joshi was a great performer who I had the opportunity to see live. I attended many music concerts, and this experience has stayed with me.

What is your plan after retirement?

Regarding my retirement plan, I have decided to join IIT Kanpur. The director of the institute reached out to me, and his persuasions eventually led me to consider it seriously. He shared that the campus has transformed into a beautiful place with many exciting activities. Interestingly, he went on to become the Vice-Chancellor of Banaras University just a couple of years ago. Now, I am looking forward to joining IIT Kanpur, but I have made the decision to not take on any PhD students at this point, which I think will be good for me.

Professor Urjit Yajnik with Professor Uma Shankar, graduating class of '23 and editorial team

Interviews taken by,
Soham Mitra (M.Sc. Physics 1st year)
Riya Verma (M.Sc. Physics 2nd Year)
Tina Garg (B.Tech. EP 3rd year)

THINKING BEYOND PHYSICS

"Discovering Your Purpose and Path"

Gopal Goyal

It may seem unusual to propose such an article in a Physics department magazine, we believe that it's important to address the topic of leaving physics as a career choice. We know that you love the laws of the universe and all that jazz, but let's be real - sometimes studying physics can be a real drag. The complex equations, abstract theories, and seemingly gloomy job prospects after graduation associated with certain fields ofstudy can be overwhelming and cause one to feel discouraged. That's why we are proposing an article that's a little outside the box. We want to explore the idea of ditching physics as a career choice and talk to those who have taken the leap to pursue other paths. Now, prepare yourself for an exploration of the vast and remarkable world beyond the realm of physics.

We have **Gopal Goyal** (M.Sc. Physics, 2nd year) and **Janak Ruia** (B. Tech EP,4th year) who have recently made such a transition from Physics to Software Development or Engineering.

Janak Ruia

Can you let us know about your background?

Gopal: I am from Bharatpur, Rajasthan. I completed my schooling from a local school. After that, I got admission in Rajasthan University to pursue BSc Physics(hons.) degree. Eventually I secured admission into IIT Bombay in MSC Physics.

Janak: I was born and brought up in Mumbai, and I completed my schooling at Witty International School. Additionally, I also received my JEE coaching in Mumbai. After getting a good rank in JEE, I took admission here at IIT Bombay in the "Engineering Physics" discipline.

What sparked your initial interest in Physics?

Gopal: Initially, my interest was in Physics and Mathematics. As I did not prepare for competitive exams like JEE or NEET during my schooling in Bharatpur, I started exploring various career options available to me. After some research, I discovered that I could either join government jobs, engineering jobs, or research jobs. Since I was interested in pursuing research, I contemplated choosing either mathematics or physics. However, after conducting more research on the opportunities in the research field, I concluded that physics had greater potential.

Consequently, I opted to pursue BSc Physics (Honors) and even prepared for the JAM exam independently in my first year. This is how I came to the decision of pursuing a possible career in physics.

Janak: During my school days, I developed a habit of reading random articles in my free time. This is how I stumbled upon astrophysics and astronomy, which really caught my attention. I began reading such articles regularly, and my interest in physics grew. I started paying more attention to the physics topics taught in school, and eventually decided to pursue physics as a career option, specifically in astronomy and astrophysics. That was the initial spark that led me to pursue physics.

Can you share about the transition moment and factors which led to such transition?

Gopal: During my second year of studying physics honors, the lockdown was imposed. During the start of lockdown, my brother taught me C++ for about 2 weeks. It was then, I started to realize that programming was an intriguing field for me as it involved a lot of problem-solving skills and development opportunities. Unlike research, where it takes a long time to see the results, programming allows for quicker project completion with the ability to showcase the end product to anyone. Developing products, designing apps, and web applications for users to interact with was more interesting and interactive forme. Although my background was in physics, I chose this field because of my interest and the potential forearning money.

Janak: I have been contemplating whether I want to build a career in physics for a while now. In myfirst and second year, I was pretty confident that I wanted to pursue a PhD in physics. However, during theinternship season, I started to consider the possibility of trying an internship in industry instead of a research-based one. On the first day of the season, I made the decision to explore the industry side of things and began applying to companies. I was offered an internship in quantitative development and realized that the underlying mathematical structure of studying markets was pretty similar to what we didin physics.

This piqued my interest in other fields beyond physics. After considering the pros and cons of pursuing a physics PhD, I ultimately decided against it. While I was drawn to the idea of fulfilling a childhood dream and pushing the boundaries of human knowledge, I couldn't ignore the limited scope of a niche topic, the specialized lifestyle that came with it, and the financial issues that it would bring. Instead, I became interested in other fields like quantitative finance after my internship experience. I didn't want to commit to a static lifestyle and wanted to explore different things, so I transitioned to the industry without a clear ideaof what I wanted to do next.

How have the Physics Skills been helpful to you during this journey?

Gopal: I think particularly the problem-solving skills helped me a lot. The ability to analyze complex systems and data is a valuable skill that physicists bring to computer science jobs. Furthermore, the abilityto work with mathematical models and equations is beneficial in areas such as machine learning and artificial intelligence. Overall, the analytical mindset developed while studying physics can provide a strongfoundation for a career in computer science.

Janak: In my current field of software engineering, there is more focus on system design and logical problem-solving rather than rigorous mathematics. However, my EP degree equipped me with strong mathematical rigor, which has proven useful in fields like quantitative finance and robotics control theory. While software engineering may not have much overlap with physics, problem-solving skills are essential in this field. It involves finding the most efficient solution to a given problem.

Can you share about the challenges you faced during such a transition in your career?

Gopal: One of the biggest challenges I faced when applying for computer science jobs as a physics major was convincing companies to consider me. Many hiring managers were skeptical about why a physics major would want to work in computer science or engineering, and I had to prove that my skills were just as valuable as those of a CS major. This was especially difficult when trying to land my firstinternship, as I lacked professional experience in the field. I applied to around 50 internships every day,but faced numerous rejections and even some companies that rejected me without an interview. However, I knew that perseverance was key to overcoming this challenge. I continued to apply to as many positions as possible and eventually landed an interview with a company that was willing to consider me. I preparedthoroughly and was able to impress them with my skills, eventually securing the internship. While facing rejection was discouraging at times, I learned that it was important to stay persistent and continue putting in effort until I found the right opportunity.

Janak: It seems like there were two major challenges that I faced. Firstly, I needed to complete the remaining physics coursework to earn my B.Tech. degree. Secondly, when I started preparing for job placements, my grades suffered. I had to prepare myself to absorb such grades, since previously I was getting high grades. Before I realized that I didn't want to continue in physics, maintaining good grades was easy because my motivation was to understand physics for research purposes. However, after deciding to leave physics, every course felt like an additional burden, making it difficult to maintain good grades. This lack of motivation made it harder to continue with my degree.

Can you share with us your exploration journey like how you explored or identified that this is myikigai or at this stage it seems to be my ikigai?

Gopal: In my second year of graduation, I focused on learning data structure and algorithms for six to eight months. After that, I started exploring web development and learned Java, HTML, CSS, JavaScript, and React node. I even completed an internship in web development. However, when I lookedfor job opportunities on the internship/job portal at IIT Bombay, I found that only data science jobs were available. Therefore, I decided to learn data science and started studying machine learning algorithms from books in January. By March, I had a good understanding of the machine learning concepts and started studying NLP. Soon after, I got an internship in data science and worked for nine months while managing my studies. However, when it was time for placements, I had to quit the internship.

But they were happy to have me back once I secured a placement, and I plan to join them again in the coming week.

Janak: I was in my fourth year of college, and placement season was fast approaching. I knew I wanted a dynamic lifestyle, but that was a pretty broad constraint. While my friends had already decided what they wanted to do, I was interested in two to three different fields: robotics, quantitative finance, and software engineering.

I needed to prepare for my placement, and for that, I had to choose one field out of these three. I considered preparing for all three, but my preparations would take a hit because of the limited time. The other option was to choose one, and initially, I was convinced that quantitative finance was the best optionfor me since I had a strong background in mathematics. But as I talked to seniors who were actively working in quantitative finance, I realized that the lifestyle waspretty hectic. They guided me to apply externally and not rely only on campus placements. Private equity also caught my attention, as I saw it as a way to gain knowledge of working with startups.

So, I shifted my focus to preparing for quantitative finance while keeping software engineering as my backup plan. I studied core finance fundamentals for private equity, but it wasn't the right fit for me. I soonrealized that I was not much of a finance person. Instead, I focused on learning data structures and algorithms, which are used in both software engineering and quantitative finance and finally in the placements, I got my job as a Software Engineer. That was my exploration journey.

What advice would you give for juniors?

Gopal: I believe that many students feel confused because they are not dedicating enough time to one field. I've noticed that those who put in proper effort and time into computer science-related fields, such as DSA, web development, or machine learning, tend to develop a genuine interest and understanding of the subject matter. On the other hand, some of my friends were also unsure about pursuing jobs related to computer science because they lacked the confidence to deliver quality work. I think this is because they haven't put in enough hard work and dedication in that particular field. When I first started coding, I was also confused for around seven months, my brother kept encouraging me duringthose times. After several months of dedicated practice and hard work, I began to see tangible results andgain confidence in my abilities. In my experience, it takes around seven to eight months of consistent practice to develop a solid foundation in a field. I personally devoted my time to DSA problems and development during this period, which helped me gain the skills and confidence I needed to excel.

Janak: I would advise those considering a career in physics to weigh the day-to-day life they wouldlead in the field, which can be slow and not always full of exciting discoveries. For those thinking ofleaving physics, I recommend exploring internships in different fields to find their passion and align it with their life goals. I recommend juniors preparing for software engineering roles by practicing leet coding and learning about data structures and algorithms. I suggest taking advantage of as many internship opportunities as possible, even during the academic semester, to gain practical knowledge and insights beyond what is taught in textbooks. Internships matter a lot more than course projects, so try your best getting internships. Ultimately, I believe that everything happens for the best, and one's career path may change over time as they grow and learn more about themselves and their passions. Just keep exploring till you find your sweet spot or, you know, “ikigai”.

Do you see yourself ever trying to explore the intersection of physics and your current field?

Gopal: I am interested in joining some companies like gaming companies, IBM, TCS, or KLA, as they often seek individuals with knowledge in both physics and computer science. I believe this is becausegaming companies require a lot of physics knowledge for game development, and programming skills such as C Sharp are also used in game development. As a result, programmers with expertise in both fields can excel in this industry, and I would be interested in exploring this opportunity if it arises.

Janak: Although I have a strong interest in Physics, the lifestyle of a Ph.D. scholar did not appealto me. However, if given the chance to work in a technology field that involves Physics, such as Quantum Computing, I would eagerly seize the opportunity. Physics holds a special place in my heart and has madean indelible mark on my life.

In the end, Leaving the field of physics is a significant decision that should not be made lightly. However, it's essential to follow your heart and explore other areas of knowledge where your talents and curiosity can thrive. Whether you choose to pursue a career in physics or a different field, it's never too late to make a change forthe better. To provide more insight, our next article, "Shifting to Physics," will explore the mindset of those who made the transition to physics.

Interviews taken by,
Satyam Tiwari (M.Sc. Physics 1st year)
Tina Garg (B.Tech. EP 3rd year)

SHIFTING TO PHYSICS

We are thrilled to present to you the inspiring stories of two individuals who made the bold decision to make their career transition from other fields to physics. ***Devesh Dhole***, a first-year MSc Physics student, recently embarked on this exciting new path, while ***Prof. Varun Bhalerao***, an Astrophysicist in our Department of Physics at IITB, serves as a shining example of a successful career shift.

Prof. Varun Bhalerao

By sharing their stories, we aim to provide you with a comprehensive understanding of the mindset required to pursue a career in physics from the perspective of both a student and a professional. Join us as we delve into the captivating journeys of Devesh and Prof. Bhalerao to discover how they navigated their way to the world of physics.

Could you share a bit about your background with us?

Devesh: I come from a town called Amravati, Maharashtra and completed my schooling from there only. After my 12th, I moved to Goa to pursue BE Honours in Computer Science from BITS Pilani Goa Campus, which I completed in 2019. Luckily, I got a job in Flipkart via college placement, due to which I relocated to Bangalore. I worked there for around two years and three months before resigning. Afterwards, I began preparing for JAM to get admission to the MSc Physics program through which I got admission at IIT Bombay.

Prof. Bhalerao: Throughout school and junior college, I was active in astronomy competitions. I participated in Olympiads. I got selected for camps at IUCAA and NCRA in Pune. I got the opportunity to attend sessions held by senior astrophysicists in India. While participating in all these activities, I discovered that astronomy is fun. I gave JEE and was not able to get the branch that I wanted in my first attempt. So I took up mechanical engineering at a local college and gave JEE again, getting a better rank. Partly by peer pressure and partly by choice, I ended up taking electrical engineering.

I discovered that electrical engineering was fun, and I also liked astrophysics. I was able to make the most of this intersection of interests by working on astronomical instrumentation. I have built stuff to be used by GROWTH India Telescope, AstroSAT, Daksha, and many more. I got to work on various telescopes and a NASA mission during my PhD. Now I have students with similar backgrounds working with me on projects. One of my students did a BTech in Mechanical Engineering and is now doing an Astrophysics PhD here.

Devesh Dhole

What caused your initial fascination with the field of Computer Science/Electrical Engineering?

Devesh*:* After schooling, I was ignorant and unaware of the various career paths available to me. My parents and other people suggested that computer science was the best branch to pursue. I didn't even realize that I could pursue a career in Physics. My decision was largely influenced by social pressure, and I chose computer science because it was considered to have better placements and job prospects.

What were the key factors that motivated you to make the shift to physics, and could you walk us through the moment when you made the decision?

Devesh: It wasn't a decision that I made quickly; it took me several years to come to the realization that I wanted to pursue something different. It all started with philosophical debates with friends, which gradually transitioned to science debates. Over time, these debates led me to develop an interest in physics and the natural sciences, even though I had been pursuing a career in computer science. Although I enjoyed my job and was earning a good salary, I couldn't shake the desire to explore my interests further. However, I wasn't yet confident enough to make such a significant career change. To gather more information and gain clarity, I talked to people in the field of physics, including those who had already made the transition from other fields. I also delved into popular science literature to get a sense of what it would take to pursue physics as a career.

After a year of contemplating and researching, I began to study physics rigorously while still working my job. I wanted to be sure that I was truly passionate about it and could handle the mathematical rigor of the field. After two years of job, I finally felt confident enough to take the leap and quit my job to focus on physics full-time. Although it was a difficult decision, I knew it was the right one. (Future Prospects) I have always been fascinated by physics, especially astrophysics and cosmology. Currently, I am focusing on learning general relativity and exploring cosmology to answer big questions about the universe. I see myself in the computational part of physics, using my coding knowledge to simulate and analyse data.

Prof. Bhalerao*:* I like science. Both my parents are from a science background. As far as astronomy is concerned, I liked it to the same extent as everyone did as a kid. I would often look up at the sky, moon, and constellations. When we used to go on outstation trips, I used to look at the stars from the car. The real interest came from the Astronomy Olympiads that I participated in. I discovered that it was fun, and I was reasonably good at it.

What challenges have you faced while making this transition?

Devesh: The major difficulty that I faced when making a significant change in my life was the internal struggle of self-doubt. I had to convince myself that I could do it, despite feeling inadequate or inexperienced. Overcoming this self-doubt was a gradual process that required taking small steps each day, learning from my experiences, and gaining confidence in my abilities. I had to focus on the present and not judge myself too harshly on a larger scale, which helped me to stay motivated and keep moving forward.

In addition to the internal struggle, I also faced external pressures from family and friends who were not supportive of my decision. They questioned why I wanted to make this change and expressed concerns about the risks involved. However, I realized that, ultimately, I had to do what was right for me and take whatever steps were necessary to achieve my goals. Overall, making a significant change in life requires a combination of internal strength and perseverance, as well as the ability to overcome external pressures and stay true to oneself.

Prof. Bhalerao: The first hurdle is convincing others that you actually know what you are doing. When I was applying for my PhD, I had interviewers tell me that they did not have engineers applying to them and they did not know what to do with me. Fortunately, I had interviews from Caltech and Harvard. Telling them that I knew enough physics was tricky.

The second hurdle comes after the transition, during the PhD. While I was studying electronics for four years, the others had spent those four years studying physics and did a lot better than I did. I had to work extra hard to catch up. I had to prioritise. I still have not caught up on a bunch of things. I still have not studied the general theory of relativity. My work doesn't need it, so I don't study it. I have the confidence that if I need it, I will be able to learn it.

You should be able to ask for help wherever you need it. People at Caltech were friendly whenever I asked them for help. You should be willing to take help from someone if they are better at something than you are. If you're doing those things, then you will be able to catch up.

How did your background skills help you in this transition?

Devesh: Coding has become crucial in every field as there is a lot of complex data that needs to be processed and interpreted. It has been helpful for me in my first semester computational work, and I believe it will continue to be beneficial in the future. Unless you go into hardcore theoretical stuff, coding will be used everywhere, and it saves time by not having to learn coding and computational work in physics.

Prof. Bhalerao*:* Once I managed to catch up, I had certain special skills which the others did not have. I fared better in labs because I had been doing hands-on things during my engineering degree. The mindset of a physics-trained person and of an engineer is different. You approach problems in a different way. The engineering approach to solutions differs from the scientific approach to solutions, and that background also helped in some places. It was useful because I knew how to approach a problem from an engineering perspective.

On one of my birthdays, to make fun of me, my friends gifted me this mechano-kit with metal plates with holes, you put screws and make small toys like a car. In the lab, we needed to make a temporary mount where we had to mount a knife edge in front of x-ray beams. I actually used that kit because, to fabricate it, it would have taken two weeks to make a plan and send it to the workshop, but here, because it was just small, metal plates with holes. I could easily screw them together to make a rig that works, and it was fun. I sent a photo to them, telling them that their gift was actually used to calibrate the x-ray telescope.

If you want to transition from engineering to physics, you shouldn't disown your engineering background. It is always useful. You should find ways in which you can leverage it.

Were there any courses that you did at IIT that encouraged you further to pursue physics?

Prof. Bhalerao: I wouldn't say that anything or anyone encouraged me proactively. Nobody walked into my class and said that electrical engineers should now become physicists because then someone else should have walked in and told us to become biologists. Someone else should have walked in and told us to become chemists. But wherever I approached people, they gave me support.

Encouraging, in the way of prodding me and pushing me, was not there, but encouraging, in the way of giving support, was always there. If I came to physics people and talked to them, they were always willing to help. We had Professor Shevgaonkar at that time in electrical engineering, who was a radio astronomer. My BTP was with him. The astronomy club was active, so that support was there. There was no discouragement, and there wasn't a push, but there was support.

What advice would you like to give to those who are contemplating making such a transition?

Devesh: If you're considering pursuing a career in a particular field, first clarify why you want to do it and ensure that you have a genuine passion for it. Consider the financial risks involved, as it may take several years of study and struggle before you can obtain a stable job. Research the courses and programs involved, speaking with current or former students to gain an understanding of what the experience will be like. Talk to people who have completed a PhD to understand the difficulties involved, but maintain a passion and love for your field that will help you overcome any struggles. Pursuing a postdoc and, eventually, a professorship can provide greater stability in the long term.

Prof. Bhalerao: The first thing is you actually should explore and try to do a project or a course or read a textbook because that will tell you what the field actually is about.

A lot of people get excited about a topic by watching documentaries on Discovery or Nat Geo. But just as your day-to-day life is not what Bollywood movies would lead you to believe, details of actual research are not necessarily like what you see in documentaries.

Another part of that advice is that it is okay to have something as a hobby and not make it a career. For example, I like classical music, and I absolutely suck at it. I wouldn't be able to make a profession out of it, and I didn't try because I realised early enough that I wasn't good at it. But more than that, I don't have the patience to sit for *riyaz* for hours every day. There are parts of it which I don't understand at all or don't even like. It doesn't have to be a career.

If my primary motivation for astronomy was that I liked looking at galaxies through a telescope, then I'm in the wrong field because maybe if I was doing a job I don't know in software or something, then at night, I would be free enough to look towards the skies. I'm not. So, you have to understand what that career really means and come to terms with it.

We hope that the stories of Devesh and Prof. Bhalerao have inspired you to consider the possibility of transitioning to physics, should you ever feel the urge to do so. As they have demonstrated, it's never too late to follow your passion and pursue the career of your dreams. Whether you're a student or a seasoned professional, with hard work, dedication, and a willingness to learn, anything is possible. And who knows, maybe someday we'll read about your journey from another field to physics. So don't be afraid to take that leap of faith and explore the possibilities that lie ahead. There will be challenges, but you must have the right mindset to overcome such challenges. The world of physics awaits you.

Interviews taken by,
Satyam Tiwari (M.Sc. Physics 1st year)
Tina Garg (B.Tech. EP 3rd year)

From IIT Bombay to ETH Zurich

Studying abroad as an exchange student is a transformative experience that can broaden one's horizons, enhance personal and academic skills, and foster cultural awareness. ***Jai Israni***, a 4th-year B. Tech student in the physics department, had the opportunity to spend a semester studying at *ETH Zurich* in *Switzerland*. In this article, we would like to share Jai's experience as an exchange student, from discovering the opportunity to navigate the challenges and opportunities of studying abroad. Join us on a journey with Jai as he shares his story of studying abroad and discover what it's like to be an exchange student.

Jai Israni

What motivated you to study abroad, and how did you choose the university and country where you would study?

Some background on why I chose to go on the exchange - having visited Europe a couple of times in the past as a tourist, I had grown a liking towards the continent's culture, history, food, people and the natural paradise that it cradles. I could only dream of spending an entire semester there. When I got nominated for the exchange at ETH Zürich, supported by two Swiss scholarships, the offer was simply undeniable. In the words of my friend Carlos, from Spain, who is starting his Masters there, '*ETH is the MIT of Europe*'. And I was sold immediately.

What was the application process for the exchange program like, and what were some of the challenges you faced during this process?

The standard process of sending your nominations, including a CV, transcript, and course mapping approval. Keep some extra courses on your list, in case some others that you have chosen do not run in that particular semester.

What were some of the biggest cultural differences or surprises you encountered while studying abroad, and howdid you adapt to them?

Switzerland is all about quality, efficiency and elegance. Known for its time-keeping, Swiss people have no idea of 'delays' or 'Sorry for being a minute late'. If one respects these ideologies, they're going to love it.

How did the academic and social experiences at the foreign university compare to your experiences at our institute?

Academics at ETH are quite demanding. Most theory classes I took at ETH had a single final exam that was held in January or February. Some were in a written 3-hour format, while some were oral. Except for one, I took the rest from the International Relations Office at IITB. I would highly advise you not to prepone the exams if you haven't studied sufficiently during the semester.

ETH advises you to take a minimum of 20 credits and a maximum of 30 per semester. That might look like a small number initially but don't underestimate the advice, as classes can be quite demanding, and passing an exam requires scoring around fifty to sixty percent. My particle physics class was instructed by seven different scientists/professors coming in from CERN every week to lecture on their fields of expertise.I did a lab module here, called a '*praktika*', and I can vouch that ETH provides top-notch experimental facilities. But at the same time, each student's report must go through multiple iterations for improvements suggested by the assistant, besides plagiarism checks. They give you an entire week to collect data for each experiment and ample 'weeks' to type the report while you proceed with other ones. However, the final version ends up looking more like a research paper. That's how Swiss people are trained!

What advice would you like to give to other students who are considering studying abroad asexchange students, especially in Switzerland?

- Start the visa process early.
- Don't delay in booking your accommodation as it gets full pretty quickly.
- For those in physics, check out the VMP organization's website for exam papers from previous years.
- You are allowed to take courses that are taught in German but beware, as you will end up self-studying those.
- If you like chocolates, try out every chocolate shop in Bahnofstraße.
- For travel, purchase the Zone pass for your zone of stay in Zürich, the ETH's zone (if different from the first one), i.e., 110, and the Half-Fare Travelcard for travel within the entire of Switzerland (I am assuming you would want to travel around).

What do you think are the personal benefits of such an experience?

- The Swiss work ethic and their approach to university-level education left a lasting impression on me.
- During my time there, I had the chance to engage with students from different countries and immerse myself in their cultures, which resulted in the formation of valuable friendships.
- Switzerland is beautiful. It is a perfect blend of countryside and urban cities, although a major portion is countryside. Being there in the fall semester, I got a chance for summer and winter activities. My day began with a Toblerone and ended with a Lindt. On the early morning of December 9, I woke up in my room in Zürich to find it snowing outside. I was stunned; that was the first snowfall I had ever seen, and I still remember that feeling. The city looked entirely different under a whitish glow. This happened overnight and persisted till the end of my stay in Switzerland.

In conclusion, Jai Israni's semester as an exchange student at ETH Zurich in Switzerland was a once-in-a-lifetime experience that allowed him to expand his knowledge, skills, and cultural awareness. Jai adapted to a new academic and social environment during his journey, but he persevered and succeeded in the end. His story is a testament to the transformative power of studying abroad and the incredible personal growth that can be achieved by stepping out of one's comfort zone. For anyone considering studying abroad, Jai's journey offers a glimpse into the endless possibilities that await and the unforgettable memories that can be made.

STUDENT'S CORNER

The Metered Metric Space

Might be rare to write a poem merely to prove a point,
But I'm here to prove a theorem, maths and words are not disjoint.
Manifolds and metaphors, they seem mistakes to mix?
My my, you're clearly new to meters and metrics, kiddo!

My rhythm is so radical with heptameter lines,
Not even the Lagrangian could minimize my rhymes!
I'll integrate so many terms into lines two to the fourth,
Best hold on to your integers and prepare to be floored!

I'll alliterate algebra, turn your products into powers,
Dual-wield bra ket vector spaces and personified flowers.
When I call mugs donuts it's metaphor and topology,
My Haikus so symmetric you'd think it's group theory

Call me Euclid, how I'll be redefining the genre's meta,
Limitless in trying to be the best, so call me an epsilon-delta.
My words strike like functions spike, yup that's a simile,
I differentiate to the Dirac, that's why they call me Green.

Rehmat Singh Chawla (B.Tech. EP 3rd year)

Quantum Research

My research interests are in the field of quantum communication and quantum information theory. In particular, I am interested in utilizing the theory of entanglement manipulation of quantum states for efficient distribution of entanglement over large-scale and long-range quantum networks for secure communication. This research goal is relevant for the current epoch of quantum technologies which have progressed tremendously over the last couple of decades. Communication networks therefore need to be secure against potential attacks by adversaries who can access the tremendous power of quantum computation. This can be achieved via security provided by quantum communication which relies on entanglement between the nodes of the network.

Establishing entanglement over large distances between two arbitrary nodes of a network is a challenging task due to decoherence induced by environmental noise. One way to tackle this problem is to first generate short-range entanglement between neighbouring nodes of a network and then connect these initial states using entanglement swapping. Entanglement swapping is used to distribute entanglement by connecting quantum states entangled over smaller distance and forming a longer-range entangled state. An important question in this regard is how much entanglement survives after the entanglement-swapping operation is performed. These questions boil down to a study ofthe entanglement properties of bipartite mixed quantum states - that I am currently investigating.

My future work will build on these results to identify the distributions of quantum states onnetwork edges that can result in high-fidelity, high-rate entanglement between nodes of large-scale quantum networks. Ultimately, my goal is to design useful quantum networkprotocols for communication, sensing and distributed computation.

Md Sohel Mondel

Anyons: A strange discovery in physics

Approximately 40 years ago, an MIT professor who got bored by the classification of particles in two states gave a theory of a new type of particle named Anyons. These particles are different from other particles.

In the world of physics, we divide elementary particles in 2 groups, namely Fermions and bosons. Fermions are particles which follow the Pauli exclusion principle and have half-integralspin. No two fermions can exist in a single state. Electrons, protons, and neutrons are common examples of fermions. The property that no two particles can exist in the same a state confirms that all matter cannot collapse to a single point. Solid matter is formed due to this property.

Another type of particle is a Boson. Bosons have an integral spin, and two or more two bosons can exist in a single state. Photons are a common example of bosons. We have lasers with the property of bosons that two bosons can clump together. Lasers are streams of photons in which all photons are in the same quantum state.

Anyons are the particles that do not lie in any group, i.e. fermions and bosons. In the early 1989s, scientists think a new type of particle exists in 2-dimension. But these particles can exist only at temperatures close to absolute zero, and high magnetic fields.

An MIT professor Frank Wilczek predicted the presence of anyons in the 1980s and gave it its name. Anyons are not like conventional particles. They are quasiparticles. Quasiparticles are particles which have properties like position and mass, but we can't separate them, these properties are a result of collective behaviors of other conventional particles. Just like you cansee geometric shapes formed by the group of birds returning to their homes in the evening.

What makes the Anyons special? Particle memory - if a fermion moves around another fermion, its quantum state does not change, similarly for a boson. But in the case of Anyons, if one orbits another, their collective quantum states shift. It might require three or more five or more revolutions to come back to the original state. This slight shift in the wave packet is like a memory of the trip. This property is very useful in quantum computing, and scientists areworking on it.

Abhinav Agarwal (M.Sc. 2nd year)

DEPARTMENT TRADITIONAL DAY 2023














SYMPHY 2023


Encoding two classical bits
Z encoding
Decoding
outcomes
Measure both qubits in the Z basis
X encoding
Measure both qubits in the X basis
Department of
PHYSICS
IIT
Bombay
PP-63
Strong Interaction between J-Aggregate Molecules and Surface Plasmons
Symphy 2023
FINDING THE RARE: DISRUPTION OF A STAR BY SUPERMASSIVE BLACK HOLE
Dynamics of Driven Active Chain

SYMPHY is the annual symposium organized by the Research Scholars' Association of Physics (RSAP), IIT Bombay. It provides a platform for research scholars and young scientists of the department to learn about emerging areas of physics and interact with eminent scientists from different reputed institutes of the nation. The program includes invited talks by distinguished scientists from all areas of physics, faculty members as well as research scholars of the department.

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~Editorial team

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