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The Bulletin is the official organ of the IAPT. It is a monthly journal devoted to upgrading physics education at all levels through dissemination of didactical information of physics and related areas. Further, the Bulletin also highlights information about the activities of IAPT. All communications should be addressed to:

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Editorial

Recent IAPT Examination and its Relevance

IAPT is known for its flagship activity the National Standard Examination in Physics. IAPT examinations started in 1988 seems to be more relevant in the present day of 2025. Starting from 1988 NSEP became popular among Physics students and teachers in the country. From 1997 NSEP became the first stage for the selection of students representing India in the most coveted event of International Physics Olympiad (IPhO). Moving on the similar footing, National standard examination in Chemistry was started from 1998 to find a team of Indian students for IChO-1999 and subsequently the NSEB for International Biology Olympiad from 2000. Under an MOU between the department of Atomic Energy, Govt of India and the Indian Association of Physics Teachers, the sole responsibility to conduct the NSEP, NSEC and NSB lies with IAPT through the Chief Coordinator (Examination). With the passage of time, the organisations namely the Association of Chemistry Teachers (ACT) and the Association of Teachers in Biological Science (ATBS) came in to existence. An understanding was developed that these two organisations will support IAPT and the responsibility of developing subject content for Chemistry was entrusted to ACT and that for Biology to ATBS. The three organisations are since then working cohesively for bringing good name to the country in the international era.

In 2006 IAPT decided to prepare team India for another important intra-country activity known as the **Asian Physics Olympiad** (APhO) and to participate in this prestigious event for the students from Asia and Oceania. The National Standard Examination in Junior Science (NSEJS) for students below and up to class 10 came up in the same year 2006, as the first stage examination in India for the International Junior Science Olympiad (IJSO). This examination really induced noticeable encouragement among junior students up to class 10. Recently in December 2024 all the six Indian students participating in IJSO – 2024 at Bucharest in Romania fetched six Gold medal. Not only the Gold medal, the team India was declared to have the first rank among all the 83 countries.

As on date IAPT has been successful to conduct NSE – 2025 i.e. the NSEP (Physics), NSEC

(Chemistry), NSEB (Biology), NSEA (Astronomy) and NSEJS (Junior Science)

Recently on Nov 22 and 23, 2025 in an excellent way. To encourage students to come forward in

the race for competition, IAPT awards certificate to the top performers at all NSE as the

1. National Top 1% of the enrolment in each subject.
2. State Top 1% of the state enrolment in each subject.
3. Centre Top 10 % at each centre in each subject.
4. Merit certificate is awarded to all the students who qualify for the next stage known as the Indian National Olympiad (INO)

On the basis of the performance at NSE and the specified state quota about 400 students are shortlisted for the INO the second stage of Olympiad program. The selection here is separately for 200 students from group A (group of all students of class 12 on November 30) and group B (group of all students of class 11 and below on November 30) for INPhO, INChO and INBO but for 250 from each group A and group B for INAO. There being no group at INJSO level a total of 300 students is shortlisted from those appearing for NSEJS. To achieve a gender balance, this year there shall be a 15% horizontal reservation for female students for each of the INO. It is made clear that there is no gender reservation beyond this level however top 20 students are taken from each group for Physics Chemistry and Biology while for Astronomy the number from group A is 15 and from group B is 35. The students appearing for various INOs are shortlisted to attend the most exertive and exhaustive Orientation Cum Selection Camp for two weeks for finally selecting students to represent the country at international level. The OCSCs for seniors are organised by HBCSE-TIFR Mumbai while the same for IJSO is the responsibility of IAPT.

Of course, NSE has progressed year after year since its inception in 1988 but the recent efforts of IAPT examination office Dehradun along with many of the well-wishers has brought the overall enrolment to the extent of 2,39,937 and the number of registered examination centres as 1942. This shows that IAPT has spread NSE well throughout the country.

As per the decision of the Board for International Junior Science Olympiad on the age criterion, only students of age 13 to 15 year can appear at NSEJS (Only those born in 2011 and 2012 for NSEJS 2025). Most of the students of class 10 in India have thus been deprived of appearing for NSEJS. This caused a lot of disappointment among this group. A number of students and guardians have placed, before the chief coordinator, the norms and criterion laid down by the Indian Government for an age of 6 years for the admission to class 1. Having discussed the matter in the examination committee, the **Standard Examination in High School Science** (SEHSS) has been started from 2025. The SEHSS – 2025 for the students of class 10, 9 and 8 has been successfully conducted on 30.11.25. I am sure this examination will create enthusiasm among school students and will provide an appropriate platform towards excellence in science. IAPT shall be conducting **Orientation Camp for Science Excellence** (OCSE) for top 25 students from each of the five zones North, South, East, West and the central thereby developing a specific scientific temperament among the best students of this age in the country.

Another equally important component of this activity is the **National Graduate Examination in Physics** (NGPE) for students of BSc I, II and III (Pass, Hons and Integrated) conducted pan India every year in the month of January. More than 300 colleges/ University departments have been keenly taking interest in NGPE. This is the only voluntary examination which provides opportunity to meet the bright minds and to show their capabilities of best experimental skill through NGPE Part C (An examination in experimental skill). Top 25 are called for NGPE Part C and the Top 5 are awarded Gold Medal and a cash prize of Rupees twenty thousand only (Rs 20,000.00) each.

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Physics News

Finding information in the randomness of living matter

When describing collective properties of macroscopic physical systems, microscopic fluctuations are typically averaged out, leaving a description of the typical behavior of the systems. While this simplification has its advantages, it fails to capture the important role of fluctuations that can often influence the dynamics in dramatic manners, as the extreme examples of catastrophic events such as volcanic eruptions and financial market collapse reveal. Due to their overwhelming complexity, predicting outcomes by analyzing these fluctuations in living or active matter systems is not possible using traditional methods of physics.

In recent research, Martin Johnsrud and Ramin Golestanian from the department Living Matter Physics (LMP) at MPI-DS succeeded in developing a theoretical description that can rigorously characterize the role of fluctuations in systems. The physicists thus developed a suitable mathematical tool to extend the existing field theories, and they are now able to make predictions about systems out of equilibrium, such as active matter.

Read more at: https://phys.org/news/2025-11-randomness.html

Original Paper: Physical Review Research (2025). DOI: 10.1103/xx4z-lj5c

What would a small black hole do to the human body? Scientist aims to answer that

Finding the gravitational effects would be if a primordial black hole passed through the human body, helping scientists better understand the properties of dark matter. Primordial black holes are hypothetical black holes that formed in the early universe, possibly within the first second after the Big Bang. They have potential masses ranging from 100,000 times less than a paperclip to 100,000 times more than the sun. Some researchers think these black holes may make up some, or all, of the universe's dark matter. The article examined two potential gravitational effects caused by a primordial black hole passing through the human body: supersonic shock waves and tidal gravitational forces. While these findings could help scientists determine the mass of primordial black holes as dark matter, do you need to add death by primordial black hole to your list of fears? A smaller primordial black hole could pass through you, and you wouldn't even notice it. However, the density of these black holes is so low that such an encounter is essentially never going to happen.

Read more at: https://phys.org/news/2025-11-small-black-hole-human-body.html

Original Paper: International Journal of Modern Physics (2025). DOI: 10.1142/s0218271825410032

Entanglement-enhanced optical lattice clock achieves unprecedented precision

Optical lattice clocks are devices that measure the passing of time via the frequency of light that is absorbed or emitted by laser-cooled atoms trapped in a repeating pattern of light interference known as optical lattice. These clocks are significantly more precise than classical clocks and could pick up subtle physical phenomena. They could also be used to test the predictions of various physics theories and could help to improve the performance of existing timekeeping, sensing and communication systems. Building on earlier research in the field, Dr. Yang and his colleagues set out to explore the possibility that entanglement could be used to boost the precision of optical lattice clocks. To do this, they developed an optical lattice clock based on entangled strontium atoms and compared its performance to that of conventional optical clocks. The researchers compared the measurements taken by their clock and they found that their design led to significant improvements, with their clock achieving a remarkable fractional frequency precision of 1.1×10^{-18}. The team's new optical clock design could soon inspire the development of other entanglement-enhanced optical clocks.

Read more at: https://phys.org/news/2025-11-entanglement-optical-lattice-clock-unprecedented.html

Original paper: Physical Review Letters (2025). DOI: 10.1103/6v93-whwq

Soumya Sarkar
IISER PUNE

December: This Month in the History of Physics

December, the closing month of the year, has often been the opening chapter of new eras in physics. From the modest laboratories of Paris and Moscow to the quiet reflections of Manchester and the startling announcements in New York, December has gifted the scientific world discoveries that redefined the very laws of Nature. Let us walk through five remarkable milestones that happened in different Decembers across the history, and see how they shaped our understanding of the universe.

1898 – The Curies Discover Radium

The story begins in Paris, in a shed that once served as a medical school dissecting room. Here, Marie Curie and Pierre Curie undertook one of the most arduous programs in science. Their material was pitchblende (uraninite) from Joachimsthal in Bohemia, known to contain uranium. Yet precise measurements revealed something astonishing: the ore's radioactivity was many times greater than uranium alone. A new, highly active element had to be hidden within.

Working patiently, the Curies processed tons of ore, using chemical separations to remove uranium, lead, and other known elements. Still, the residue remained strongly radioactive. Step by step, they concentrated this activity until they identified two new elements: **polonium** in July 1898, and, in December 1898, the far more potent **radium**.

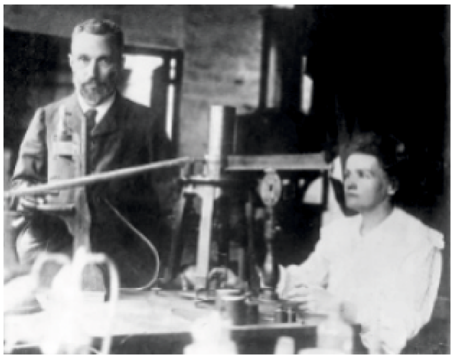

Fig. 1: The Curies in their lab (1904)

Radium's emissions were extraordinary. Careful studies showed they consisted of three distinct types, named by Rutherford as alpha, beta, and gamma rays—helium nuclei, fast-moving electrons, and highly penetrating electromagnetic waves. These revealed that radium's nucleus was breaking down spontaneously, releasing immense energy.

This shattered the view of atoms as immutable and indivisible. Radium became the cornerstone of radioactivity research, opening the path to Rutherford's decay model and the modern nuclear atom. Its rays soon found medical use in radiotherapy, though at tragic cost: prolonged exposure harmed many, including Marie Curie herself. Yet the eerie glow of radium lit the way to the nucleus, showing atoms as reservoirs of untapped energy.

1938 – Discovery of Nuclear Fission

In December 1938, German chemists **Otto Hahn** and **Fritz Strassmann** bombarded uranium with neutrons, expecting to produce heavier transuranic elements. Instead, their chemical tests revealed **barium**, an element only half the mass of uranium.

Across the border in Sweden, physicist **Lise Meitner** and her nephew **Otto Frisch** explained the result: the uranium nucleus had actually split into two fragments. This process, soon named nuclear fission, released enormous energy—about 200 MeV per fission, far exceeding any chemical reaction. Einstein's relation, $E = mc^2$, provided the explanation: a tiny loss of nuclear mass was converted into immense energy. Moreover, each fission emitted additional neutrons, capable of inducing further splits—a chain reaction.

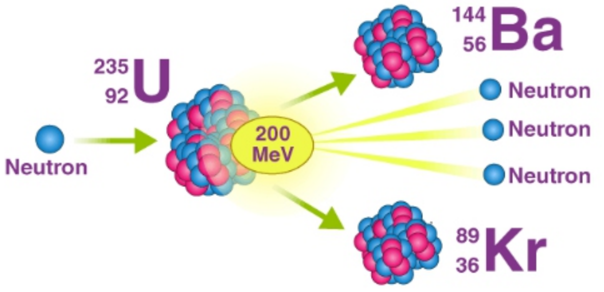

Fig. 2: Nuclear Fission happens when a Uranium-235 atom is bombarded with a neutron. The U-235 atom then splits into two lighter nuclei Barium and Krypton.

The implications were immediate. Within four years, **Enrico Fermi** achieved the first controlled fission chain reaction in Chicago, heralding the nuclear age. The same principle, tragically, became the basis for atomic weapons, forever reshaping global politics.

The December discovery of nuclear fission revealed that nuclei were not only mutable but could be fractured to release colossal energies. It remains one of the most consequential discoveries in the history of science—a gateway to both nuclear power and nuclear peril.

1956 – The Fall of Parity Conservation

For decades, physicists assumed parity conservation i.e., the laws of physics should remain unchanged under a mirror reflection. This symmetry was considered as fundamental as energy conservation. Yet in the mid-1950s, **Tsung-Dao Lee** (passed away last year on August 04) and **Chen-Ning Yang** (passed away recently on Oct. 18, 2025), two young theoretical physicists questioned whether the weak nuclear force truly respected parity. The critical test came in December 1956, when **Chien-Shiung Wu** at Columbia University carried out a brilliant experiment. She used cobalt-60 nuclei, cooled near absolute zero, and measured the directions of electrons emitted in beta decay. If parity were conserved, electrons would emerge symmetrically. Instead, Wu observed a clear preference: electrons were emitted opposite to the nuclear spin.

Fig. 3: Chien-Shiung Wu in the lab, (scientificwomen.net)

The result was stunning- nature distinguishes between left and right. The weak interaction is inherently chiral, violating mirror symmetry. This shattered the long-held belief in universal symmetry among the forces of nature.

Lee and Yang received the 1957 Nobel Prize for their theoretical breakthrough, though Wu's pivotal experimental role went unrecognized by the Nobel Committee. Her achievement, however, remains legendary. The fall of parity conservation laid crucial groundwork for the **Standard Model**, where broken symmetries define the behavior of fundamental particles. That December day changed our conception of the universe's laws forever.

Closing Reflections

These Decembers, spread across centuries, highlight physics as both a human endeavour and a cosmic quest. From the Curie's ramshackle lab to Wu's frozen cobalt, from the uranium nucleus splitting in Berlin to the political tremors of the nuclear age—each December discovery reshaped our world.

Together, they remind us of a striking pattern in science: great advances often arrive quietly, born from persistence, curiosity, and courage. December, with its long nights and reflective calm, seems almost symbolic for such breakthroughs. As each year closes, we are reminded that science, like time itself, is always moving forward toward deeper understanding, wider horizons, and sometimes unsettling revelations.

Photo Courtesy

[1] https://www.edn.com/marie-and-pierre-curie-discover-radium-december-21-1898/

[2] https://www.iaea.org/newscenter/news/what-is-cherenkov-radiation?utm_source=chatgpt.com

[3] https://byjus.com/physics/what-is-nuclear-fission/

[4] https://www.lindahall.org/about/news/scientist-of-the-day/chien-shiung-wu/?utm_source=chatgpt.com

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International Conference on Physics Education ICPE 2005

World View on Physics Education in 2005: Focusing on Change

Inaugural Address: Injecting Beauty of Science in Teaching

Dr. A. P. J. Abdul Kalam
President of India

I am indeed delighted to inaugurate the **International Conference on Physics Education titled "World view on Physics Education in 2005: Focusing on Change" organized by the University of Delhi in collaboration with international participants (21 to 26 August 2005, Vigyan Bhavan).** I greet the organizers, eminent physicists, physics education researchers, educators, distinguished guests and the other participants in the Conference. I was very happy to read the book titled "One hundred reasons to be a scientist" brought out by the Abdus Salam International Centre for Theoretical Physics. I suggest that at least ten of the personalities who have childhood experience in science can be brought out as a booklet for introduction in school curriculum at 10 and 10+2 level. Keeping in mind the main theme of the Conference, I would like to discuss with you about: "Injecting Beauty of Science in teaching."

My experience with school students

During the last five years, I have met 600,000 students in all parts of the country in the age group of students between 10 to 17 years. I make it a point to answer at least 10 to 15 questions wherever I go, in addition I have answered thousands of questions through my website. I would like to illustrate the typical searching minds, particularly to the teachers, scientists, Education Planners so that you will know the ambient conditions of the Indian students while discussing about the "Physics Education: focusing on change".

Question on Gravity: On 20th August 2005, I went to Bangalore and participated in the inauguration of Silver Jubilee of Karnataka Rajya Vijnana Parishat. The function was attended by children of 12 different Bangalore schools. After my address, some of the children asked very interesting scientific questions which I would like to share with this audience. Master Prajwal P. Acharya of 9th Standard, Prarthana School, asked me "What is the relationship between Time & Universal Gravitation?" I appreciated this beautiful question. In my answer I told him that the concept of time, space and universal gravitation is a very exciting and interesting one. "Gravity is the force of attraction between massive particles due to their mass. Weight is determined by the mass of an object and its location in a gravitational field. While a great deal is known about the properties of gravity, the ultimate cause of the gravitational force remains an open question. General relativity is the most successful theory of gravitation to date. It postulates that mass and energy curve, space-time, resulting in the phenomenon known as gravity." There are books on the subject and websites that explain these concepts extremely well. I asked the students to study further.

Question on Ocean exploration: Master Bharath Choudhari M. - 10th Standard, Athena Public School,

asked me "Why we are not exploring the World (Ocean) more than the Universe (Space)?" In my answer I told him that Ocean is restricted to the surface of the earth whereas the space is unlimited. The reaching the depth of the ocean is becoming tougher than reaching large heights in the space. In spite of the difficulty in reaching the depth of the ocean, we still explore the ocean and many benefits accrue to the mankind. And there are many treasures of knowledge waiting from the depth of the ocean.

Question on Science and Philosophy: Another student from the audience asked "What is the difference between a Scientist and a Philosopher". For this question, I answered – the thinking process is common both to the philosopher and the scientist. Scientist deals with theory which has to be validated. Philosopher postulates theological, philosophical and spiritual thoughts, the validation seems to be the societal dynamics. The science ultimately results in technology and benefits the society. Philosophy, may give the way life is to be led in a dynamic society.

Question on Deep Impact on the Comet: I received an email from a 15 years old school boy from a north eastern state school on 5-July-2005, the day after the event "Mr. Kalam please tell me how important the Deep Impact spacecraft impacting on the comet Tempel-1?" I was very happy to receive this question, even though I know the event I didn't give thoughts. Then immediately I have to give an answer, I have searched the information in many websites and then sent the following answer.

"A few days back one important event took place in space. That was the impact of the NASA spacecraft called deep impact smashing into the comet Tempel-I, with enough force to create football stadium sized crater with a depth of a 14-storey building. The spacecraft was navigated by an Indian Shyam Bhaskaran – the deep impact travelled 431 million km in 172 days escaping from the earth orbit and intercepted the comet at a straight distance from earth at 134 million km. The comet was orbiting around the Sun every five and half years. This is a landmark in space exploration. This event is important to divert in case of asteroids which may hit the earth in future. One such large asteroid 1950 AD is expected to hit the earth on March 16, 2880 AD. Like the "Deep Impact" many spacecrafts are required to be sent with high energy material to divert or break the asteroid to move it out of the earth orbit."

Still the boy was not satisfied, he again sent an email asking what is the probability of hitting the earth? The email correspondence is continuing. What are the messages emanating out these four questions? I am giving these queries from the young and my interaction, to all of you so that the experienced scientists and teachers should welcome such questions during the classes or during the interaction while they are giving the lectures elsewhere. Particularly for students between the age 14 and 17, it is very important to inject the beauty of science, challenge of science and bliss of science which one achieves. This is the period the students make up their mind, whether they should go far science, engineering, medical, bio, law or humanities.

Saturday, I was in the campus of Indian Institute of Science, Bangalore for felicitating Prof. CNR Rao, a solid state chemist and pioneer in India on Nano Science, by scientific community at Bangalore. Prof. CNR Rao in his acceptance remarks said "The working in science itself is the greatest award a scientist can dream of". This thought is reflected in his biography "Science as a way of life".

Propagate the probing of scientific minds

A. Towards Raman Effect:

Why is the sea blue? The view has been expressed that the dark blue of the deep sea has nothing to do with the color of water. It is simply the blue of the sky seen by reflection. Sir CV Raman then questions this view describing his own experiment on board the ship: Observations made in this way in the deeper waters of Mediterranean and Red Sea showed that the color so far, from being impoverished by suppression of sky reflection was wonderfully improved here by. It was abundantly clear from the observation that the blue color of the deep sea is a distinct phenomenon itself and not merely an effect due to reflected sky light. Later Raman draws attention to the connection between the color of deep waters and the Einstein-Smoluchowski formula. Naturally he starts with that the sky is blue because of scattering of light by the molecules in the upper atmosphere. The color of the sea is a different matter. Rayleigh believes it was all due to reflection, but Raman gives an entirely different view, that in this phenomenon, as in the parallel case of the color of sky, molecular diffraction determines the observed luminosity and in great measure also its color. Hence the birth of the Raman Effect. Now let us study how great scientists in their school days got shaped for science. First let us take up the example of Albert Einstein.

Teachers influence

Albert Einstein's life, we find that his interest in science started early, beginning with his encounter with magnetism, which he called "the first miracle". He was given a compass by his father and Einstein was endlessly fascinated by the fact that invisible forces could make the object move. This experience made a lasting impression on him. His interest in compasses was reinforced when he found a caring mentor to hone his ideas. At the age of 12, he experienced second wonder in a little book given by his mentor Max Talmud on Euclidean plane geometry which he called "Holy Geometry Book". Einstein called this his "second miracle". Here Einstein made contact with the realm of pure thought. Without expensive laboratories or equipment, he could explore universal truth, limited only by the power of human mind. Mathematics became an endless source of pleasure to Einstein especially if intriguing puzzle and mysteries were involved.

Visualizing pictures: Einstein's father was in an electro-chemical business. Being in the midst of electromagnetic contraptions awakened an intuitive understanding of electricity and magnetism in Albert Einstein. It sharpened his ability to develop graphic, physical pictures that would describe the laws of nature with uncanny accuracy. This trait, the ability to see everything in terms of physical pictures, would mark one of Einstein's great characteristics as a physicist.

Freedom to Learn: Though born in Germany, Einstein moved to Zurich Polytechnic Institute in Switzerland. The entry into the polytechnic did not require a high school diploma, just a passing grade on its tough entrance examination was sufficient. Einstein failed in the entrance examination but he did exceptionally well in the Maths and Physics section. That impressed the principal and he promised to take him during the following year without an entrance test. The message we get from this experience is about having a flexible system of admission. Also, an ability to spot the aptitude of the student in a particular subject and nourishing the talents. In addition, Einstein enjoyed the liberal atmosphere of the Swiss school.

Simplicity in description: Unlike lesser scientists who often got lost in Mathematics, Einstein thought in terms of simple physical pictures – speeding trains, falling elevators, rockets and moving clocks. These pictures would unerringly guide him through the greatest ideas of the twentieth century. He wrote "All physical theories, their mathematical expression notwithstanding, ought to lend themselves to so simple a description that even a child could understand". This is a very important message for all physics researchers and physics teachers. Herein lies the birth of famous simple, elegant and very powerful energy equation $E=MC^2$, which decided war and peace system of the world. In the profession of teaching, teachers are indeed playing the role of creating the creative minds. Sir CV Raman's questioning 'why the sky is blue" leading to Physics Nobel Prize, is indeed inspiring teaching material. Similarly, spotting an outstanding talent in physics in spite of his failing the school entrance, is another important message: how come the Swiss school spotted one of the greatest scientific minds in 20th century, Albert Einstein?

My teacher: Prof. Satish Dhawan

Now I would like to share with you one experience I had with my teacher Prof. Satish Dhawan. I joined Defence Research and Development Organisation (DRDO) in 1958 at Aeronautical Development Establishment at Bangalore. There I took up the development of Hovercraft. Hovercraft design needed the development of a ducted contra-rotating propeller for creating a smooth flow balancing the torques. I did not know how to design a contra-rotating propeller though I knew how to design a conventional propeller. Some of my friends told me that I can approach Prof. Satish Dhawan of Indian Institute of Science, who was well known for his aeronautical research, for help in designing the ducted contra-rotating propeller. I took permission from my Director Dr. Mediratta and went to Prof. Satish Dhawan who was sitting in a small room in Indian Institute of Science with lot of books in the background and a blackboard on the wall. Prof. Satish Dhawan asked me what the problem was that I would like to discuss. I explained the problem to Prof. Dhawan about my project work. He told me that it is really a challenging task and he would teach me the design if I attend his classes in IISc between 2.00 p.m. to 3.00 p.m. on all Saturdays for the next six weeks. He was a visionary teacher. He prepared the schedule for the entire course and wrote it on the black board. He also gave me the reference material and books I should read before I start attending the course. I considered this as a great opportunity and I started attending the discussion and started meeting him regularly. Before commencing each meeting, he would ask critical questions and assess my understanding of the subject. That was for the first time that I realized how a good teacher prepares himself for teaching with meticulous planning and prepares the student for acquisition of knowledge. This process continued for the next six weeks. I got the capability for designing the contra-rotating propeller. Prof. Dhawan told me that I am ready for developing the contra-rotating propeller for a given hovercraft configuration. That was the time I realized that Prof. Satish Dhawan was not only a teacher but also a fantastic development engineer of aeronautical systems. Later during the critical phases of testing Professor Dhawan was with me to witness the test and find solutions to the problems. After reaching the smooth test phase, contra-rotating propeller went through 50 hours of continuous testing. Prof. Satish Dhawan witnessed the test himself and congratulated me. That was a great day for me when I saw the contra-rotating propeller designed by my team performing to the mission requirement in the hovercraft. However, at that time, I did not realize that Prof. Satish Dhawan would become Chairman, ISRO and that I would get the opportunity to work with him as a Project Director in the development of satellite launch vehicle SLV-3 for injecting the Rohini Satellite into the orbit. Nature has its own way to link the student's dream and the real life later.

Conclusion

Physics is a fascinating subject. Mastery in physics needs understanding of mathematics. Mathematics in combination with science shines. What is needed is confronting theory with experimentation. For enabling the student to capture the thought, the student should be motivated to visualize and imagine the phenomenon as done by Einstein who reasoned that if you could run alongside a light beam then the light beam should be perfectly at rest. This means that the light beam as seen by the runner would look like a frozen wave, a still photographer away. Learning physics needs freedom to think and freedom to imagine. Both have to be provided by our education system. Teachers have to become capacity builders and facilitators. They have to ask questions which are challenging and allow the student to think and come up with an answer. Teachers must also find answers to the questions asked by the students or at least the approach through which the student can find an answer. Eventually the teacher has to create a lifelong autonomous learner who will blossom into a physicist.

My best wishes to all the participants of this Conference and success in their mission of finding the new vistas in physics education.

May God bless you.

End Note: Dr. A. P. J. Abdul Kalam, as was his practice, made available the script of his inaugural address at ICPE 2005 on his website maintained as President of India shortly after it was delivered. This article was then published in the International Newsletter on Physics Education (October 2005 issue, No. 50, p 8-10) brought out by the International Commission on Physics Education (ICPE) for greater outreach.

World View on Physics Education in 2005: Focusing on Change A Personal Reminiscence

Pratibha Jolly
Convener and Organizing Secretary, ICPE 2005 [1,2]
[1]Principal, Miranda House, University of Delhi, Delhi (2005-2019)
[2]Chairperson, International Commission on Physics Education (2005-2011)

The International Union of Pure and Applied Physics (IUPAP) was established in 1922 to foster international cooperation in physics and help in its application towards solving problems of concern to humanity. It functions through its specialized commissions and working groups that bring together renowned domain experts nominated by its member countries. Commission C14, the International Commission on Physics Education (ICPE) came into being in 1960. The primary mandate of ICPE is to promote, organize and endorse, with the support of IUPAP, international conferences, meetings, workshops and other actions aimed at improving the teaching of physics worldwide. It has brought out seminal books, publishes a newsletter bi-annually, and in recent times has organized several *Physware* series of *Educate the Educator* workshops.

India had the special privilege of hosting an ICPE conference in 2005 from 21 to 26 August at Vigyan Bhavan, New Delhi, with Miranda House, college for women at the University of Delhi as the organizer. The conference assumed special significance for two reasons. One, it was the first time that India was hosting an IUPAP conference on Physics Education. Two, the year 2005 had been declared the World Year of Physics (WYP) to commemorate one hundred years of Einstein's groundbreaking research papers on the photo-electric effect, Brownian motion, special relativity and the mass-energy equivalence, all published in the "miracle year" 1905. As physics awareness took centre stage, issues relating to physics education and outreach became extremely significant.

As the ICPE conference returns to India in 2025, another celebratory year, the *Internation Year of Quantum Science and Technology* (IYQ), it is befitting to reminiscence about ICPE 2005. Even after twenty years, the discourse and deliberations remain pertinent.

ICPE 2005 Theme

Aptly titled *World View on Physics Education in 2005: Focusing on Change,* ICPE 2005 aimed to capture the spirit of the year. Planned as a broad overview, it presented comprehensively issues and examples of praxis highlighting the following themes

Changes in the ways of teaching-learning of physics: the role of hands-on minds-on activities; experiments and evidence; mathematics; ICT and new technologies.

Changes in the understanding of the teaching-learning process: cognitive issues emanating from physics education research; research-based diagnostic tools and instruments for assessment; role of classroom research; the image of physics and beliefs about learning.

Changes in the content of physics as a discipline: introducing emerging areas of physics in the classroom; building a perspective about structure of knowledge in physics; connecting research in physics to teaching-learning; and physics in multidisciplinary contexts.

Changes in the context of physics teaching: bridging the gap between schools, colleges, universities and the workplace; nurturing women in physics; connecting to cultural contexts; and enhancing public understanding of physics in a modern society.

ICPE 2005 brought together physicists, physics educators, renowned physics education researchers and curriculum developers on a common platform to share their experiences. It was attended by around 350 participants including 108 international participants from 30 countries, with vibrant participation from the neighboring countries of South Asia, East Asia and other developing countries where Physics Education Research (PER) was not well established or altogether missing. The largest contingent after India were from Japan (26), US (19) and Europe (16). Rarely had so many of the best known PER leaders come together on a single conference platform. Their presence ensured successful elaboration of the conference themes.

The conference included 28 invited talks in plenary sessions; 37 oral presentations in 11 parallel sessions; 9 workshops; and a poster session with 87 contributions. A concerted attempt was made to present such examples of praxis and resource material that could be gainfully employed by physics teachers to enhance the quality of their classroom teaching; and also enrich their professional lives. Those who were attending a Physics Education Conference for the first time admitted that the deliberations had opened a new vista and constituted a paradigm shift from the traditional, motivating them to adopt innovative research-based practices.

Special Inaugural Day Program

In keeping with the celebratory spirit of the event, the Inaugural Day Program on 22 August was designed to be special. In addition to the registered conference participants, invited was a large stakeholder group: physicists from across institutions in the city; early career researchers; teachers and select meritorious student groups from undergraduate colleges and senior secondary schools; policy makers; representatives from industry and the corporate world. Vigyan Bhavan Plenary Hall was filled to its capacity with over 1300.

The Conference was inaugurated by the President of India, Dr. A. P. J. Abdul Kalam, himself a scientist. The presence on the dais of Dr. R. Chidambaram, then Principal Scientific Advisor (PSA) to the Government of India and Dr. V.S. Ramamurthy, then Secretary, Department of Science and Technology, reflected the value attached to the conference by the Government.

Talking of *Injecting beauty of science in teaching*, with insightful examples of the questions posed to him by students and the strategies adopted by great teachers of science, Dr. Kalam generated awesome delight amongst the diverse international audience. The 1998 Physics Nobel Laureate, Horst L. Stormer from Columbia University and Lucent Technologies, in his eloquent keynote address, *Communicating Physics: a personal account,* elaborated the process of scientific learning and discovery with panoramic historic and pedagogic insight. Breaking protocol, Dr. Kalam sat amongst the audience to hear Stormer. A broad overview of the concerns of Physics Education Research (PER) was presented by Edward F. Redish from University of Maryland, College Park, who in his engaging and highly interactive talk focused on *Changing student ways of knowing: what should our students learn in a physics class?* K.R. Sreenivasan, Director, The Abdus Salam International Centre for Theoretical Physics (ICTP) at Trieste, Italy, gave a highly motivating talk aptly titled *Today's physics for tomorrow: the world of physics beyond 2005*. A further glimpse of physics at the frontiers was provided by Anton Zeilinger, Director, Institute of Experimental Physics, Vienna, in his talk *From Einstein to Quantum Information.* Renowned for his pathbreaking experiments with entangled photons, he went on to win the anticipated Nobel Prize in 2022. Lawrence Krauss, Director, Centre for Education and Research in Cosmology and Astrophysics, Case Western Reserve University, Ohio, gave a talk provocatively titled *Einstein's biggest blunder? A cosmic mystery story*. The ability of all the speakers to make some of the most difficult concepts in physics accessible to the diverse audience – while holding their attention through the day – raised the bar and set the tone.

Technical Program

The technical sessions from 23-26 August, open to the 300 registered participants and special invitees, dwelt in depth on the specific conference themes. Additionally, satellite programs were held for greater outreach.

Research on teaching-learning process and development of research-based curriculum

Seminal work by Physics Education Research Groups (PERG) across the world has generated a greater understanding of cognitive aspects of teaching-learning. Considered a leader, Lillian C McDermott of University of Washington, Seattle, gave brilliant insight into how PER is providing a key to student learning and jolted the uninitiated with convincing data. At a hands-on workshop, she guided the participants through the *University of Washington Interactive Tutorials* which have been found to be highly successful in recording significant learning gains. Laurence Viennot, University of Paris, spoke of her pioneering work on *Rituals in teaching physics* and how to raise intellectual satisfaction among students while illustrating what physics is drawing examples from her book by the same title. Edward F. Redish elaborated the critical importance of problem solving and effective use of mathematics in physics. With examples ranging from algebra-based classes to graduate quantum mechanics, he showed how the gap between what students think is being presented and what physicists actually mean can cause severe comprehension problems. Arvind Kumar, Director Homoi Bhabha Centre for Science Education presented the status of *Physics Education Research in India* with some examples. Several speakers talked about adopting problem-based learning (PBL) techniques and skill-based instructional design wherein problem-solving skills are explicitly taught. Presentations made a strong case for greater use of mathematical modeling as a tool for promoting physics understanding.

Role of hands-on minds-on activities and ICT in physics teaching

PER has shown convincingly that learning environments that allow students to take an active part in their learning can lead to large conceptual gains compared to traditional instruction. Priscilla Laws, Dickinson College, Pennsylvania, who pioneered the effective use of microcomputer-based data-acquisition systems, presented *RealTime Physics Laboratory* guides covering Mechanics, Thermodynamics, Electric Circuits, and Optics developed based on outcomes of PER. Ron Thornton from Center for Science and Math Teaching, Tufts University, demonstrated how sequences of microcomputer-based *Interactive Lecture Demonstrations* (ILDs) using real experiments and student interaction can create an active learning environment in large or small lecture classes. Laws and Thornton also presented examples of how video capture and video analysis tools can provide an easy but very powerful way to help introductory physics students learn about two-dimensional motion. Ewa Mioduszewska and Ton Ellermeijer from University of Amsterdam conducted a workshop presenting material from ePHYS, a European project to implement good practice of ICT with high school physics teachers. During the workshop, the participants explored the open-learning environment COACH which integrates the use of computer-based data-acquisition system, dynamical modeling, data-analysis, and video-capturing and analysis. Richard Bacon, University of Surrey, presented the SToMP (Software Teaching of Modular Physics) learning environment, designed using distance learning principles. Ian Jhnston, University of Sydney, Australia, gave comprehensive exposure to courseware integrating computation. Other presentations showcased computer interfaced experiments; virtual labs; virtual reality courseware; Python based simulations and Java Applets; online training packages for teachers; and use of wireless computing technologies that provide opportunities to set physics lectures outside of the classroom thereby alleviating passive learning styles. All this was significantly novel in 2005.

Low-cost Demonstrations and Laboratories

It is often possible to enthuse students to think about the physics concepts using very simple demonstrations. Most students enjoy playing with toys and manipulative materials. Several presentations reinforced the role of low-cost home kits, practical work and concept centered experiments. A group of Shikoku Teachers from Japan calling themselves *Lady Cats*, presented a workshop on Paper Craft Experiments. Another Japanese group called *Stray Cats*, presented an engaging workshop to demonstrate essential introductory physics concepts with home-assembled demonstrations. Janchai Yingprayoon from

Thailand gave a wonderful example of *Fun with physics* using locally produced low-cost high-tech materials Vijaykumar Verekar from Goa presented a nonstop hour long show of science demonstrations with a school bag lab consisting of nothing more than straws, plastic bottles and other easily available no cost materials.

Implications of emerging technologies on the content of classroom physics

Large scale changes in physics curriculum pose many challenges to successful implementation. Jon Ogborn, University of London, described the example of the UK project *Advancing Physics* which created a new course in physics for 16-18 years old at the end of high school. It includes contemporary content in very engaging ways. Further examples of curricula developed in other countries such as Sweden and

Brazil gave a flavor of what it entails to make large scale changes: the constraints to be negotiated and the opportunities to be exploited for reshaping topics, bringing contemporary flavor, and improving the effectiveness of teaching methods.

An emerging area which was specifically highlighted was *Photonics*. Alex Mazzolini, Swinburne University of Technology, Australia, described the efforts introducing photonics to high school and university physics programs using hands-on approach. Subsequently, he has led along with David Sokoloff a very large number of UNESCO sponsored *Active Learning in Optics and Photonics* (ALOP) workshops across the developing world. To give a flavor of increasing importance of physics in other fields as also every day life, Dean Zollman, Kansas State University, gave a talk on *Modern miracle machines*, introducing contemporary physics in the context of medical applications.

Physics in varying contexts and physics for all

A special session was devoted to importance of communicating physics in diverse contexts. Dean Zollman described how the *International Bicycle Project* is developing materials using the bicycle as a vehicle for teaching. Schlichting Joachim from Germany gave a spectacular presentation titled *Learning to see what everybody can see*. Using appropriate photographs and paintings, he showed how difficult it is to interpret the real-world phenomena on the basis of classroom physics; and how with analysis of these objects, students can be trained to see the world from a physicists' point of view. Ken Laws from Dickinson College, Pennsylvania, further reinforced that attempts at understanding the scientific basis of most art forms can contribute to effective science teaching. In an extremely enjoyable talk, he presented the *Physics of Dance* with a companion ballerina demonstrating his ideas through graceful movements. Choosing examples from ballet and Indian Classical dance form *Kathak*, he showed how typical dance movements can be seen and understood using the concepts of physics.

Special Session on Nurturing Women in Physics: IUPAP set up a Working Group on Women in Physics in 2002. Beverly Hartline, who played a pivotal role in its activities gave a talk sharing the status report of women in physics around the world and suggested actions for their retention and advancement. This was followed by a Panel Discussion. In an inspiring gesture of solidarity, Nobel Laureate Horst Stormer, joined the panellists and made insightful suggestions about encouraging women to work in physics at the frontiers.

Industry-academia-government interaction

Dr. Chidambaram, PSA, talked of *Frontiers of physics and cutting-edge technologies*, emphasizing the need for India to undertake globally competitive research in addition to research that feeds critical technologies for societal requirements. He advised that physics education focusing on change must recognize the multidisciplinary aspects of cutting-edge technologies. Satish K. Kaura, Chairman and Managing Director of Samtel Color Limited, gave an insightful talk on *Bridging industry to academia*, describing the unique tripartite experiment of setting up the Samtel Centre for display Technology with the active involvement of the Indian Institute of Technology, Kanpur and the Government.

Satellite Events for School Students

Dwindling student interest in physics is a global concern. Special motivational programs were designed for school students and ran parallel to the conference at the National Science Centre, New Delhi. Each program drew more than three hundred enthusiastic students from various schools of the city. Ken Laws gave a special demonstration talk on *Physics of Dance and Movement*. The Japanese groups *Lady Cats* ran a workshop on *Art of Paper Craft and Physics* while *Stray Cats* set up a stage science show. Lawrence Krauss, author of books such as *Physics of Star Trek* and *Beyond Star Trek* gave a talk by the same title, using science fiction films as a medium for instruction. R. Shankar, Yale University, addressed about 500 school students motivating them to careers in physics.

Other Highlights

The conference was dotted by events that make conferences a rich canvas.

– *ICPE Medal 2005* was bestowed by President Kalam on Sevin Sjoberg, Professor in Science Education, University of Oslo, a leading researcher from Norway for his work in the broad field of social relations and science education, including important studies of gender differences, and of social and cultural differences.

– *One Hundred Reasons to be a Scientist* published by ICTP, Trieste (2004) was also released by the President.

– *ICPE 2005 Exhibition Stalls* included displays of highly commended physics books and journals; innovative scientific equipment, multimedia resources, computer software, and innovative curriculum packages for use in physics classrooms. Globally recognized leaders, Vernier International and PASCO Scientific along with their Indian distributors, INDOSAW and EDUTECH generated enthusiastic response.

– *ICPE 2005 Portrait Gallery* was a specially curated set of several sketches of Einstein. Also added were portraits of Horst Stormer, the invitee Nobel Laureate and celebrated women physicists who won the Physics Nobel and those who were bypassed.

– *Live EDUSAT transmission and Web cast* showcased the technological capabilities of the country. Indian Space Research Organization (ISRO), Development and Educational Communication Unit (DECU), Indira Gandhi National Open University (IGNOU) and the National Informatics Centre (NIC) facilitated transmission of the conference proceedings in real time to viewers of EDUSAT and IGNOU networks across the country. All sessions were web cast in real time by NIC for viewers across the world.

Conference Impact and Action Plans

The feedback on the conference was extremely positive. The synergy between the policy makers and academia was clearly visible. PSA and also the Chair of the conference, Dr. R. Chidamabaram, sat through the entire conference. He mooted the idea of establishing a vibrant program for *Research and Innovation in Physics Education* in India. He invited the organizing institute Miranda House and the convener of the conference to take the lead in this direction. This ultimately led to the establishment of the *D S Kothari Centre for Research and Innovation in Science Education* at the college in 2007.

Acknowledgments

The conference was held at mega scale to mark WYP celebrations in the country. It managed to accrue adequate funding, sponsorship and support from a large number of national and international organizations and entities, too numerous to list herein. One name stands out. I am personally grateful to Dr. Chidambaram for nudging me to take the leap as he kept raising the bar. ICPE 2005 would not have been possible without the intense work by the academic and steering committee; and the local organizing committee: faculty, support staff and student volunteers of Miranda House. Last but not the least, I express heartfelt gratitude to the Indian Association of Physics Teachers (IAPT). It was the award of IAPT-APS Kilambi Ramavataram Fellowship in 1994-95 that enabled me to work with leading PER groups in the US and build a strong network of global connections without which I could not have conceptualized ICPE 2005. The success of ICPE 2005 conference catapulted India to lead the ICPE commission. I am sure ICPE 2025 will deepen that association.

Welcome Message

Dear Colleagues and Friends,

Welcome to the IUPAP International Conference on Physics Education 2025, co-hosted by IIT Ropar, IISER Mohali and Indian Association of Physics Teachers (IAPT) in India after 20 years. This prestigious event brings together physics researchers, teachers, educators, and planners from around the world. The conference theme, *"Preparing for the Future in the age of Virtual labs, AI and quantum technologies,"* is highly relevant in today's rapidly evolving world. Attendees will engage with renowned plenary speakers, invited talks, workshops, and paper presentations exploring the latest trends and innovations in physics education.

IAPT is proud to be associated with this flagship event of the International Union of Pure and Applied Physics (IUPAP) C14 Commission on Physics Education. The conference offers a unique platform for networking with global leaders in physics education, sharing best practices, and collaborating on initiatives shaping the future of the field.

A special welcome is extended to international delegates. National participants are encouraged to actively engage in discussions and activities, contributing to the advancement of physics education in India and beyond.

We look forward to exploring the vibrant world of physics education together! With Warm Regards

PK Ahluwalia
President IAPT

Quantum Imaging Techniques: Principles, Milestones, and Prospects

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Abstract: Quantum imaging utilizes non-classical properties of light, such as entanglement, sub-Poissonian photon statistics, and quantum correlations, to achieve imaging and sensing capabilities that surpass the performance limits imposed by classical physics. This review briefly provides a comprehensive overview of four foundational quantum imaging approaches: Quantum Ghost Imaging (QGI), Quantum Illumination (QI), Imaging with Undetected Photons (IUP), and Sub-Shot-Noise Imaging (SSNI). A brief overview of the history, theoretical foundations, techniques, applications, limitations, and future trends of quantum imaging approaches are presented. The current challenges and future directions necessary for transitioning these quantum imaging approaches are highlighted from laboratory proof-of-concept demonstrations to real-world technological applications in fields ranging from secure sensing to ultra-low-light microscopy.

1. Introduction to Quantum Imaging

The primary goal of optical imaging is to extract spatial or spectral information about an object. Classical imaging techniques are fundamentally limited by constraints such as diffraction, noise (shot noise and thermal noise), and detector limitations in certain spectral bands. Quantum imaging, however, harnesses the quantum correlations inherent in non-classical light sources—suchably entangled photon pairs or squeezed light—to overcome these classical bounds. The development of nonlinear optics, particularly Spontaneous Parametric Down-Conversion (SPDC), provided the stable, high-quality sources of correlated photons essential for realizing early quantum imaging schemes. This field of research seeks not only to enhance traditional metrics like spatial resolution (super-resolution) and signal-to-noise ratio (sub-shot-noise sensing) but also to enable entirely novel functionalities, such as imaging with photons that never interact with the object. Recent advances have shown that nonclassical superposition states, such as Schrödinger cat and compass states, exhibit sub-Planck structures in phase space, leading to enhanced parameter sensitivity beyond the standard quantum limit. These states enable Heisenberg-limited precision by leveraging fine interference fringes in the Wigner phase-space representation, making them powerful resources for quantum metrology and sensing applications [1].

1.1 The Foundational Limitations of Classical Imaging

The science of optical imaging, which underpins everything from biomedical microscopy to astronomical observation, has historically been governed by the principles of classical electromagnetism. While tremendous advancements in laser technology, optical instruments/components, and digital sensors have pushed performance to near-theoretical limits, fundamental constraints persist, chiefly dictated by the quantum nature of light itself. Classical imaging systems face three primary limitations that quantum optics [2-13] seek to address: the shot-noise limit (SQL), the classical noise ceiling, and the spectral-matching challenge.

The SQL arises because light is quantized into discrete packets, called "photons". When detecting a coherent light source, the arrival of these photons at the sensor follows Poissonian statistics. If N photons are detected over a given interval, the fundamental uncertainty (noise) in that measurement is $\Delta N = \sqrt{N}$. This is the standard quantum limit, and it represents an irreducible minimum level of noise in any intensity measurement using classical light. Any measurement that attempts to resolve changes below this level of noise is fundamentally limited, imposing a ceiling on the sensitivity of classical absorption, phase, and displacement measurements. Overcoming this limit, known as achieving sub-shot-noise performance, is a central motivation for quantum imaging protocols like sub-shot-noise imaging (SSNI).

Beyond the SQL, classical systems often contend with substantial classical noise sources, such as thermal noise (blackbody radiation) emanating from objects at ambient temperatures or electrical noise in the detector and readout circuitry. In high-loss environments, such as long-range sensing or deep-space communication, the faint signal reflected from a target is completely overwhelmed by bright, uncorrelated thermal background noise. Classical solutions to this problem rely on increasing transmission power or improving cooling, both of which are costly and technologically demanding. Quantum approaches, notably Quantum Illumination (QI), offer an alternative path by utilizing quantum correlations to differentiate the faint signal from the overwhelming thermal background, a capability unavailable to classical radar or lidar systems.

Finally, the spectral-matching challenge restricts imaging when the optimal wavelength for probing an object is not compatible with the optimal wavelength for detection. For instance, mid-infrared (MIR) light (∼3−8 μm) is ideal for chemical spectroscopy and non-invasive medical diagnostics due to molecular vibrational resonances. However, high-resolution MIR cameras are often slow, bulky, cryogenically cooled, and prohibitively expensive. Conversely, silicon-based CCD/CMOS cameras operating in the visible and near-infrared (NIR) range are fast, cheap, and offer high resolution. Classical imaging cannot bridge this gap; if you probe with MIR, you must detect with MIR. This limitation motivated the development of schemes like Imaging with Undetected Photons (IUP), which decouples the probe and detection wavelengths entirely.

1.2 The Quantum Toolkit: Non-Classical Light Sources

To overcome these classical bounds, quantum imaging relies on the unique properties of non-classical light, where photons exhibit correlations that cannot be explained by classical probability theory. The primary resources employed are entanglement and squeezing. Entanglement, famously described by Einstein as "spooky action at a distance," involves two or more quantum particles whose fates are inextricably linked, regardless of their spatial separation. In the context of quantum imaging, this relationship is typically manifest in the spatial, momentum, or temporal correlation of photon pairs ($\hat{a}$ and $\hat{b}$). For example, in ghost imaging, detecting photon $\hat{a}$ at a specific location instantly implies photon $\hat{b}$ is located at a correlated position. It is this non-local correlation, rather than the intrinsic properties of individual photons, that carries the image information. Squeezing, on the other hand, is a quantum effect that reduces the uncertainty (quantum noise) of one observable—such as position, phase, or quadrature—below the SQL at the cost of increasing the uncertainty of its conjugate observable, in accordance with the Heisenberg uncertainty principle. For imaging and metrology, the relevant variable is often the difference in photon number (intensity) between two coupled light beams (often called twin beams). In a two-mode squeezed vacuum (TMSV) state, the noise in the difference between the photon counts of the two modes, $\Delta(N_S - N_I)$, can be significantly suppressed below the shot-noise level of the individual beams. This allows for differential measurements (as used in SSNI and QI) to effectively cancel out the common-mode quantum noise inherent in the source, unlocking sub-shot-noise sensitivity.

1.3 Enabling Technology: Spontaneous Parametric Processes (SPDC)

The practical realization of nearly all quantum imaging approaches is made possible by the development of efficient nonlinear optical processes capable of reliably generating these non-classical states of light. The most common of these is Spontaneous Parametric Down-Conversion (SPDC), a second-order non-linear process. In SPDC, a high-energy pump photon (P) interacts with a non-linear crystal (e.g., BBO, KDP) and spontaneously decays into two lower-energy daughter photons, traditionally labeled the signal (S) and the idler (I). Conservation of energy and momentum dictates the strong correlations between these pairs:

$$\left.\begin{aligned} \omega_P &= \omega_S + \omega_I \\ \boldsymbol{k}_P &= \boldsymbol{k}_S + \boldsymbol{k}_\mathrm{I} \end{aligned}\right\} \quad (1)$$

where ω and $\boldsymbol{k}$ are the frequency and wave vector, respectively. Depending on the phase-matching condition, SPDC can produce:

1. **Entangled pairs** (Type-II SPDC), used in the foundational QGI setup.
2. **Twin Beams** (Type-I SPDC or Four-Wave Mixing), exhibiting strong photon number correlations used in SSNI.

The continuous nature of the generation process means that the field is fundamentally in a two-mode squeezed vacuum state, which provides the underlying quantum resource for both intensity correlations (QGI/SSNI) and entanglement-enhanced detection (QI). The robustness and high quality of photons generated via SPDC are key to the seminal demonstrations of QGI [2] and IUP [10].

1.4 The Quantum Advantage Paradigm

The four primary approaches reviewed herein represent distinct paradigms for exploiting quantum light, each offering a unique quantum advantage:

- **Quantum Ghost Imaging (QGI):** Exploits spatial non-locality to separate the imaging function (carried by a high-resolution detector) from the illumination function (carried by the object-illuminating beam and a bucket detector). The quantum advantage is found in superior signal-to-noise ratio in low-light environments compared to classical correlation imaging [2].
- **Quantum Illumination (QI):** Leverages continuous-variable entanglement (TMSV) for secure and sensitive target detection in bright thermal noise. Its advantage is a 6 dB improvement in the error exponent compared to optimal classical radar, achieved even when the entanglement is destroyed by the noisy channel [7].
- **Imaging with Undetected Photons (IUP):** Utilizes the principle of induced coherence to transfer phase information from an undetected probe beam (e.g., in the infrared) to an interfering detected beam (e.g., in the visible). The advantage is spectral conversion, enabling the use of high-performance visible detectors to "see" in non-visible spectral ranges [10].
- **Sub-Shot-Noise Imaging (SSNI):** Employs photon-number squeezed twin beams and differential detection to suppress the SQL. The advantage is a direct enhancement in sensitivity for measurements like absorption or phase shifts, allowing for lower contrast resolution or reduced photon dosage on sensitive samples [12].

Therefore, quantum imaging transcends the limitations of classical optics by reframing the imaging problem not in terms of classical intensity, but in terms of non-classical correlations. This shift enables functionalities ranging from noise reduction to non-local imaging and spectral translation, charting a course toward next-generation sensing technologies. The following sections explore these four pillars of this burgeoning field.

2. Quantum Ghost Imaging (QGI)

2.1 Theoretical Mechanism

Quantum ghost imaging (QGI) is a second-order correlation technique that relies on the spatial correlation between photon pairs, historically generated via SPDC. These photons exhibit strong correlations in their spatial degrees of freedom, specifically conjugate variables like position and momentum. The classic QGI setup splits these two beams: the signal and idler beams, as shown schematically in Fig. 1. The signal photon passes through the object (O) to be imaged and is collected by a bucket detector (D_S), which has no spatial resolution. The idler photon travels along a separate path and is recorded by a spatially resolving detector (e.g., a CCD camera, D_I).

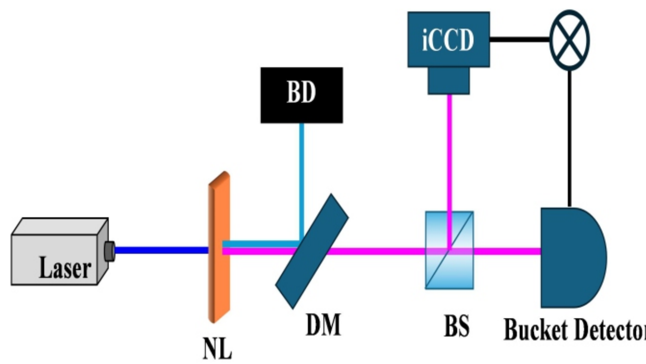

Figure 1: Schematic of the au generated via SPDC [2]. NL: Nonlinear Crystal; DM: Dichroic Mirror; BS: Beam Splitter; BD: Beam Dump.

The image of the object, $O(\mathbf{r}_S)$, is reconstructed by measuring the coincidence counting rate, which is proportional to the intensity correlation function $G^{(2)}(\mathbf{r}_S,\mathbf{r}_I)$ between the bucket detector (which registers N_S) and the specific pixel $\mathbf{r}_I$ on the camera (which registers N_I). The image is thus retrieved by correlating the measured intensities:

$$Image(\boldsymbol{r}_I) \propto \sum_{k=1}^{K} [N_S(k) \cdot N_I(\boldsymbol{r}_I, k)] \tag{2}$$

where k indexes the measurement events. This results in the object's spatial information being transferred non-locally from the signal path (where spatial resolution is lost) to the idler path (where the image is formed).

2.2 Historical and Seminal Work

The concept of ghost imaging was first demonstrated using true quantum entanglement by Pittman, T. B., et al. in 1995 [2], employing SPDC sources. This landmark experiment showcased the surprising non-local nature of the effect. However, the field experienced an intense debate regarding the necessity of quantum entanglement. Seminal work by Bennink, R. S., et al. in 2002 [3] demonstrated an analogous ghost imaging effect using classically correlated pseudo-thermal light (light generated by passing a laser beam through a rotating diffuser). This led to the widely accepted conclusion that the correlations necessary for ghost imaging are based on intensity fluctuations, which can be shared by both quantum and classical sources. The resolution to this debate led to the rise of the most practical variant: Computational Ghost Imaging (CGI), proposed by Shapiro, J. H. [4] and demonstrated by Bromberg, Y., et al. [5]. CGI eliminates the need for the idler camera entirely. By illuminating the object with a sequence of known, random speckle patterns and recording the total intensity with a single-pixel detector, the image can be reconstructed computationally by correlating the measured bucket signals with the known illumination patterns. This significantly simplifies the hardware requirements.

2.3 Quantum Advantage and Applications

While classical/computational ghost imaging dominates practical applications due to its simplicity, QGI retains a crucial advantage in the low-light regime. Quantum sources exhibit a greater signal-to-noise ratio (SNR) and higher visibility compared to classical thermal sources at extremely low light levels [2]. This is particularly important for imaging highly sensitive biological samples or for covert surveillance.

Key Applications:

- **Imaging through Turbulence**: The correlation measurement can be resilient to atmospheric disturbances that affect the signal path.
- **Multi-spectral Imaging**: Non-degenerate SPDC can produce signals and idler photons at different wavelengths, allowing a high-resolution camera at one wavelength (e.g., visible) to form an image of an object probed at another (e.g., infrared), where high-resolution detectors are expensive or unavailable.

3. Quantum Illumination (QI)

3.1 Theoretical Mechanism

Quantum Illumination (QI) is an entanglement-enhanced target detection approach, often considered for quantum radar or lidar applications, designed to overcome the challenge of detecting a low-reflectivity object embedded in a background of bright thermal noise. The approach relies on generating a Two-Mode Squeezed Vacuum (TMSV) state, a form of continuous-variable entanglement, where the signal beam ($\hat{a}$) and the idler beam ($\hat{b}$) are highly correlated. The schematic of QI system is shown in Fig. 2. The signal beam ($\hat{a}$) is sent out to probe the distant target area, through a high-loss, noisy environment. The idler beam ($\hat{b}$) is directed into a quantum memory component at the receiver's location or a local delay line (a major challenge, often requiring a quantum memory). The reflected signal photons, mixed with massive thermal background noise ($\hat{e}$), are collected at the receiver. The entanglement between the signal and idler is completely destroyed by this process—the channel is entanglement-breaking. The key is a joint, optimal quantum measurement (e.g., a phase-conjugate receiver) performed on the noisy returned signal and the retained idler. The process of target detection is formulated as a Bayesian or Neyman-Pearson hypothesis test: Hypothesis H_0 (target absent) vs. Hypothesis H_1 (target present).

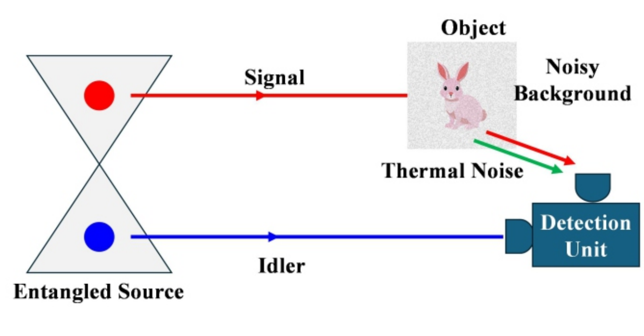

Figure 2: Schematic of the quantum illumination [7].

3.2 Seminal Work and The Quantum Advantage

The theoretical concept of QI was introduced by Lloyd, S. in 2008 [6], who demonstrated that entanglement could provide an enhanced sensitivity compared to classical illumination using the same average number of transmitted photons. This initial work was rapidly followed by the generalization of the protocol to practical Gaussian states (TMSV) by Tan, S.-H., et al. (2008) [7]. The most surprising feature of QI is that its quantum advantage survives the entanglement-breaking channel. The approach provides a 6 dB improvement in the error probability exponent for target detection compared to the optimal classical radar using coherent-state illumination [7]. This advantage, often quantified as a reduction in the probability of detection error, arises not from the residual entanglement (which is zero) but from the strong, non-classical correlations between the retained idler and the faint, noisy reflection. The idler acts as a non-classical label that allows the receiver to effectively distinguish the reflected signal from the uncorrelated thermal background noise that plagues classical receivers. Early experimental demonstrations, such as by Lopaeva, E. D., et al. in 2013 [8], validated the principle in the optical regime. The theoretical extension to the microwave domain, crucial for true radar applications, was proposed by Barzanjeh, S., et al. (2015) [9].

3.3 Challenges

The primary challenge for practical QI is the requirement for quantum memory to store the idler beam. For high-bandwidth radar applications, the idler may need to be stored for microseconds or even milliseconds, which is extremely difficult to achieve with current quantum memory technology. Recent research focuses on schemes that relax or eliminate the need for long-lived quantum memory.

4. Imaging with Undetected Photons (IUP)

4.1 Theoretical Mechanism

Quantum Imaging with Undetected Photons (QIUP) is perhaps the most counter-intuitive quantum imaging approach. It enables image acquisition at an arbitrarily chosen wavelength λ_{probe} without ever detecting a photon at λ_{probe}. It relies on the principle of induced coherence without induced emission, a concept rooted in the quantum mechanical rule that interference occurs only if the possible origins of a photon are fundamentally indistinguishable.

The typical setup of QIUP is shown in Fig. 3 which employs two non-linear crystals, NL1 and NL2, both pumped by the same laser beam. NL1 and NL2 independently generate signal (S) and idler (I) photon pairs through SPDC. Consider a green laser light is divided into two beams (Beam 1 and Beam 2) by a beam splitter (BS1). One of these beams (Beam 1) pumps NL1 and generates a pair of photons with distinct wavelengths known as the idler (red) – I1, and signal (yellow) – S1, through SPDC. This idler (I1) is allowed to pass through the object, O, and it carries the amplitude and phase information from the object and reflects at the dichroic mirror DM2. The idler after reflected from DM2 is aligned with another laser beam (Beam 2) previously divided by the BS1. This laser beam illuminates nonlinear crystal NL2 and generates another set of idler (I2) and signal (S2). The collinear idler of NL2 aligns with the NL1 idler. The idler I1 and the idler I2 (from NL2) are overlapped such that they are made indistinguishable in all properties (frequency, path, polarization). The signal photon from NL1 (S1) is sent towards a detector. Crucially, the idlers are never detected. The signal photons S1 and S2 are then recombined at a beam splitter (BS2). Because the idler path is made indistinguishable, the source of the signal photon (NL1 or NL2) becomes undefined. This ambiguity leads to quantum interference between the signal amplitudes.

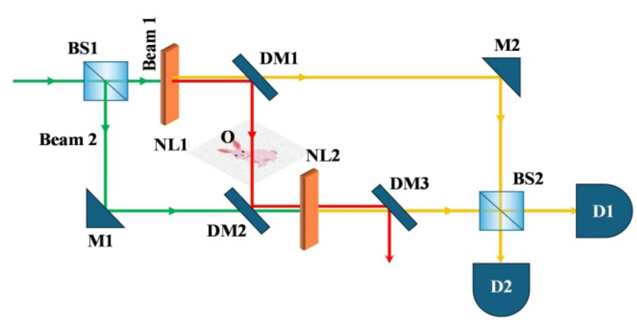

Figure 3: Schematic of the experimental setup of QIUP [10]. BS*i*: Beam splitter; M*i*: Mirrors; NL*i*: Non-linear Crystals; DM*i*: Dichroic Mirrors; D*i*: Detectors.

The object's information (O), which only interacted with the I1 photon at the probe wavelength λ_{probe}, is imprinted onto the phase of I1. Since I1 and I2 are indistinguishable, this phase information is transferred to the interference pattern of the detected signal photons S1 and S2 at the detection wavelength λ_{detect}.

4.2 Seminal Demonstration and Applications

The seminal experimental demonstration of IUP was achieved by Lemos, G. B., et al. in 2014 [10]. They successfully produced images where the detected signal photons were in the visible range (e.g., 820 nm), while the undetected probe photons interacting with the object were in the infrared range (e.g., 1550 nm).

4.3 Quantum Advantage

The primary advantage is spectral conversion: it allows imaging in spectral ranges where high-performance detectors are not readily available or are extremely expensive (e.g., mid-infrared or terahertz). By using a bright, high-resolution visible-light camera to capture the signal interference, one effectively gains access to the probing capabilities of the non-visible wavelength.

4.4 Key Applications

- **Infrared Microscopy**: Imaging heat-sensitive biological samples or chemical processes using mid-infrared light while detecting with a highly sensitive visible CCD camera.
- **Low-Dose Imaging**: Using the optimal probe wavelength to interact with the sample, while detecting the image-bearing signal at a different wavelength that is less harmful to the object.

5. Sub-Shot-Noise Imaging (SSNI)

5.1 The Shot-Noise Limit

All measurements based on light intensity are subject to the shot-noise limit (SQL), also known as the Standard Quantum Limit. Shot noise originates from the quantized (discrete) nature of light—photons—whose arrival times at a detector follow Poissonian statistics. The fundamental noise ΔN in a measurement of N photons is $\Delta N = \sqrt{N}$. This noise sets a limit on the minimum change in absorption or phase that can be resolved.

5.2 Theoretical Mechanism

SSNI approaches aim to bypass the SQL by employing light with sub-Poissonian statistics or by exploiting quantum correlations to perform noise cancellation. The most effective method involves the use of twin beams (also generated by SPDC), which exhibit strong photon-number correlations:

$$\Delta(N_S - N_I)^2 < \Delta(N_S)^2 + \Delta(N_I)^2 \qquad (3)$$

where N_S and N_I are the number of signal and idler photons, respectively. The variance of the difference in photon counts between the two beams is significantly smaller than the variance of a classical measurement, allowing the noise to be cancelled out.

The SSNI mechanism for absorption imaging works via a subtraction technique (or optimized subtraction). Figure 4 shows the schematic of the SSNI setup. Type II SPDC produces quantum correlated beams in a nonlinear crystal (NL). One of the beams probes a low absorptive object (O) before being noticed by a camera, whereas the second beam is detected directly by another section of the same camera. The signal beam (S) probes the object, whose absorption α changes the photon number, $N_S' = \alpha N_S$. The idler beam (I) acts as a reference, N_I. The estimate of the absorption, $\hat{\alpha}$, is determined by correlating the measured N_S' with N_I using the relationship: $\hat{\alpha} \propto \langle N_I - N_S' \rangle$. Because the noise fluctuations in the twin beams are highly correlated, subtracting the reference noise from the signal effectively suppresses the quantum noise associated with the light source itself, leading to a precision below the SQL. By subtracting the intensities detected within each of the beams, part of the shot noise in the object's image can be removed. BD represents a beam dump.

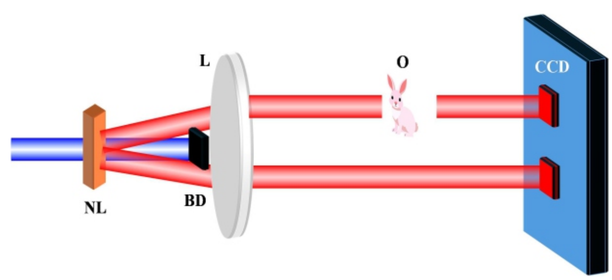

Figure 4: Schematic of the sub-shot-noise quantum imaging [12]. NL: Nonlinear Crystal; BD: Beam Dump; O: Object; L: Lens.

5.3 Seminal Work and Challenges

Early work on sub-shot-noise measurements was achieved by measuring temporal fluctuations [11]. The first proof-of-principle demonstration of SSNI for imaging a two-dimensional absorption mask in a wide-field configuration was presented by Brida, G., et al. in 2010 [12].

5.4 Quantum Advantage and Trade-offs

The advantage is a quantum enhancement in sensitivity, crucial for imaging objects with very low contrast or for minimizing the total photon dose on a delicate sample. A critical challenge in SSNI is the trade-off between resolution and quantum enhancement [13]. Achieving high resolution requires small pixel integration areas, but smaller areas intercept fewer correlated photons, reducing the efficacy of the quantum noise cancellation. Optimizing the detection scheme and utilizing higher-performance detectors are necessary to push the resolution limits while maintaining the quantum advantage.

6. Challenges and Future Directions

While quantum imaging has demonstrated compelling proof-of-concept advantages across all four approaches, several significant challenges must be addressed for widespread deployment. The future of this field is focused on the following parallel efforts: practical integration, robustness against real-world noise, and exploring novel quantum degrees of freedom.

6.1 Practicality and Scaling

The most pressing challenge is the transition from laboratory setups, which rely on complex, alignment-sensitive bulk optics, to robust, compact, and affordable devices.

- **Integrated Photonics:** Moving from bulk SPDC crystals to on-chip integrated quantum sources (e.g., waveguide sources) is essential for scaling these technologies into deployable sensors and microscopes.
- **Detector Technology:** The protocols require high-efficiency, low-noise, and often time-resolving detectors (e.g., Single-Photon Avalanche Diode (SPAD) arrays) to precisely measure the non-classical correlations, especially in QGI and QI.

6.2 The Need for Speed and Real-time Processing

- **Acquisition Speed:** QGI, in its original quantum form, suffered from slow acquisition due to coincidence counting. While CGI accelerated this, advancing sensor technology is vital for real-time quantum correlation measurements.
- **Data Processing:** The retrieval of quantum images (particularly in QGI and SSNI) involves complex correlation or subtraction algorithms. Development of dedicated quantum-enhanced image processing hardware and efficient algorithms is necessary for high-speed operation.

6.3 Advancing the Quantum Resource

The performance of these protocols is intrinsically linked to the quality of the quantum light source.

- **Source Brightness:** Increasing the brightness and flux of entangled and twin-beam sources without sacrificing the quality of the quantum correlations is paramount.
- **Wavelength Flexibility:** For IUP, designing SPDC sources that can reliably produce high-quality entanglement between widely separated wavelengths (e.g., visible and far-infrared) remains a major engineering feat.

6.4 Robustness and Real-World Environmental Challenges

The quantum advantages are often calculated under ideal, noiseless conditions. Their performance must be validated and optimized under real-world degradation factors. While QI is proven to be robust against thermal noise, other protocols are sensitive to channel degradation:

- **Loss Tolerance (SSNI):** Any loss in the signal path (due to absorption or scattering by the object) degrades the photon-number correlation between the twin beams, quickly pushing the sensitivity back toward the SQL. Developing better homodyne/heterodyne detection techniques that can operate with low-light, spatially correlated beams is necessary to mitigate this.
- **Atmospheric Effects (QGI):** Although QGI can be resilient to atmospheric turbulence in the signal arm (since the bucket detector is insensitive to spatial distortion), its performance is severely degraded by losses or turbulence in the reference arm.

7. Future Trends

The computational burden of correlation-based imaging is significant. Machine Learning (ML) and Artificial Intelligence (AI) are emerging as powerful tools to enhance quantum imaging:

- **Computational Reconstruction:** ML algorithms, especially deep learning networks, can be trained to recognize the relationship between the measured correlation data and the true image much faster than traditional correlation integrals, accelerating QGI/CGI reconstruction.

- **Noise Filtering and State Estimation:** AI can be used to optimally filter out noise components, improve the estimation of the quantum state used in the illumination, and even determine the most advantageous quantum state for a given sensing task, potentially improving the achieved sub-shot-noise factor in SSNI.
- **Adaptive Sensing:** ML can enable adaptive quantum imaging, where the system automatically adjusts the properties of the quantum light source (e.g., wavelength, squeezing level) in real-time based on the incoming noisy data to maximize the quantum advantage.

The convergence of quantum hardware (IQP) with computational intelligence (ML/AI) is perhaps the most exciting and promising direction for the commercialization and wide-scale adoption of quantum imaging technologies.

8. Conclusion and Outlook

Quantum imaging represents a paradigm shift in optical sensing, offering demonstrated performance enhancements over classical limits by leveraging fundamental quantum mechanics. Quantum Ghost Imaging established the power of non-local correlation sensing; Quantum Illumination proved that entanglement can offer advantages even in high-loss environments; Imaging with Undetected Photons introduced the power of induced coherence for spectral conversion; and Sub-Shot-Noise Imaging demonstrated the ability to suppress quantum noise for ultra-sensitive measurements.

The immediate future of the field points toward integrating these quantum light sources and detectors onto single, compact platforms. By focusing development on chip-scale integration and robust real-time correlation processing, quantum imaging is poised to move beyond foundational physics demonstrations and realize its potential in critical application areas, including secure communication, advanced medical diagnostics, and next-generation remote sensing technologies.

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Article

Exploring the Measurement of Speed of Light: Historical Insights and the One-Way Measurement Controversy

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1. Introduction

The speed of light is a fundamental constant in physics, often denoted by the symbol c, and it plays a critical role in our understanding of the universe. Traditionally, this constant has been defined as the distance light travels in a vacuum in one second, specifically 299,792,458299,792,458 meters. This definition serves as the cornerstone for various scientific disciplines, influencing everything from the formulation of physical laws to the establishment of measurement standards. However, the conventional understanding of light's speed raises intriguing questions that challenge the very foundations of physics.

Historically, the measurement of light's speed has evolved through centuries of inquiry and experimentation. From ancient Greek philosophers who speculated about the nature of light to modern physicists employing sophisticated technology, the quest to understand how light behaves has been a pivotal aspect of scientific exploration. Despite numerous advancements, a critical assumption persists: all measurements of light's speed have been conducted using a two-way method, where light travels to a point and returns. This raises a profound question: what is the speed of light in a one-way journey?

The concept of one-way speed has significant implications for the principles of simultaneity and the structure of spacetime itself. While the two-way speed of light has been extensively measured and confirmed to be c, the one-way speed remains largely unexplored. For the first time, it was discussed by Poincare and Einstein.[1,2] After being overlooked for many years, the Poincaré-Einstein synchronization problem gained renewed attention in 1977 due to the research conducted by Mansouri and Sexl. Their findings revealed that the one-way speed of light is still not definitively established, which allows for the possibility of differing speeds of light in opposite directions.[3] This oversight invites speculation about the underlying nature of light and the potential existence of asymmetries in spacetime that could affect its propagation.

This article delves into the historical context of light speed measurements, underscoring the critical reliance on two-way speed assumptions and the philosophical questions they engender within the field of physics. Throughout history, from the early speculations of ancient philosophers to modern experimental techniques, the quest to measure light's speed has predominantly utilized two-way methods—where light travels to a point and returns—resulting in a well-established value of c. However, this conventional approach raises profound inquiries about the nature of light's one-way speed, which remains largely unexplored. By examining the evolution of measurement techniques and the implications of the two-way assumption, we aim to illuminate the complexities surrounding this fundamental constant, inviting further exploration into the principles of simultaneity and the structure of spacetime itself.

2. Early Attempts at Measurement

2.1 Ancient History

Many Greek philosophers, including Aristotle, believed that light travels at infinite speed, as we can see stars in the sky the moment we open our eyes.[4] In contrast, Empedocles posited that since light moves, it must have a finite speed. Unfortunately, ancient Greek science relied more on deductive reasoning than experimental testing, leading to conclusions drawn from pure logic rather than empirical evidence.[5]

2.2 Beckman and Galileo

In 1629, Dutch physicist Isaac Beckman proposed an experiment involving an observer viewing the flash of a cannon reflected in a mirror.[6] He positioned various mirrors at different distances and asked observers if they noticed any difference in the time it took to see the flash from each mirror. Unsurprisingly, they did not. Nine years later, Galileo claimed to have conducted a similar experiment using a lantern placed several miles away. He positioned two observers on different hills, separated by a known distance. Observer 1 uncovered the lantern, and as soon as Observer 2 spotted the light, they uncovered their own lantern. Galileo used the time intervals between the two lamps being uncovered and the distance to estimate the speed of light.[7] While he could not definitively conclude whether light travels instantaneously, he suggested that if it did not, it must be exceedingly fast.

2.3 Roemer, Huygens, and Halley

In 1667, the Accademia del Cimento in Florence announced plans to experiment with a lantern placed one mile away, reporting no delay between the uncovering of the lamp and its observation. It was not until nine years later, in 1676, that Ole Roemer nearly accidentally measured the speed of light for the first time.[8] Due to the extreme speed of light, the technology available at that time was insufficient for making the precise measurements required on Earth. However, Roemer's observations of astronomical phenomena, particularly the vast distances involved, enabled him to make crucial measurements.

While studying the Jovian moon Io, which was known to complete an orbit around Jupiter in 42.5 hours, Roemer sought to use this orbital period as a universal clock for navigation. He observed that the duration for Io to emerge from behind Jupiter lengthened as Earth distanced itself from the planet.

He calculated that the time difference between Io's emergence when Earth was closest to Jupiter and when it was farthest was 22 minutes. However, he miscalculated; the actual time difference is 16 minutes and 40 seconds. Although Roemer collected significant data, he did not calculate the speed of light himself. Instead, he sent his findings to Christian Huygens, who determined the speed of light to be approximately 212,400 kilometers per second (about 132,000 miles per second). Huygens seemed more interested in establishing that light has a finite speed than in the exact measurement itself.[9]

In 1694, Edmund Halley calculated that light takes 17 minutes to traverse the diameter of Earth's orbit. Using this value, he estimated the speed of light to be 300,000 kilometers per second (186,000 miles per second), remarkably close to the value we accept today.[10]

2.4 James Bradley

In 1729, James Bradley made another significant measurement of the speed of light, albeit unintentionally, while attempting to determine the stellar parallax of a star known as Gamma Draconis. Stellar parallax is a well known method to determine the distances to nearby stars by observing the apparent shift in their positions relative to more distant stars as Earth orbits around the Sun. However, Bradley noticed discrepancies in the positions of the stars compared to his expectations.

He discovered that these discrepancies were due to a phenomenon known as stellar aberration. This occurs because the light from stars appears to come from slightly different directions due to the movement of the Earth. To illustrate, imagine standing outside on a rainy day: if raindrops fall straight down and you begin to walk, the rain will seem to come at you at an angle. If you run faster, the angle of the rain will increase even more. This is analogous to how light from stars is affected by the Earth's motion. Using sophisticated mathematics, Bradley was able to calculate the speed of light, arriving at a value of approximately 301,000 kilometers per second.[11]

3. Advancements in Measurement

3.1 Hippolyte Fizeau

In 1849, we encountered the experiment conducted by Hippolyte Fizeau. In this experiment, he positioned one telescope in Siren, Paris, and another telescope 8.3 kilometers away in Montmartre. The telescopes were aligned to face each other. One of the telescopes was equipped with a lamp and a toothed wheel resembling a cogwheel, which had 720 equally spaced teeth. The setup allowed light to pass through the gaps between the teeth as it traveled to the second telescope. After reflecting off that telescope, the light returned to the first telescope and passed through the wheel's teeth again before being observed.

As Fizeau spun the wheel, there came a moment when the light would exit through the gap between two teeth, but upon its return, it would strike the next tooth, resulting in no light being observed. He discovered that at a speed of 12.6 revolutions per second, the returning light from the telescope 8 kilometers away was blocked by the next tooth. Utilizing this information, Fizeau calculated the speed of light to be approximately 315,320 kilometers per second, yielding an error of about five percent. This experiment was significant as it marked the first time a time-of-flight method was employed to determine the speed of light.[12]

3.2 Weber & Kohlrausch

Around the same time, several scientists were exploring electromagnetism. In 1856, Weber and Kohlrausch focused on calculating electromagnetic and electrostatic forces. They used a device known as a laden jar, which stores a high-voltage electric charge. This apparatus consists of a glass jar with metal foil lining both the inside and outside. A metal rod protrudes from the jar, and a chain connects this rod to the inner metal foil. The inner foil is charged by linking it to an electrostatic generator, similar to rubbing a comb back and forth on a piece of nylon cloth. Meanwhile, the outer foil is grounded, resulting in the inner and outer foils storing equal but opposite charges. Weber and Kohlrausch calculated that the ratio of these two values was remarkably close to the speed of light that Fizeau had measured in the 1860s.[7]

3.3 Leon Foucault

In 1862, Leon Foucault conducted a similar experiment to determine the speed of light. Although he employed various modifications of this experiment over time, the core principle remained consistent. Foucault utilized a light source and a rotating mirror. As light strikes the mirror, it reflects onto a second mirror. When the light bounces back from this second mirror, the rotating mirror has shifted slightly, causing the light to be reflected at an angle rather than back to its original point. By knowing the rotation speed of the mirror and the angle at which the light is reflected, one can calculate the speed of light.

This experiment was significant because it involved shorter distances than previous methods. Foucault calculated the speed of light to be 298,000 kilometers per second, with an error margin of only 0.6 percent.[14]

3.4 James Clerk Maxwell

He calculated that the speed of these electromagnetic waves was 310,740,000 meters per second, which he identified as the speed of light. He correctly concluded that light is merely another form of electromagnetic radiation, akin to radio waves, microwaves, and ultraviolet (UV) rays. This realization implies that we can determine the speed of light indirectly, without directly measuring it.[15]

In 1907, scientists Rosa and Dorsey built upon this concept to calculate the speed of light. They utilized known values for electric permittivity and magnetic permeability to derive an estimate for the speed of light. Their calculations yielded a value of 299,788 kilometers per second, which is remarkably close to the currently accepted value. [16] This innovative approach demonstrated how theoretical physics could lead to precise measurements, further solidifying our understanding of electromagnetic phenomena.

3.5 Albert Michelson

No discussion of the speed of light would be complete without mentioning Albert Michelson, who devoted much of his career to studying this phenomenon. He designed several innovative experiments to explore the nature of light. In collaboration with Edward Morley, Michelson conducted the famous Michelson-Morley experiment, which aimed to detect the luminiferous ether. At that time, it was believed that, similar to ripples on the surface of water, light waves required a medium-referred to as luminiferous ether-in which to propagate. Michelson measured the speed of light at right angles to see if any differences could be attributed to the presence of ether; however, they found no variation in the speed of light in either direction. This experiment provided strong evidence against the existence of ether and marked the beginning of a new path that ultimately led to the theory of relativity.

Additionally, Michelson conducted a variation of Foucault's experiment using a one-mile (1.6 kilometers) long vacuum tube and an eight-sided mirror. By employing a series of mirrors, he managed to make the light travel a distance of five miles (approximately eight kilometers). This experiment yielded a speed of light measurement of 299,796 kilometers per second, making it the most accurate time-of-flight experiment of its time, with an accuracy of 12 parts per million.[17] These time-of-flight experiments aimed to measure how long it takes for light to travel from an emitter to an observer, typically involving the reflection of light off a surface and its return to the observer. While these experiments were significant in the history of light measurement, they faced accuracy challenges and are not the methods used to measure the speed of light today. Modern approaches, such as cavity resonance, have replaced these earlier techniques and are more commonly employed in educational settings, particularly in college or university physics courses.

4. Modern Measurement Techniques

4.1 Cavity Resonance

The next method used to measure the speed of light is known as cavity resonance. Since light is an electromagnetic wave, it behaves similarly to other electromagnetic waves, such as microwaves and radio waves. This means it possesses both a wavelength and a frequency. The wavelength is the distance between two peaks, while frequency is the number of waves that occur per second, measured in hertz (1 hertz equals one wave per second). The speed of light can be calculated using the formula:

$$c = \text{wavelength} * \text{frequency}$$

In the late 1940s, Essen and Gordon Smith employed this technique to measure the speed of light using a cavity resonator, which is a hollow metal tube. Microwaves generated within this tube bounce around in such a way that, at specific frequencies, the number of wavelengths corresponds to a whole number. By measuring the wavelength and frequency of the waves, they could apply the aforementioned equation to determine the speed of light. Essen and Gordon Smith achieved a result of 299,792,500 meters per second, remarkably close to the accepted value today.[18]

4.2 Home Experiment

You can perform a variation of this experiment at home if you have a microwave oven. First, remove the turntable so that the food does not spin—this is crucial. Next, take a plate and cover it with chocolate or cheese slices. Place the plate in the microwave and turn it on. The chocolate will begin to melt at the antinodes of the wave, which are the highest and lowest points, representing half a wavelength. Measure the distance between two melted spots and multiply by two to find the full wavelength. The back of the microwave should indicate the frequency. By multiplying the two values together, you can calculate the speed of light.[19]

4.3 Interferometry

Next, we move on to interferometry. This technique was initially applied using radio waves in 1958 by Frome, but with the advent of lasers, Evenson and his colleagues refined the method in 1972. The basic premise is the same for both approaches: if I take an electromagnetic wave of a known frequency—such as a laser beam—and direct it at a half-silvered mirror, the beam splits into two at 90 degrees to each other. Each resultant beam travels to a mirror and is reflected back. If both beams traverse the same distance and return to the same point, they will undergo constructive interference, where the peaks and troughs coincide. If one adjusts one of the mirrors to move it back a certain distance, the waves will experience destructive interference, causing the peaks of one wave to align with the troughs of the other, effectively canceling each other out. By doing this, we can accurately measure the wavelength of the electromagnetic wave or laser light. In 1972, Evenson calculated the speed of light to be 299,792,456 meters per second, which is just 2 meters per second different from the currently accepted value of 299,792,458 meters per second.[20]

5. Maiden Claim of the Study

A significant advancement in determining the speed of light was presented in the article titled "A One-Way Speed of Light Experiment," published in the *American Journal of Physics* in October 2009.[21] The study, conducted by Eduardo D. Greaves, An M. Rodríguez, and J. Ruiz-Camacho from Simón Bolívar University, demonstrated the possibility of performing a one-way measurement of the speed of light using a time-of-flight technique. The experiment utilized a He–Ne laser beam modulated by a single oscillator, which traversed a distance to a sensor. The output signal returned via a coaxial cable to a digital oscilloscope, allowing the researchers to measure the phase difference between the reference and sensor signals as a function of the distance traveled by the light. Remarkably, the results were within 0.4% of the accepted value of c, providing compelling evidence for the possibility of measuring the speed of light in one direction. This experiment addresses long-standing controversies regarding the measurement of light speed and offers a practical approach to exploring this fundamental constant.

6. The Problem and the Conclusion

After reviewing this extensive history, one might wonder about the fundamental issue: while scientists have measured the speed of light, have they truly measured its one-way speed? All the experiments detailed above have only measured the two-way speed of light. There is no proof that the speed of light is the same in both directions. It is conceivable that light could travel at half of c in one direction and instantaneously on the return journey, resulting in a round-trip speed of c. This leads to profound questions about the nature of spacetime. Is there a preferred direction? The universe exhibits various asymmetries, and physicists have proposed internally consistent theories where light speed differs in forward and reverse directions. Notably, Albert Einstein, in his 1905 paper on the "Electrodynamics of Moving Bodies," emphasized that the speed of light is defined to be the same in both directions, a convention known as the Einstein synchronization convention. He argued that this is not a supposition or hypothesis but a stipulation to define simultaneity.

For over a century, scientists have sought to measure the one-way speed of light, yet it remains elusive. While the round-trip value is c, does the one-way speed have a defined value? If not, what does this mean for the concept of simultaneity? When is "now" on other planets? Does it make sense to discuss simultaneous events separated by distance? Perhaps the next major leap in physics will provide insights into these compelling questions, leading us to wonder why we did not recognize them sooner.

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Report (Sub RC-08F)

On the Second Invited Talk

Under the Celebration of International Year of Quantum Mechanics (IYQ-2025)

Date: 10th Nov. 2025 **Time:** 7.00 PM to 8.00 PM

Organized by: IAPT Sub-RC 08F, Marathwada Region, Maharashtra.

Topic:-"Quantum Materials and Brief Description of Nobel Prize in Physics-2025".

Speaker: Dr. M. S. Jogad, Coordinator Dept of Physics, KSWUB, (Ex-Principal SB College of Science Gulbarga

The inaugural lecture of this series was conducted on 24th July 2025 via Google Meet. The second lecture of this series was conducted on 10th November 2025 via Google Meet.

The meet was hosted by Dr. R G Vidhate, Secretary, Sub RC. Dr. D R Sapate the President Sub RC, introduced the speaker. Prof. Jogad guided the audience through a comprehensive exploration. His talk highlighted the recent advancements in quantum materials and their potential applications in quantum technology.

His lecture adeptly bridged classical physics with modern innovations, including quantum technology, classical collision, quantum tunneling, quantum devices, superconductivity, its origin, Bosons, magnetic resonance, the burgeoning field of quantum technologies. He Spoke on the work of scientist Dr. Homi Bhabha and explained the quantum mechanics and quantum materials in a simple manner. The session was chaired by Dr. K. M. Jadhav. Professor, Emiretus, MGM University, Chhatrapati Sambhajinagar.

The subsequent interactive Q&A session fostered engaging discussions and thoughtful questions, all of which Prof. Jogad addressed with remarkable clarity and depth.

The event concluded with a vote of thanks proposed by Dr. Jiteddra Kaushalya, a member of RC- 08F,

Key Highlights of the Lecture:

Quantum technology 2.0

Emphasis on Indian scientists Dr. Homi Bhabha & their global impact

Emerging quantum technologies and their future implications

Active audience engagement during Q&A

R G Vidhate

Secretary

Report (Adarsha Anveshika)

Activity-1

Teachers Orientation Programme

Date: 10 August 2025. Venue: Mitra Institution (Bhowanipur Branch)

Adarsha IAPT Anveshika organized five hours teachers orientation programs in collaboration with Anuranan Science Awareness at Mitra Institution Bhawanipur, Kolkata.

Total 25 teachers from different schools and colleges participated in the workshop, Mrs.Madhumita Mazumder, Mrs. Rinku Das, Mr Nani Gopal Mondal, and Mr Debmalya Sen were the resource persons for the sessions. Dr. B N Das, Dr. Bidhan Kumar Bhowmik were present as observers.

The sessions were Interactive, and the participants enjoyed the sessions. During the open house session, the participants requested to organise such programme at least twice a year. Certificate of participation was awarded to all participants. Anuranan provided refreshments for all participants for the workshop.

Activity-2

Hands on Experiments in Physics

Date:16th October 2025, Thursday, Time: 11:00 Hrs to 03:30 Hrs**,**

Adarsha Anveshika organised a four -hours interactive “Hands on Experiments in Physics” in association with Anuranan - Science Awareness and Rabindra Mahavidyalaya Tarakeswar, Hooghly. West Bengal on 16th October 2025, at Muktarpur High School. Muktarpur, Hooghly (W.B.).

Debmalya Sen, Dr Uday Kumar Khan and Dr Somnath Pal were the resource persons for the sessions in which a total of 107 girls from the school participated.

The workshop was designed with innovative classroom experiments, science shows in interactive methods to make physics enjoyable for the students.

Students enjoyed the sessions and actively participated in the discussion. 30 minutes tiffin break was given to the students between the sessions.

Dr Bidhan K Bhaumik organised a physics quiz session and prizes were given to the successful students.

Debmalya Sen

Report (RC-23)

Engaging Young Minds: A Quantum Celebration

Venue: St. Bede's College, Shimla

Date: October 31, 2025

Organized by: St. Bede's College, Shimla in Collaboration with RC 23.

To mark the *International Year of Quantum Science and Technology (IYQ 2025)*, the Department of Physics at St. Bede's College, Shimla, in collaboration with RC- 23, organized a one-day program titled ***“Engaging Young Minds: A Quantum Celebration”*** on October 31, 2025.

The event brought together around 150 enthusiastic physics students from various reputed schools and colleges: Rajkiya Kanya Mahavidyalaya Shimla, Government Degree College Sanjauli, Government degree College Kotshera, Shimla, UIIT H.P. University, Shimla, Sacred Heart Convent School Dhalli, and Jesus & Mary School (Chelsea). The program served as an engaging platform for young learners to explore the wonders of quantum science and appreciate its intense influence on modern technology.

Inaugural Session

The program commenced with a formal inaugural ceremony. Principal Dr. Sr. Rosily T.L. welcomed the chief guest and other participants. Prof. P. K. Ahluwalia, President, IAPT, graced the occasion as the Chief Guest. In his address, he emphasized the importance of nurturing curiosity and researchoriented thinking among students to keep pace with the rapidly advancing domain of quantum science.

Technical Sessions

Prof. P.K. Ahluwalia delivered an insightful talk on ***"Louis de Broglie's Quantum Legacy",*** highlighting the revolutionary impact of de Broglie's wave-particle duality concept on the evolution of quantum mechanics.

Following this, Dr.Sapna Sharma, Head of the Department of Physics, St. Bede's College, conducted a session titled "***Quantum Mechanics Through the Lens of Virtual Resources."*** Her presentation introduced students to innovative digital tools and virtual simulations that make abstract quantum phenomena more accessible and comprehensible. The session demonstrated how technology can serve as a bridge between theoretical understanding and visual experience.

The talks were followed by an interactive quiz session, conducted by the quiz masters Dr.Sarveena Assistant Professor, Physics, St. Bede's College & Dr.Neha Katoch, Assistant Professor, Physics,Govt. Degree College Kotshera. The quiz saw active participation from the students, reinforcing their understanding of key quantum concepts in an engaging manner.

Poster Exhibition

A poster exhibition was organized as a part of the event, showcasing the evolution of Quantum Science and Technology over the past century. The exhibits paid tribute to the pioneering scientists such as Max Planck, Albert Einstein, Schrödinger, Heisenberg, and Dirac & S.N.Bose whose ground breaking work laid the foundation for this transformative field. The creativity and depth of research displayed by the participants were widely appreciated by the faculty and guests.

Documentary Screening

The day concluded with the screening of a documentary titled **"Quantum Opportunities."** The film explored the future possibilities of quantum research and its wide-ranging applications in computing, communication, cryptography, and materials science. It provided an inspiring glimpse into how quantum science continues to shape the technological frontier of the 21st century.

The event was attended by the Principal, members of the Science Faculty of St. Bede's College, and faculty representatives from all participating institutions. The program succeeded in fostering scientific curiosity and enthusiasm among young minds, offering them valuable insights into the fascinating world of quantum mechanics.

Through this collaborative initiative, St. Bede's College and RC -23 reaffirmed their commitment to promoting science education and inspiring the next generation of physicists to explore, innovate, and contribute to the ever-evolving field of Quantum Science and Technology.

Sapna Sharma
Secretary

Report (RC-03)

XII IAPT National Student Symposium on Physics (NSSP-2025)

The 12[th] National Student Symposium Physics (NSSP-2025) was organised from October 10 to 12, by Indian Association of Physics Teachers (IAPT) in collaboration with the Department of Physics, Panjab University, Chandigarh. A total of 88 students from different regions across India, - Himachal Pradesh, Rajasthan, Punjab, Haryana, Delhi, U.P., Maharashtra, Uttarakhand, Tamil Nadu, West Bengal and other states, actively participated in the event.The symposium featured 19 oral and 27 poster presentations. Six invited talks and one keynote lecture were delivered on current and emerging areas of physics. The students visited the Cyclotron, Pre-Incubation RUSA lab and XRD lab facilities of the department. The event, with its thought provoking talks and networking sessions, inspired peer and faculty engagement and created a vibrant academic environment.

Day 1 (October 10, 2025) began with the inaugural session at 10:00 am which started with Panjab University anthem. The Director, Research and Development Cell of Panjab University, Prof. Meenakshi Goyal in her inaugural address outlined the rich heritage of Panjab University from pre-partition days to the present and explained the Honours School System which was in vogue. She applauded the role of the Physics Department in the overall development of research ethos of the University. She noted the shared mission of both IAPT and Panjab University in taking Science beyond Boundaries.

The chairperson of the Department of Physics PU, Professor S.K. Tripathi recalled the tradition of promoting research culture at Physics Department, Panjab University, starting from Lahore

days before partition which is continuing till day. He traced the history, starting from Cosmic ray balloon experiments, Nuclear Emulsion lab, Nuclear, Atomic, Molecular spectroscopy labs, that the department made significant contributions and involved in International collaborations like CERN, DZERO, ALICE, Fermi lab, KEK Japan, JINR Dubna, to national level collaborations at TIFR, CVECC Kolkata, NSC Delhi, IOP Bhubaneswar to name a few. He recalled the contributions of Physics faculty to IAPT and fondly reminded that the department houses IAPT office and senior faculties are still actively involved in bringing out IAPT bulletin from Chandigarh.

In his Inaugural address, President of IAPT, Prof. P. K. Ahluwalia, thanked the University and department in hosting the NSSP 2025 and spoke about various efforts being made by IAPT in reaching the unreached. Celebrating 100 years quantum physics, in his keynote address Prof. Ahluwalia walked through the evolution of Quantum Mechanics and reminisced the start of the quantum era with scientists like Planck, De-broglie, Bensen, Einstein, Bohr, Frank Hertz and many more. He highlighted how intuition works in physics citing the example of De-Broglie and Einstein. He mentioned an interesting association of De-broglie with India as he was the first person to be awarded Kalinga award by UNESCO upon which he came to India to deliver popular science lectures.

Following this, total of 9 oral presentations by students were held, covering a wide spectrum of physics domains — from nuclear and quantum physics to atmospheric science, astrophysics, and emerging areas like machine learning and ethics in nanoscience. The diversity of topics reflected the broad interests of the student community and the interdisciplinary nature of modern physics research. Each presentation was followed by a Q&A session, allowing peers to engage in thoughtful scientific exchange. Guided and explained by the research scholars of the department, the participants toured various departmental facilities including the Cyclotron, XRD lab and the Pre-incubation lab. The day ended with a gripping lecture by Prof. Sandeep Sahijpal, from Panjab University, on Space Technologies and their role in understanding our universe. Prof. Sahijpal talked about space missions, remote sensing, telecommunication, defense technologies, meteorological studies and weather forecast.

On Day 2, the day started with another round of oral presentations by students, on topics like photonics, material sciences and many more. Prof Arvind, of IISER Mohali, delivered a talk on quantum cryptography. He highlighted that algorithm-based codes can be learnt and hence there is a need for a more secure methodology. Prof Arvind explained the use of Quantum Entanglement and Bell's state in quantum key distribution, in a very simple and easy-to-understand way. Two sessions of poster presentations were held. In total, 27 posters were presented by student in the hallway of the department of physics, which created an interactive learning space where participants interact and share each their experience with each other and faculty members provided insightful feedback. Prof. P. K. Ahluwalia concluded Day 2 with a personal and insightful talk on Enrico Fermi, focusing on his life journey and his monumental contributions to physics. Rather than a technical overview, the session offered a reflective account of Fermi's influence as a teacher and a scientist.

Day 3, started with student presentations. Prof. J. S. Bagla, from IISER Mohali, delivered the first invited talk of the day on observing and characterising black holes. Prof. Bagla talked about the evolution of our understanding of gravity and light and how that led to the general theory of relativity. Prof. Bagla talked about the works of Einstein, Swarszchild, Chandrashekhar among many more into formulating the theory of black holes and reminded us that while we have solid evidence for the existence of black holes, a concrete proof is still awaited. Prof. Manjit Kaur, presently faculty of Amity University (former faculty at PU, Chief Editor of IAPT Bulletin) in her Invited talk spoke about the tiny to the tiniest zoo of particles that consists our whole universe and our current status in the field of particle physics and collider technology we have built. The event concluded with a valedictory session held in the Prof. B.M. Anand Auditorium, named in honour of the distinguished former faculty member of the institute. All student participants were awarded certificates and a biography of Prof. Anand, acknowledging his lasting contributions to physics education. Additionally, selected students received books as awards for their outstanding poster and oral presentations, based on faculty evaluation. The certificates and awards were distributed by Prof. S.K. Tripathi and Prof. P.K. Ahluwalia, bringing the three-day symposium to a memorable and inspiring close.

IAPT RC3 EC members, veterans, senior faculty of physics department, scholars, and students, LOC NSSP2025 members attended and contributed their mite in the successful conduct of NSSP 2025.

Selected oral / poster abstracts shall appear in the bulletin. Full booklet NSSP2025 is available at https://drive.google.com/file/d/16enhN97wkxaNGbrE41mTWqDDCcUdBIIF/view?usp=sharing

Two of many 'memories'

First of all, I want to express my heartfelt gratitude to IAPT for organizing such a wonderful, vibrant, and inspiring event. Over the past three days, this symposium has been an amazing journey — filled with learning, excitement, and new connections!

It has helped me explore the latest advancements in Physics and more importantly, it has given me the chance to interact with brilliant minds from across our country- Tamil Nadu to West Bengal, Gujarat to Uttar Pradesh, Delhi to Punjab. I've met students from every corner of India, each bringing their own regional flavor, ideas, and energy into the world of Physics.

And that's what makes this event so special! Because of IAPT's vision and effort we, the students of different states, different thoughts, and different dreams, have come together under one roof — united by our passion for Physics and our love for learning.

This experience has truly shown me how India's young minds, when brought together, can create magic — sharing knowledge, spreading enthusiasm, and making our nation proud!

Thank you, IAPT, for this incredible platform and unforgettable experience. Let's keep the spark of Physics alive and continue making India shine!

Ms. Sargun Khurana, GGDSD College, Chandigarh

This was my first time attending such an event, and it was truly unforgettable. The symposium opened my eyes to new dimensions of physics, enriching my knowledge and sparking inspiration...

The entire experience was exceptional, from the insightful sessions to the warm hospitality. The hostel facilities, food, and overall arrangements were outstanding, making my stay comfortable and memorable….

Yusuf Siddique, 4th-year B.Sc. (Hons) student from Aligarh Muslim University.

C. N. Kumar
Coordinator NSSP2025

Report (Midnapur College)

Two-Day Physics workshop for Class-XI

A two-day Physics workshop for Class XI was organized on October 16-17, 2025, by IAPT-Midnapore College CSC. Thirty-seven student from 7 Higher Secondary schools actively participated in this workshop. The experiments based on the HS syllabus were designed and prepared indigenously under the active guidance of Dr. S C Samanta, the acting president of IAPT-Midnapore College CSC. Dr. M.N. Goswami Department of Physics, Midnapore College Mr. Sanjay Kumar Pal, Mr. Papun Mandal, Assistant Teacher of Physical Science, Ananadapur High School; Mr. Pradip Kumar Mohanti, Mr. Sukumar Bera, retired HM of the HS school, and four other teachers from different schools were the resource persons in this Programme. The student participants performed most of the experiments given below. At the end of the Workshop, the Teacher-in-Charge of Midnapore College handed over the certificates to the student participants.

List of Experiments		Required Materials
Expt. - 1	Measurement of refractive index of the material of a convex/ concave lens	Spherometer, lens (concave, convex), glass slab etc
Expt. - 2	Density of a given material	Meter scale, Slide Calipers and Kitchen balance etc
Expt. - 3	Resistivity of copper coil when the length of the copper wire is not known	Screw gauge, DMM, Kitchen balance, Beaker, Copper coil etc
Expt. - 4	Measurement of density and water and other liquids at room temperatures	Measuring Cylinder, Thermometer etc
Expt. - 5	Characteristics of DC source and Galvanometer	DC source (electrochemical cell of potato/ mobile charger), DMM, Resistors, Table Galvanometer etc
Expt. - 6	Uniform motion and viscosity of Mobil	Burette filled with Mobil, Pea nuts / sugar globules etc
Expt. - 7	Study of exponential motion and measurement of viscosity	Cylindrical bottle filled with water and fitted with a horizontal viscosity tube etc
Expt. - 8	Study of uniform deceleration	A leaky cylindrical bottle filled with water.
Expt. - 9	Study of the uniformly accelerated motion, Jmeasurement of static and dynamic friction coefficient	Inclined plane, wooden block etc
Expt.- 10	Rolling friction and measurement of 'g'	Friction table, Aluminum channel, steel ball.
Expt. - 11	Measurement of time period for different lengths, Concept of one second, Determination of 'g'	A set of simple pendulum etc.
Expt. - 12	A study of decay of its amplitude in air with and without magnetic field	A set of simple pendulum with a magnet as its bob
Expt. - 13	Study of conservation of energy	A set of simple pendulum etc.
Expt. - 14	Measurement of Young modulus	Wire stretched between two nails, weights etc
Expt. -15	Measurement of surface tension	Two microscopes' slides separated by copper wire rtc
Expt. -16	Measurement of surface tension of water	A medical Syringe fitted with needle of different diameters etc
Expt. - 17	Measurement of density of liquids.	'U' tube, measuring cylinder etc
Expt. - 18	Verification of Boyle's law and measurement of atmospheric pressure	2m long 4mm dia plastic tube inserted in water in another onJe metre plastic pipe of larger dia
Expt. - 19	Calibration of thermistor	Thermometer, thermistor, DMM, beaker, ice etc
Expt. - 20	Measurement of Latent heat of ice and specific heat of sand of kerosene	Calibrated thermistor/thermometer, DMM, thermo flask, ice etc
Expt. - 21	Newton's Law of cooling	Calibrated thermistor/thermometer, DMM, thermo flask, a glass filled with warm water etc
Expt. - 22	Measurement of Young modulus of rubber	Solid rubber tube of rectangular/circular cross section etc
Expt. - 23	Parallelogram law of forces	Ordinary lab set for the purpose but developed at the CSC, etc

Makhanlal Nanda Goswami

Report (RC-12A)

Anveshika Physics Bharata Yatra-Jagruta Jatra at Mysuru

Spark Lab – Where Ideas Ignite Through Experiments

Organized By: Ammanni- Anveshika & IAPT RC12A, Bengaluru

In Collaboration With: Mysore District PU Physics Lecturer Forum and BGS PU College

On 21st and 22nd November, a two days Experimental Science Workshop for PU Teachers, was organized at, GS PU College, Kuvempu Nagara, Mysuru , in which 60 teachers participated.

Day 1 Highlights

- **Assembling of dignitaries:** Esteemed guests, educators, and organizers gathered, setting a tone of respect and anticipation.
- **Introduction to the event:** A warm welcome outlined Spark Lab's vision as a hub for experimental science learning.
- **Speeches by honorary guests:** Distinguished speakers emphasized the importance of hands-on science education and collaborative pedagogy.
- **Lighting of the Anveshika Physics Bharat Yatra Deepa:** A symbolic lamp-lighting ceremony, accompanied by song and speech, marked the official inauguration. The music of wonder was immediately translated in Kannada, to the pleasure of all the rural teachers!
- **Lab setup:** Experimental stations were prepared with precision, ensuring accessibility for all participants.
- **Guiding participants:** Teachers were directed to their respective stations, fostering curiosity and exploration.
- **Experiment explanation:** Facilitators provided clear instructions and scientific insights, bridging theory with practice.
- **Hands-on experimentation:** Participants engaged with experiments in their own creative ways, sparking discussions and collaborative problem-solving.
- **Concluding with high tea:** The day ended with refreshing exchanges that reinforced community and shared learning.

Day 2 Highlights

- **Enthusiastic start:** The second day began with renewed energy and eagerness among participants.
- **Active interaction:** Teachers engaged deeply, exchanging ideas and suggesting innovative approaches to experiments.
- **Igniting curiosity:** The program visibly sparked interest, as educators connected concepts from textbooks with hands-on experiences.
- **Sharing of findings:** Participants presented their experimental observations to peers, creating a vibrant atmosphere of collaborative discovery.
- **Thrilling feedback:** Teachers expressed excitement and appreciation, highlighting the workshop's impact on their teaching practice.
- **Honouring contributors:** Resource persons and MDPPFL organizers working behind the scenes were recognized for their dedication.
- **Support from JSO Cell:** Timely provision of experimental kits and innovative ideas was acknowledged, along with sharing resources designed for Junior Science Olympiad students—empowering teachers to go beyond the syllabus.
- **Vote of thanks:** The program concluded with gratitude extended to all contributors, participants, and supporters, reinforcing the collective spirit of Spark Lab.

Reflections

Across two days, Spark Lab proved to be a transformative experience for PU science teachers. It blended **experimentation, cognitive insights, and collaborative learning**, igniting curiosity and equipping educators with tools to inspire their students, teaching community but also reaffirmed the power of hands-on science in nurturing a culture of inquiry.

Sarmistha Sahu
Coordinator

CONVENTION 2026

January 11, 2026 (Sunday)

Indian Association of Physics Teachers
Regional Council -15

Thinking Beyond Boundaries :
From Concepts to Realities - Innovating the Physics Classroom

Organized by

IAPT, RC-15

in collaboration with

Department of Physics, Victoria Institution (College)

Time : 10.00 am to 5.00 pm
Venue: Victoria Institution (College)

The Roadmap

- Registration: 9:30 am - 10:15 am
- Inaugural Session: 10:30 am - 11:00 am
- Invited Talk : 11:00 am - 11:45 am
- Tea Break: 11:45 am-12:00 pm
- Parallel Sessions: i) Poster Presentation by Participants, ii) Demonstration of Hands-on Innovative Experiments by Selected Students: 12:00 pm - 2:00 pm
- Lunch Break : 2:00 pm - 2:30 pm
- Journey of IAPT RC 15 : 2:30 pm – 2:45 pm
- Interactive Session : 2:45 pm - 3:45 pm
- Valedictory Session : 3:45 pm - 4:15 pm

Inviting posters from physics teachers and students of School, College, University

Theme :

1) Classroom Physics Teaching Related,
2) Laboratory Physics Teaching Related,
3) Beyond Classroom Physics Teaching .

Poster should be printed on a single sheet of paper [Size : A0 (84.1cm X 118.9cm), Orientation: Portrait]

Advisory Committee

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Dr. Subhas Chandra Samanta, IAPT
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Ms. Kathakali Biswas, VIC

REGISTRATION OPEN (Fee : 100/-)

Registration will close on December 15, 2025

Name of the A/c : Indian Association of Physics Teachers RC 15
Branch : Manicktala (Calcutta)
Account No : 11152796006
IFSC : SBIN0001715

Registration Link : https://forms.gle/8Go3FzCMcfNwF9Ue6

Reach us:- iaptrc15@gmail.com

Exploring Conceptual Change - What is it all about?

In this article, we discuss conceptual change - a pivotal theme in science/ physics education research. Our experience reveals that students find it extremely difficult to understand or come to terms with certain topics, even after hours—or even years—of instruction. These difficulties should be contrasted with those that can be resolved by sheer practice (like mastering a procedure or technique) or by clearly remembering certain facts, definitions, etc. The defining characteristic of such difficulties—the subject matter of conceptual change—is that they involve a radical `change' in the very nature of our thinking. The following article gives an overview of the history of research along these lines and its philosophical underpinnings.

DiSessa, A. A. (2014). **A history of conceptual change research: Threads and Fault Lines**

https://escholarship.org/content/qt1271w50q/qt1271w50q.pd

The transition from what is often called the `Aristotelian' way of thinking about motion to Newtonian Mechanics, is an illustrative example of the conceptual `change' we are discussing. The later propounds highly counterintuitive ideas such as: motion does not necessarily imply a force or the time taken by a falling body to reach the ground is independent of its mass. It is not uncommon to find students who have spent years learning physics but still thinks that motion requires a force or heavier bodies fall faster. Administering and analyzing concept inventories like the FCI will provide us the empirical evidence to substantiate these claims, in case one is skeptical.

Now comes the crucial question: how do we facilitate this conceptual change in our teaching? Researchers have proposed diverse pedagogies and strategies, with a shared emphasis on creating opportunities for students to surface their intuitive thinking and engage with it—allowing refinement rather than replacement. There is broad agreement that ignoring or dismissing these ideas as "wrong" is unproductive. Interested readers may explore the following article for further discussion along these lines:

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International journal of science education*, *25*(6), 671-688.
https://www.tandfonline.com/doi/pdf/10.1080/09500690305016

Beyond education, the conceptual change literature also examines pivotal moments in the history of science, where scientists pioneered radically different ways of thinking about the world. A prime example is Maxwell's work on electromagnetism, details of which can be found in:

Nersessian, N. J. (2009). **Conceptual change: creativity, cognition, and culture**. In *Models of discovery and creativity* (pp. 127-166). Dordrecht: Springer Netherlands.

In fact, there are parallels in the nature of the change and restructuring in thinking required by scientists in the context of discovery and by students in the context of learning or education. A useful reference discussing this story of ontogeny recapitulating phylogeny, and trials and tribulations in both is:

Nersessian, N. J. (1989). Conceptual change in science and in science education. *Synthese*, *80*(1), 163-183.
https://link.springer.com/content/pdf/10.1007/BF00869953.pdf

K K Mashood
HBCSE - TIFR, Mumbai

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