Office of the Principal Scientific Adviser
to the Government of India

vigyan dhara

विज्ञान धारा

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'India's Quantum Stride'

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FEATURE STORY:
QUANTUM HOTSPOTS IN INDIA

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In this edition of Vigyan Dhara, PSA Prof. Sood discusses the excitement around the contemporary theme of quantum science and technology.

FOREWORD

Quantum Science and Technology (QST) is the new frontier of scientific R&D, and it promises to usher in a technological upheaval. The entire world is investing heavily into this upcoming area, including India. This field primarily tries to harness the scientific laws and principles operating at atomic and sub-atomic scales for engineering applications for the benefit of humankind. As the phenomena, and the scientific laws and principles governing them, at the atomic and sub-atomic scales are quite different from the ones with which we are familiar in our day-to-day experiences in the macroscopic world, there is a mystique surrounding QST. I am happy that my Office is bringing out this special issue of our newsletter Vigyan Dhara on a very contemporary theme of QST this time.

For our readers at large, it may be useful if I retrace this 'Quantum" journey briefly, because a feeling is often given in popular media that QST has suddenly happened. I must dispel this impression or belief. Quantum Mechanics or Quantum Physics was born slightly over hundred years back in order to explain certain phenomena that seemed to be "anomalies" as per the laws and principles of Classical Physics which had acquired a very formidable structure by that time. Starting with Max Planck's hypothesis, the basic theoretical principles behind Quantum Physics got established roughly during the first quarter of the 20th century with landmark contributions by Schrödinger, Heisenberg, Max Born, Neils Bohr, Dirac, von Neumann, Einstein, our own S.N. Bose, Pauli, Fermi and several others. It was shown that Nature operated as per Quantum Mechanical laws and principles at the level of molecules, atoms and at sub-atomic scales; and as per Classical Mechanics at the day-to-day macroscopic scales. At the atomic and sub-atomic scales, matter behaved in a manner quite contrary to our day-to-day experience, but the predictions of Quantum Mechanics were proven true by very careful and extremely precise experiments. The culmination of all this is the Standard Model of Particle Physics that seems to explain all that we have observed so far in the atomic or sub-atomic realm. Through sustained and sterling contributions by a very large number of physicists, it was also established how individual atoms and molecules apparently lose their "individual quantum signatures" when aggregated to form macroscopic systems like various materials with which we are familiar.

While this is true, it is also a fact that the "quantum imprint" survives even in macroscopic matter in the form of its various physical and chemical properties.

Why copper is a good conductor of electricity and why ceramic is a bad conductor of electricity is basically governed by the structure of these materials at the atomic scales. However, what we "engineer" are materials and systems at the macroscopic scale based on their gross properties. Over the years, we learnt how to manipulate these materials to change their properties as per our needs, or make structures with desired properties and functionalities. This led to what we call today the "First Quantum Revolution", transistor being a great example of such developments which changed the world in a very profound way.

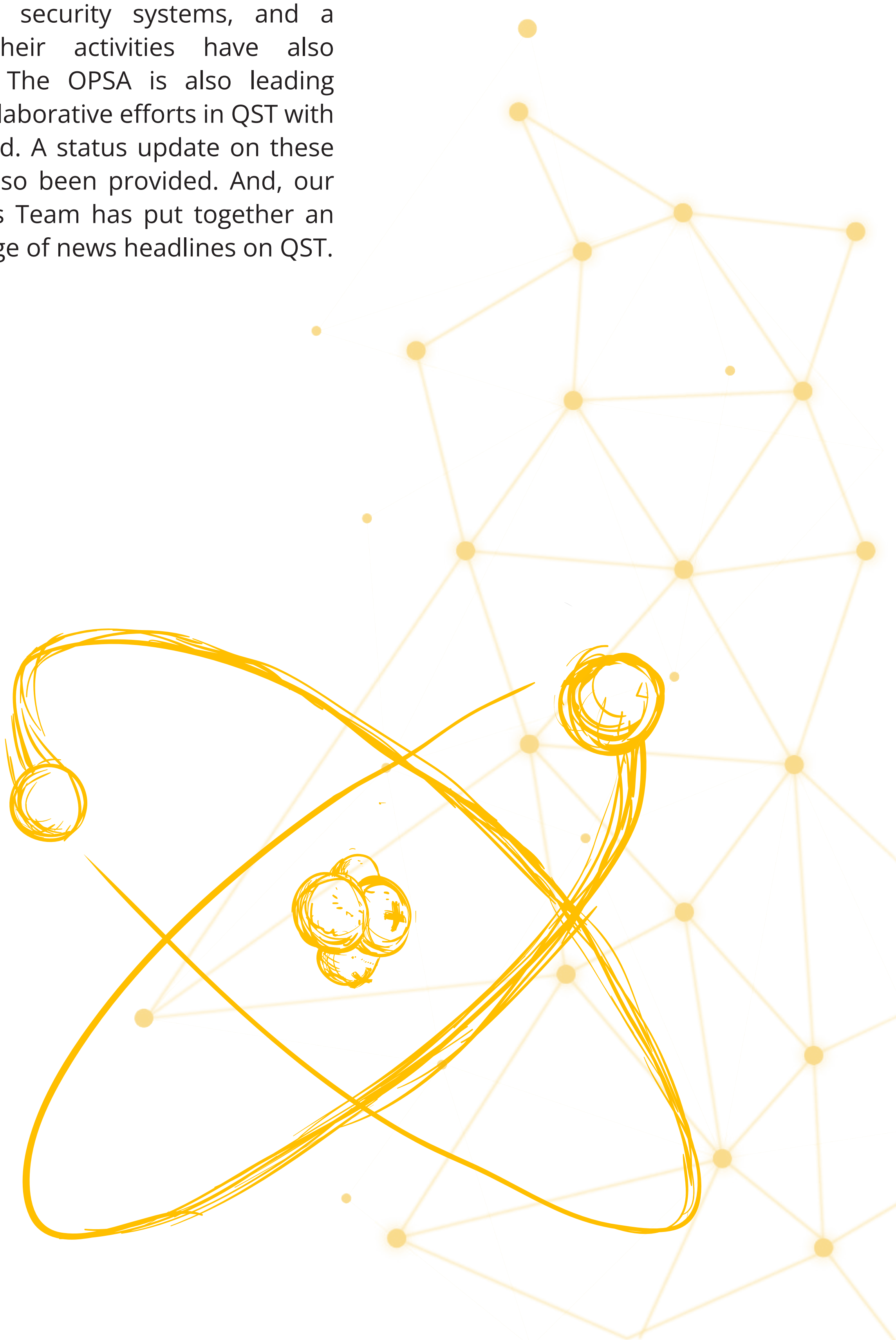
When we talk of QST today, we are talking of the "Second Quantum Revolution". How is it different? Here we are able to "engineer" physical systems consisting of individual atoms or few atoms, where these particles have not yet lost or averaged out their quantum heritage and are governed by the laws and principles of Quantum Mechanics. This gives us new ways to harness their behaviour for new kinds of uses for humankind. Even this has not happened suddenly. Richard Feynman talked of the possibility of a Quantum Computer way back in 1982. It is only now that such a device is being realized. In between we have over four decades of intense R&D in low temperature physics, nano and materials science and engineering, atom and ion traps and Bose Einstein condensation, sophisticated microscopy, ion beam engineering and so on. It has not happened in a day. The Nano Revolution around 2000 gave a big push to such R&D but let us not forget that Nano Science itself was foreseen by Richard Feynman in 1959, and it took about 40 years for "Nano" to flower. It is thus quite befitting that the United Nations has declared 2025 as the International Year of Quantum Science and Technology to recognize the 100 years since the initial development of Quantum Mechanics.

My purpose of recounting the R&D-continuum behind QST is to lift the veil of mystery behind these developments and emphasize to our readers that seemingly revolutionary developments in S&T are a long saga of painstaking work by thousands of scientists and engineers who prepare the ground in a particular area for it to (seemingly suddenly) flower. Vigyan, in fact, flows like a Dhara! I am happy that we have put together in this issue of Vigyan Dhara articles that cover various facets of QST from the Indian point of view.

The pioneering work of S.N. Bose started Quantum Statistics, and is an important cornerstone of the edifice of Quantum Physics. We bring an article on this great Indian contribution by the S.N. Bose National Centre for Basic Sciences, Kolkata, an institution set up by the Government of India to honour the memory of S.N. Bose. We also bring an article explaining different facets of QST to a general reader by a leading scientist of the country. There is yet another article by a leading scientist explaining the intricacies of a QST-based gravimeter of extreme accuracy, a sensing device of immense importance. The Government of India took early note of the importance of QST for the well-being and security of our Nation and started funding R&D in this area; something that culminated in the approval of the National Quantum Mission (NQM) in April 2023 with an allocation of ₹6003.65 crores for 8 years. This is a very substantial push, at par with many scientifically-mature nations of the world. The write-up by the Department of Science and Technology (DST), the Lead Agency for NQM, and the interview with Chairman, Mission Governing Board, NQM, bring out various facets of NQM and the plans for its implementation leading to focused deliverables with active collaboration between research and academic institutions, startups and industry.

We have also included first-hand views from two leading quantum start-ups in the country. The Society for Electronic Transactions and Security (SETS), established in 2002 under the aegis of the Office of the Principal Scientific Adviser to the Government of India (OPSA), is intensely pursuing R&D and translational work in digital security systems, and a write-up on their activities have also been included. The OPSA is also leading international collaborative efforts in QST with the US and Quad. A status update on these initiatives has also been provided. And, our Communications Team has put together an interesting collage of news headlines on QST.

I sincerely hope that this issue of Vigyan Dhara will not only convey the scientific excitements of QST but will also convince our readers about the important steps taken by the Government of India to enable our Nation to acquire a global leadership position in this emerging field.



THE SECOND QUANTUM REVOLUTION IN THE MAKING

By Prof. R. Vijayaraghavan

Prof. R. Vijayaraghavan, Head, Quantum Measurement and Control Laboratory, Tata Institute of Fundamental Research, Mumbai pens an article explaining different facets of QST

Modern-day computers are extremely powerful and versatile machines and have rapidly evolved over the last several decades, revolutionizing our lives in ways we probably never imagined. Tasks like writing this article or computationally-intensive tasks like video rendering can be done trivially with a laptop. These machines can perform these tasks by storing and processing information in the digital domain, i.e. in the form of 0's and 1's, also known as binary digits or bits. As the size of the transistor, the elementary building block of these machines shrunk, and their speed increased, computers became faster and more powerful.

But did you know that despite all these fantastic developments, there are several kinds of computations that modern-day computers cannot do efficiently today? For example, if we ask a computer to find the two prime numbers whose product gives 15 (=3 x 5), it can do that in no time. However, it is estimated that finding prime factors of a 2048-bit number will take nearly 20 quadrillion years using the most powerful data centres of the world! This impossibility of finding prime factors of large numbers is at the heart of an encryption system called RSA encryption, which is widely used to protect your data when communicating over the internet and in other places. This problem is very hard to solve because the number combinations to search for the answer increase exponentially with the size of the number. Another example is solving equations of quantum mechanics, which is at the heart of all fundamental processes in nature. Here, too, the computational resources needed just to represent the state of the system under investigation, say a molecule, blow up with the number of atoms in that molecule. So, solving the equations for the hydrogen molecule (H_2) is trivial, whereas solving them for the aspirin molecule ($C_9H_8O_4$) is impossible.

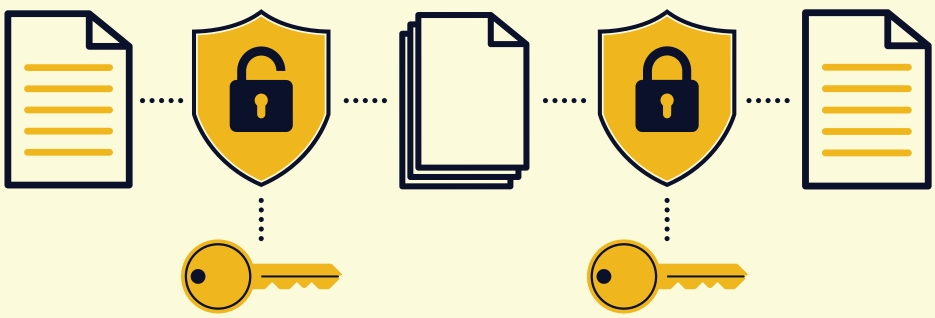


Image of RSA encryption for representation

Does this mean that these kinds of problems will remain insolvable? The answer is no, but one has to change the way we store and process information, and the answer comes from quantum mechanics.

Quantum Mechanics was primarily invented to understand the world of atoms and electrons. We learned in high school that the atomic model is similar to the solar system, with a nucleus in the centre (like the sun) and electrons orbiting around it at different distances (like the planets). However, this description turns out to be incorrect. The quantum mechanical equations only allow you to calculate the probability of finding the electron in a certain region of space, but the exact position or speed of the electron is unknowable. Furthermore, the electrons can only possess certain discrete values of energies corresponding to different spatial distributions around the nucleus. However, the equations also allow solutions which are a combination of the solutions for the discrete energy levels. We call these superposition states, which are combinations of two or more solutions. As different solutions have different energies and different spatial distributions, the answer to questions like what the energy of the electron is or where the electron is, becomes mysterious. To add to the mystery, when one measures the energy of the electron in such a state, one finds only discrete values corresponding to one of the solutions in the superposition. Moreover, the discrete value you measure is random, and after measurement, the state changes to the one corresponding to the answer!

But what does all this have to do with computation? We can consider using these discrete quantum states to represent our two binary digits 0 and 1. These states are represented using the new symbols |0> and |1> to emphasize that they are quantum states, and such a system is called a quantum bit or qubit. However, because these are quantum states, you can put this system in a superposition of |0> and |1>, which was not previously possible. This is the main idea behind quantum computing, i.e., the use of quantum states to store and process information and exploit the new features of superposition and entanglement, which are special superposition states involving more than one qubit.

Image of qubits for representation

With one qubit, you can prepare the system in a superposition of two states |0> and |1>. With two qubits, we have four possible discrete states, |00>, |01>, |10> and |11> and we can prepare the system in a superposition of all four. Now scale this to N qubits and you can create a superposition of 2^N states. For even a modest N=300 qubits, the number 2^N is enormous and more than the number of atoms in the visible universe! When a quantum computer operates on N qubits, the computational playground is exponentially larger, which offers the ability to do new types of computation. The examples of hard problems discussed earlier also had exponentially large requirements, and one can say that the quantum computer's exponentially large playground counteracts the exponentially large requirements of certain problems to enable a solution. However, one still has to deal with the randomness associated with the measurement of the qubit as we can not accept random answers. The quantum algorithm or programme has to manipulate the quantum states in such a way that the final answer is not random.

Not all problems are suitable for speeding up using quantum computing methods. And one also needs a sufficiently large number of qubits for practical applications. Apart from atoms and ions, scientists are building quantum computers using electrons, photons and superconducting electrical circuits to name a few. The largest system built to date by IBM uses superconducting circuits and has 1121 qubits. All systems built to date suffer from errors due to the fact that qubits are inherently unstable, and their states get disturbed easily. This makes long computations unreliable but steady progress is being made to address these issues. Once resolved, quantum computers will provide solutions to yet unsolvable, or relatively hard to solve, problems in materials science, logistics, and finance and even help make new fundamental discoveries.

Quantum Mechanics enables other applications apart from computing as well. The fact that measurement of a quantum system yields discrete answers and changes the quantum state itself can be used to ensure tamper-proof communication. The technique called Quantum Key Distribution (QKD) exploits this property to establish encryption keys that are guaranteed to be secure by the laws of physics. This method may replace the current RSA encryption methods mentioned earlier as they are vulnerable to future attacks from quantum computers. Certain carefully chosen quantum systems can be designed in such a way that some inherent property is made extremely sensitive to certain external perturbations. Such systems can be used as sensitive detectors with a wide range of applications in defence, medicine and industrial processes. The energy difference between the discrete levels of some quantum systems can be known very precisely and is robust to external perturbations. Consequently, when electrons go from the higher level to the lower level, they emit light at an extremely well-defined frequency (or colour). Such systems can be used to make very precise time-keeping devices called atomic clocks, which are crucial for applications in navigation, security, and fundamental science experiments.

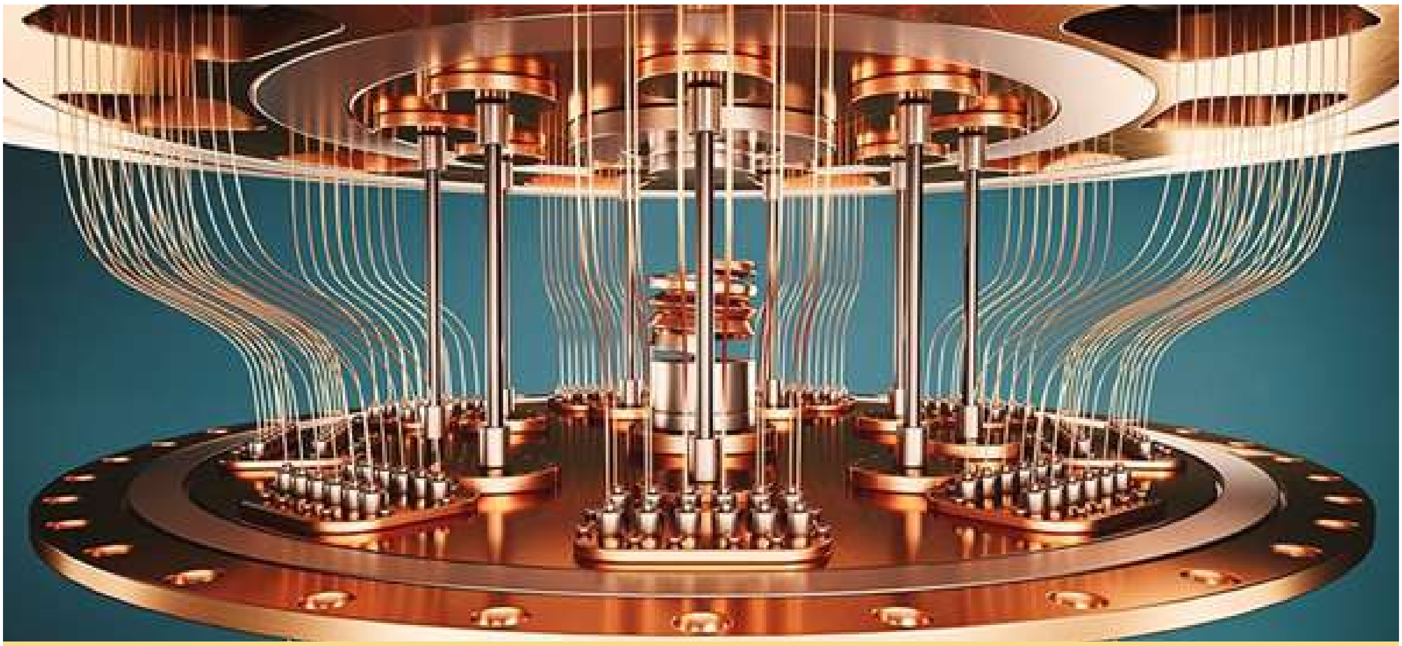


Image of quantum computer for representation

The so-called Second Quantum Revolution is poised to exploit quantum superposition and entanglement to develop new and extremely powerful quantum technologies in computing, communication, sensing, and metrology. Significant research and development are taking place around the world to fine-tune these technologies and create practical applications. India has also entered this race in a big way with the launch of the National Quantum Mission. Exciting times lie ahead!

EVOLUTION OF QUANTUM PHYSICS – S.N. BOSE'S PATH-BREAKING CONTRIBUTION FROM INDIA

By Dr. Tanusri Saha-Dasgupta and Dr. Manik Banik


Dr. Tanusri Saha-Dasgupta, Director, S. N. Bose National Centre for Basic Sciences and Dr. Manik Banik, Associate Professor, Department of Physics of Complex Systems, S. N. Bose National Centre for Basic Sciences, Kolkata share their insights on S.N. Bose's pioneering work in quantum physics.

Science plays a crucial role in understanding the mysteries of Nature. The macroscopic world we inhabit, with its tangible and visible aspects, is governed by the laws of classical physics. For instance, Newton's Laws of Motion and Newton's Law of Gravitation, the cornerstones of classical physics, explain how an apple falls from a tree to the ground. Similarly, James Clerk Maxwell's seminal equations provide a comprehensive description of electromagnetic radiation. In the nineteenth century, physics appeared to be a complete discipline. This perception was so strong that in 1874, Philipp von Jolly, the advisor of Max Planck, advised his young student against studying theoretical physics, claiming there was little left to discover. However, towards the end of the nineteenth century and the beginning of the twentieth century, several experiments were conducted with microscopic physical systems, producing results that could not be explained by classical physics. One such example is the phenomena of blackbody radiation, in which all incident radiation is absorbed, as in the case of light from the Sun during a solar eclipse. Classical laws failed to explain the experimentally measured spectra of blackbody radiation. While the low-frequency part was explained by Wien's Displacement Law and the high-frequency part by the Rayleigh-Jeans Law, there was no consistent theory to account for the entire spectrum. To resolve this puzzle, a revolutionary idea was put forward by Max Planck. He introduced the concept of oscillators that emit energy in packets called "quanta." Interestingly, in 1905, Einstein, in his celebrated explanation of the photoelectric effect -- which earned him the Nobel Prize in 1921 -- heuristically introduced the idea that radiation behaves like discrete quanta. Thus, amidst the momentous cultural and socio-political upheavals that took place in the 1920's, internationally as well as nationally in India, a silent revolution unfolded in the realm of natural science, with the birth of ideas, leading to what we call "Quantum Physics" today.

At a deeper philosophical level, Planck's and Einstein's descriptions fundamentally deviated from the well-established classical worldviews. These required revolutionary concepts, such as the idea that particles could be indistinguishable, energy could be quantized into small packets instead of being continuous, and light could consist of particles.

Against this backdrop of intense scientific activities in Europe, a modest man from Bengal in India, Satyendra Nath Bose, got deeply interested in the revolutionary new physics emanating from Max Planck's hypothesis of "quanta" and Einstein's quantum description of light. In 1917, Bose was appointed a lecturer in Physics at Calcutta University. Together with his classmate, Meghnad Saha, he authored two papers on the influence of finite volume molecules on the physical Equation of State. During his tenure at Calcutta University, Bose also worked on topics such as solution of stress equations of equilibrium in elasticity and deduction of Rydberg's Law from a quantum theory of spectral emission.

In 1921, Bose moved to the newly established Dacca University (now in Bangladesh), as a Reader. While teaching his students at Dacca University, he noticed a logical inconsistency in all the earlier derivations of the Planck distribution. This observation led to a groundbreaking discovery introducing the concept of indistinguishability of particles into the evolving quantum theory. Based on his work, Bose prepared a manuscript and sent it to Philosophical Magazine for publication. However, the paper was not accepted. Following this, Bose sent a letter to Einstein, a stranger to him at that time, along with a five-page article seeking his "perusal and opinion." Einstein immediately recognized the potential of Bose's discovery, translated it into German, and submitted it for publication in Zeitschrift für Physik. The paper was received by the journal on July 2, 1924, and published in the December 1924 issue. This paper on what is now called the Bose-Einstein Statistics, marked the beginning of Quantum Statistics, a major milestone in the evolution of Quantum Physics. Einstein extended Bose's idea, used to explain blackbody radiation, to ideal gases and wrote a back-to-back article in the same issue on the theory of ideal Bose Gas and Bose-Einstein Condensation.

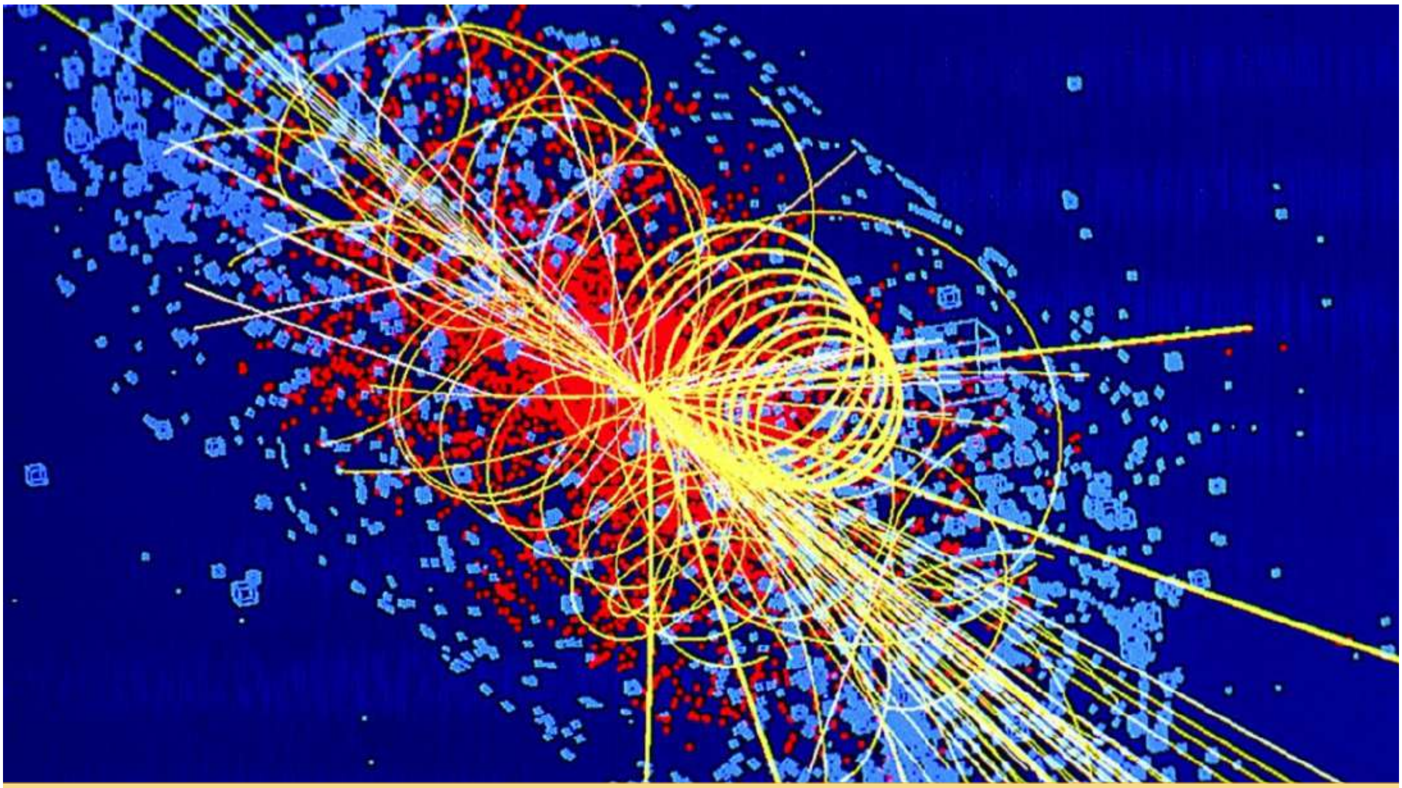


Image of Higgs Boson for representation: Image Credit – CMS Experiment

Today, we know that there are two kinds of particles in Nature: one like the photon, representing quanta of light, with the spin being an even multiple of ħ/2, obeying Bose-Einstein (BE) statistics, and the other like the electron, with the spin being an odd multiple of ħ/2, obeying Fermi-Dirac (FD) Statistics. Both statistics use the fact that in the quantum realm, particles are indistinguishable. In FD distribution, at most one particle can occupy a given quantum state, while in BE distribution, any number of particles can occupy a given state. The fundamental particles in Nature are thus categorized into 'bosons', named by Paul Dirac to commemorate Bose's contribution, and 'fermions'. Bose's paper is considered to be among the most revolutionary publications that led to the new quantum mechanics. As mentioned above, Bose's paper gave birth to Quantum Statistics, this year being the 100th year of this landmark discovery. While Bose himself did not receive a Nobel Prize, several Nobel Prizes were later awarded for the work related to bosons. For instance, the 2001 Nobel Prize in Physics was awarded for "the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates," and the 2013 Prize was awarded for "the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles," namely, the Higgs Boson (popularly called the God particle).

Bose's pioneering contributions enabled the development of quantum theory, the most successful framework for describing microscopic phenomena that drives advancements in cutting-edge technologies. The span of these technological applications is so vast that it can be divided in two distinct eras: the first quantum revolution and the second quantum revolution.

Satyendra Nath Bose. Image Credit: S.N. Bose National Centre for Basic Sciences Archive

While the first quantum revolution, that happened a century ago, exploits non-classical behaviours of ensembles of quantum systems to pioneer technologies such as semiconductors, lasers, and MRI, the second quantum revolution of today focuses on actively controlling and manipulating non-classical properties like coherence and entanglement in elementary quantum systems. This aims to develop information protocols and computing machines that would surpass the capabilities of classical systems. We can now engineer artificial quantum systems like quantum dots and excitons, tailoring their electronic and optical properties to specific requirements. Bosons find their relevance in this second revolution too. For instance, Boson Sampling emerges as a significant computational problem that leverages the unique behaviour of indistinguishable particles and offers a potential demonstration of quantum computational advantage where quantum computers could outperform classical computers.

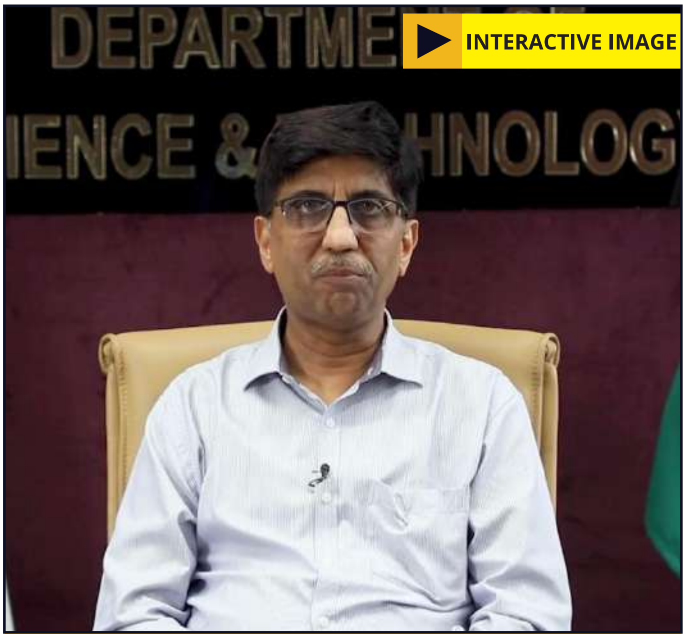
In essence, Bose's early work continues to influence and inspire research of today. Globally, both private and public institutions and industry are vigorously pursuing R&D for making breakthroughs in this domain; aiming to unlock the full potential of quantum technologies. India's National Quantum Mission is a notable initiative in this direction, which seeks to position India at the forefront of quantum research and innovation, highlighting the strategic importance of quantum technologies for the Nation.

We hope that the seminal contribution of Prof. S. N. Bose towards the development of Quantum Physics will continue to inspire young Indians, and they would work towards securing a position of global leadership for India in Quantum Science & Technology.

The S. N. Bose Archive and Museum at S. N. Bose National Centre for Basic Sciences, the Institute set up by the Government of India (Department of Science and Technology) to honour the life and work of Professor Satyendra Nath Bose (Image Credit: S. N. Bose National Centre for Basic Sciences, Kolkata)

NQM- LAUNCHING INDIA INTO QUANTUM FUTURE

By Dr. JBV Reddy



Prof. Abhay Karandikar, Secretary, Department of Science and Technology shares his insights on National Quantum Mission. Scan the image with Overly App to watch the full video.

Dr. JBV Reddy, Scientist 'F', Mission Director, National Quantum Mission, Frontier and Futuristic Technologies (FFT) Division, DST pens the article detailing the progress of National Quantum Mission since it's inception.

The National Quantum Mission (NQM) is set to position India as a pre-eminent global leader in Quantum Technologies, with the potential to transform diverse sectors such as communications, healthcare, space exploration, finance, and energy. As a flagship endeavour endorsed by the Prime Minister's Science, Technology and Innovation Advisory Council (PM-STIAC), the NQM aims to harness advanced scientific research for India's sustainable development objectives.

The Department of Science and Technology (DST) is designated as the principal implementing agency and has commenced significant preparatory measures. These initiatives involve comprehensive stakeholder engagement and multi-level consultative processes conducted within a collaborative framework.

Anticipating the strategic imperative of the quantum technologies, DST had proactively initiated the Quantum Enabled Science & Technology (QuEST) program in March 2019. This visionary initiative has catalysed the advancement of quantum research by funding 51 projects, with a total outlay of ₹186.95 crore.

In addition, DST established a Technology Innovation Hub (TIH) in quantum technology at the Indian Institute of Science Education and Research (IISER), Pune, in October 2020. This initiative being undertaken as a part of the National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS), represents a substantial investment of ₹170 crore.

As a part of its intramural research initiatives, various autonomous institutions of DST—notably the Raman Research Institute in Bengaluru, the Jawaharlal Nehru Centre for Advanced Scientific Research in Bengaluru, and the S. N. Bose National Centre for Basic Sciences in Kolkata—have initiated research programs in various areas of quantum technology applications. They have substantially accelerated Research and Development (R&D) in quantum technology in India, thereby setting the stage for transformative innovations and pioneering discoveries in the field.

India's National Quantum Mission is a strategic initiative focused on propelling research and development in four pivotal domains: Quantum Computing, Quantum Communication, Quantum Sensing & Metrology, and Quantum Materials & Devices. This transformative endeavour seeks to cultivate, nurture, and expand scientific and industrial R&D in these areas through a collaborative ecosystem. By fostering synergistic partnerships among academia, industry, startups, and government, the NQM aims to catalyse ground-breaking advancements and breakthroughs in quantum technologies.

The Mission's overarching objectives include developing quantum computers, highly secure quantum communication systems leveraging Quantum Key Distribution (QKD) and Post-Quantum Cryptography, quantum clocks and sensors, quantum materials and devices as well as human resource, global collaborations, and nurturing an ecosystem of quantum technology startups.

NQM Mission Governing Board finalising implementation strategy and timelines of NQM; Image Credit: DST Website

A formal solicitation for proposals to establish Thematic Hubs (T-Hubs) was issued on January 20, 2024 inviting submissions from academicians, scientists, and technologists in academic institutions and R&D Laboratories. Given the multidisciplinary nature of quantum technology, the establishment of T-Hubs is envisioned through a consortium-based approach, involving multiple institutions. Hence, the proposals are structured to form Technical Groups across various domains within the four primary technology verticals. Lead Principal Investigators of these Technical Groups will assume responsibility for the establishment and operation of the respective T-Hubs.

Call for Proposals to set up Thematic Hubs under NQM; Image Credit: DST Website

The Call for Proposals elicited an overwhelming response from India's quantum community, attesting to the nation's burgeoning interest and capacity in this domain. About 384 proposals have been received and are currently undergoing rigorous evaluation.

The NQM will provide strategic support to transformative initiatives characterized by well-defined, measurable outcomes across all four thematic areas. By adopting a mission-oriented approach, the program aims to expedite the maturation of technologies to high Technology Readiness Levels (TRLs). This concerted effort is anticipated to create a substantial competitive edge for the nation.

Brainstorming session held;
Image Credit: DST Website

A consultative forum was convened to engage with quantum technology startups and conduct a comprehensive analysis of the emerging technological landscape. After these discussions, guidelines have been prepared to support startups under the Mission.

By cultivating a synergistic ecosystem encompassing researchers, industry leaders, and policymakers, DST aims to ensure the Mission's strategic alignment with the overarching goals of global competitiveness and the creation of a robust, expansive quantum technology landscape.

The National Quantum Mission is targeting to complete its major milestone of finalizing the constitution of T-Hubs and launching projects across all quantum domains. Adhering to a meticulously defined roadmap, the NQM team is operating in mission mode to ensure sustained, timely progress towards the realization of the Mission's objectives:

i. Finalizing the selection of Technical Groups and subsequently establishing Thematic Hubs (T-Hubs),

ii. Launching Pivotal Research Initiatives,

iii. Developing National Facilities,

iv. Developing a Highly Skilled Workforce,

v. Fostering Entrepreneurship and Innovation,

vi. Bolstering International Collaborations.

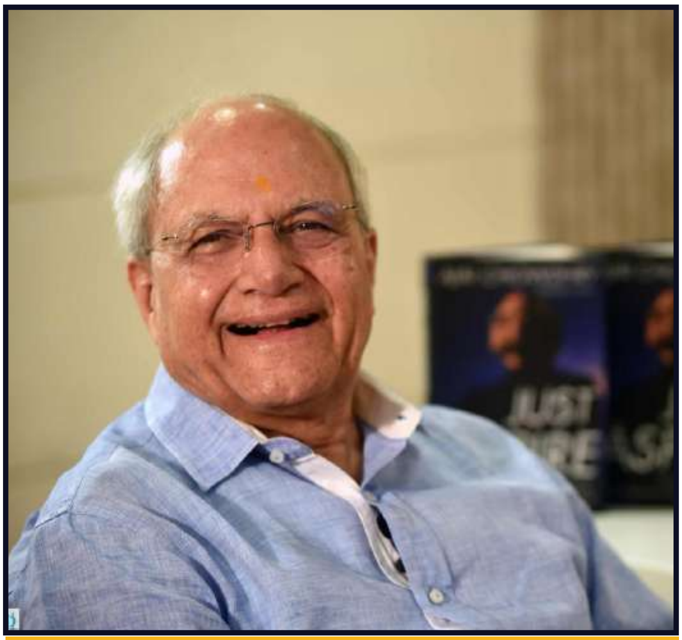
The continued support of DST and the concerted efforts of all stakeholders are indispensable for the realization of the Mission's vision. Such collaborative synergy will be instrumental in achieving the Mission's ambitious goals and establishing India as a global leader in quantum technologies in the years to come.

IN CONVERSATION

Making India Quantum Ready: A Dialogue with Dr. Ajai Chowdhry

— Interview by Dr. Preeti Banzal and Dr. Praveer Asthana

— Written by Sanchita Jain



Dr. Ajai Chowdhry, Mission Governing Board Chair, National Quantum Mission

Dr. Preeti Banzal, Adviser, OPSA and Dr. Praveer Asthana, PSA Fellow, OPSA

Private companies need to play an active role in investing in R&D for India to transition into a 'product nation' from a service economy, says Dr. Ajai Chowdhry, Mission Governing Board (MGB) Chair of recently-launched National Quantum Mission (NQM) and co-founder, HCL Technologies, in a candid conversation with Dr. Preeti Banzal, Adviser, OPSA, and Dr. Praveer Asthana, PSA Fellow, OPSA while discussing NQM's objectives, the role of public-private partnerships, and the importance of building a robust Research and Development (R&D) culture in India.

Here are a few excerpts from the conversation:

Dr. Banzal: Thank you for meeting us today to share your insights for the Vigyan Dhara newsletter. To begin with, please share your vision of NQM and how an effective rollout of the Mission is being planned.

Dr. Chowdhry: The National Quantum Mission is a major Mission envisaged under the Prime Minister's Science, Technology and Innovation Advisory Council (PM-STIAC), and approved by the Cabinet in 2023. We've been moving at 'quantum speed', aiming to design, develop, and create quantum technology products. The Mission is structured around four thematic hubs: quantum computation, quantum communication, quantum sensing & metrology, and quantum materials & devices.

We received a remarkable response to the Call for Proposals with 384 proposals received from scientists across the country. Our goal is to group similar research efforts within each hub, fostering collaboration and ensuring we're all working towards achieving the Mission's eight-year objectives.

Beyond the scientific community, we're also engaging with industry and startups. Out of 45 startups we have connected with, we've shortlisted 14 for further support, categorizing them based on their state of development. Our plan includes providing them with mentorship and funding. On the industry front, we've initiated discussions with several software companies. Despite the large number of proposals, we aim to announce the thematic hubs by mid-August, and our team is working tirelessly towards this goal.

We're on track, and quite excited about the future of this mission.

Dr. Banzal: It's very encouraging to hear about the number of proposals received. Moving on, you've had a good opportunity to assess India's current capabilities in quantum technology. How do you see India's role evolving in the global quantum technology ecosystem over the next decade?

Dr. Chowdhry: Our primary objective is to achieve Atma Nirbharta. One of the ways to do that is by developing a 1000-qubit computer within eight years. This ambitious target entails building robust capabilities across the country. To build our talent pool, we've signed an MoU with the All India Council for Technical Education (AICTE) to introduce MS programs in quantum technology and a minor in Quantum for B.Tech programs in physics and computer science.

We're also open to global collaborations, but cautious about ensuring that they genuinely contribute to our Mission without risking talent churning and exodus. This is a significant challenge, given the disproportionate global demand and shortage of available skilled professionals in this field.

Dr. Asthana: Given your industry expertise, I have a specific question. How do you see the Indian industry participating in quantum technology, particularly in quantum computing? What should we prioritize, and what should proceed in parallel?

Dr. Chowdhry: See, many Indian software companies are heavily involved in engineering and R&D exports, currently estimated at $39 billion, though the real value could be much higher. We want to leverage this strength in engineering and control systems for quantum computer development presently. Our goal is to make these companies collaborate with academic institutions and thematic hubs, and encourage them to invest in quantum computing from now itself, even if the returns seem far off, as this is the right time to start.

Dr. Asthana: Quantum Technology is indeed at the cutting-edge of science, and the upfront R&D requires significant investment. How do you foresee the industry adapting to the challenges of such high-risk, high-cost initial investments in quantum technology, especially by way of setting up facilities and carrying out initial R&D before seeing returns?

Dr. Chowdhry: For this, we plan to provide the four thematic hubs with a complete environment for innovation. This way, industries can invest in talent rather than expensive equipment. Our focus is on getting private companies to invest their people into these hubs, rather than making large equipment purchases upfront. Historically, private R&D in India has been underinvested resulting in the public sector shouldering the majority of the investment. To transition from a service-based economy to a product-based nation, we need to boost private R&D. NQM will help leverage public funding to support private sector R&D, thereby helping to absorb the initial R&D investments in a technology domain as deep as Quantum Technology.

Scan the image using Overly App to hear more from Dr. Chowdhry about creating synergies between scientists for collaboration

Our thematic hubs will have the infrastructure for supercomputing and quantum computing time, but we'll be cautious not to overspend. Instead of buying quantum computers, which can quickly become obsolete, we may prefer to purchase computing time as needed. We're inviting global companies to bring their machines here at their cost, and we'll use our own experts to work on these systems. This way, we will avoid the high costs of purchasing some of the equipment and ensure that we make the most of our international collaborations.

Dr. Banzal: Given the long development timelines for quantum technologies, how enthusiastic are the 14 startups you mentioned about entering this field? What is your sense of their readiness and potential for expanding their involvement in quantum technology?

Dr. Chowdhry: Many startups in quantum communication have already laid a solid foundation. However, much more is needed. The thematic hubs will play a crucial role in mentoring these startups, offering access to testing facilities, quantum computing resources, and other tools to accelerate their progress. Currently, venture capitalists (VCs) are still grappling with investing in deep tech areas like quantum technology, but there has been growing interest since NQM's launch. The Mission will provide initial funding, mentoring and resources to help startups advance faster than they could on their own.

Despite our current funding being modest compared to global leaders like China, this is a promising start. To put things in perspective, China's investment in quantum technology is around $15 billion, whereas our initial commitment is about $750 million. Just as the Semiconductor Mission received additional funding after proving its value, we hope that the successful progress of NQM will encourage further investment from the government.

Dr. Asthana: Given the concerns about quantum computers potentially breaking existing encryption schemes and the need for post-quantum cryptography as a near-term measure, how is NQM addressing these security challenges? Are there efforts in place to develop capabilities for post-quantum cryptography and other security schemes?

Dr. Chowdhry: Absolutely, addressing information security in the quantum era is crucial. The issue isn't whether quantum computers will arrive—it's when. We need to prepare now because adversaries could be harvesting data that future quantum computers might crack. This isn't something we can afford to delay. In India, we need to focus on becoming quantum-safe as soon as possible. The challenge is that while organizations recognize the importance, they're hesitant to invest in new technologies like post-quantum cryptography and other security schemes without proof of their effectiveness. To address this, the NQM is working on establishing testing and certification facilities. These will validate that quantum security solutions work, which is essential for overcoming skepticism and encouraging adoption.

Dr. Asthana: Sir, revisiting the question on human resource development in Quantum S&T, I would like to mention that there is a large latent capacity lying dormant in the form of our college and university teachers. They have the necessary background and training, but their research potential remains untapped because of lack of opportunities. In fact, they could meet some of our human resource requirements in the shortest possible time. This is not something new. This has been effectively utilized in the form of an "Associateship Programme" by the Inter-University Centre for Astronomy & Astrophysics, Pune, and the Inter-University Accelerator Centre, New Delhi wherein college and university teachers are facilitated to spend a few months every year doing research in these centres. This scheme led to a resurgence of research in Astronomy & Astrophysics and Experimental Nuclear Physics in colleges and universities. I also tried this in a distributed fashion in the Centres of Excellence that we had created under Nano Mission which I happened to lead for a long time. Do you think we can try this cost and time-effective model under the National Quantum Mission as well?

Dr. Chowdhry: That's very interesting and heartening to know because I think we haven't thought about this at all. This could be something very good for us to look into.

Dr. Banzal: Well Sir, this has certainly been an insightful discussion. We have all learned a lot. In closing, now I request you to share your final remarks.

Dr. Chowdhry: I'm genuinely optimistic about this program. The responsibility entrusted to me by the government is significant, and I'm grateful for the opportunity to contribute to this crucial work. Quantum is a complex and emerging field, and joining the NQM has been a learning journey for me. I've immersed myself in understanding it and continue to learn every day. Despite the challenges, I remain very hopeful and excited about the potential impact of this program.

FEATURE STORY: QUANTUM HOTSPOTS IN INDIA

PUSHING THE QUANTUM LIMIT: How QNu Labs is pioneering indigenous quantum solutions

Q→NU Proactively Quantum™

By Ranjini Raghunath

Mr. Sunil Gupta, CEO, QNu Labs

In 2016, when demonetisation was announced, Sunil Gupta, one of the founders of QNu Labs, sensed that a sea change was coming. The country's cash-based economy would soon be shifting to a digital economy, giving rise to a host of new challenges. The founders, who had been in the cybersecurity industry for decades, realised that there could be no digital economy without digital trust. "At that time, India's approach to cybersecurity was fragmented," Mr. Gupta recalls. "We felt that the time has come for India to look at developing a next-generation cybersecurity platform of its own that can make India future safe."

2016 was also the same year that saw the launch of QNu Labs, India's first deep tech startup that would tap into the realm of quantum physics – instead of AI, which hackers were already exploiting – for cybersecurity solutions.

"We needed to create technology that would give enterprises at least a five-year headstart over hackers," Mr. Gupta, the company's CEO, explains. "We knew that quantum computers might probably be here by 2030. So, even if it took five years to build our products and five years to deploy, we would still be about five years ahead of hackers before they get a large enough quantum computer to threaten existing encryption."

Over the last decade, QNu Labs has emerged as a trailblazer in India's fledgling quantum tech market. Founded by Sunil, Srinivasa Rao Aluri, Mark Mathias, and Anil Prabhakar, it was first incubated at the IIT Madras Research Park but later moved to the heart of Bengaluru city. The company has been offering quantum-safe data encryption and secure communication solutions to a variety of organisations in the finance, telecom, defence and government sectors. Among its flagship products are Tropos, a quantum random number generator (QRNG); Armos, a quantum key distribution system and QShield, its Enterprise Service Platform that leverages both quantum and post-quantum cryptography (PQC) technologies.

In Quantum Key Distribution (QKD), photons or packets of light in random physical states are used to generate secure keys in such a way that anyone attempting to eavesdrop on the communication channel between two entities cannot do so without disrupting the quantum state, which can be easily detected. QNu Labs is among a handful of organisations globally that have shown how QKD and PQC can be used for securing data in transit and at rest over any communication medium.

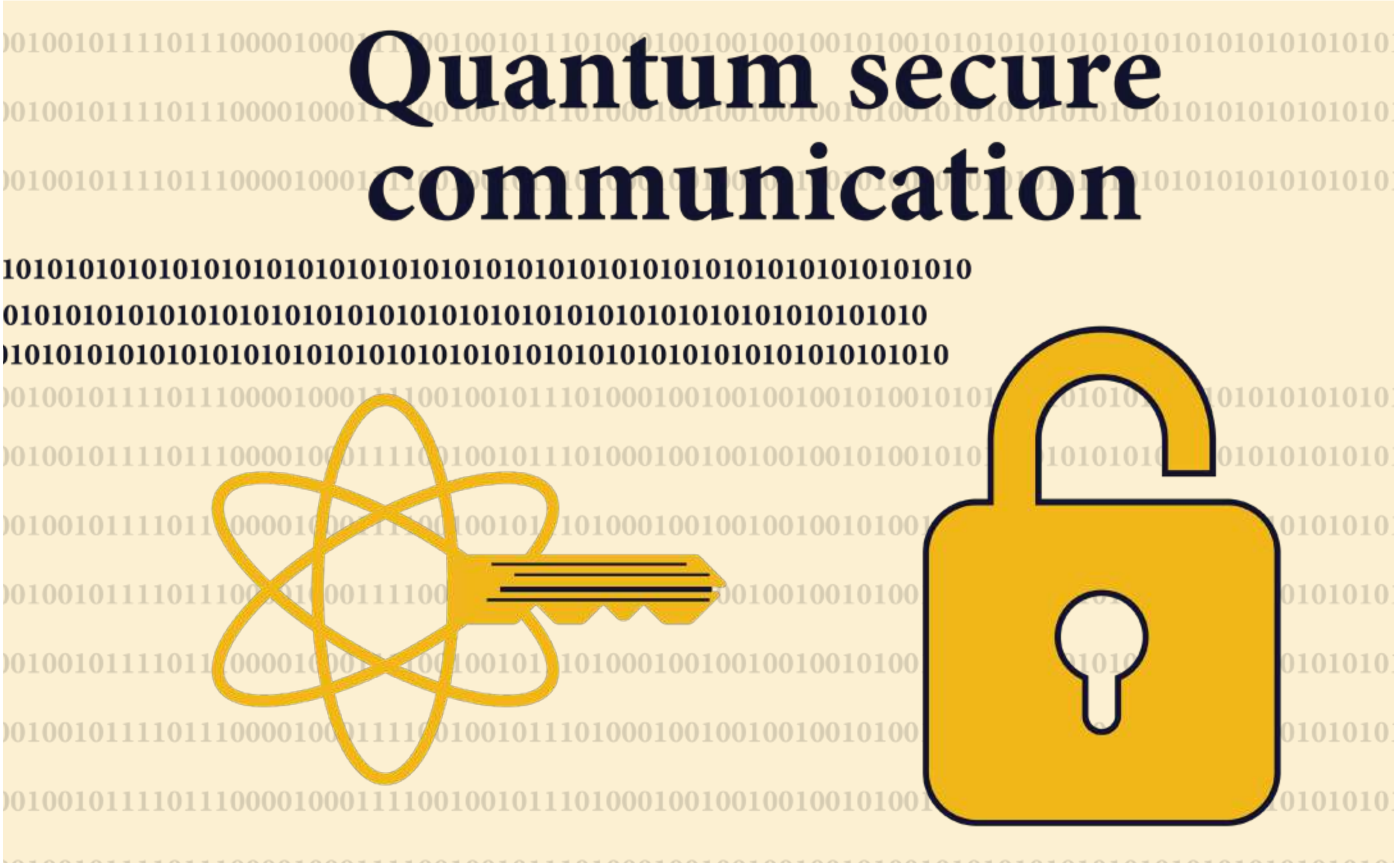


Image of quantum secure communication for representation

In a global first, they were able to successfully generate quantum-secure keys over a distance of 150 km (33dB loss) on an existing optical fibre network.

“QKD comes in different flavours,” Mr. Gupta explains. “For example, if you want to connect two cities 1,000 km apart, we have a technology called ‘trusted relay node’ in which we can put several QKD boxes in series, daisy-chain them, and extend the secure key generation over the required distances.

QNu Labs’ quantum tech solutions are working on projects aimed a strengthening the nation's defence and security, and is also expanding its offerings to other clients, including banks, healthcare and blockchain companies. The company is seeking to tie up with the oil and gas sector and the telecom sector as well. Mr. Gupta elaborates: “With the initiative of Department of Telecommunications (DOT), we are also working with a consortium to build India’s first quantum-secure 5G phone which will use our quantum module.”

Overcoming challenges

When QNu Labs was conceived, the idea was to build a company that would not only be a pioneer in India but would also be a global provider, according to Mr. Gupta. “The challenge for us was threefold,” he recalls. “How would we form a good team? Who will fund us? And how will we create a market for quantum security technology?”

In its early years, QNu Labs received support from industry initiatives such as the Cisco Launchpad Accelerator, NetApp Excellerator, Intel Startup program and Nasscom Deeptech Club. Later, the Technology Development Board, which is a part of the Department of Science and Technology, gave them a loan to commercialize the technology.

Today, QNu Labs employs about 100 people. QNu has also taken on the responsibility of creating an ecosystem with several other companies in this space. "We have shortlisted 50 companies in India across different industry verticals and have a targeted plan of doing awareness sessions, proof-of-concepts and pilots," Mr. Gupta says.

QNu Labs also pursued the go-to-market strategy of collaborating with original equipment manufacturers such as Cisco and Thales, working to integrate their products and solutions with these companies' existing solutions, instead of competing with them.

In addition, QNu Labs' founders knew that clients who were used to traditional encryption would be largely unfamiliar with the quantum mechanics principles that underpinned their products. "We realised that we had to keep the learning curve for our customers very small," explains Mr. Gupta. "I would tell my team that the implementation of Armos in the field should be 'Plug n Play' - as simple as connecting a PS4 game station to the TV."

QNu Labs has also cracked the challenge of creating a local market.

Scan the image with Overly App to listen more from Mr. Gupta about overcoming various challenges

Nation-building

What makes QNu Labs' products stand out, Mr. Gupta says, is that they are fully conceptualised, designed and manufactured in the country.

The idea is that people outside (and even inside) the country need to have greater faith of India-made products, Mr. Gupta explains: We have sent our products to more than 40 locations through different modes of transport, and the products have worked without any issues so far."

When they were setting up QNu Labs, the founders knew that they only had one chance to show that quantum physics-based products could work and make an impact in the Indian market. Mr. Gupta recalls: "We went in with the idea that if we succeed, others will get inspired; if we fail, others will learn from our experience."

Mr. Gupta says that efforts by startups like QNu Labs have "broken barriers" and shown how India can make frontier technologies with people working within the country. "I keep telling my team that we have a once-in-a-lifetime opportunity to be pioneers of this technology in the country. We are not copying someone else's roadmap or vision but rather charting our own vision and future. We feel like we are adding an important brick towards building the nation."

Mr. Gupta is also optimistic about the growth of India's startup ecosystem, which he feels is moving in the right direction. He believes that sufficient and timely funding and a supportive policy environment will further accelerate this growth and that the draft National Deep Tech Startup Policy is a significant step forward in that direction.

(Ranjini Raghunath is Communications Officer at the Indian Institute of Science, Bangalore.)

FEATURE STORY: QUANTUM HOTSPOTS IN INDIA

The QpiAI Story: An Indian Quantum Computing Firm for Research, Healthcare, Finance & Transportation

By Ananthapathmanabhan MS

Dr. Nagendra Nagaraja, CEO, QpiAI

"I think I can safely say that nobody understands quantum mechanics." Physicist Richard Feynman explicitly uses these words in his 1965 lecture on quantum mechanics. While understanding quantum mechanics may be tough as it is counter-intuitive to phenomena in our macro-world,
the truth is that principles of quantum mechanics can be exploited, at least in some areas if not all. With quantum mechanics, it is possible to find novel applications to provide aid to fields such as finance, road traffic, healthcare research, and so on.

QpiAI: A Quantum Help to Support Research and Development

This potential is being explored and realized by QpiAI, an Indian startup focused on integrating AI and quantum technologies in enterprise solutions, focusing on near-term practical applications such as drug discovery.

At this stage, the mission of QpiAI "is to provide immediate or near-term practical advantage across various industry use-cases with actual realizations in enterprise workflows interfacing with analytics and security."

For example; in drug development, "the issue arises from a patient's standpoint, as what they require is a drug which acts effectively on them with minimal side effects," says Dr. Nagendra Nagaraja, CEO of QpiAI.

"To arrive at that level of precision while designing a drug, you need to have very efficient computation."

Quantum computation helps speed up the process of finding the right molecular matches to design the best possible combination of molecules in drug design.

It is this computing speed which gives quantum computing an edge over traditional computers for three reasons: the speed of calculations, the time taken to train a machine, and the vastness and variety of the data used in computation.

"For instance, if you continue to add more features for credit card fraud detection, a classical computer will eventually require an exponentially longer training time. This is where quantum computers excel, as they overcome the issue of extended training time," explains Dr. Nagaraja.

Also, in terms of energy, quantum computers work differently from classical ones. In quantum computers, most of the energy is required to cool down the quantum computer rather than running the computer. But with a classical computer, more energy is required to run the computer rather than cooling it down.

As Dr. Nagaraja mentions, "what the quantum computers can do with 26 kilowatts, the classical one can take up to 15,000 kilowatts." Realizing the potential of quantum technology, the Government of India, in April 2023, approved the National Quantum Mission with an allocation of around ₹6000 crores.

QpiAI-developed Quantum Processor: Trion Universal Optimisation Processor; Image Credit: QpiAI Website

Made and Make in India

QpiAI is an Indian company that aims to deliver solutions to research institutions in India. Dr. Nagaraja highlights QpiAI's plans to release its first quantum computer soon, with ongoing research and customer access to follow. The company aims to provide Indian research institutions the choice to buy from a local supply chain, enhancing self-sufficiency and trust in the technology and its pricing.

QpiAi will also shake hands with the government to supply this quantum computer and upgrade its processing power by introducing more quantum bits.

"The ease of computation worldwide is not solely dependent on the number of qubits, but also on the usable qubits. Developing usable qubits is the main part of research."

Usable qubits are the ones which are fit to use for a specific application.

Bull's Eyes on the Quantum Computing

As per the 2024 *Quantum Technology Monitor report*, published by McKinsey and Company, Quantum Computing will hit the market with a high score by generating value worth trillions of dollars within the next decade. They mention, "four sectors—chemicals, life sciences, finance, and mobility—are likely to see the earliest impact from quantum computing and could gain up to $2 trillion by 2035."

The report also suggests that "with quantum talent growing, countries need to focus on broad collaborations to build strong capabilities."

"The kind of collaborations we have speaks for that; we have collaborations not only with universities but also with institutes like DRDO and ISRO," says Dr. Nagaraja. QpiAi also has MoUs with at least six universities across India, including with the IITs, and the RV College in Bengaluru, and is looking forward to working with them.

"We are going to invite all these people once we have this quantum computer installed and then we would like to take strategic steps with that (to) serve their interest."

As opposed to doing a science project, according to Dr. Nagaraja, QpiAI is more into commercializing quantum computers.

"National Quantum Mission has earmarked ₹6000 crores to advance quantum technology and we also have institutes spending crores on research- not only the government institutes, but the private institutes too- and they all require the technology. They want to see their researchers working on quantum computers where they can develop and try appropriate algorithms," says Dr. Nagaraja.

According to Dr. Nagaraja, the best way to convince people about QpiAI's progress is with some numbers rather than speaking."

"I am very lucky to get the team which I have right now, they're the best in the world. And we are attracting more talent. We are hiring PhDs and postdoctoral researchers," says Dr. Nagaraja.

As Dr. Nagaraja adds, "As a small startup, we have done a great deal of work to get around the present constraints."

Although the fabrication laboratories (fabs), where the systems are built, have not reached full capacity in India, eventually the company will build its own fab that doesn't cost much- just around $60 million. He also mentions that QpiAI will endeavour to remove the constraints of fabrication.

He mentions that the availability of government funding for all players in the national quantum ecosystem – academia, startups, and industry – will greatly accelerate India's progress in this highly competitive field.

Scan the image using the Overly App to hear Dr. Nagaraja share his insights on convincing investors to invest in long-term technologies like quantum computing

He stresses the importance of developing all aspects of the technology within India, from research to manufacturing, to ensure a secure and reliable supply chain. As he confidently states, "We want everything to be from India."

(Ananthapathmanabhan MS is Senior Editorial Assistant at Indian Institute of Science, Bangalore)

FEATURE STORY: QUANTUM HOTSPOTS IN INDIA

Titanic Might Not Have Sunk with a Quantum Gravimeter on Board

By Vivek Kumar and Sanchita Jain

Prof. Bodhaditya Santra working in his lab at IIT Delhi

"If a quantum gravimeter had been on board the Titanic, the ship might not have sunk," reflects Prof. Bodhaditya Santra, Assistant Professor, IIT Delhi. He explains that these advanced devices have the potential to detect minute changes in gravitational fields, including those caused by submerged icebergs. By identifying gravitational anomalies ahead of the ship's course, crucial early warnings could have allowed for course corrections, potentially averting the disaster.

Gravimeters are instruments designed to measure the gravitational pull at a specific location. Traditional gravimeters, such as MEMS-based (micro-electromechanical systems) or superconducting gravimeters, rely on mechanical oscillations or spring-mass systems. These can be divided into two categories: relative gravimeters and absolute gravimeters. Relative gravimeters measure the change in gravitational force between two points, making them ideal for comparative measurements. Absolute gravimeters, on the other hand, provide direct measurements of gravitational acceleration, offering precise data crucial for scientific and industrial applications. Absolute gravimeters can be used in the calibration of relative gravimeters.

Image of Titanic wreckage for representation

The Advent of Quantum Gravimeters

Quantum gravimeters represent a significant leap in gravimetric technology. Utilizing the principles of quantum mechanics, these devices promise unprecedented precision and versatility. At the heart of quantum gravimeters is the technique of laser cooling and trapping of neutral atoms. This method pioneered in the 1980s, has since evolved to enable various quantum applications, including sensing, computing, and simulation.

Image of gravimeter for representation

Prof. Santra explains that the process begins with laser cooling, where atoms are cooled to temperatures below 100 micro-Kelvin. "At such low temperatures, the atoms' velocity decreases significantly, allowing them to behave almost like stationary objects when subjected to gravity. When these cooled atoms are allowed to fall, their movement under gravity can be precisely measured," he notes.

Moreover, by using pairs of Raman pulses, scientists can create a superposition state, splitting the atom cloud into two quantum states. These states can be manipulated and recombined using light pulses, forming a matter-wave interferometer. This interferometer operates on principles similar to the Mach-Zehnder interferometer used in optics, but with atoms instead of photons. The gravitational force imprints a phase shift on the quantum states, providing highly accurate gravitational measurements.

From Lab to Field

Quantum gravimeters offer several advantages over traditional gravimeters in the realm of quantum sensing. Firstly, they provide absolute measurements of gravitational acceleration, eliminating the need for frequent calibration required by relative gravimeters. This makes them ideal for high-precision applications such as geophysical surveys, oil and natural gas exploration, and mineral prospecting.

Additionally, the potential for miniaturization makes quantum gravimeters suitable for deployment in the field. Compact versions of these devices can be mounted on trucks or even drones, significantly expanding their application range. "Imagine being able to survey areas prone to natural disasters, like regions with frequent sinkholes or landslides, with the accuracy of quantum technology," Prof. Santra enthusiastically mentions. These gravimeters can provide valuable data for disaster prevention and mitigation.

Advancing Gravimeter Technology in India

India's recent announcement of the National Quantum Mission signifies a substantial leap towards innovation, gravimeter technology included. The country's focus on enhancing geophysical surveys through absolute quantum gravimeters offers promising prospects for various sectors, including archaeology and geothermal energy exploration. "India's efforts in this field are part of a global movement to advance gravimeter technology, enhancing resolution and transportability," says Prof. Santra.

India's diverse geographical landscape presents unique challenges and opportunities for applying gravimeters. "Gravimeters could be used to survey potential geothermal energy sites in the Himalayan region," Prof. Santra explains. "These surveys are crucial for identifying hotspots where geothermal plants can be established, contributing to India's renewable energy goals."

As another example, gravimeters could be employed in the Deccan Plateau to map subsurface water reservoirs. "Accurate mapping of groundwater is essential for sustainable water management, especially in arid regions. Quantum gravimeters provide precise data that can guide the drilling of new wells," Prof. Santra explains.

Scan the image using Overly App to hear more from Prof. Santra regarding the interdisciplinary nature of quantum gravimetry and its future applications

Global and Indian R&D Efforts

Globally, efforts are underway to develop mobile gravimeters capable of conducting extensive surveys, including the UC Berkeley Group's truck-mounted gravimeter, which has successfully mapped terrains. Additionally, research groups in the UK, US, France, Germany, and Australia among others are exploring drone-mounted and marine-based gravimeters. These advancements indicate the feasibility of mobile gravimeters and their potential for widespread application.

In India, several laboratories are actively engaged in gravimeter research. The initial steps involve creating lab-based gravimeters, followed by transitioning them to mobile platforms such as small drones. The drones with gravimeters mounted on them can be used to survey the terrain in a way similar to Google which surveys for street maps with cameras aboard cars. "Despite the challenges posed by India's diverse and extreme climate conditions, researchers are optimistic about achieving significant milestones within the next decade," expresses Prof. Santra.

Policy Recommendations for Advancing Quantum Gravimetry

To capitalize on the potential of quantum gravimetry, Prof. Santra makes several policy recommendations:

1. **Developing Skilled Manpower:** Establishing training programs and educational initiatives to cultivate expertise in quantum technologies is essential. Collaborations with academic institutions can help create a pipeline of skilled professionals.

2. **Building Manufacturing Capabilities:** Setting up manufacturing hubs for high-precision components within India is critical. Public-private partnerships can facilitate the development of these hubs, ensuring a steady supply of domestically produced subcomponents.

3. **Encouraging Industry Collaboration:** Encouraging collaborations between research institutions and industries can accelerate the development and commercialization of quantum gravimetry technologies. Incentives for industry participation in research and development projects can be beneficial.
4. **Creating a Regulatory Framework:** Developing standards and regulations for the deployment and use of quantum gravimeters is necessary. This framework should ensure the safe and effective application of these technologies across different sectors.

Quantum gravimetry stands at the intersection of fundamental science and practical applications, with the potential to transform various fields through precise gravitational measurements.

While challenges remain, focused policy support, enhanced funding, and the development of domestic manufacturing capabilities can drive significant advancements. The next decade promises exciting developments as researchers and policymakers work together to overcome obstacles and realize the full potential of this cutting-edge technology.

(Vivek Kumar is a Scientist at OPSA and Sanchita Jain is Communications Specialist at OPSA.)

FEATURE STORY: QUANTUM HOTSPOTS IN INDIA

SETS: Addressing Quantum Computing Threats with Cutting-edge Solutions

By Sanchita Jain

Image of QKD for representation

As digital technologies rapidly evolve, they bring both unprecedented opportunities and significant risks. Among the most pressing emerging threats is the potential of quantum computing to break current cryptographic systems. This risk poses serious concerns not only for personal data but also for critical infrastructure, financial systems, and national security.

The Society for Electronic Transactions and Security (SETS), established in 2002 under the aegis of the Office of the Principal Scientific Adviser to the Government of India, is at the forefront of developing solutions to counter these threats.

The Quantum Threat and SETS' Vision

Quantum computers, leveraging principles of quantum mechanics, have the potential to perform calculations exponentially faster than classical computers. This capability threatens to break currently-used public key cryptographic systems, which are crucial for securing communications globally. Recognizing this threat, SETS, has intensified its work on pioneering research and development in information security, cryptology, secure protocols, and network security.

Initially, SETS concentrated on building foundational expertise by establishing facilities like the Advanced Facility for Information Security and Cryptology (AFISC) and pursuing R&D in Hardware Security and Network Security. Over the years, SETS has expanded its domain to include Quantum Security covering new and emerging areas such as post-quantum cryptography (PQC) and quantum key distribution (QKD), reflecting its commitment to stay ahead of evolving threats.

Mitigating Quantum Threats:PQC and QKD

PQC involves developing new cryptographic algorithms that can resist attacks from quantum computers. Current public key systems, such as Rivest–Shamir–Adleman (RSA) and Elliptic Curve Cryptography (ECC), could be easily broken by quantum algorithms like Shor's, necessitating the development of quantum-resistant alternatives. SETS is actively researching and developing proof-of-concept solutions in PQC and enabling policy frameworks towards migration to quantum-resilient systems and networks.

QKD leverages the principles of quantum mechanics to enable unconditionally secure communication. It is a cryptographic method that allows two or more parties to establish a shared secret key. The security of QKD is assured by the fundamental properties of quantum mechanics, making it immune to eavesdropping. At both global and national levels, QKD technologies are being explored for various applications, including strategic communications and the banking and finance sectors.

Challenges in Implementing Quantum-Resistant Solutions

Despite the promise of PQC and QKD, several challenges must be addressed to ensure successful implementation. One major challenge is the computational and practical complexity of new cryptographic algorithms. PQC algorithms often require more computational resources and are slower than present day algorithms, making their integration into existing systems challenging. SETS is working on optimization mechanisms to make them viable for real-world applications.

Another challenge is the need for mature standards and guidelines for deploying quantum-resistant technologies. As the field is still in its nascent stages, there is a need for comprehensive frameworks to guide the transition from classical to quantum-resistant systems. SETS is actively participating in national and international standard-setting initiatives to address this gap.

In addition, the implementation of PQC in various protocols and systems, such as SSL/TLS, VPNs, and secure communication networks, requires careful evaluation of the algorithms' performance and security. The quantum security community is assessing the strengths and weaknesses of different PQC candidates, and SETS is contributing to this global effort.

National and Citizen-Centric Security Concerns

SETS' advancements in PQC and QKD are crucial for both national and citizen-centric security. The organization is actively developing quantum-resistant solutions for the strategic sector, including defence and critical infrastructure, where hardened PQC solutions can coexist with secure quantum communication networks. For citizen-centric applications, SETS is working alongside the Controller of Certifying Authorities (CCA), the Ministry of Electronics and Information Technology (MeitY), and domain experts to establish guidelines for migrating to PQC in the Public Key Infrastructure (PKI) ecosystem. These efforts aim to protect everyday digital communications, such as those in web browsers and email services, ensuring that citizens' personal and financial information remains secure in the quantum era.

Setting Standards and International Collaboration

In addition to its research and development efforts, SETS is playing a crucial role in setting cybersecurity standards. The organization collaborates with the Bureau of Indian Standards (BIS), MeitY, and the Telecom Standards Development Society, India (TSDSI) to develop national standards for cybersecurity in the quantum era. These standards are essential for ensuring the interoperability and security of cryptographic systems across different platforms and applications.

SETS' efforts are also aligned with global initiatives led by the National Institute of Standards and Technology (NIST) in the United States, which is spearheading efforts to standardize quantum-resistant cryptographic algorithms. By engaging in these collaborations, SETS ensures that India remains at the forefront of international efforts to secure digital communications against quantum threats.

The Quantum Security Research Lab

Recently, on the 23rd Foundation Day of SETS on June 25, 2024, Principal Scientific Adviser to the Government of India Prof. Ajay Kumar Sood launched the Quantum Security Research Lab. This lab is dedicated to advancing research in quantum cryptography and quantum-safe technologies. It aims to develop indigenous technologies for quantum cryptography, including long-distance quantum communication networks, satellite/free-space quantum key distribution systems, and chip-based quantum processors.

The lab will serve as a hub for collaboration among researchers, industry, and end-users, fostering the development of comprehensive quantum-safe solutions. It will also focus on capability development, offering hands-on training and workshops in these cutting-edge areas. Dr. Parvinder Maini, Scientific Secretary, OPSA highlighted the significance of this initiative: "SETS is not only addressing today's cybersecurity challenges but is also preparing for the future with standard-based development for international collaborations in areas like quantum communication and 6G. It is imperative to collaborate with industry to advance our technologies from research to field deployment."

PSA Prof. Ajay Kumar Sood inaugurating the Quantum Security Research Lab during 23rd Foundation Day

Dr. Parvinder Maini, Scientific Secretary, OPSA delivering her remarks on 23rd Foundation Day

Industry-Academia Collaboration

To enhance the translational aspects of its research, SETS is collaborating extensively with academia and industry. It engages researchers and students in cutting-edge projects and provides hands-on training in advanced cybersecurity technologies. SETS also partners with industry players to commercialize its R&D outcomes, including PQC-based enterprise solutions and quantum-safe communication systems. These collaborations are crucial for scaling up the deployment of quantum-resistant technologies and ensuring their widespread adoption.

As part of its commitment to advancing cryptographic research, SETS is hosting the 25th Edition of INDOCRYPT 2024, in collaboration with the Institute of Mathematical Sciences (IMSc), Chennai and Chennai Mathematical Institute (CMI). Scheduled for 18-21 December 2024 in Chennai, this prominent international cryptographic event will attract key researchers from around the world, showcasing cutting-edge developments in the field.

DR. N. SUBRAMANIAN, Executive Director, SETS

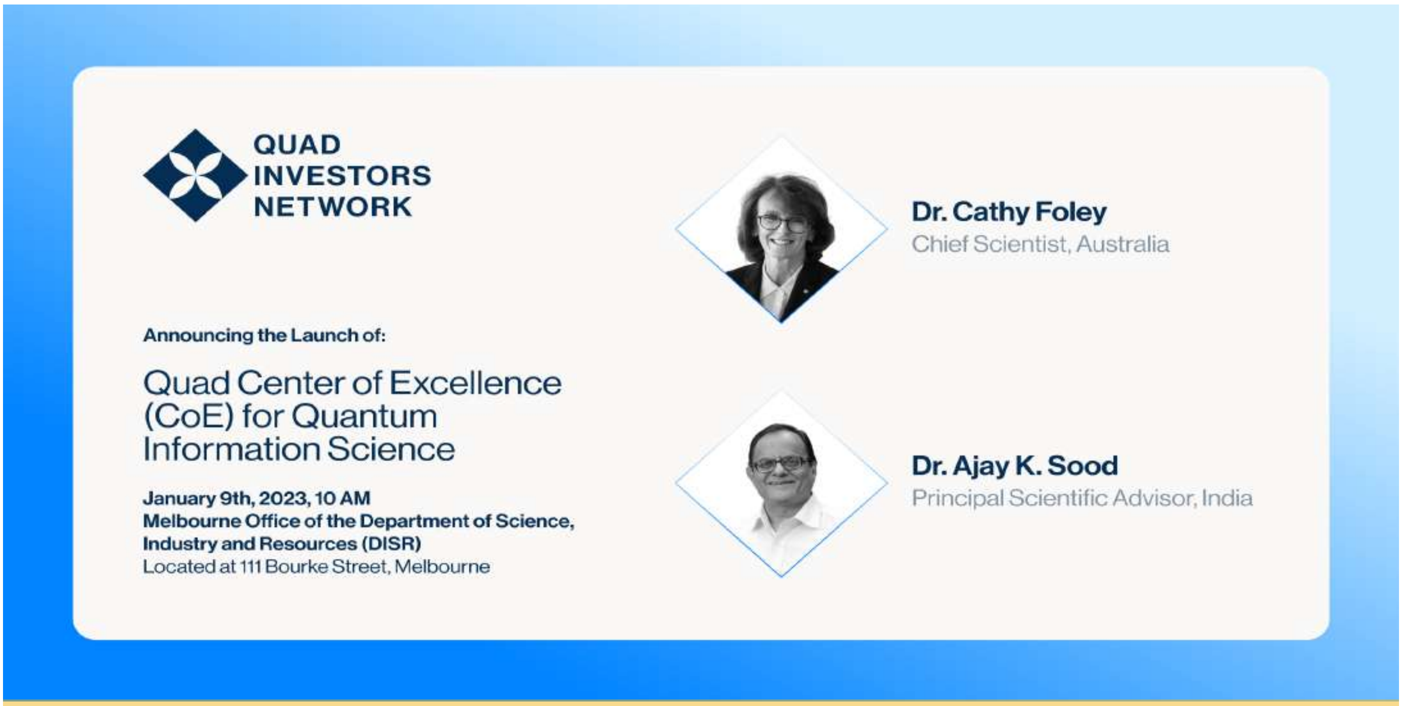
As quantum computing technology advances, the need for robust and secure cryptographic solutions becomes increasingly urgent. SETS is at the forefront of addressing these challenges, developing PQC and QKD technologies to protect critical digital infrastructure. Through initiatives like the Quantum Security Research Lab and collaboration with international standard-setting bodies like NIST, SETS is working towards ensuring that India remains secure in the face of emerging quantum threats.

(Sanchita Jain is Communications Specialist at OPSA.)

OPSA'S GLOBAL INITIATIVES FOR QUANTUM COLLABORATION

Strengthening Quantum Leadership: Quad Centre of Excellence in Quantum Information Sciences (Quad CoE-QIS)

By Communications Team, OPSA



Launch announcement of Quad Centre of Excellence for Quantum Information Sciences, Image Credit: QuIN

The Quad nations—Australia, India, Japan, and the United States—are taking significant steps to bolster their leadership in Critical and Emerging Technologies (CETs), particularly in Quantum Information Sciences. This initiative, known as the Quad Centre of Excellence in Quantum Information Sciences (Quad CoE-QIS), represents a major collaborative effort among the Quad countries to advance in this cutting-edge field.

Tracing the origins

The Quadrilateral Security Dialogue, or Quad, was initially established in 2004 following the Indian Ocean Tsunami. Over the years, it has evolved into a significant regional alliance. During the first Quad Summit on September 24, 2021, in Washington DC, the member nations committed to cooperating on CETs, including Quantum Information Sciences.

The formation of a leader-level working group marked the beginning of a concerted effort to promote cooperation in this area. By the second Quad Summit on May 23, 2022, in Tokyo, the idea of the Quad Investors Network (QuIN) was conceived. QuIN aims to enhance access to capital for critical and emerging technologies across the Quad nations.

The third Quad Summit, held on May 20, 2023, in Hiroshima, Japan, saw the official launch of QuIN. It focuses on facilitating investments in strategic technologies such as clean energy, semiconductors, critical minerals, and quantum technologies. Additionally, an international Advisory Board for QuIN was established, along with five expert working groups dedicated to artificial intelligence, semiconductors, clean energy and critical minerals, mobile networks, and quantum information sciences. The Working Group on Quantum Information Sciences is known as the Quad Centre of Excellence in Quantum Information Sciences (Quad CoE-QIS).

Quad CoE-QIS: Objectives and Structure

The Quad CoE-QIS aims to create a robust network linking industry, private capital, academia, and government stakeholders across the four Quad nations. This collaboration seeks to drive curriculum development, shared research questions, and common policy frameworks. The ultimate goal is to secure Quad leadership in quantum information sciences and build resilient, reliable supply chains based on the principles of a free and open Indo-Pacific.

The Centre's initial leadership comprised Dr. Cathey Foley, Chief Scientist of Australia, and Prof. Ajay Kumar Sood, Principal Scientific Adviser to the Government of India, as co-chairs. They were joined by Dr. Hiroaki Aihara from Japan and Dr. Celia Merzbacher from the USA, ensuring representation from each Quad nation. The Quad CoE-QIS includes expert members from government, academia, and industry from each country, with India having already nominated its five members.

Key Milestones and Future Directions

The Quad CoE-QIS was officially launched with its first meeting in Melbourne, Australia, on June 9, 2023. During this meeting, country presentations highlighted the national status and future roadmaps for quantum technology-related activities in each nation. Key recommendations included expanding the leadership to four co-chairs, one from each Quad nation, and establishing four Task Forces led by Australia, India, Japan, and the US. These Task Forces focus on Ecosystem and Workforce Development, Communications, Computing, and Sensors, respectively.

On November 7, 2023, the Task Forces were officially launched, setting goals and identifying Key Performance Indicators for the Centre and the Task Forces. As a near-term objective it was decided that the Task Forces would prepare a Report/White Paper outlining opportunities for the Quad nations to achieve global leadership in Quantum Science and Technology and detail strategies for attaining this position. This report has now been completed and released to the public on August 2, 2024 and can be accessed here.

> "With this Report, the Quantum Centre of Excellence and its Task Forces have made an impressive start towards synergizing the strengths of the Quad nations to achieve a global leadership position in Quantum Science and Technology."
>
> *-PSA Prof. Ajay Kumar Sood*

The Quad CoE-QIS represents a significant step forward in strengthening the Quad nations' collaboration in quantum science and technology, positioning them as leaders in this vital and rapidly evolving field.

Indo-US Quantum Coordination Mechanism under the US-India Initiative on Critical and Emerging Technologies (iCET)

By Communications Team, OPSA

Image for representation

In 2022, the United States and India embarked on a significant partnership through the US-India Initiative on Critical and Emerging Technologies (iCET). This initiative, led by the National Security Councils of both nations, aims to enhance cooperation in cutting-edge technologies, with a strong focus on quantum technologies.

Inaugural Meeting and the Quantum Coordination Mechanism

The iCET's inaugural meeting, held in Washington DC, on January 31, 2023, set the stage for deepening collaboration. A key outcome was the establishment of the Indo-US Quantum Coordination Mechanism, co-led by Prof. Ajay Kumar Sood, Principal Scientific Adviser to the Government of India, and Dr. Charles Tahan, Director of the National Quantum Coordination Office (NQCO) at the White House. This mechanism is designed to facilitate research and industrial cooperation in Quantum Information Science and Technology (QIST).

Building a Quantum Future

The first US-India Dialogue on QIST, held online on May 3, 2023, brought together experts from government, industry, and academia. Discussions covered government perspectives and the academic and industrial landscapes in both countries, focusing on testing, certification, and workforce development through bilateral cooperation at all levels. After the first US-India Dialogue on QIST, both sides have taken the discussions further for Indian expert visits to U.S. universities and labs, making such facilities accessible to Indians.

Joint Statements and Progress

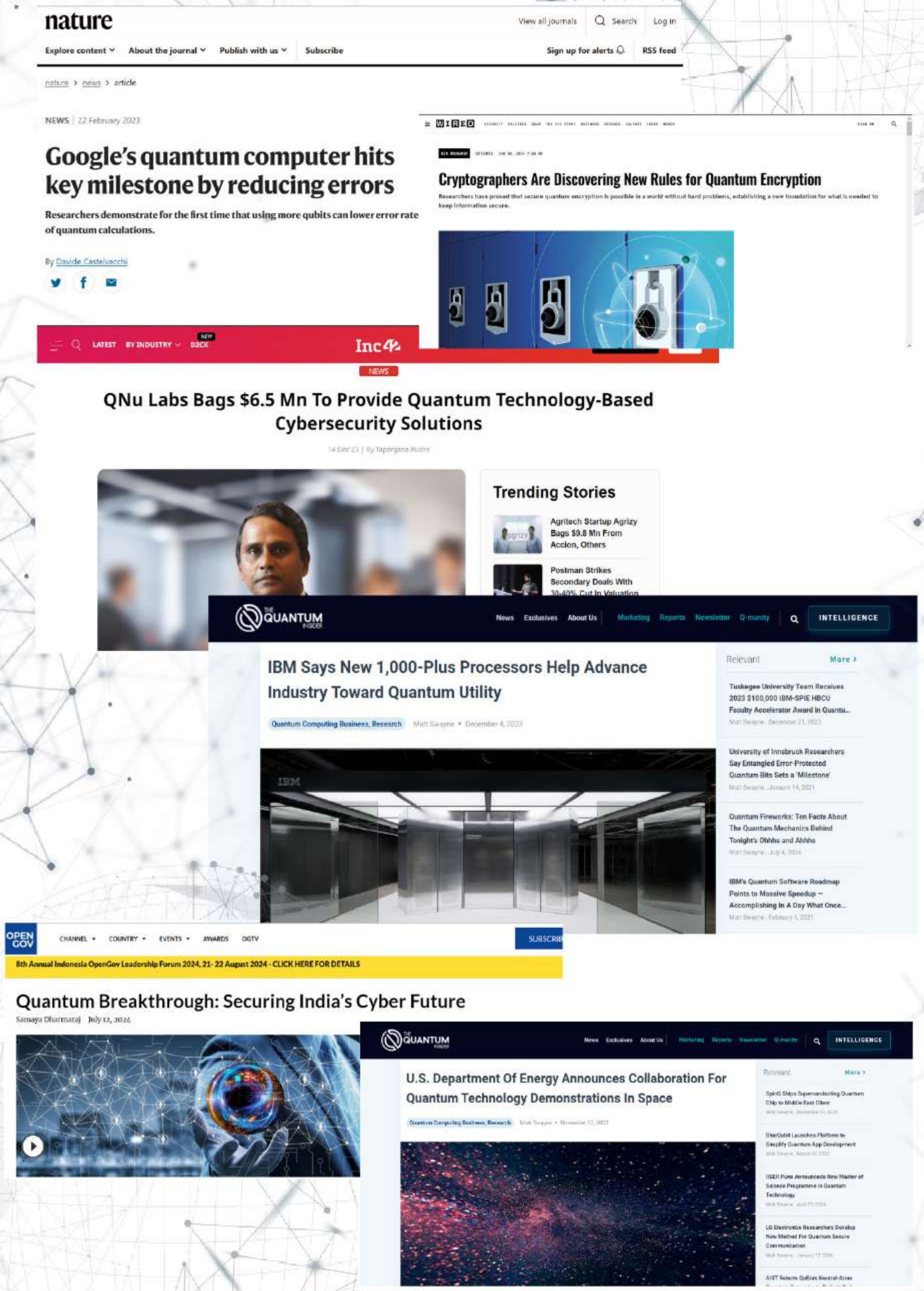
In a joint statement on June 22, 2023, President Joe Biden and Prime Minister Narendra Modi emphasized key initiatives, including India's participation in the Quantum Economic Development Consortium (QED-C) and the Quantum Entanglement Exchange, as well as the development of an Indo-US Quantum Cooperation Agreement. QED-C is a consortium of industry, academic institutions, government entities, etc. Organizations from 39 nations, including India, can become members by paying a membership fee and can avail themselves of a variety of services and privileges.

Accordingly, in September 2023, the S.N. Bose National Centre for Basic Sciences in Kolkata joined QED-C. India also joined the Quantum Entanglement Exchange in September 2023.

The U.S. National Security Advisor (APNSA) Jake Sullivan and the Indian National Security Advisor (NSA) Ajit Doval chaired the second meeting of the U.S.-India iCET in New Delhi on June 17, 2024. In the meeting, both sides discussed and agreed to initiate new collaborative activities in quantum science and technology, including launching a workshop on post-quantum cryptography at the University of California, Los Angeles, and facilitating visits of Indian technical experts from academia and the private sector to visit U.S. national laboratories and quantum institutions.

The Indo-US Quantum Coordination Mechanism is meant to create a framework to formalize the commitment of both nations for sustained bilateral collaboration in the areas of quantum science and technology.

QUANTUM STRIDES AROUND THE WORLD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