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ISSN 2277-8950

Bulletin of THE INDIAN ASSOCIATION OF PHYSICS TEACHERS

A MONTHLY JOURNAL OF EDUCATION IN PHYSICS & RELATED AREAS

VOLUME 18 NUMBER 7 JULY 2026

A soccer ball floats in microgravity in this March 2, 2026, picture from the International Space Station. The space station crew tested soccer balls to study how internal mass affects motion and stability in microgravity. The findings have improved understanding of how embedded technologies, including match-ball sensors, can influence performance during play.

Through research aboard the International Space Station and technology developed for exploration, NASA continues to demonstrate how discoveries made for space can benefit people on Earth—including athletes and fans participating in the world's most popular sport.

Link: https://www.nasa.gov/image-article/soccer-meets-space-science/

Bulletin of The Indian Association of Physics Teachers

http://www.indapt.org.in

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

Mathematics and Physics of Mathematical Physics

It is said that mathematics is the language of physics. Indeed, we find that the analysis of any topic in physics is not complete without mathematics. So, the whole of physics is mathematical. Then, why we bring some topics under the heading 'Mathematical Physics'. Another issue of concern in this regard is some stakeholders' using the expressions 'Mathematical Physics' and 'Mathematical Methods in Physics' interchangeably. As a matter of fact, topics such as Differential Equations (Ordinary and Partial); Complex Variables; Integral Transforms; Special Functions; Vector Algebra; Determinants, Matrices, Group, Rings. Fields, etc. are all mathematical methods in physics.

Now, there are mathematical methods which embrace physics in a unique way, so as to feel that some physics emerge out of the mathematics. Let us consider a very simple example of writing the equation of motion of any object in one dimension; it is bound to be a second order differential equation in x & t. The equation will depict the relation: force = mass x acceleration, where acceleration is essentially the second derivative of x w.r.t t. In order to solve this equation, one has to integrate the equation twice w.r.t time. The first and the second integration respectively yield the velocity and position. This apparently simple operation helps us to realize that position and velocity are *two independent* co-ordinates, which I can swear that many students do not understand at the first instance, whereas it happens to be cornerstone of Lagrangian and Hamiltonian Mechanics (in the latter momentum assumes the role of velocity, primarily to provide an easy passage to the dimension of 'action' and most importantly the uncertainty principle).

The fact of position and velocity co-ordinates being independent plays a vital role in conceptualization of phase of an oscillator while studying SHM as well as phase space in statistical mechanics. The very fact that *two* degrees of freedom are associated with a vibrational mode emerges from this concept of independence.

Going back to the second order differential equation, there can be two situations – the force being a function of time or that of position. The former is a mathematically simpler case, while the latter (as it happens *inter alia* in case of an SHM) is handled first by multiplying both sides of the differential equation by the first derivative of the dependent variable w.r.t the independent variable. This is the general procedure, while in case of differential equation of motion this derivative happens to be velocity. Thus, the left side of the equation takes the form (force x velocity), i.e., power, which is the time-derivative of energy; and so, its integration is a reflection of the principle of energy which can be verified. Thus, again some crucial physics emerging from mathematical operations!

Examples are plenty – like the connection between optics and the principle of least action, some special functions like the spherical harmonics appearing to be tailor-made for the (θ, φ) part of the solution of the Schrödinger Equation of hydrogen atom or that of partial differential equation of potentials satisfying Laplace's Equation; phasors in electric circuits getting explained using complex analysis and so on.

I conclude by stating that there are instances of illustrative confluences between physics and mathematics; but physics becomes mathematical when one embraces the other; otherwise, the latter always stands by the former by providing exact explanations.

Chinmoy Kumar Ghosh

Physics News

World's largest particle smasher halts for upgrade to boost hunt for dark matter

The world's most powerful particle accelerator will shutter operations soon this summer for four years of renovations to dramatically boost its collision capacity and the potential for unlocking one of the greatest mysteries of the universe: dark matter. Activity will stop as the extraordinary device undergoes upgrades aimed at further increasing the precision and intensity of particle collisions. Once completed, the enhanced particle smasher, bearing the new name High Luminosity LHC (HL-LHC), is scheduled to begin operations in June 2030 and to run for about a decade. The total cost of the upgrade is expected to come in at 1.2 billion Swiss francs ($1.5 billion). The upgrade will require fully replacing the components in 1.2 kilometers (0.75 miles) of the 27-kilometer (17-mile) tunnel. Once operational, between 140 and 200 collisions will occur each time two packets of particles meet inside detectors in the tunnel, up from 60 currently. The lab's main hope, meanwhile, is to produce two Higgs bosons simultaneously, which would be a first, and see them interact.

Read more at: https://phys.org/news/2026-06-world-largest-particle-smasher-halts.html

More Information: https://phys.org/news/2026-01-cern-chief-upbeat-funding-particle.html

Electron-Ion Collider's radiofrequency controls system passes first real-world test

The U.S. Department of Energy's (DOE) Brookhaven National Laboratory has reached a key early milestone in developing radiofrequency control systems for the Electron-Ion Collider (EIC)-a next-generation research facility that will collide electrons with ions to reveal how the building blocks of matter are held together. At the heart of any particle accelerator are radiofrequency (RF) systems, which use electromagnetic waves to accelerate particle beams to near-light speed and keep them tightly controlled. The system tested here is low-level radiofrequency (LLRF), acts as the "brain," precisely controlling those RF fields to ensure stable and accurate operation. The LLRF system plays a critical role by controlling RF cavities, which transfer energy to particle beams. It must continuously monitor conditions and make rapid adjustments to maintain precise voltage and phase. This represents a significant advance over legacy RHIC systems, which relied on larger, less integrated electronics. Looking ahead, the common platform is expected to serve as a foundation for many EIC subsystems, enabling coordinated system development and efficient data sharing.

Read more at: https://phys.org/news/2026-06-electron-ion-collider-radiofrequency-real.html

Provided By: https://phys.org/partners/brookhaven-national-laboratory/

How do flocking birds and schools of fish move? New research offers crystal-clear answer

Flocking birds and schools of fish are a familiar sight. While previous research has uncovered the broad dynamics driving these movements, their underlying intricacies remain a mystery. The findings, reported in the journal *Physical Review Fluids*, offer detailed insights into the hydrodynamic and aerodynamic interactions crucial in aerospace and automotive engineering, robotics and energy harvesting. The research team proposed a mathematical model to explain these movements, one akin to those of soft crystalline materials, or soft crystals. The researchers subsequently saw a connection between crystalline organization and how birds or fish move together while adjusting their movements and formation in response to air or water flows, predators or objects such as rocks or buildings. The wings were 3D-printed from plastic and driven by motors to flap in water, which captured how air flows around bird wings during flight. Overall, the flappers as a group behaved as the researchers had conceptualized, one of several experiments that offered support for their proposed model.

Read more at: https://phys.org/news/2026-06-flocking-birds-schools-fish-crystal.html

Original Paper: Physical Review Fluids (2026). DOI: 10.1103/tp8s-76vr

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July: This Month in the History of Physics

July 1876: IACS begins its journey

The Indian Association for the Cultivation of Science (IACS), was the first institute in Asia for doing fundamental research. It was founded by Dr Mahendralal Sircar, a prominent M.D. physician and a social reformer, exactly 150 years back on July 29, 1876. Dr Sircar envisioned to provide a platform for the general public of India for providing exposure to modern science and its developments. It was modelled in the line of science societies of Europe and initially popular scientific lectures by eminent personalities were organised at IACS that was housed in a small building at 210 Bowbazar Street, at the central part of Calcutta (now Kolkata). Funds came not only from generous donations by landlords and social reformers, but also from small contributions by common people. The Association as it is still popularly called had an organising committee consisting of Dr Sircar, an educator and social reformer Ishwar Chandra Vidyasagar, a Jesuit priest and professor Father Eugene Lafont and some other luminaries at that time.

IACS building at Bowbazar Street, Calcutta

A second and a very prominent phase of IACS began with the arrival of Sir C V Raman, then a civil servant in the Finance Department. Raman along with his student KS Krishnan started the famous Raman scattering experiment with very simple instruments. Raman went on to win the 1930 Nobel prize in physics for this work. After the independence its character changed and it became a full-fledged research institute with government support and Prof MN Saha became its first Director. Many frontline scientists have worked and are still working in this premiere institute.

July 1687: Path of a Planet

Following a discussion with Christopher Wren (1632-1723) and Robert Hooke (1635-1703), Sir Edmund Halley (1656-1742) visited Newton (1642-1727) in Cambridge University to ask the possible path of a planet around the Sun had gravity depended as inverse square law of distance. Newton immediately replied, 'An Ellipse' as he had already solved it. On request, he sent a short paper to Halley detailing the solution. Newton was basically a reclusive person and was least interested in publication of his findings to avoid unnecessary squabbles on his works. With Halley's encouragement, Newton wrote three huge books successively from mid- 1684 to early 1687. During that period, he retreated totally from the outside world that had detrimental effects on his physical and mental health. Halley edited the manuscripts and bore the entire cost to publish them from the Royal Society in a single volume in Latin with the title Philosophiae Naturalis Principia Mathematica (Mathematical Principles of Natural Philosophy) on July 5, 1687. At that time, Physics was considered as a part of natural philosophy. This 510-page book in Latin was the first foundation book of modern classical mechanics to ensure its acceptability by the eminent European scholars in this field.

Sir Isaac Newton

The Book I contained three basic laws of motion and inverse square law of gravitation in vacuum without friction. Book II dealt with motions in resistive media and speed of sound. Book III explained tides, paths of comets, shape of the earth, etc. It was established that the same laws govern the motion of celestial bodies and bodies on earth. However, initially the book was not well accepted by scholars mainly for two reasons.

First, Newton, by intention, presented the subject in a way difficult for the amateurs to grasp easily and make baseless comments. Although meanwhile Newton had invented the method of fluxion, a version of calculus, he used classical Greek geometry with propositions and lemma applied to triangles and arcs. Secondly, gravitational attraction through vacuum without any direct contact was not acceptable then by many. However, recognition by people like French mathematician L' Hospital (1661-1704) and Dutch physicist Christiaan Huygens (1629-95), and the subsequent proof of Earth's curvature, predicted next appearance of Halley's comet in 1758 coming true, etc put the book on strong footing.

July 1905: Brownian Motion and Einstein

One of the revolutionary papers of Einstein (1879-1955) in 1905, his miraculous year, was on explanation of the Brownian motion first observed by the British botanist Robert Brown (1773-1858) in 1827 on pollen grains suspended in water. The paper was published on July 18, 1905 in Annalen der Physik. It presented the theory for the random motion of solid microscopic particles in water or aqueous fluids assuming underlying molecular mechanisms. By then, the motion was known as Brownian motion. But Einstein was hesitant to use this term as he wrote, 'It is possible that the movements ….. are identical with the so-called Brownian molecular motion; however, the information available to me ….. is so lacking in precision, that I can form no judgement in the matter'. Einstein formulated the problem as, 'We must assume that the suspended particles perform irregular movement on account of the molecular movement of the liquid'. He derived an expression for the mean square displacement of a spherical Brownian particle in terms of known parameters of the liquid and the Avogadro's number. Exhaustive and meticulous experiments by Jean Perrin (1870- 1942) during 1908 - 09 confirmed Einstein's theory in explaining the Brownian motion. But this paper was important for another reason also. Depending on John Dalton's (1766-1844) atomic theory, Kinetic theory of gases was developed by Rudolf Clausius (1822-88), James Clarke Maxwell (1831-79) and Ludwig Boltzmann (1844-1906). Later it was extended by Boltzmann applying probability distribution of molecular velocity. But a group of the-then eminent scientists including Ernst Mach (1838-1916) and Wilhelm Ostwald (1853-1932) vehemently opposed the very existence of atoms. Before Einstein, Carl Nageli (1817-91) and William Ramsay (1852-1916) went against practical possibility of observation of Brownian particles based on atomic collisions. Einstein, taking an example of a spherical Brownian particle of radius one micron, showed that the root mean square displacement could be of the order of a few microns, when observed over a period of one minute. Here Einstein undoubtedly proved that Boltzmann was totally correct with his theory. Had it been verified a few years earlier, Boltzmann might not have taken his own life in 1906 out of frustration.

July 1969: Man Puts His First Foot on Moon

The month of July also marked with a pioneering achievement in the history of space science. The Apollo 11 mission of NASA was planned for landing on the surface of the moon. And on July 20, 1969 the first human footprint was marked on the lunar soil by Neil Armstrong (1930-2012). He was followed by Edwin Aldrin (b 1930) and the historical quote of Armstrong in this context was, "That is one small step for (a) man, one giant leap for mankind".

Astronaut from Apollo 11 on the Moon

It covered a total distance of 4,49,800 km including the orbital paths round the earth and the moon, and the transit path between them in 102 hrs and 45 mins. It was a mission that in a way fulfilled human dream and the analysis of rock samples from the moon put our knowledge on a strong foundation. This mission of NASA was a declaration about the fruitful collaboration of science and technology. If we keep in mind that the mission was carried out nearly sixty years back one must appreciate the level of precision involved in the entire programme.

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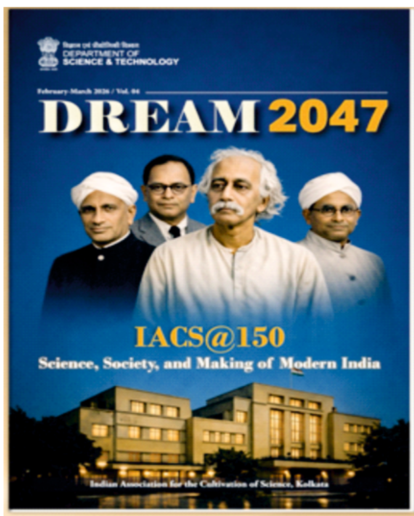
IACS@150

The Department of Science and Technology in the latest issue of DREAM 2047, dedicated to the Indian Association for the Cultivation of Science (IACS), Kolkata, India's first scientific research institutions. The issue has been brought out to mark the completion of 150 years of its establishment. It presents a comprehensive account of IACS's historical legacy, biographies of eminent scientific figures, and insights into ongoing research across multiple disciplines. It also highlights the institution's significant contributions to India's scientific development and its continuing role in advancing research and innovation. The current issue may be accessed through the link provided below. We request all the IAPT fraternity to go through it thoroughly and disseminate this further within your networks.

https://www.indiascienceandtechnology.gov.in/february-march-2026-vol-04-dream-dream2047



Article

IACS at 150 Years: Atomic and Molecular Science: A Journey of the Last Fifty Years

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ABSTARCT: In July 2026 Indian Association for the Cultivation of Science, the first research institute of modern India is going to complete 150 years. Over the decades the institute has grown in various directions over many scientific disciplines. The present article is a summary of the growth and evolution of theoretical research in the field of atomic, molecular and optical sciences in the last fifty years.

INTRODUCTION

The Indian Association for the Cultivation of Science (IACS), established in July 1876 at 210 Bow-bazar Street, Calcutta, is a national institution of higher learning dedicated to fostering high-quality fundamental research and education in frontier areas of the basic sciences. Founded by Dr. Mahendra Lal Sircar, a visionary physician and philanthropist, the Association's activities in its early years were supported by generous public contributions. It was conceived and planned against the backdrop of the great cultural renaissance and intellectual awakening of nineteenth-century Bengal. As originally envisioned, the institution was to be "solely native and purely national." Its founding objective—"to cultivate science in all its departments both with a view to its advancement by original research and to its varied applications to the arts and comforts of life"—continues to guide its mission today. During its formative years, from 1876 to around 1907, the Association primarily served as an institute for teaching the basic sciences through lectures delivered by eminent scholars such as Sir J. C. Bose, Sir Asutosh Mukherjee, Chuni Lal Bose, and others. A transformative phase began in 1907 when C. V. Raman, who had come to Calcutta as a senior officer in the Finance Department of the Government of India, became a member of the Association and started conducting research in his spare time after official duties. As Raman's research gained momentum, students from across India gradually assembled in Calcutta to work in the intellectually stimulating environment of the Association. Until the early decades of the twentieth century, the Association remained the only institution in India where advanced research in the physical sciences could be pursued. Many of the country's most distinguished scientists carried out their research here. The Institute gained international recognition when C. V. Raman conducted his monumental work on physical optics, leading to the discovery of the celebrated Raman Effect, for which he was awarded the Nobel Prize in Physics in 1930—the first Nobel Prize in Science awarded to an Indian. During this period, he also made pioneering contributions to the study of low-angle X-ray scattering. K. S. Krishnan, S. Bhagavatam, P. Krishnamurthy, B. B. Ray, K. Banerjee, L. Srivastava, N. K. Sethi, C. Prasad, and S. K. Banerjee are among the many illustrious scientists who worked at the Association and significantly enriched its research activities during the early decades.

In 1946, the Association embarked on a new phase of development under the dynamic leadership of Meghnad Saha. He envisioned the creation of an active research school dedicated to fundamental investigations while continuing the Association's pioneering work in X-rays, magnetism, and optics, areas in which it had already established considerable expertise through Raman's contributions. A new campus was subsequently established at Jadavpur, evolving into a sprawling complex of basic research laboratories, to which the facilities from central Calcutta were gradually relocated. Dr. Bidhan Chandra Roy played a pivotal role in acquiring the land for the Jadavpur campus through a Government of West Bengal gazette notification dated November 20, 1947. Soon thereafter, three new departments of

Chemistry—Physical, Organic, and Inorganic—along with several departments in Physics, were established to expand research in multiple directions. Research carried out at the Association in areas such as the theory of gravity, collision theory, polymer chemistry, stereoselective synthesis of organic molecules, and coordination chemistry received widespread international recognition.

Today, IACS is an autonomous institution under the Department of Science and Technology (DST), Government of India. Research projects undertaken by its faculty members are supported by numerous national funding agencies, including DST, CSIR, DAE, and MNES, as well as private industries and international organizations such as the NSF, UNDP, and funding bodies from Japan, the European Union, Sweden, and other countries. In recent years, the Institute has been granted the status of a deemed-to-be University by the University Grants Commission (UGC).

AFTER A CENTURY

In 1976, IACS completed a century of its glorious existence. Although primarily an institute of basic research, it has consistently pursued the diverse applications of fundamental scientific discoveries. Over the last fifty years, several far-reaching developments have transformed the landscape of basic sciences, which may broadly be categorized into theoretical sciences, physical sciences, chemical sciences, biological sciences, materials sciences, and interdisciplinary sciences. At IACS, major areas of application include organic electronics, solar energy research (silicon-based and nanoparticle-based hybrid solar cells), the development of novel light sources such as "cold" LEDs, drug synthesis, bioactive gels, inorganic materials for water purification, green chemistry, and carbon dioxide sequestration for mitigating global warming, to name just a few.

It is impossible to summarize these developments, even briefly, in a single article in a meaningful manner. My modest aim here is to provide an overview of the theoretical research carried out over the last fifty years in selected areas of atomic, molecular, and optical physics. The common thread running through these topics is the fundamental quantum laws governing microscopic motion. This brief account presents an overlapping perspective that connects research from an earlier era with some of the ongoing theoretical investigations. Our scope, however, is not broad enough to encompass the remarkable experimental advances in optics, spectroscopy, and many other areas that have taken place during this period.

We conclude this section with a disclaimer that the coverage is necessarily selective and not exhaustive, and that some significant contributions may have been inadvertently omitted.

FROM ATOMIC COLLISIONS TO CAVITY QED AND COLD ATOMS

Understanding scattering dynamics is essential for modelling astrophysical environments, planetary nebulae, and fusion plasmas, as well as for plasma diagnostics. From the mid-1950s to the mid-1990s, researchers at IACS made foundational contributions to theoretical atomic collision physics, particularly in the scattering and ionization of hydrogenic targets by electron and positron impact. These fundamental few-body problems have long served as benchmark systems for testing atomic collision theories.

The group led by N.C. Sil and collaborators extensively employed the Glauber approximation and eikonal theories to calculate differential and total cross-sections for the elastic scattering and excitation of hydrogen atoms. These approaches successfully bridged the gap between perturbative methods, such as the Born approximation, and more sophisticated close-coupling techniques. The researchers further developed boundary - corrected continuum intermediate-state approximations to describe the ionization of atomic hydrogen and hydrogenic ions by charged-particle impact. A major focus of their work was the comparison of collision dynamics involving incident electrons and positrons, where the attractive and repulsive nature of the projectile-target interaction leads to qualitatively different scattering behaviour. Their studies demonstrated how the projectile charge influences angular distributions and cross-sections, particularly in symmetric scattering geometries and single-ionization processes. They also calculated triple differential cross-sections for the ionization of hydrogen atoms in both the ground state and metastable excited states, such as (2s) and (3s), providing valuable theoretical benchmarks for coplanar symmetric geometries. By incorporating dynamic distortion of the target electron cloud together with exchange effects, their models achieved highly accurate predictions even in complex collision environments. Systematic investigations of hydrogenic ions further revealed how increasing the effective nuclear charge modifies scattering amplitudes and suppresses ionization cross-sections relative to neutral hydrogen.

Beginning in the early 1990s, theoretical research in atomic and optical physics at IACS entered a new phase under the guidance of D S Ray and collaborators, with the initiation of studies in cavity quantum electrodynamics (QED). Their work focused on few-atom, few-photon radiative processes confined within optical cavities, with the primary objective of developing new methods for generating, manipulating, and characterizing non-classical states of light. Significant contributions from this period include a general scheme for generating arbitrary two-colour cavity fields, the realization of a Hermitian phase-difference operator, an analytical expression for the time-dependent micro-maser spectrum, and an exact solution of a radiation-matter interaction problem in the presence of Kerr nonlinearity. The group also predicted cavity-induced enhancement of atomic relaxation and suppression of the Mollow triplet, a novel phenomenon that was experimentally verified in later years.

Subsequently, B Deb and co-workers expanded the theoretical programme into the fields of cold atoms, ultracold quantum collisions, and quantum optics. Their research established important connections between fundamental scattering theory and emerging areas such as quantum technologies, cold chemistry, and waveguide quantum electrodynamics. In the area of cold atomic collisions and ultracold chemistry, the group investigated low-energy quantum collisions, elucidating the role of atomic hyperfine interactions in determining scattering properties in the millikelvin and sub-millikelvin temperature regimes. Their studies clarified the mechanisms by which ultracold atoms bind to form molecules under externally applied fields, with particular emphasis on photo-association, magneto-association, and magneto-optical association. They also developed advanced multichannel quantum defect theory techniques for calculating multichannel wavefunctions and predicting cold-collision properties, successfully analysing both (s)-wave and (d)-wave Feshbach resonances in atomic systems such as rubidium and lithium. In waveguide quantum electrodynamics, the group explored correlated light scattering and cavity-free light-matter interactions in one-dimensional waveguide systems. Their theoretical studies demonstrated how atoms that are side-coupled or directly coupled to a waveguide can mediate effective photon-photon interactions, including Kerr-type nonlinearities, at the few-photon level, thereby providing promising building blocks for scalable quantum networks. The group's research also extended to quantum computation and quantum simulation, where they investigated the implementation of quantum logic using dark states and Rydberg parity gates in highly controllable atomic arrays. These studies established theoretical frameworks for exploiting strongly interacting atomic systems as versatile platforms for quantum information processing and quantum simulation.

MOLECULES: ELECTRONIC STRUCTURE AND DYNAMICS

Theoretical research on molecules at IACS has evolved through several distinct yet interconnected directions, ranging from the development of advanced electronic structure methods to molecular dynamics, non-adiabatic processes, nonlinear laser-matter interactions, ultracold quantum systems, and modern computational chemistry. These contributions have significantly advanced the understanding of molecular structure, dynamics, spectroscopy, and chemical reactivity.

One of the most influential contributions originated from the group led by D. Mukherjee, which pioneered the formulation of State-Universal (SU) and Valence-Universal (VU) Multi-Reference Coupled Cluster (MRCC) theories. Although single-reference coupled-cluster methods are remarkably successful for closed-shell molecules, they become inadequate for systems exhibiting strong electronic degeneracies or near-degeneracies, such as open-shell radicals, bondbreaking processes, and electronically excited states. The MRCC formalism developed at IACS overcame these limitations by introducing a multi-determinantal model space together with its orthogonal complement. By defining a wave operator acting on the model space, the many-electron Schrödinger equation was transformed into an effective Hamiltonian problem, while the cluster ansatz constructed from multiconfigurational reference functions ensured proper size extensivity. This framework enabled the simultaneous treatment of multiple electronic states and avoided the breakdown of conventional perturbative approaches. Over the following decades, the methodology was further generalized to relativistic electronic structure theory through Dirac-Fock multi-reference formulations, making possible highly accurate calculations for heavy-element chemistry and core-excitation spectra.

While these developments revolutionized electronic structure theory, another important direction emerged through the work of S. P. Bhattacharyya and collaborators in chemical molecular dynamics. Their studies elegantly connected molecular structure and reaction dynamics by monitoring the evolution of chemical reactions through simple descriptors such as bond order. The group developed time-dependent Fourier grid methods for investigating quantum molecular dynamics and introduced stochastic optimization algorithms for electronic structure calculations. Evolutionary computational techniques based on simulated annealing and genetic algorithms were successfully employed to locate global minima on multidimensional potential energy surfaces, reducing computational costs by several orders of magnitude compared with conventional deterministic approaches. These methodological developments culminated in a widely recognized monograph that continues to serve as an accessible introduction to modern optimization and machine-learning-inspired approaches in theoretical chemistry.

Traditional electronic structure calculations rely heavily on the Born-Oppenheimer approximation, which separates electronic and nuclear motion. A major research programme led by S. Adhikari focused on extending molecular quantum mechanics beyond this approximation by developing accurate multidimensional diabatic potential energy surfaces and advanced time-dependent wave-packet methods for simulating spectra and scattering dynamics in non-adiabatic molecular systems. The group introduced practical formulations of the Curl condition within the framework of the Extended Born-Oppenheimer equations, enabling accurate quantum simulations using effective single-surface descriptions even in situations where Born-Oppenheimer breakdown effects are significant. They further derived explicit Adiabatic-to-Diabatic Transformation (ADT) equations for multimode, multistate Hilbert spaces involving three to six coupled electronic states, allowing the construction of smooth and single-valued diabatic potential energy surfaces from complex electronic structure calculations. Rigorous evaluation of non-adiabatic coupling terms enabled systematic mapping of conical intersections arising from Jahn-Teller and pseudo-Jahn-Teller interactions. These theoretical developments were successfully applied to interpret photoelectron spectra and reaction dynamics in systems such as the benzene radical cation, the NO^3 radical, and the reactive scattering process D^+ + H2.

Nonlinear light-matter interactions formed another important area of theoretical research. S. S. Bhattacharyya and collaborators investigated high-harmonic generation in molecular ions subjected to intense femtosecond laser fields through detailed wave-packet dynamical studies. Their work explored ultrashort - pulse - induced asymmetric fragmentation of molecular ions, quasi-stationary resonances generated by intense infrared fields, and coherent control of vibrational population transfer in lithium diatomic molecules in the presence of rotational manifolds. These studies significantly enhanced the understanding of ultrafast molecular dynamics under strong-field conditions.

Closely related investigations were carried out by the group led by S. Saha, which employed non-perturbative Floquet techniques to examine the influence of highly excited molecular electronic states on high-harmonic generation in simple diatomic systems such as the hydrogen molecular ion. The group also investigated multiphoton dissociation and autoionization processes by analysing fragment branching ratios and angular distributions using time-independent close-coupling methods. Their studies further demonstrated coherent control of molecular population transfer using intense chirped and unchirped femtosecond laser pulses through Stimulated Raman Adiabatic Passage (STIRAP), providing valuable insights into laser-driven quantum control.

T. K. Raidastidar and collaborators made significant contributions to the theoretical understanding of intense laser-molecule interactions and quantum coherence. They developed a theoretical framework demonstrating that matter fields possess non-local U (1) gauge transformation symmetry, thereby establishing a non-thermodynamic arrow of time at the atomic scale. The group also showed that complex two-photon absorption can exhibit a linear dependence on laser intensity, providing an early theoretical basis for understanding correlated multiphoton absorption in gases and high-harmonic generation. Their investigations extended to multiphoton double ionization, above-threshold ionization, resonance-enhanced multiphoton ionization (REMPI) of hydrogen molecules, and laser amplification through quantum interference without population inversion.

Another major research direction concerned Bose-Einstein condensates (BECs), pursued by K. Raidastidar and collaborators. Their work included studies of momentum-dependent (s)-wave and (d)-wave interactions in ultracold condensates together with extensive numerical simulations of coupled Gross-Pitaevskii equations describing atomic and molecular condensates. These investigations examined vortex-lattice formation in rotating double-well traps, coherent coupling between dipolar atomic and molecular condensates through magnetic Feshbach resonances, and the dynamics of atomic and molecular solitary waves in coupled atom-molecule condensates. These studies substantially advanced the theoretical understanding of nonlinear collective behaviour in ultracold quantum gases.

The theoretical description of strongly correlated electronic systems and photo-induced molecular processes forms another vibrant area of research at IACS. The group led by D. Ghosh has developed and applied Density Matrix Renormalization Group (DMRG)-based methods together with hybrid quantum chemical frameworks capable of accurately treating large active spaces in molecular excited states, particularly in conjugated organic systems and biomolecular chromophores. The group has also introduced computational strategies that combine high-level quantum chemistry with statistical learning techniques to predict excitation energies across large molecular families, including fluorophores. Significant methodological advances have further been achieved in hybrid quantum mechanics/molecular mechanics (QM/MM) approaches and polarizable embedding methods for realistic simulations of excited-state dynamics in condensed-phase environments.

Computational chemistry has been further strengthened through the work of A. Dutta and collaborators, whose research focuses on the electronic structure and dynamics of novel materials for energy storage and optoelectronic applications. Their studies include first-principles modelling of two-dimensional materials such as graphene and their silicon analogues, investigations of strain-induced topological insulating phases, and solvent-phase exfoliation mechanisms. The group has also designed organic molecules exhibiting singlet fission for enhanced light-emitting efficiency and Aggregation-Induced Emission (AIE) characteristics for applications in organic light-emitting diodes and biosensing. Additional research themes include homogeneous and heterogeneous catalysis, quantum mechanical tunnelling phenomena such as carbon tunnelling, and post-transition-state dynamics that govern product selectivity in chemical transformations.

Another important direction bridges fundamental molecular mechanisms with modern data-driven computational science. The group led by A. Paul employs Density Functional Theory (DFT) together with high-level electronic structure methods to investigate complex reaction mechanisms, with particular emphasis on small-molecule activation, carbon dioxide reduction on nanoscale clusters, chemical hydrogen storage, and metalloenzyme modelling. The group has also developed machine-learning models capable of rapidly predicting spin-state energy gaps in (3d) transition-metal complexes using physically interpretable descriptors derived from high-spin electronic configurations, thereby avoiding computationally demanding ab initio calculations while maintaining excellent transferability. Their research further encompasses bond dissociation pathways, photo-protecting group mechanisms, and fundamental bonding models in diatomic molecules.

Collectively, these diverse theoretical investigations have established molecular science at IACS as a vibrant and internationally recognized research programme, spanning fundamental electronic structure theory, quantum dynamics, nonlinear optics, ultracold matter, and computational molecular design while continuously adapting to emerging challenges in chemistry, physics, and materials science.

CONCLUSION

The discussion presented above offers a bird's-eye view of the research carried out in atomic, molecular, and optical physics at IACS by various groups across the Departments of Physics and Chemistry over the past five decades. Given the breadth and diversity of these contributions, it is difficult to weave them into a single, comprehensive narrative. Instead, we have focused primarily on the fundamental quantum phenomena and the theoretical methodologies that have shaped research in these areas.

The remarkable advances in computational power and numerical techniques, together with the widespread availability of sophisticated software packages, have transformed the study of electronic structure and molecular dynamics in increasingly complex molecules and materials. These developments continue to reveal novel and often unexpected properties of molecular aggregates, low-dimensional systems, and functional materials.

A significant part of the current research programme at IACS is also aligned with the objectives of the National Quantum Mission, reflecting the growing importance of quantum science and technology. Building on its rich legacy and sustained excellence in fundamental research, the Institute continues to be a vibrant centre of scientific activity and innovation.

As this year marks both the sesquicentennial celebration of IACS and the centenary of quantum mechanics, we stand at the threshold of the second quantum revolution. It is our hope that the Institute will continue to play a leading role in advancing quantum technologies and related interdisciplinary research in the years to come.

ACKNOWLEDGEMENTS

The author gratefully acknowledges Professor Bhupati Chakraborty for his constant encouragement, inspiration, and Professor Arnab Ghosh of IIT Kanpur for many valuable discussions during the preparation of this article. The author is also sincerely grateful to Professor Manjit Kaur for her kind invitation to contribute this article. Although my long association with this institute in various capacities since 1977 is extremely motivational, too much familiarity sometimes becomes an impediment also for objective assessment of a work from a larger perspective. I have therefore carefully avoided to be judgemental on any issue in this article. After all, science is a collective effort. And the present article narrates the story of our journey over the last fifty years in the field of theoretical atomic and molecular science at IACS.

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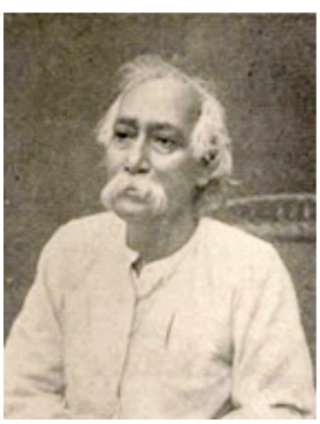
Article

IACS: The Oldest Research Institute of the Country Turns 150

Bhupati Chakrabarti

(A former [1977-1981] Ph.D. student at IACS)

In Europe during the 16th-17th century a section of educated and well-to-do people mainly from the upper strata of the society began to take interest in science, still designated as 'natural philosophy' with some awe and curiosity. After Galileo we had people 'doing science' in different countries in western Europe and some of their contributions are very much part of the science that we study and teach even today. The need for the right kind of platforms where these like-minded people could meet and share their ideas, visions and could discuss their findings in the laboratories, emerged. Or some of them wanted to present interesting experiments where novelties are be appreciated was the motivation for having such bodies. That way Royal Society of London came up in 1660 and it is acknowledged as the first scientific society. It had the patronage of the King Charles I of England. To put the things in perspective let us underline that Sir Isaac Newton who later was the President of this society for a long period was barely eighteen years old when the society came up.



Dr. Mahandra Lal Sirkar

In the world that lies beyond the Europe and the Americas the first scientific society came up in Kolkata with the initiative of an MD physician Dr Mahandra Lal Sirkar (1833-1904) who later turned into a homeopath.

It was 1876 the society named as Indian Association for the Cultivation of Science (IACS) emerged in Calcutta (now Kolkata) with the objectives like the science societies of Europe. By that time a good number of these had become functional in France, Italy, Holland, Germany, Russia and in a few more countries in Europe and in the USA and Canada on the other side of the Atlantic. However, the uniqueness of the IACS was that it was not only in Asia but was also in a country that had been ruled by colonial rulers from Britain for nearly 120 years at that point of time in 1876. This year IACS completes 150 years of its magnificent journey.

During that period of the British rule, Calcutta was the capital of India and had lot of commercial and educational activities primarily with British initiatives were going on in that part of the country. But science was yet to get a front seat and Dr Sarkar had the desire and a vision to do exactly that. The Association was housed at 210 Bowbazar Street in central Calcutta and Dr Sirkar tried to pull the people of science whosoever were there in Kolkata at that time to be the part of the activities of the 'Association' as it used to get fondly referred to. The Jesuit father from St Xavier's College (Estd. 1862) Fr. Eugene Lafont who was a teacher of physics came down to deliver lectures on physics before the people who were educated but did not have any formal exposure of science. Later his student Jagadish Chandra Bose (later Sir J.C. Bose) also joined him in this venture. Both of them supported the academic activities of IACS in a significant way.

Apart from the propagation of science the Association also ran on a nationalistic spirit. It could attract the frontline Bengali scholars and social reformers like Pundit Iswar Chanrda Vidyasagar, Keshab Chandra Sen, Sir Asutosh Mukherjee, Pramathanath Bose were among the members of the first Trustee Board of IACS. Very distinguished personalities from various walks of public life were among its patrons. The dream of Dr Sirkar was to have a platform for high level of discussions on science for the local Indians with educational exposure and financial ability and providing them with an exposure of the science being done at Europe. In this context it needs to be mentioned that the Asiatic Society was an academic body that came much earlier than IACS in 1784. It published journals, conducted discourses on various areas, but it was by and large a body for the Britishers and other Europeans. Indians could be its members only from 1829, but scientific discourses formed a very small part of the activities of the Asiatic Society. On the other hand, a section of educated and enlightened Bengali population of the city came forward to support Dr Mahendra Lal Sirkar as the interest to know about science being done particularly in Europe gathered momentum in the last quarter of the nineteenth century.

A second and very glorious phase of IACS began with the arrival of Chandrashekhar Venkata Raman who first visited it on an afternoon of 1907. Raman was new in Kolkata and arrived there as a high-level government officer as the Deputy Accountant General.

Sir C.V. Raman

An outstanding student, Raman was not even twenty years old, and had arrived from Madras (now Chennai) after completing his M. Sc in Physics and successfully appearing in the Indian Finance Service Examination. That way he was still fresh from his physics classroom and a board displaying the name of IACS on Bowbazar Street drew his attention while he was on his way to his office. That made Raman a curious visitor to the Association. Dr Mahendra Lal Sirkar had by that time passed away and his son Amrita Lal Sirkar was at the helm of affairs as the Secretary of the Association.

And the rest is history. Raman started working at IACS using whatever the facilities it had. He worked before and after his office hours. And this continued for nearly ten years before he joined the Physics department of Calcutta University as its Palit Professor with a salary that was half of his government salary. Raman, Noble Prize and IACS

Jadavpur Campus of IACS

became the part of the folklore. It was amazing that ninety-six years ago, the first Nobel in science could be won by a physicist working outside Europe or the Americas. After the independence the Association was given a formal shape as a research institute under the tutelage of the government of India and the State government. Its location shifted from central part of the city to the southern part at Jadavpur and Prof M.N. Saha became its first Director. For the Association a second campus known as SMART (Syamaprasad Mukherjee Advanced Research and Training) campus is coming up at Baruipur at the southern fringe of the city.

Many outstanding scientists of our country mainly from the broad fields of physics, chemistry and biology have worked here forming a rich academic faculty here. A good number of frontline scientists were and are still the part of IACS faculties. The list is too long to mention here. Moreover, a significant number of reputed scientists, working in India and abroad had their trainings as Ph.D. students in their formative years in the different laboratories and departments of IACS. And the alumni of IACS at different points of time have contributed and are still contributing to the scientific growth of India.

Article

Simulation of Proton Therapy for Cancer Treatment Using Geant4

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Abstract: Proton beam therapy is an advanced type of external beam radiotherapy that provides more accurate cancer and tumor treatment results than traditional treatment methods. Proton therapy uses the Bragg peak effect as its unique physical property results in delivering maximum radiation dose directly within tumor at a depth while giving significantly lower doses to the surrounding tissues. Also, the proton beam stop precisely inside the tumor, resulting in virtually no exit dose to surrounding healthy tissues. Geant4 functions as an advanced toolkit that can accurately replicate proton beam interactions and study its effects. In the present work, Geant4 simulations were performed to study and analyze Bragg peak, proton ranges and dose distribution.

1. Introduction

Proton therapy is an advanced form of radiation treatment method used for cancer. Proton therapy uses protons which deliver most of their energy at a specific depth within the tumor site. The conventional x-ray radiation therapy deposits radiation energy along its entire path throughout both cancerous and normal tissues. This characteristic enables more precise cancer tissue identification while simultaneously protecting surrounding healthy tissues from radiation exposure thereby reducing treatment related side effects [1-2].

The therapeutic proton beam production requires accelerators such as cyclotrons or linear accelerator (LINAC), which accelerate protons to high energies required for treatment [3]. The process produces high-energy particles which travel through the body and deposit their maximum energy at a well-defined region at a depth known as the Bragg peak. Beyond this point, the dose decreases sharply to nearly zero level. Oncologists use this characteristic to adjust the radiation dosage according to the tumor's specific dimensions, configuration and location. As a result, the radiation dose is confined to the tumor while limiting the radiation spread beyond the tumor boundaries which minimizes radiation exposure of nearby healthy tissues and critical organs. Patients end up having less side effects as tired nausea, and the damage to normal tissue, sort of. Proton therapy reduces the odds that patients will develop long term complications, for example growth abnormalities, secondary cancers, developmental disorders and more. Proton therapy has become a standard therapy. It is a method for various cancers, primarily because it possesses fantastic therapeutic benefits. It is particularly as per patients who have central nervous system, it is beneficial. tumors, head and neck cancer, lung cancer, liver cancer of soft tissue, cancer of prostate, cancer of the skin, cancer in children, bone sarcoma, left breast cancer, esophageal tumors in the gastrointestinal tract and cancer.

The proton therapy systems can do an extremely accurate dose delivery. The proton beams are shaped, and then it's delivered by advanced beam delivery techniques, such as pencil beam scanning i.e., basically producing a narrow beamlet (a pencil beam) and then directing it towards the tumor volume. That is, doctors can precisely control the location of the radiation in space, making it possible to treat small and irregularly shaped tumors without exposing the surrounding healthy tissues and sensitive organs. They are known to be effective in practice, such as in the CATANA (Centro di AdroTerapia e Applicazioni Nucleari Avanzate) facility in Italy where they are employed for the treatment of ocular tumors using a specially prepared low-energy proton beam of 62 MeV [4].

There they use very focused proton microbeams in the treatment of uveal melanoma, with the target being to bring the dose extremely accurately to the eye, while maintaining the function of other critically important structures, such as the optic nerve and retina. The overall clinical applications are that low-energy proton beam setups with well-defined accuracy for targeting may contribute to the effective control of tumors, while the reduction of the complications of a treatment is observed in sites that are difficult to treat.

However, proton therapy is still reliant on the precise calculation of the proton range the distance travelled by the protons in body tissue before they come to a halt. This range is significant because it has a strong influence on the target area that receives the radiation and the sparing of healthy tissue. The actual range of protons in biological media is not just one thing though, it depends on multiple factors. The stopping point moves closer along with the tissue is dependent on one major factor: the initial energy of the protons. Additionally, the proton density and composition of the tissue surroundings confuses the situation by adding further penetration depths variations among tissues, including bone and muscle. In reality it is not a single and simple effect, it is more of a property of the material that conducts the whole energy drain and hence the range varies from tissue to tissue.

Using the Geant4 [5] toolkit for proton therapy simulations, the present study allows researchers to produce accurate simulations of proton interactions with matter and calculation of the resulting absorbed dose distributions in biological tissues. The absorbed dose of ionizing radiation is sort of measured in the International System of Units (SI) by using the gray (Gy). In practice this unit is the same as the amount of radiation energy deposited into 1 kg of material (1 Gy = 1 J/kg). The gray is used as a fundamental parameter in radiation dosimetry for assessing dose layouts in radiation therapy considering a rather direct relation to the energy transferred from radiation to matter. This paper is divided into three parts. The methodology is discussed in Section 2, the results are presented and analysed in Section 3 and the final part is the summary of the main results.

2. Methodology

GEANT4 (Geometry and Tracking) [5] is an open-source and powerful Monte Carlo simulation toolkit jointly developed by CERN and KEK for modeling the interactions of particles with matter. It is very flexible and has a high level of accuracy, and is used widely in medical physics, high energy physics, space science, Radiotherapy, nuclear medicine and radiation. protection. The GEANT4 simulation package can be used to perform a detailed simulation of: particle transport, electromagnetic and hadronic interactions, and can model complex geometries including patient anatomy, detector, shielding materials. It provides accurate calculations of radiation dose to humans and has ability to analyse proton energy loss including the production of Bragg peak. The Bragg curve represents the variation in stopping power or linear stopping power i.e., energy transfer (LET) as a function of the penetration depth in a medium. The basic Bethe–Bloch equation describing the energy loss of charged particles is given by:

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}ln\frac{2m_ec^2\beta^2\gamma^2T_{max}}{I^2} - \beta^2 - \frac{\delta}{2}\right] \quad 1)$$

where $K = 4\pi N_A r_e^2 m_e c^2$, N_A is the Avogadro number, r_e is the classical electron radius, m_e is the electron mass, c is the speed of the light, z is the charge of the incident particle, Z is the atomic number of the absorber, A is the atomic mass of the absorber, $\beta = v/c$ of the incident particle, $\gamma = 1/\sqrt{(1-\beta^2)}$ is the Lorentz factor, T_{max} represents the maximum energy transfer in a single collision, I is the mean excitation energy, and δ stands for the density correction factor. Equation(1) shows that the energy loss of a charged particle is roughly inversely related to the square of its velocity, or maybe, you can say it depends in that way. So, as a result the particle ends up having a much greater rate of energy loss when its speed, goes down. That is, when the velocity decreases, the loss ramps up quite quickly. At the very end of its range, a particle starts dumping the largest share of its energy inside a tiny, almost cramped, region, and that's how the Bragg peak just kind of shows up. When a charged particle, for example a proton, moves through some medium it keeps losing energy step by step mostly because of interactions with atomic electrons. The random variations in how much energy is lost, along with the actual penetration depth, are called range straggling. After the Bragg peak the delivered dose drops fairly fast, down to almost zero, so it doesn't keep going the way X-rays do, since X-rays still deposit energy past the targeted zone. That's how proton therapy can deliver an extremely targeted dose of radiation to the tumor and at the same time minimize the radiation received by the healthy tissue around the tumor.

The proton stopping powers are obtained from a combination of theoretical model material and evaluated data libraries which are embedded into the electromagnetic physics component of Geant4 [6]. In addition, Geant4 heavily relies on data available from the National Institute of Standards and Technology (NIST) in particular from the PSTAR database, as well as on the recommendations from the Radiation Units and Measurements (ICRU) reports. It is these references that can provide fairly accurate stopping power numbers for protons in various media such as water and so on and also are useful in comparing / checking the performance of the models to be used later in the simulations.

The stopping power calculations in GEANT4 are fundamentally based on the Bethe-Bloch formalism. Since the original formulation was developed for elemental materials, its application to compounds such as water requires additional considerations. Water is commonly used as a phantom material for proton energy deposition studies because its composition closely matches that of human soft tissue. The Bragg additivity rule is applied, where the stopping power of a compound is estimated as the weighted sum of the stopping powers of its constituent elements according to their fractional composition. To further improve accuracy, compound-specific parameters, such as the mean excitation energy, along with density effect and low-energy shell corrections, are included. Through this approach, GEANT4 accurately adapts the Bethe-Bloch formalism to realistic biological media, enabling precise simulation of proton energy loss and dose deposition in water and tissue-equivalent materials.

Geant4 utilizes this approach to implement the Bethe–Bloch formalism and perform accurate simulations of proton energy loss in biological materials. The study reported in Ref. [7] presents a detailed analysis of Bragg peak characteristics for proton beams over the therapeutic energy range, emphasizing the importance of using multiple parameters to accurately characterize depth-dose distributions. The authors evaluate conventional range indicators, such as R_{90} and R_{80}, which represent the depths in a medium (typically water) where the absorbed dose decreases to 90% and 80% of the maximum dose on the distal (falling) side of the Bragg peak, respectively. In addition to these parameters, the study investigates the full width at half maximum (FWHM), distal fall-off width, and peak-to-entrance dose ratio, which is defined as the ratio of the maximum dose at the Bragg peak to the dose in the entrance region. The results show that increasing proton energy leads to greater penetration depth, a broader Bragg peak, and a less steep distal dose fall-off. Therefore, the development of accurate proton therapy treatment plans requires a balance between achieving the required penetration depth and maintaining a sharp and localized dose distribution. The authors conclude that the R_{73} parameter provides a more robust and reliable definition of proton beam range compared with FWHM, which is highly sensitive to variations in the initial energy spread of the proton beam. The authors further demonstrate the reliability of Monte Carlo simulation techniques by comparing stopping power values obtained using the GATE simulation framework with reference data provided by NIST. The comparison shows agreement within about 1%, and that kind of confirms the accuracy of the physical models used in the simula tions. These findings suggest that Monte Carlo methods can correctly figure out dose distributions, and also help describe proton beam properties ,which are both really needed for effective proton therapy treatment planning. The study also points to why the validated simulation techniques matter a lot, for doing precise Bragg peak analysis and for getting better clinical outcomes.

Researchers also make use of the SRIM (Stopping and Range of Ions in Matter) simulation software along with its TRIM (Transport of Ions in Matter) module to look at how ions slow down, how far they go, and what kind of energy loss patterns show up in different materials [8, 9]. These tools lean on semi-empirical models, built from a large body of experimental data, so they can deliver quick estimates for how ions interact, inside both elemental and compound substances. With SRIM/TRIM it becomes possible to examine ion depth penetration , ion trajectories, and the energy deposition profile, in a pretty direct way.

Even though SRIM/TRIM can do some assessment for

Bragg curve checks, and stopping power calculations too, by giving depth based energy loss data in stuff like water, it still has a bunch of limitations compared to more complete Monte Carlo frameworks, like Geant4. More precisely SRIM/TRIM just does not model the fine grained stuff very well, like complicated shapes in a geometry, or the generation of secondary particles and also the more advanced particle transport behaviors. Therefore, while SRIM/TRIM is valuable for preliminary investigations and validation of stopping power data, it is not suitable for high-precision dosimetric studies and advanced proton therapy simulations that require detailed physical modeling.

The Geant4 simulation methodology employed in the present study involves defining a geometrical setup containing a water phantom. Water is commonly used as a standard reference medium in dosimetric studies because its radiological properties, including electron density and effective atomic composition, closely match those of soft biological tissues. Therefore, dose measurements obtained using a water phantom provide a reliable approximation of dose distributions in muscles and other soft tissues. However, this equivalence is not exact for all biological materials. Tissues with significantly different compositions, particularly bone, possess higher density and effective atomic number, resulting in different stopping power and energy absorption characteristics. Consequently, while water provides a reliable estimate for most soft tissues, correction factors or advanced computational modeling techniques are required to accurately estimate dose distributions in heterogeneous regions containing bone or air cavities.

For the Geant4 simulations, 10,000 protons were shot into a water phantom which has a density of 1 g/cm^3. The initial proton beam parameters were defined with energies of 50, 70, 90, 110, 130, 150, 170, 190, 210, 230, and 250 MeV, an initial position of (0, 0, 0) cm, and a propagation direction along the +z-axis. The physics list in Geant4 is a collection of all particles and their associated physical processes that are included in the simulation application. For the present analysis, the selected physics models were PhysListEmStandard and G4HadronElasticPhysics, which account for proton interactions such as excitation, ionization, and proton-nucleus elastic scattering. PhysListEmStandard is a modular helper class registers essential EM processes like ionization, Bremsstrahlung, and multiple scattering using the default Geant4 EM models. G4HadronElasticPhysics builds elastic scattering models and cross-sections for hadrons. As the incident protons travel through the water phantom, they undergo these interactions, leading to gradual energy loss and the deposition of radiation dose along their path.

3. Results

Fig.1 shows the Geant4 simulation of proton trajectories in a water phantom for proton energies of 50, 70, 90, 110, 130, 150, 170, 190, 210, 230, and 250 MeV. The simulation results show that protons gradually lose their energy while travelling through the medium and deposit the maximum energy near the end of their trajectories, forming a Bragg peak as described by Eq. (1). It is observed that as the proton energy increases, the Bragg peak occurs at a greater depth due to the increased penetration range of the proton beam. The lower-energy protons deposit their energy over shorter distances and form Bragg peaks at shallower depths within the water phantom.

Fig.2 presents the natural logarithm of the stopping power (dE/dx) as a function of depth in the water phantom, showing the proton range and range straggling. The calculated ranges, straggling and R_{73} parameter for different proton energies are listed in Table 1. The results show that the proton range, straggling and R_{73} in water increases with increasing initial proton energy. These variations in range have significant implications for the treatment of the cancer or tumor. Shallow tumors, such as skin cancers, can be effectively treated using low-energy proton beams, whereas deep-seated tumors, such as brain, lung, and prostate cancers, require high-energy proton beams to reach the target volume.

Thus, accurate determination of proton range is an essential parameter for proper treatment planning and dose delivery. An overestimated proton range may cause the Bragg peak to extend beyond the tumor, potentially leaving parts of the tumor under-dosed, while an underestimated range may result in excessive radiation exposure to healthy tissues located before the tumor. Hence, the range data presented in Table 1 can assist in selecting appropriate proton beam energies according to the depth and location of the tumor.

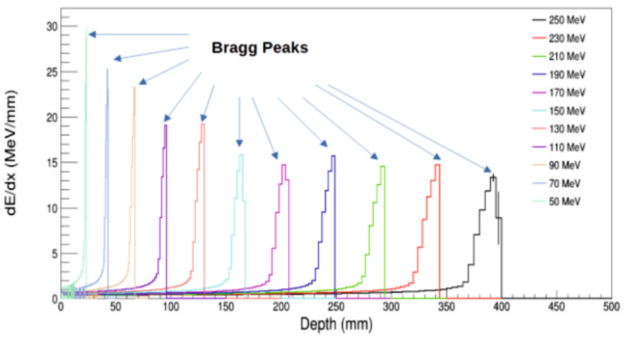

Fig 1. Bragg peaks of proton beams with energies of 50, 70, 90, 110, 130, 150, 170, 190, 210, 230, and 250 MeV in a water phantom obtained using Geant4 simulations.

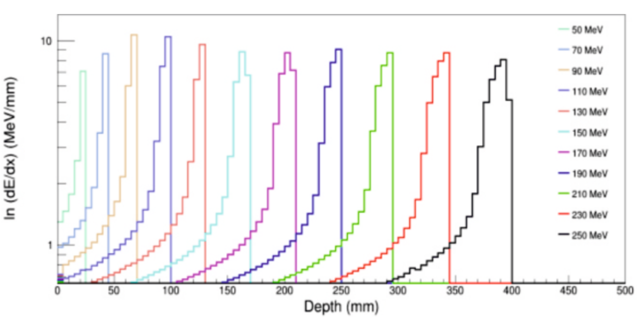

Fig 2. Natural logarithm of the stopping power, (dE/dx) (MeV/mm), of proton beams with energies of 50, 70, 90, 110, 130, 150, 170, 190, 210, 230, and 250 MeV in a water phantom obtained using Geant4 simulations.

Another important parameter, the full width at half maximum (FWHM) of the Bragg peak, was evaluated for all proton energies, as shown in Table 1. The results indicate that the FWHM gradually increases with increasing proton energy due to enhanced range straggling and the broader distribution of energy deposition near the end of the proton path. The range straggling values for different proton energies are also presented in Table1, which also show an increasing trend with increasing proton energy.

Table1. Range, straggling and R_{73} of the Bragg peaks, for proton beam with energies from 50 to 250 MeV in a water phantom obtained using Geant4 simulations.

Energy (MeV)	Range (cm)	Straggling (cm)	R_{73} (cm)
50	2.3	0.5	2.4
70	4.3	1.2	4.4
90	6.7	1.9	6.9
110	9.5	2.6	9.9
130	13.0	4.9	13.0
150	16.6	5.0	16.5
170	20.7	5.3	20.9
190	24.9	5.5	24.9
210	29.4	5.8	29.5
230	34.4	6.2	34.4
250	39.9	6.7	39.5

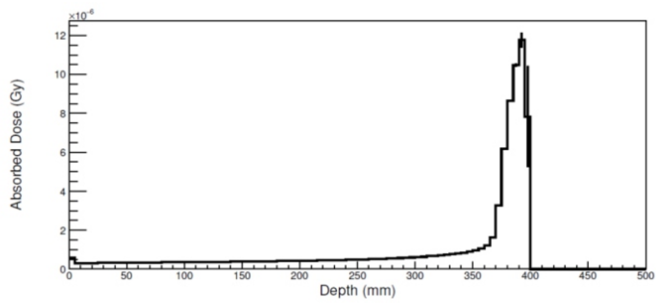

Fig. 3 shows the absorbed dose of 11.7 μGy obtained in the water phantom using a proton beam energy of 250 MeV through Geant4 simulations. The variation of total absorbed dose as a function of proton beam energy in the water phantom is shown in Fig. 4.

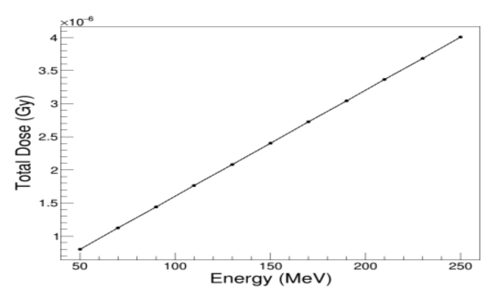

Fig 4. Variation of the total absorbed dose as a function of proton beam energy in the water phantom obtained using Geant4 simulations.

The observed linear relationship between the total absorbed dose and proton energy suggests that, within the investigated energy range, the energy deposited in the medium increases proportionally with the initial energy of the incident protons. This is a sort of recognizable pattern of deposition of energy, with higher energy protons giving up more energy to the medium because they penetrate deeper, and then encounter more interactions within the medium. Also, it's predictable, you know, the same logic is always applied and the energy transferred is always greater with a greater penetration. Results from these are used to draw conclusions in the next section.

4. Conclusions

This is a state-of-the-art radiation treatment that uses proton beams as opposed to traditional X-rays to effectively kill cancer cells, providing a more targeted area of dose delivery and reducing the radiation dose to surrounding healthy tissues particularly beneficial in children who have tumors near sensitive organs as well as near other critical organs. But proton beams can be used to treat the patient with a millimeter level accuracy, which can reduce the chance of complications in sensitive areas such as the brain, eyes, and spinal cord. On top of that it can lower the chances of secondary cancers that might come from extra, unnecessary radiation exposure.

In general, this is an effective treatment modality for numerous types of cancer including those of the brain and spinal cord, head and neck, lung, prostate, pediatric, gastrointestinal, sarcomas and ocular tumors, including uveal melanoma.

Optimization of proton therapy, really requires having a pretty solid understanding of how protons interact with biological tissue, and that's not just sort of vague. The Geant4 toolkit, a robust and widely-used Monte Carlo simulation platform, provides the necessary tools to simulate proton motion, proton energy deposition, Bragg peak characteristics, and proton dose patterns, as utilized in clinical treatment planning. The simulations were also compared to experimental measurements and trusted reference dosimetric results, and appeared highly credible for application in the clinic, thus it is not only theoretical.

From the Geant4 runs it also shows, that proton beams form Bragg peaks at different depths based on the starting energy. In the study, for example, the proton beam at the 50 MeV had a penetration (or the "range" value) that was approximately 2.3 cm into a water phantom. Those range traits are important in selecting the energy of the beam to be used for the tumor position and depth. Tumors in the deep tissues require more powerful proton beams because energy is required to penetrate their depth. Meanwhile, tumors that are more on the surface can be managed effectively with lower-energy beams.

The simulations further indicated an absorbed dose around 11.7 μGy in the water phantom when using a 250 MeV proton beam. Also, the total absorbed dose was seen to rise in an almost straight, linear fashion as proton energy increased, across the energy interval they examined.

The future of proton therapy is in the direction of compact and relatively low cost proton therapy systems, which might make it easier for more people around the world to access this advanced kind of care. More research is still needed, not only to improve outcomes but also to broaden where it can be used, like in breast cancer cases, metastatic diseases, and other difficult tumour sites. If more proton therapy centers get established worldwide, that could lower the overall expenses, and also, make proton therapy more widely available to patients who need it.

Acknowledgement

The author acknowledges the support from the Department of Physics, Chandigarh University.

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Article

Introducing the concept of an experiment module around a Laboratory Exercise

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Abstract : The importance of hands-on and experiential learning in the mode of conducting demonstration experiments / projects in classrooms can enhance students' understanding and retention of theoretical concepts. We propose a method of selecting representative experiments that encompass a wide range of concepts and can lead to the preparation of an experiment cluster which contains many related but open-ended experiments. This idea is aimed at creating a standardized approach to teaching these experiments, making them more structured and beneficial for students. The presentation of a standard experiment cluster in Q/A mode seems to be a useful approach to convey the information and benefits of these experiments to others.

Introduction

Dr D P Khandelwal [1] suggested umpteen times that we must repeat an experiment by varying as many parameters as possible to build confidence in all possible conceptual contents linked with a lab exercise. Lab-based education, often referred to as hands-on or experiential learning, holds significant utility and benefits across various educational contexts. This approach emphasizes active engagement and practical application, allowing students to learn by doing rather than through theoretical instruction. Based on the educational goals, objectives, standards, and content outlined in the National Curriculum Framework for School Education 2023 [2], demonstration experiments, in the context of education, refer to practical activities or hands-on experiments conducted by teachers or students in classrooms to demonstrate and reinforce concepts taught in theoretical lessons. These experiments make learning more interactive, engaging, and memorable, allowing students to understand and apply theoretical concepts in real-world scenarios. Teachers should promote active participation, discussion, and inquiry-based learning among students.

One can perform a syllabus-based experiment following more than one procedure, which can be looked at from different angles. It is possible to come across a large number of experiments as the by-products during the exercise of a single experiment. In this connection, we propose selecting some important representative experiments, each of which must encompass a wide range of concepts and many by-product experiments. A standard module must be framed for each of the representative experiments. Below is an attempt to build up a sample. An experiment cluster is here to prepare around a standard lab exercise like 'to determine the figure of merit and resistance of a table galvanometer'. This exercise is included in the Physics Laboratory Manual for Class XII, published by NCERT [3]. An alternative way to do the said experiments is proposed, and the precise determination of the resistivity of a low resistance with its temperature-dependent study becomes possible, which is communicated in an international journal. It may be mentioned that many such experiments have been performed as project experiments in IAPT-Midnapore College for Centre for Scientific Culture (CSC) and shown in different Workshops organized by IIT, Kharagpur, for senior secondary students, in which CSC was a collaborator. A standard experiment cluster is presented here in Q/A mode, of which almost all the experiments have already been performed at the CSC.

Modular Framework of Experiments

Question/Task1: Let us consider the experiment for measuring the resistance of a table galvanometer and its Figure of Merit (FoM). The alternate procedure is other than what is given in the texts.

Expt.1. The galvanometer, a mobile phone charger as the power source (PS), 33 kΩ pot, and a 100 Ω resistor are taken for the experiment and connected in series. Dividing the voltage across a 100 Ω, measured by a digital multimeter, resistor by100 Ω the current, I through the circuit is determined. By varying the 22 kΩ, pot current I is varied and for each the voltage across100 Ω resistor and the galvanometer are measured using a multimeter. A graph between the voltage across the galvanometer and the current through it, helps to find the resistance (G) of the galvanometer; the linear nature of the graph justifies Ohm's law also. Again, if for each current I, each galvanometer deflection d is also noted and I- d graph is drawn then from the slope of the rectilinear graph it is possible to determine the figure of merit, FoM which is equal to the current needed to produce deflection equivalent to one division of the galvanometer.

Question/Task 2: Some curious students may ask about the order of resistance of the connecting wires.

Expt.2: In that case, a connecting wire of resistance (S) has to be connected across the galvanometer and a milliammeter in series with the charger to measure the net current I drawn from the PS. The galvanometer current (I_g) is derived from the relation, I_g = (fig of merit) x the corresponding galvanometer deflection, and the remaining part (I_s) of the current I flowing through S is calculated following the relation, $I_s = I - I_g$. From these parameters, the resistance S of the connecting wire is measured and found to be of the order of milliohm. This is negligible compared to the resistance of other elements.

Along with of the study, we can explore the temperature dependence of resistivity of copper wires. To this aim we can immerse the same copper wire specimen in the form of a coil (of larger length in comparison with the wire used before) in a conventional heat bath to raise its temperature. The two ends of the coil should be connected across the galvanometer so that it will act as a shunt, as before, but with a larger resistance. Following the same method of earlier S measurement, we can determine the variation of its resistance with temperature by measuring the source current and the galvanometer current by noting the deflection of the galvanometer. The conductivity variation of copper in the moderate temperature range will be then found to be linear, as expected in conformity with the reported literature.

When the galvanometer is shunted by the connecting wire, the galvanometer deflection measures the current in milliampere. $I = I_g\ (G+S)/S = \{(\mathrm{FoM})(d)\}\ (G+S)/S$.

So, the new fig of merit (I/d) ~ (FoM) (G/S). The FoM of the galvanometer can be enhanced many times with larger (G/S) ratio using smaller and smaller shunt resistance S.

Question/Task3: The natural question comes, how far is the measurement correct?

Expt.3: In that case, measuring the values of the length and the cross-sectional area of the wire and using the value of its resistance (S), the resistivity, and hence conductivity of the material of the wire, is determined. If its value conforms to the value given in the literature, the measurement is considered correct. So, we have a recipe of measuring resistance as low as milliohm!

Question/Task4: Can the galvanometer be used as a microammeter?

Expt.4: Actually, the galvanometer with FoM of about 15 μA per division *can be used as a microammeter* that can measure a maximum current, 15 x 30 (maximum deflection = 30) = 450 μA. So, it can be used in many experiments, particularly in electronics, where a microammeter is needed. Specifically, *it may be used as a light intensity detector* when used appropriately in conjunction with an LDR (Light

Dependent Resistor), both to be connected in series with a 1.5 V Dry cell.

Varying the distance between the light source and the LDR, the corresponding deflections are noted. These data can be used to *verify the inverse square law in photometry.*

Question/Task5: Is there any scope to measure current in the ampere / mA range?

Expt.5: Choosing an appropriate value of the length of a metal wire as a shunt, one can convert the galvanometer into an milliammeter or ammeter. Even using a thick and shorter connecting wire as a shunt, the galvanometer could be converted into an ammeter of the much higher range of ampere.

As for an example, if the galvanometer with FoM 15 μA per division and resistance, G = 100 Ω is to be used as a milliammeter of range of 0 -15 mA, its new FoM is 1mA per division. So, its figure of merit has to be increased by 1000 times. Hence the shunt resistance needed is S = G/1000 = 0.1Ω. To convert the galvanometer into an ammeter one needs much smaller shunt resistance to be connected across the galvanometer. One has to calculate and cut appropriate lengths of copper wires considering its gauge and resistivity for such conversions.

Question/Task 6: Is there any possibility that the galvanometer may be used as a microvoltmeter?

Expt 6. The galvanometer is a microvolt meter in the range of (0 – 450) x *G* microvolt. One can use it again in an electronic experiment where the potential difference is of the order of μV.

Question/Task7: Can it ever be used as a DC voltmeter?

Expt.7. Let us connect a 33 k pot, 5V power supply (a mobile charger), and the galvanometer in series. The pot is adjusted to obtain the full galvanometer deflection (nearly 30 divisions). So, the galvanometer is now a DC voltmeter in 0-5 V range; one volt corresponding to 6 divisions.

Question/Task 8: Then how to find the resistance of this newly devised DC voltmeter?

Expt.8. The DC voltmeter (the combination of the galvanometer and the pot in its place) is connected in series with two 10 k resistors and the 5V power supply. Using the voltages across the PS and one of the 10 k resistors, it is possible to measure the voltmeter resistance. As the voltmeter and 10 k are in parallel, the equivalent resistance will be less than 10 k. So, the voltages (one across 10k resistor and another across 10k resistor in combination with the voltmeter) will be different as a natural consequence. Then comparing these two voltages, the resistance of this newly devised DC voltmeter is obtained.

Question/Task9: Can the range of the newly devised DC voltmeter be increased?

Expt.9. In Expt.7, the pot's resistance is increased further so that the deflection becomes half of the full scale i.e 15 divisions. In that case, the galvanometer could be used as a voltmeter of range 0-10V. This way, the galvanometer can be converted into voltmeters of higher ranges using electronic pots of higher resistance.

Question/Task10: How do we measure by the resistance of this DC voltmeter in the increased scale (Expt. 9)?

Expt.10.: In that case, a 1000 μF electrolytic capacitor is charged by connecting it across the mobile phone charger. The capacitor will be immediately charged fully. Then the capacitor is discharged through the original galvanometer converted into a voltmeter. Voltmeter readings (the galvanometer deflection *d*) would change with time *t*. The slope of the linear graph between the ln(*d*) vs *t* graph would yield the resistance of the voltmeter.

Question/Task11: Is there any provision to measure the leakage current in the circuit of Expt. 10?

Expt.11. The leakage current from the capacitor is insignificant during the discharge of a charged capacitor through a high resistor. But during charging it is easily measurable. To study leakage current, the PS, the galvanometer and a 10/20k resistor are connected in series. (It is better to take a capacitor of 3300 μF, so that time constant is large in that case).

Initially galvanometer deflection would be large but with time it would decrease exponentially. After a long considerable time the graph would be parallel to the time axis showing the presence of the leakage current. The galvanometer deflection gives the measure of the leakage current.

Question/Task12: Can the above process(es) be employed to verify the laws of series and parallel combinations of capacitors?

Expt.12: Certainly, from the study of the charging and discharging of the capacitor as in Expts 10 and 11, time constant of the circuit and hence the capacitance of this capacitor could be determined. Again, repeating these experiments with the combinations of capacitors their equivalents could also be determined leading to the validity of the respective laws.

Question/Task13: When students read the context of semiconductors, they encounter the variation of *V-I* characteristics from ideal *ohmic behaviour*. How do they experience experimentally?

Expt.13. In the Expt.1, a Negative Temperature Coefficient (NTC) thermistor is used as a specimen instead of the 100 carbon resistor. Using a DC power supply (mobile charger), the voltage in mV across it and the current through it are obtained by measuring the galvanometer deflection. As the current is in microampere range, one can verify that its *V-I* characteristic supports Ohm's law. They can use the converted milliammeter (from the galvanometer) and repeat the study. In this case Joule heating would be appreciable and the resistance of the NTC would change. The experiment will show: The *V-I* characteristic of the NTC is *not linear* and its material behaviour is *nonohmic*.

Question/Task14: When students read the temperature coefficient of resistance for semiconductors, they encounter the idea of the Negative Temperature Coefficient (NTC) of resistance. Could temperature-dependent resistance be studied for the NTC thermistor?

Expt.14: In the Expt. 13, the NTC thermistor is inserted along with a thermometer in a test tube filled with sand, and it is initially kept in boiling water, which is allowed to cool with time. The resistance of the thermistor (R) is determined at different temperatures (T) in Kelvin scale and a straight line graph of the ln$R$ vs 1/T variation.

Question/Task15: Will the ln$R$ vs 1/T straight line graph be used to measure an unknown temperature?

Expt.15: Certainly, the thermistor with this ln$R$ vs 1/T calibration graph of the straight nature must act as a thermometer. When the NTC thermistor is immersed in a heat bath of unknown temperature, the ln$R$ value is put on the graph, and the corresponding temperature is known.

Question / Task16: Is there any scope to measure the band gap of a semiconducting material?

Expt.16: From the slope of the ln$R$ vs 1/T straight line graph, one can estimate, from its slope the bandgap of the semiconducting material with which the thermistor is made of. By replacing the thermistor with a p-n junction rectifying diode, one can also find the bandgap energy for the diode materials. Even the diode characteristics at elevated temperatures may help to design a thermometer

Question/Task17: Can we verify Newton's law of cooling?

Expt.17. If, in the Expt. 14, temperature (T) is recorded at different times (t) along with the room temperature (T_0), the ln(T- T_0) vs t curve should be a straight line which confirms Newton's law of cooling.

Question/Task18: Is there any way to measure the specific heat of a liquid from this temperature-dependent study?

Expt.18. If the Expt. 17 is repeated by keeping the test tube in a hot oil (mustard) bath and the corresponding cooling curve is drawn, it is possible to find the specific heat of mustard oil by comparing the slope of the straight line with that obtained from the Expt. 17. Even that can be done for solids too.

Question/Task19: We can try some experiments with an AC source. Can we design an AC voltmeter?

Expt.19: For this purpose, we design a variable AC source with the help of a potentiometer divider circuit and a step-down transformer. This variable ac source is connected to a bridge / half wave / full wave rectifier, and the variable DC output voltage is measured. The AC input versus DC output graph can act as a calibration curve. From this curve, one can find the ac input when the DC output is measured with the voltmeter (converting the galvanometer into a voltmeter).

So, a combination of the rectifier circuit and the DC voltmeter prepared out of the galvanometer may be used as an AC voltmeter.

Question/Task20: We can use the AC voltmeter in Expt. 19 and a step-down transformer together to verify the laws of series and parallel combinations of capacitors.

Expt.20: The potential divider circuit with a step-down transformer as mentioned in the Expt. 19 can be used to study an ac RC circuit using a carbon resistor and a ceiling fan condenser. The results help to find the capacitance of the condenser. The experiment can be repeated with two condensers and their combinations leading to the verification of the respective laws.

A General Precaution

In this short communication, details of the designing aspects of all the twenty experiments have not been discussed. But for implementation using the circuits, one has to keep that very much in mind. As for an example, the electronic pots/and carbon resistors, ordinarily available in the market/lab have wattage of 250 mW, these would burn if they are used to control currents in higher mA range or Ampere range. In that case, devices with higher wattage are to be used, after some calculation.

Conclusion

To conclude, this open-ended approach for experiments plays a crucial role in instigating the potentials of critical and creative thinking, finally providing a holistic and well-rounded learning experience. By combining theoretical knowledge with practical application, students gain a deeper understanding of the subject matter, acquire valuable skills, and develop the mindset needed to succeed in their future endeavours.

References:

[1] D.P. Khandelwal, 'Physics Education in India-Challenges and Opportunities', January Issue p. 4 (2021) (reprinted from the original, published in IAPT Bull, January 1989)

[2] https://www.ncert.nic.in/pdf/NCFSE-2023-August_2023.pdf

[3] https://ncert.nic.in/pdf/publication/sciencelabora orymanuals/classXII/physics/lelm306.pdf

Article

Wien's Resonators And Planck's Photons

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Abstract: The complex assumptions Wien introduced in the thought experiment using a cavity led Planck to reconsider them to introduce discontinuous emission and absorption of energy. More importantly, it is discussed what was Planck treating in the cavity in his 'desperate' formulation.

1. Introduction

The radiation emitted by a body is characteristic of its temperature. Radiation energy is spread over different wavelengths. The investigation into distribution of energy in different wavelengths led to important insights in physics. A body at a temperature in an environment both emits and absorbs radiation. Fery thought of a cavity [1] with smooth surface in a body at some temperature. The cavity is filled by thermal radiation emitted by the inner surface of the cavity. The surface also absorbs part of the emitted energy, and the process eventually establishes an equilibrium in the cavity. The distribution of energy in different wavelengths was thought to be analogous to the distribution of kinetic energy among the molecules of a gas confined in a container. The problem in case of a gas was first studied by Maxwell theoretically revealing that most of the molecules possess energy near the average value. The number of molecules with energy much larger than the average as well as the number with energy much less the average are considerably smaller. The theory developed by Maxwell-Boltzmann was highly successful in different ways to study a gas [2].

A serious problem, however, developed when attempts were made to extend the Maxwellian distribution for gas molecules to radiation confined in a cavity. There was no binding on number of radiation waves with lengths smaller and smaller within the cavity. This had disastrous consequences. Most of the radiation energy in the cavity would be carried by the smaller and smaller waves. Most of the radiation energy would lie in the harmful ultraviolet region. The consequence was known as ultraviolet catastrophe. What was true for cavity radiation would be true in general also. Possibly no life could have developed in an environment filled with harmful ultraviolet radiation.

2. Making cavity radiation black

A small opening in the cavity was assumed to make the cavity radiation black. The opening in the cavity would allow external radiation of all lengths to enter the cavity. The polished surface of the cavity would repeatedly reflect the incident radiation within the cavity itself without allowing it to leave the cavity. Furthermore, a cone in the cavity just opposite the small opening, would further deter the falling radiation from leaving the cavity and to make the cavity radiation black. A small part of the black body radiation inside the cavity was needed to investigate the distribution of radiation energy in different wavelengths. The results now compared well with Maxwellian distribution for the gas molecules in an enclosure. The experimental result [3] showing no ambiguity, had to be explained. Rayleigh-Jeans' formula could explain the result, with some success, in the longer wavelength region [4] from the thermodynamical point of view. Wien adopted a completely unconventional approach to explain the finding, between energy density and wavelengths.

3. Hypothetical Resonators

Wien could not work out how the smooth surface of the cavity could radiate and absorb energy, and thereby establish an equilibrium in the cavity. Wien thought of some resonators to exist in lieu of the surface particles to vibrate, radiate and also absorb energy [5]. Wien, equally importantly, assumed that the resonators could emit and absorb energy of any wavelength. However, Wien's thoughts failed to provide an agreement with the experimental finding of energy distribution in different wavelengths. Rayleigh-Jeans' explanation for distribution of energy in the longer wavelengths failed to explain distribution in the shorter range of wavelengths. Precisely to remove this drawback, Wien introduced the hypothetical resonators.

4. Planck's radicalism

Max Planck was also deeply drawn into the problem of distribution of energy in black body radiation. Wien's failure to account for the pattern of distribution in the shorter range prompted Planck to carefully scrutinise the assumptions introduced by Wien. Planck retained the resonators, retained the assumption that resonators could emit and absorb, but differed, in the most significant way, with the assumption that resonators could emit and absorb energy of any wavelength. Planck disbelieved this idea and suggested that a resonator could emit and absorb only discontinuously, or discreetly. Planck's idea was a radical departure from the existing conception regarding emission and absorption of radiation.

The cavity radiation was now consisted of two parts. One part was contributed by the hypothetical resonators, with emission and absorption taking place in discreteness. The small opening allowed radiation from outside to make the cavity radiation black. This part was also thought to be continuous. This was natural as the idea of Planck's quantum of energy was proposed in 1900 only. Following Planck's idea the part entering the cavity through the opening consisted of solar photons available in the atmosphere. It may be safely assumed that Planck too didn't think of the solar photons partly filling the cavity. Planck assumed the resonators to emit and absorb discretely. Therefore, the cavity was filled with only photons. What Planck was dealing with was a photon gas in the cavity and could successfully explain distribution of energy over the entire range of wavelengths in the cavity [6].

5. Conclusion

Wien's cavity was actually filled with solar photons entering through the small opening in the cavity in addition to emission of radiation by the surface particles of the cavity. Planck's formulation was treating a photon gas and the formulation explained the entire distribution of radiation energy in different frequencies of the photons made of solar photons and the discrete radiation emitted by the atoms and molecules of the cavity surface.

References

[1] M N Saha & B N Srivastava: A Treatise of Heat, The Indian Press (Publications) Private Ltd. 1958, 633-634

[2] ibid, (1), 133-145

[3] ibid., 661

[4] ibid., 663

[5] ibid., 667

[6] ibid., (1), 668-678

Clarification: Some readers have flagged concerns about a few untenable overstatements in the article 'Facets of the Heisenberg Uncertainty Principle', by V. Potbhare and N. D. Chavda, published in the June 2026 issue of the Bulletin. Our referees did not endorse these remarks, pointing out that they are hyperbolic. The referees, however, did not demand the deletion of these remarks, they only gave the authors some latitude. They certainly did not endorse those overstatements. The Editorial Board of the Bulletin and the referees do not endorse all the contents of articles published in the Bulletin. That responsibility is with the authors. Poetic or scriptural references are rarely admissible, except when they genuinely enrich stylistic expression **without** damaging the scientific value. Having said that, the IAPT is fully committed to preventing the publication of misleading and unsubstantiated content. We urge all authors and referees to apply the highest standards of scientific scrutiny.

Report (NAEST)

Joy of Physics

An inspiring and engaging session on **'NAEST' by Adarsha-IAPT Anveshika was conducted by Mr. Debmalya Sen,** bringing the joy of Physics alive through exciting experiments and hands-on demonstrations on **May 19, 2026.** Students enthusiastically explored fascinating concepts of motion, electricity, magnetism, optics, and everyday Physics through simple yet powerful activities.

The session encouraged curiosity, scientific temperament, and experiential learning, making Physics more interactive and enjoyable for young minds. The live demonstrations not only simplified complex concepts but also inspired students to observe science in their daily lives and develop a deeper love for innovation and discovery.

This program paved the way for bulk registrations from DAV Model School IIT, Kharagpur for **NAEST 2026.**

G. Lily

Report (RC-18)

Regional Annual Convention-2026
Reimagining Physics Education in the 21st Century

The Annual Convention of the IAPT RC-18, was held successfully on 7th June, 2026 at The ICFAI University Tripura, Agartala, under the theme **"Reimagining Physics Education in the 21st Century."** The convention was organised by RC-18 in association with the Department of Physics, ICFAI Science School, The ICFAI University Tripura.

The event attracted more than 100 participants, including Physics Teachers, Academicians, Researchers, and Students from different institutions across the region. The convention served as a valuable platform for discussing emerging trends, pedagogical innovations, and future directions in physics education.

Inaugural Session:

The programme commenced with a welcome address by Prof. (Dr.) Biplab Halder, Hon'ble Vice Chancellor, The ICFAI University Tripura, who emphasised the importance of quality science education and interdisciplinary learning in contemporary academic environments.

Mr. Swapan Majumdar, Secretary, IAPT RC-18, formally introduced the convention and highlighted the relevance of the theme in the context of rapidly changing educational perspectives and learner expectations in the 21st Century Challenges .

Prof. Rekha Ghorpade, General Secretary, IAPT, addressed the participants through an online message and reiterated IAPT's commitment to strengthening physics education across the country.

The inaugural session concluded with a vote of thanks by Prof. (Dr.) A. Ranganath, Registrar, The ICFAI University Tripura and President, RC-18.

The convention was attended by several eminent academicians and educationists. The programme received the active participation of senior IAPT office bearers through online mode, including Prof. P. K. Ahluwalia, President, IAPT and Prof. Ranjita Deka, Vice President (Eastern Zone).

Technical Sessions:

The technical programme reflected the convention theme and focused on innovative strategies for enhancing physics teaching and learning.

The keynote address was delivered by **Prof. Ahluwalia**, who discussed the evolving challenges of physics education in the twenty-first century and emphasised the need for learner-centric approaches, research orientation, and technological integration.

Dr. Pramode Ranjan Bhattacharjee, Founder President of RC-18, delivered a scholarly lecture titled *"An Examination of Bragg's Law of Diffraction of X-ray,"* revisiting the historical significance and contemporary relevance of one of the foundational concepts in modern physics.

Dr. Anirban Guha, Professor, Department of Physics, Tripura University, conducted an engaging session on *"PhET Interactive Simulations,"* demonstrating how simulation-based learning can improve conceptual understanding and classroom engagement.

The final technical lecture was presented by **Dr. Dipayan Chattopadhyay**, Assistant Professor, Department of Physics, The ICFAI University Tripura, on *"AI Integration in Physics Education."* The session highlighted emerging applications of artificial intelligence in teaching, assessment, personalised learning, and educational research.

Quantum Mechanics Centenary Exhibition:

A special feature of the convention was the **Quantum Mechanics Centenary Exhibition**, organised to commemorate one hundred years of the development of Quantum Mechanics. The exhibition showcased significant milestones, contributions of pioneering physicists, and modern applications of quantum science, generating considerable interest among participants.

Valedictory Session:

The valedictory session was graced by **Prof. Sarat Kumar Patra**, Hon'ble Director, NIT Agartala, as the Chief Guest. In his address, he emphasised the need for innovation, collaboration, and continuous professional development among educators to meet the challenges of modern science education.

The convention concluded with a formal vote of thanks by **Dr. Camelia Das**, Head, Department of Physics, The ICFAI University Tripura, who acknowledged the contributions of IAPT, the university administration, speakers, participants, and the organising committee members.

Conclusion:

The Convention successfully brought together educators, researchers, and students to deliberate on contemporary issues and future possibilities in physics education. Through expert lectures, interactive discussions, and the Quantum Mechanics Centenary Exhibition, the convention provided valuable insights into innovative pedagogical practices and emerging technologies. The event reaffirmed IAPT's enduring commitment to promoting excellence in physics teaching and learning and strengthening the physics education community in the north-eastern region and beyond.

Swapan Majumdar

Participation of India in the XXVI Asian Physics Olympiad (APhO 2026) held at Busan, Republic of Korea

Selection of Team India: The list of Top 50 scores of INPhO 2026 who opted to be considered for the prestigious Asian Physics Olympiad 2026, both in Group A (Class XII) and Group B (Classes XI/X), was communicated by Prof (Dr) Anwesh Mazumdar, the National Coordinator Science Olympiads to me on 9 March 2026. The same day I collected the marks of these students in NSEP from the Chief coordinator (Examination) Prof B P Tyagi and started the process for final selection of APhO team. Due to the scheduling conflict with the Joint Entrance Examination (JEE Advanced), all selected Class XII students expressed their inability to participate in APhO 2026 one by one. Consequently, only students from Classes X and XI were available for consideration. Following extensive communication with students and their parents, and after a rigorous selection and confirmation process, the final team was constituted on 28 March 2026. The final list was forwarded to Prof Arnab Bhattacharya, the Chair National Steering committee and Director Homi Bhabha Centre for Science Education (HBCSE), Mumbai and the National Coordinator of Science Olympiads Prof Anwesh Mazumdar. With their final approval, the following team was declared:

Team India for APhO 2026

S. No.	Name of Student	Gender	Class	State
1	Raghukul Bhushan	M	XI	Telangana
2	Aayaam Jain	M	XI	Maharashtra
3	Manas Goel	M	XI	Haryana
4	Pranit Mathur	M	XI	Gujarat
5	Jinansh Jignesh Shah	M	XI	Maharashtra
6	Harshit Singh	M	X	Haryana
7	Dwarapureddi Jayanth Naidu	M	XI	Telangana
8	Svanik Goel	M	X	Haryana

Appointment of Leaders and Observer: On 31 March 2026, approval was received from HBCSE, Mumbai, regarding the composition of the delegation. Dr. Vijay Kumar and Dr. T. N. Soorya were appointed as Team Leaders, while Dr. B. P. Tyagi was nominated as the Observer. Following the approval, arrangements for air travel and visa processing were initiated immediately. During this period, geopolitical tensions in the Middle East, particularly the conflict between the United States and Iran, resulted in a substantial increase in international airfares to the Republic of Korea. Ticket prices rose nearly threefold, creating significant budgetary challenges. With the guidance and support of HBCSE, Mumbai, suitable arrangements were made and the travel bookings were successfully completed. The visa process also posed considerable challenges. Since the selected students belonged to different states (Haryana, Maharashtra, Telangana, and Gujarat). The visa applications had to be processed through both the Delhi and Mumbai Consulates of the Republic of Korea. The authorities required numerous original documents, which had to be coordinated from different parts of the country within a limited timeframe. Despite several logistical difficulties, all visas were eventually secured, with one student's visa being issued only at the eleventh hour.

Pre-Departure Camp: The Pre-Departure Camp (PDC) for Team India was conducted from 8–15 May 2026 at Graphic Era Hill University (GEHU), Dehradun, Uttarakhand. The camp was inaugurated on 8 May 2026 in the presence of Dr. P. K. Ahluwalia, President, Indian Association of Physics Teachers (IAPT), Dr. Rekha Ghorpade, General Secretary, IAPT, Hon'ble Vice-Chancellor, Graphic Era Hill University, Registrar, Dean Academics, and faculty members of the Departments of Physics of GEHU and Graphic Era Deemed to be University, Dr. Rupesh Tyagi, Secretary, RC-05, IAPT, Members of RC-05, IAPT.

Resource Persons : The following eminent academicians and physicists served as resource persons during the camp. Mr. V. H. Thakkar, Associate Professor, Sir P. T. Sarvajanik College of Science, Surat, Gujarat, Dr. T. N. Soorya, Associate Professor, Vardhman College, Bijnor, Uttar Pradesh, Dr. Y. K. Vijay, Professor, IIS University, Jaipur, Dr. B. P.

Tyagi, Chief Coordinator (Examinations), IAPT, Dehradun, Dr. Vijay Kumar, Coordinator APhO, Principal, Dhanauri P.G. College, Haridwar, Dr. Amit Raj Singh, Dr. Avijit Chamoli, Mr. Vishesh Sharma, Ms. Shruti Singh, Graphic Era Hill University Dehradun. The students underwent intensive training daily from 9:00 a.m. to 6:00 p.m. Drawing upon experiences from previous international Olympiads, special emphasis was placed on strengthening experimental skills. The camp focused extensively on laboratory experiments from previous APhOs and International Physics Olympiads, while several new experimental setups were specifically designed to enhance students' practical competence and data-analysis abilities. The valedictory ceremony was held on 15 May 2026 in the presence of the Hon'ble Vice-Chancellor, Registrar, Dean Academics, faculty members, and all resource persons associated with the camp.

Date	Activity
17 may 2026	Arrival, Registration, and Check in hotel
18 May 2026	Opening Ceremony and Theory Board Meeting
19 May 2026	Theoretical Examination
20 May 2026	Experimental Examination Discussion and Translation
21 May 2026	Experimental Examination
22 May 2026	Evaluation of the answer scripts
23 May 2026	Moderation and International Board Meeting
24 May 2026	Closing Ceremony and Award Presentation
25 may 2026	Departure and check out from hotel

Outstanding Performance of Team India: The Indian team delivered an exceptional performance at APhO 2026. Remarkably, every member of Team India received an award, reflecting the dedication of the students and the effectiveness of the training programme.

The team secured:

- **Three Silver Medals**
- **Four Bronze Medals**
- **One Honourable Ment**

Results of Team India

S. No.	Name of Student	Gender	Class	Award
1	Pranit Mathur	M	XI	Silver Medal
2	Jinansh Jignesh Shah	M	XI	Silver Medal
3	Dwarapureddi Jayanth Naidu	M	XI	Silver Medal
4	Raghukul Bhushan	M	XI	Bronze Medal
5	Manas Goel	M	XI	Bronze Medal
6	Harshit Singh	M	X	Bronze Medal
7	Aayaam Jain	M	XI	Bronze Medal
8	Svanik Goel	M	X	Honourable Mention

The achievement is particularly noteworthy because the entire contingent consisted of students from Classes X and XI, with no participation from Class XII students due to the overlap with JEE Advanced examinations.

Return to India: The Indian delegation departed Busan after the closing ceremony and arrived at Indira Gandhi International Airport, New Delhi, on 26 May 2026 at approximately 8:00 p.m. A brief felicitation ceremony was organized at the airport to celebrate the team's achievements. The students were congratulated on their outstanding performance and subsequently handed over to their parents.

Acknowledgements: The successful participation of Team India in APhO 2026 was made possible through the continuous support and guidance of Prof Arnab Bhattacharya, Chairperson National Steering Committee and Director Homi Bhabha Center of Science Education, Mumbai, Prof Anwesh Mazumdar, National Coordinator, Science Olympiads, Prof PK Ahluwalia, President, Prof. Rekha Ghorpadee, General Secretary, Indian Association of Physics Teachers (IAPT), and all the resource persons who contributed their expertise during the Pre-Departure Camp.

The remarkable performance of Team India stands as a testament to the talent, perseverance, and scientific excellence of India's young physicists and reinforces the nation's strong presence in international physics competitions. An all-round support and encouragement from the chairperson Honourable Prof Kamal Ghanshala ji and the Vice chancellor Graphic Era Hill University Dehradun is thankfully acknowledged. I need to express my gratitude to the President International Asian Physics Olympiad board to nominate Prof Vijay Kumar (India) as a member of International Advisory Board of Asian Physics Olympiad.

The Asian Physics Olympiad Cell and the Indian Association of Physics Teachers are deeply grateful to the Department of Atomic Energy and the Homi Bhabha Centre for Science Education for providing the financial support that made this event possible.

Vijay Kumar

Coordinator: IAPT-APhO

FIRST STEP TOWARDS

INTERNATIONAL SCIENCE OLYMPIADS

NATIONAL STANDARD EXAMINATION IN PHYSICS	: NSEP 2026 - 27
NATIONAL STANDARD EXAMINATION IN CHEMISTRY	: NSEC 2026 - 27
NATIONAL STANDARD EXAMINATION IN BIOLOGY	: NSEB 2026 - 27
NATIONAL STANDARD EXAMINATION IN ASTRONOMY	: NSEA 2026 - 27
NATIONAL STANDARD EXAMINATION IN JUNIOR SCIENCE	: NSEJS 2026 - 27

These are the only examinations that lead to participation of Indian students in the National and International Science Olympiads. No other examination is recognized for this purpose.

Organized by

INDIAN ASSOCIATION OF PHYSICS TEACHERS (IAPT)

206, Adarsh Complex, Awas Vikas - I, Keshavpuram, Kalyanpur, Kanpur-208017

In co-ordination with
ASSOCIATION OF CHEMISTRY TEACHERS (ACT) &
ASSOCIATION OF TEACHERS IN BIOLOGICAL SCIENCES (ATBS)

Step II Toppers from these NSEP, NSEC, NSEB, NSEA & NSEJS from each State/Union Territory will be eligible for II stage i,e Indian National Olympiads (INOs) 2027 in respective subjects (with atleast 20% girls). For details see the website: www.iapt.org.in and the student's brochure.

Step III About 40 toppers in each of INPhO, INChO, INBO, 50 of INAO and 35 of INJSO will qualify for the Orientation Cum Selection Camp (OCSC) in respective subjects for two weeks at Homi Bhabha Centre for Science Education (HBCSE), Mumbai or Banglore Indian teams to participate in International Olympiads – 2027 will be selected on the basis of performance of students in respective OCSC.

In addition, about 8 toppers from INPhO and NSEP may get an opportunity to participate in **Asian Physics Olympiad (APhO)**. The APhO will be held in May 2027.

Language: Question Papers are in English, Hindi, Gujarati, Bangla, Kannada, Tamil and Telugu or any Indian Language provided 300 students OPT for it

Awards: Students attending OCSC will be awarded Gold medals and a merit certificate in all subjects. Certificates shall be awarded to Toppers (National & State) of National Standard Examination.

Syllabus: NSEP, NSEC, NSEB: Upto CBSE class XII;
NSEA: Physics & Mathematics upto CBSE class XII along with basic Astronomy;
NSEJS: Physics, Chemistry & Biology upto CBSE class X.

Programme:

Centre registration: Aug 1 to Aug 20, 2026

Student enrolment: Aug 21 to Sep 14, 2026

1. **Enrolment at Centre:** Pay fee to Centre In-charge.
2. **Direct Online Enrolment:** A student can enrol directly online at www.iapt.org.in; He/She will pay fee through online payment.

DATE AND TIME OF EXAMINATION: SUNDAY 22.11.26

NSEP : 8:30 AM to 10:30 AM
NSEC : 11:30 AM to 1:30 PM
NSEB : 2:30 PM to 4:30 PM
NSEJS : 2:30 PM to 4:30 PM

SATURDAY 21.11.2026

NSEA : 2:30 PM to 4:30 PM

Fee Rs. 300.00 per student per subject

PREVIOUS 10 YEARS QUESTION PAPERS BOOKLET WITH ANSWERS IN EACH SUBJECT IS AVAILABLE FOR Rs. 150/- EACH FROM IAPT OFFICE KANPUR (iaptknp@rediffmail.com)

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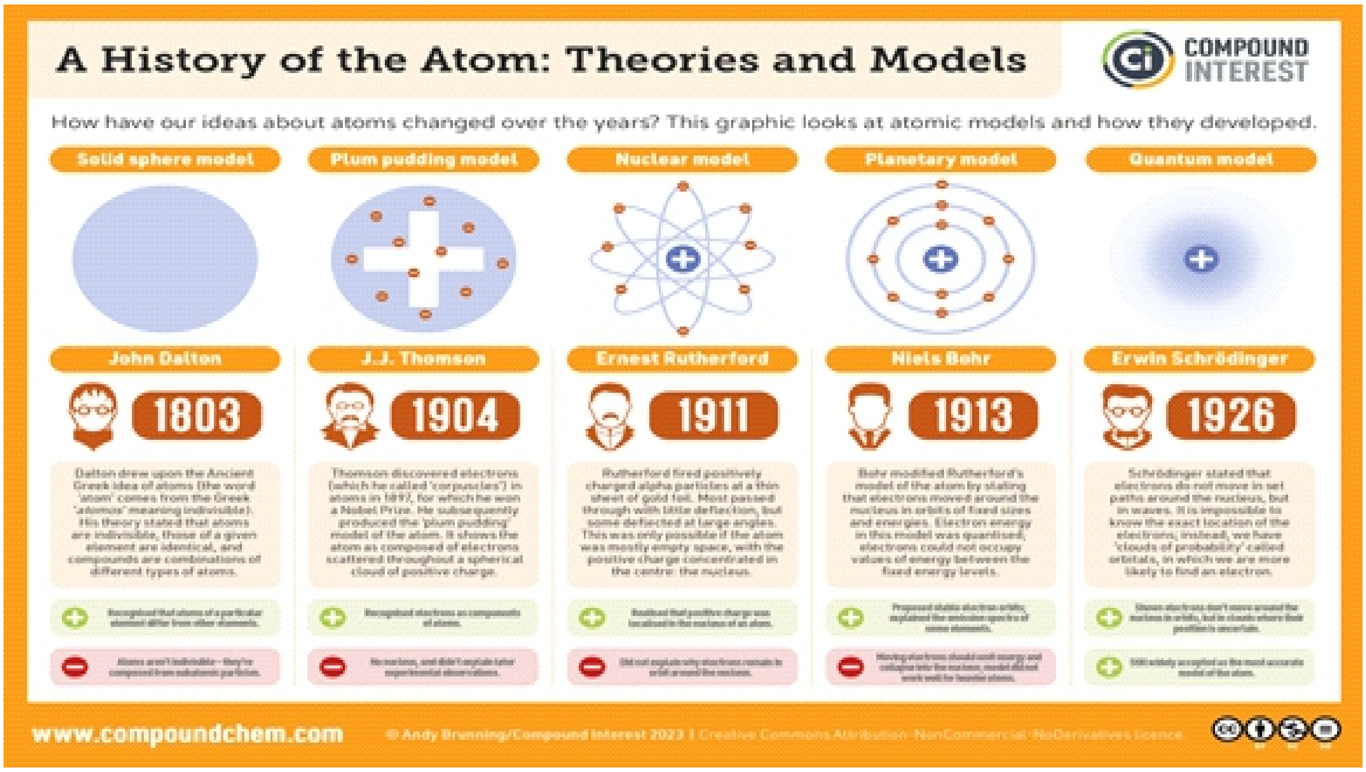
Email: iapt.nse@gmail.com
Helpline: 9632221945, 8310281694, 8533993332

For all queries regarding the examination: Student may contact local centre in-charge else the Helpline.

Unfished story of the Atom Models[**]

R. Balakrishnan, Bangalore-560076
Email: balakilatha@gmail.com



Dalton dreamed a solid sphere,
Indivisible hard and small—
No parts no charge no interior
Matter's simplest, most austere,
Identical in mass and properties

Thomson thought a different thing:
Plum pudding, rich and warm—
Electrons like the fruit would cling
To a positive, dough-like form But
Couldn't afford the gold foil

Rutherford with thin gold foil
Shot alpha rays to pass through-
Mostly empty and positive core
Some bounced back, a shock within:
A nucleus popped into view

Bohr then built a mini solar system
Orbits fixed and quantized—
Electrons jumping, no resistance,
Spectral lines explained But
Not from multi electron systems

Quantum came and swept the paths
Mathematical probability rather
Than physical reality
No more tracks, just wave-like moths,
Electron clouds and shifting phase.

Each model closer to the truth,
Yet none has the final claim—
Though clarity evolved
The atom holds a lasting youth:
A mystery still aflame with black holes
Allowing clash of quantum and gravity.

[**] **Editor's Note**: It is interesting to note that the author took the help COPILOT to give 20 points on atomic models and modified them into 5 liners on each model.

Artificial Intelligence (AI) and Education - Some Thoughts

Artificial Intelligence (AI) systems, particularly machine learning applications in science, are rapidly changing the nature of scientific practices and the world around us. This ongoing transformation is rendering many of the pedagogies and curricula currently taught in our schools and colleges obsolete. Given the complexity and pace of this change, designing and implementing future-ready educational approaches is among the most challenging problems facing educators and policymakers worldwide.

In a country like ours, where the predominant pedagogy is still based on traditional lecture methods and remains largely textbook-driven, we need to devise a gradualist transition that incorporates the productive aspects of AI. From an educational standpoint, a useful perspective for enabling such a transition is to understand AI as emerging from the study of human intelligence and learning and, more broadly, as an outcome of mathematical model building. A consideration that follows from this perspective is the need to focus on studying human learning and cutting-edge science and engineering practices in tandem. Such a stance is conducive to facilitating a unique braiding between learning sciences, education research, and cutting-edge research practices, which can then inform the design of curricula and pedagogies. International Olympiads in mathematics and science, being the closest school-level educational structures that integrate frontier scientific problem-solving practices, can help enable such a gradualist transition. Drawing insights from the expanding literature in education research on AI is another resource that can support this endeavour (see the papers discussed below as illustrative examples).

As a systematic investigation of frontier science and technology practices and human learning and education practices, in tandem, is required for the proposed redesign, the country needs more centres like the Homi Bhabha Centre for Science Education (HBCSE)—centres that focus on education and human learning while being located within an ecosystem that has direct access to cutting-edge research practices. We need to move away from the current linear approach to developing science and technology curricula, where the design of educational practices slowly follows, but never catches up with, frontier science practices. The proposed alternative is to develop a 'warped curriculum' approach, where science and engineering education structures evolve concurrently with changing scientific practices. To move towards this twinning approach, we need to consider the ability to solve novel problems and engage in sense-making as the gold standard of educational achievement, rather than competitive examinations.

Below, we briefly discuss two papers that investigate the role of AI in facilitating sense-making: the first in a general education context and the second specifically in physics education. Silvola et al. studied college students' AI-mediated sense-making in the context of academic writing assignments within an inquiry-based setting. The study suggests, as an implication for practice, that supporting students in the use of GenAI can help enrich their thinking and develop a better perspective on the uses of AI and its purposes. Zollman et al.'s paper employs the cognitive frameworks of sense-making and mechanistic reasoning to compare the responses of AI and students to a physics task. The authors maintain that AI will form a crucial part of physics education and the learning process in the future.

Silvola, A. et al., (2025). AI-mediated sensemaking in higher education students' learning processes: Tensions, sensemaking practices, and AI-assigned purposes. *British Journal of Educational Technology*, *56*(5), 2001-2018.
https://bera-journals.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/bjet.13606

K K Mashood
HBCSE - TIFR, Mumbai

Postal Regd. No. Kanpur City-28/2024-26 Date of printing 01-07-2026 Date of posting 08-07-2026 RNI No. UPENG/2009/29982 ₹ 20/-

BULLETIN OF THE INDIAN ASSOCIATION OF PHYSICS TEACHERS

FOUNDED BY (LATE) DR. D.P. KHANDELWAL

VOLUME 18 NUMBER 7 JULY 2026

IN THIS ISSUE

If undelivered please return to :

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Awas Vikas-1, Keshavpuram, Kalyanpur, Kanpur-208017

Published by Dr. Sanjay Kr. Sharma on behalf of Indian Association of Physics Teachers. For circulation amongst IAPT members/subscribers only.
Flat No. 206, Adarsh Complex, Awas Vikas-1, Keshavpuram, Kalyanpur, Kanpur-208 017, Mob. 9415404969.
Printed at Sharda Graphics Pvt. Ltd., 123/766, Factory Area, Fazalganj, Kanpur-208012, Ph. 9336845329
Chief Editor: Prof. Manjit Kaur