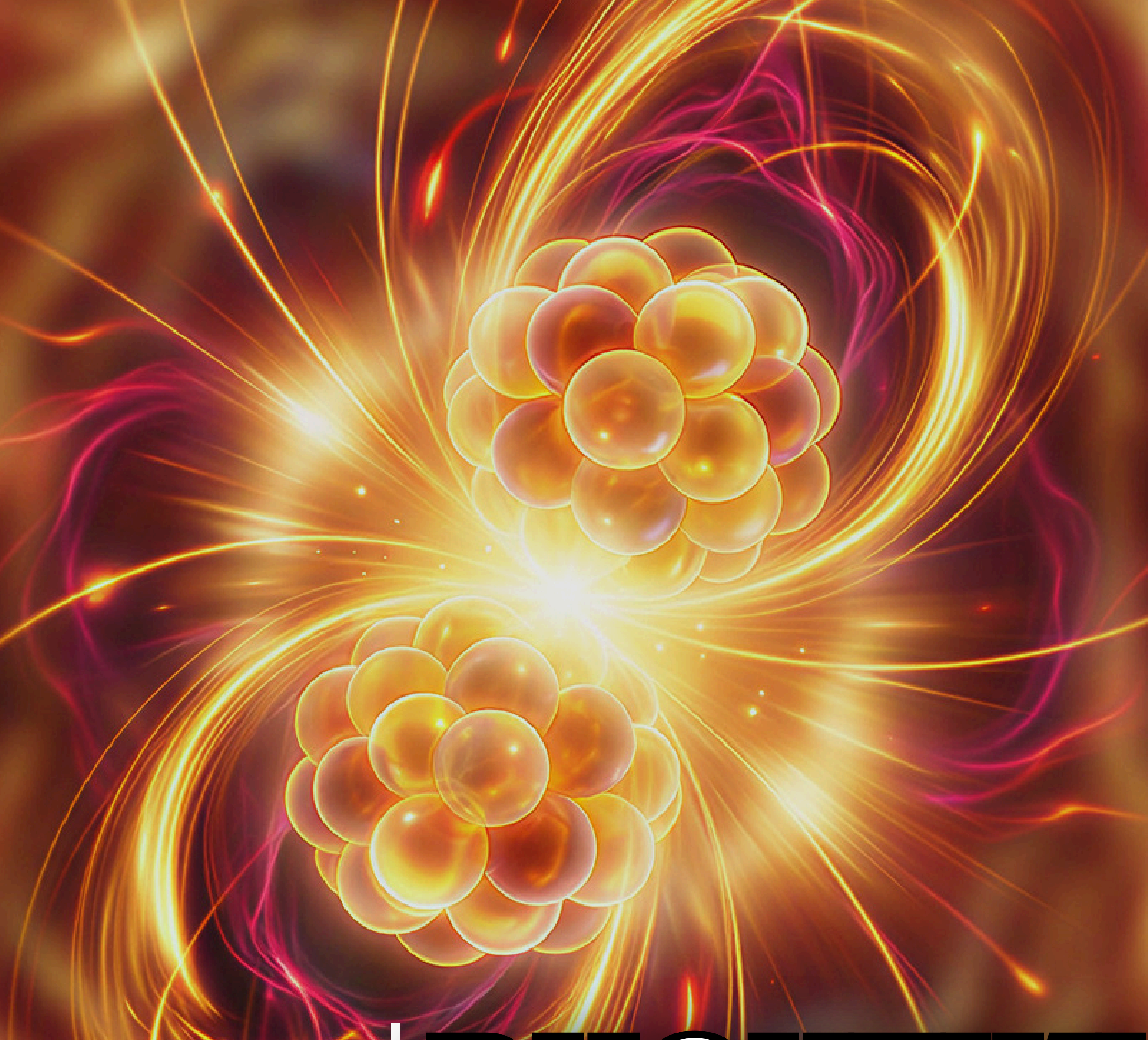

BHOUTIKI PRADNYA

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PREFACE

Special Nuclear Physics Edition – BHOUTIKI

In the vast tapestry of modern science, few fields have challenged our imagination and transformed our understanding of the universe as profoundly as nuclear physics. From probing the mysteries of the atomic nucleus to powering technologies that shape our civilization, nuclear physics stands at the crossroads of fundamental discovery and practical innovation.

With immense enthusiasm, we present this special 'Nuclear Physics Edition' of BHOUTIKI, our e-newsletter dedicated to exploring the frontiers of physics. Curated by the passionate members of the BHOUTIKI Physics Students Club, this edition journeys through the fascinating world of nuclear science unraveling its principles, tracing its historical milestones, and spotlighting its role in energy, medicine, and national development.

Whether you are a curious student eager to grasp the foundations of atomic interactions, a researcher inspired by the challenges of nuclear technology, or simply someone intrigued by the forces that govern matter at its core, this issue promises to ignite curiosity and spark reflection.

We extend our heartfelt gratitude to MES's Nowrosjee Wadia College for their unwavering support and mentorship. Their commitment to nurturing scientific inquiry continues to empower our journey from classroom learning to real-world impact.

Let this edition be a celebration of nuclei, neutrons, and the elegance of quantum forces woven together in equations, experiments, and imagination.

In-Charge
Dr. Bharat B. Gabhale

ABOUT COLLEGE

Welcome to Nowrosjee Wadia College – A Beacon of Excellence Since 1932

Established on July 21, 1932, just months after the founding of the Modern Education Society, Nowrosjee Wadia College has stood as a pillar of academic brilliance and cultural vibrancy in Pune. Guided by its inspiring motto "For the Spread of Light," the college has been instrumental in opening doors to higher education for generations of students, especially in the eastern region of the city.

Affiliated with Savitribai Phule Pune University and proudly holding autonomous status, Nowrosjee Wadia College has earned numerous accolades, including the prestigious First Best College Award from SPPU and an A+ grade from NAAC in 2017. The college continues to shine as a consecutive Divisional Winner of JALLOSH, the university's celebrated cultural fest.

Offering a rich blend of undergraduate and postgraduate NEP 2.0) programs in both Science and Arts disciplines, the college attracts bright minds from across India and abroad. With world-class infrastructure, vibrant student life, and a legacy of excellence, Nowrosjee Wadia College remains the first choice for holistic education and personal growth.

ABOUT DEPARTMENT

Department of Physics – Advancing Research and Innovation

The Department of Physics at Nowrosjee Wadia College, Pune, is a recognized postgraduate teaching and research center under Savitribai Phule Pune University (SPPU). It currently offers comprehensive academic programs leading to B.Sc., M.Sc., and Ph.D. degrees, fostering a strong foundation in both theoretical and applied physics.

A hallmark of the department is the Electro-Acoustics Research Laboratory (EARL), an SPPU-recognized center for doctoral research. Building on its legacy of excellence, the department has expanded into Materials Science, with the Advanced Functional Materials Laboratory (AFML) offering cutting-edge research opportunities in nanomaterials and functional thin films. These studies focus on conductive and transient properties crucial to thin-film device technologies.

The department has successfully guided numerous Ph.D. and M.Phil. scholars and continues to mentor several active research candidates. Its commitment to innovation is supported by grants from prestigious bodies including the American Physical Society (APS), University Grants Commission (UGC), Indian Space Research Organization (ISRO), Department of Science and Technology (DST) and Board of College and University Development (BCUD-UoP).

ABOUT BHOUTIKI

The term 'BHOUTIKI' in the Physics Club logo likely signifies 'Physics' in Sanskrit, encapsulating the foundational principles of the natural sciences. It beautifully reflects the essence of exploring the physical universe, spanning phenomena from the microscopic to the cosmic scale.

Through 'BHOUTIKI,' we aim to honour the legacy of scientific excellence and inspire a new generation of physicists to delve into the mysteries of the universe.

Throughout the year, the club will host a wide variety of activities, each thoughtfully designed to spark curiosity and deepen participants' understanding of the intricate beauty of physics. These activities include: Guest Lectures and Seminars, Workshops and Skill Sessions, Experimental Demonstrations, Science Outreach Programs, Debates and Panel Discussions, Physics Quiz Competitions, Project Showcases, Movie Screenings and Discussions, Publication of Quarterly Digest, Experiment Design Competitions, Peer Teaching and Learning, Problem-Solving Sessions, Celebration of Physics Days, Collaborations and Competitions, Educational Visits, PHYSIQUEST: The department's flagship annual event.

With this diverse range of initiatives, the Physics Students Club aims to foster a vibrant community that celebrates the pursuit of knowledge and the joy of discovery in the realm of physics.

CONTENTS

Job Opportunities of Nuclear Physics/sectors in India and Worldwide

Sanjay D. Dhole
Department of Physics, Savitribai Phule Pune University, Pune, India

Nuclear physics is a fundamental branch of physical science concerned with the structure, properties, and interactions of atomic nuclei. It addresses some of the most basic questions about matter, energy, and the forces of nature, while simultaneously enabling powerful real-world applications. Research in nuclear physics has led to transformative technologies in nuclear energy, medical diagnostics and therapy, radiation safety, space science, national security, and advanced materials. Because of its dual nature-fundamental and applied nuclear physics offers a wide range of career opportunities for students. These opportunities exist in experimental nuclear physics, theoretical nuclear physics, and several interdisciplinary and applied domains. Careers may be pursued within India or through international pathways, often involving mobility across countries and research facilities. This article presents a comprehensive and student-oriented overview of job opportunities in nuclear physics. It explains what posts and positions students can apply for at different educational stages, clearly distinguishing between experimental and theoretical roles, while placing strong emphasis on worldwide job opportunities alongside those in India.

Experimental and Theoretical Nuclear Physics have their own contexts in terms of career. Experimental nuclear physicists study nuclear phenomena by directly observing nuclear reactions, decays, and interactions. Their work relies on sophisticated infrastructure such as particle accelerators, cyclotrons, synchrotrons, nuclear reactors, radiation detectors, spectrometers, and beam diagnostics systems. Experimentalists design experiments, develop detectors, operate large facilities, and analyse complex datasets. Modern experiments often involve international collaborations and long-term experimental campaigns. Theoretical nuclear physicists develop mathematical, analytical, and computational models to explain nuclear structure, nuclear reactions, nuclear matter, and astrophysical processes. They use quantum mechanics, many-body theory, relativistic models, and numerical simulations to interpret experimental data and make predictions. Theoretical nuclear physics today is strongly connected with high-performance computing, large-scale simulations, and data-driven modelling.

In practice, experimental and theoretical nuclear physics are deeply interconnected. Career paths frequently involve close interaction between the two, and researchers often work in international teams that span continents. The career opportunities are given in details stepwise in India and worldwide.

(1) Career Opportunities After B.Sc. / Integrated M.Sc.:

At the undergraduate level, students usually enter nuclear physics through training, exposure, and skill-development positions, rather than permanent employment.

Post- Research Intern/ Summer Student

Eligibility: B.Sc. Physics and Integrated M.Sc. students

Nature of work: Research interns assist faculty members and scientists in ongoing projects. Tasks may include literature review, basic simulations, data analysis, laboratory measurements, detector testing, or coding. Experimental interns may gain hands-on experience with radiation detectors, electronics, vacuum systems, and data acquisition, while theoretical interns may work on numerical calculations, simulations, or analytical problem-solving.

In India, Institutions such as TIFR, BARC, SINP, VECC, IISc, IITs, public universities and central universities offer structured summer research programs that introduce students to nuclear physics research environments.

Worldwide opportunities: CERN Summer Student Programme (Europe), National laboratories in the USA (Brookhaven, Argonne, Los Alamos), DAAD WISE and similar exchange programs in Germany, REU (Research Experiences for Undergraduates) programs in the USA, University-based summer schools in Europe and Japan…

These internships are highly competitive, but they are often the first step toward international Ph.D. admissions and long-term global careers.

Post- Laboratory or Technical Assistant:
Some B.Sc. graduates with strong experimental skills may find employment as laboratory or technical assistants. These roles involve detector operation, radiation monitoring, electronics maintenance, or experimental setup support. Such positions are relatively rare and are typically technical rather than research-oriented.

(2) Career Opportunities After M.Sc. in Physics:
The M.Sc. level represents the main formal entry point into nuclear physics research careers.

Post- Junior Research Fellow (JRF) / Equivalent Positions
Eligibility: M.Sc. Physics with qualification in CSIR-NET (JRF), UGC-NET, JEST, or GATE (depending on the institute).

Nature of work: JRFs work full-time on research projects, usually leading to a Ph.D. degree.
In experimental nuclear physics, JRFs participate in accelerator experiments, detector development, beam diagnostics, radiation measurements, and data analysis. In theoretical nuclear physics, JRFs work on nuclear structure models, reaction theories, nuclear astrophysics, and large-scale computational simulations.

In India, JRF positions are available at DAE institutes such as BARC, TIFR, VECC, and SINP, as well as IISc, IITs, and central universities.

Worldwide equivalent positions: Fully funded Ph.D. student positions in Europe, where doctoral candidates are salaried researchers, Graduate Research Assistant (GRA) or Teaching Assistant (TA) positions in the USA, with tuition waiver and stipend, Ph.D. positions in Japan, Canada, and other Asia-Pacific countries are available. These worldwide Ph.D. positions are internationally recognized and offer strong research exposure and mobility.

Post- Project Assistant / Project JRF
Project-based positions are offered under funded research grants and may not require NET qualification. These roles involve experimental assistance, simulations, or data analysis and often act as a bridge to Ph.D. enrolment.

Post- Scientific Officer (Training Positions- India)
Organizations such as BARC recruit M.Sc. Physics graduates as Scientific Officers (C/D) through structured training programs like OCES and DGFS. Work areas include Reactor physics, nuclear instrumentation, radiation safety, accelerator operation, and applied nuclear technologies. These positions are prestigious, permanent government jobs with long-term career stability.

Post- Medical Physicist
Course- Diploma in Radiation Physics (Two years) at BARC
Work area- Medical Physicist in various hospitals for Cancer treatment.

(3) Ph.D. Positions in Nuclear Physics
Doctoral Research Scholar
A Ph.D. is essential for advanced research, academic careers, and senior scientific roles.

Nature of work: Experimental Ph.D. scholars work on accelerator-based experiments, nuclear reactions, detector systems, radiation effects, and instrumentation. Theoretical scholars focus on quantum many-body theory, nuclear forces, reaction dynamics, nuclear matter, and nuclear astrophysics.

Worldwide dimension: Even when enrolled in Indian institutions, many Ph.D. students conduct experiments or collaborative research at international facilities such as CERN, FAIR (Germany), RHIC (USA), and RIKEN (Japan), gaining valuable global exposure.

Postdoctoral Positions: The Critical Worldwide Stage

Postdoctoral Fellow (PDF / Postdoc)
Eligibility: Ph.D. in Nuclear Physics

Nature of work: Postdoctoral fellows conduct independent research, lead experimental subsystems or theoretical projects, publish high-impact papers, and mentor junior researchers.

In India, Postdoctoral positions are available through SERB-N-PDF and institute-specific fellowships.

Worldwide opportunities (career-defining stage) at CERN (Europe), Brookhaven National Laboratory and Jefferson Lab (USA), FAIR Facility (Germany), TRIUMF (Canada), RIKEN (Japan).

International postdoctoral experience is often essential for securing permanent positions worldwide.

Post- Research Associate (RA)
Research Associates hold senior research roles in Indian institutions and often transition into faculty or scientist positions.

(4) Permanent Scientist Positions:
Post- Scientist / Staff Scientist / Research Scientist
Eligibility: Ph.D., usually with postdoctoral experience

In India, BARC, VECC, SINP, DAE laboratories, DRDO, and ISRO.

Worldwide opportunities: Permanent staff scientist positions at national laboratories in the USA, Europe, Canada, and Japan, Research-only roles without teaching obligations and Long-term involvement in facility operation, detector development, and advanced nuclear experiments

These positions provide excellent infrastructure, job stability, and global recognition.

(5) Faculty Positions in India and Worldwide:
Post- Assistant Professor / Lecturer / Tenure-Track Faculty

Eligibility: Ph.D. with postdoctoral experience

Nature of work: Teaching undergraduate and postgraduate courses, supervising students, securing research funding, and running independent experimental or theoretical research programs.

Worldwide opportunities: Tenure-track assistant professor positions in the USA, Lecturer and professorship positions in Europe, Research-intensive faculty roles in Japan, South Korea, and Australia.

International postdoctoral experience is often mandatory.

(6) Worldwide Applied and Industry Careers:
Post- Medical Physicist (Worldwide)

This is one of the fastest-growing global career paths for nuclear physics graduates.

Work areas: nuclear medicine, PET/CT imaging, radiotherapy, radiation protection, and hospital safety systems. Hospitals and cancer centers worldwide actively recruit trained physicists.

Nuclear Energy and Reactor Physics
Countries such as **USA, France, China, South Korea, and Canada** offer roles in reactor physics, nuclear safety analysis, fuel cycle research, and advanced reactor development.

(7) International Organizations and Policy Roles

Highly specialized global positions exist at International Atomic Energy Agency (IAEA) and International nuclear safeguard and regulatory bodies.

These roles combine science, regulation, and international cooperation.

Nuclear physics offers a structured yet globally mobile career pathway. India provides strong foundational training, prestigious research institutes, and stable government positions, while worldwide job opportunities expand significantly at the Ph.D. and postdoctoral levels, offering access to large facilities, cutting-edge infrastructure, and long-term research careers. The analytical, computational, and experimental skills developed in nuclear physics also allow graduates to transition successfully into medicine, energy, industry, and international organizations.

Dr. Sanjay Dhole served as Senior Professor of Physics in the Department of Physics and as Director of Alumni Affairs at Savitribai Phule Pune University. His research expertise spans nuclear physics, accelerator physics, radiation physics, and nanomaterials, and he has published more than 300 research papers in internationally reputed journals. Under his guidance, 30 Ph.D. scholars and 16 M.Phil. students successfully completed their degrees.

Beyond his academic contributions, Dr. Dhole is also an accomplished science fiction writer and essayist. He has authored six science fiction books and published over 500 scientific articles in newspapers, supplements, and magazines. His science fiction works and popular science writings have been incorporated into the academic curricula of various universities, and several students are pursuing doctoral research on his literature.

Dr. Dhole's contributions to literature have been widely recognized. He has received 11 prestigious awards, including two from the Government of Maharashtra and one from the Indian Physics Association.

TRIVIA

Do You Know ?

- **A sugar-cube of nuclear matter would weigh billions of tons**
  Neutron star material is so dense that just one teaspoon would outweigh Mount Everest!

- **Nuclear reactions power the Sun**
  Every second, the Sun converts about 4 million tons of mass into energy via nuclear fusion.

- **You are slightly radioactive**
  Your body contains radioactive potassium-40 and carbon-14—totally natural and harmless.

- **Nuclear energy is millions of times stronger than chemical energy.**
  Splitting a single uranium nucleus releases ~100 million times more energy than breaking a chemical bond.

- **Atoms are mostly empty space**
  If the nucleus were the size of a marble, the atom would be as large as a football stadium.

- **Radioactivity was discovered by accident**
  Henri Becquerel found it in 1896 when uranium fogged photographic plates—without any sunlight!

Neutron as a Probe for Condensed Matter Physics and Its Connection to Real-Life Applications

Dnyaneshwar Bhosale
Technical University Munich FRM-II campus, Garching, 85747, Germany

1. Introduction: From Nuclear Fission to Material Science

The neutron, though electrically neutral, plays a central role in both nuclear and condensed matter physics. Its discovery by James Chadwick in 1932 not only revolutionized our understanding of atomic nuclei but also paved the way for powerful research tools in material science.

In a nuclear reactor, neutrons are produced primarily through the fission of uranium-235. When a U^{235} nucleus absorbs a slow (thermal) neutron, it becomes unstable and splits into two smaller nuclei, releasing ~200 MeV of energy and two to three fast neutrons (FIG 1). These neutrons can further induce fission in neighbouring nuclei, leading to a chain reaction; the same fundamental process used in nuclear power plants to produce energy and in research reactors to produce neutron beams for scientific studies.

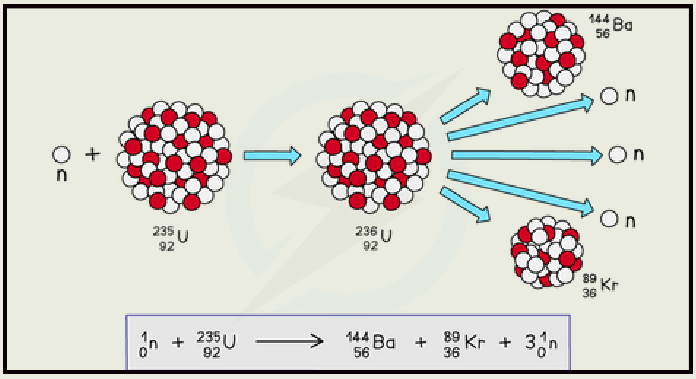

FIG 1: Uranium continuous chain reaction producing three neutrons in each cycle.

These intense beams of neutrons, moderated to suitable energies, are then guided to a variety of scientific instruments located around the reactor. A world-leading example is the Institut Laue–Langevin (ILL) in Grenoble, France. The ILL houses a high-flux reactor and a large suite of instruments dedicated to neutron diffraction, spectroscopy, nuclear, and particle physics. The instrument hall map (see figure 2) illustrates the diversity of applications; each beamline dedicated to probing different aspects of matter, from atomic arrangement to spin dynamics.

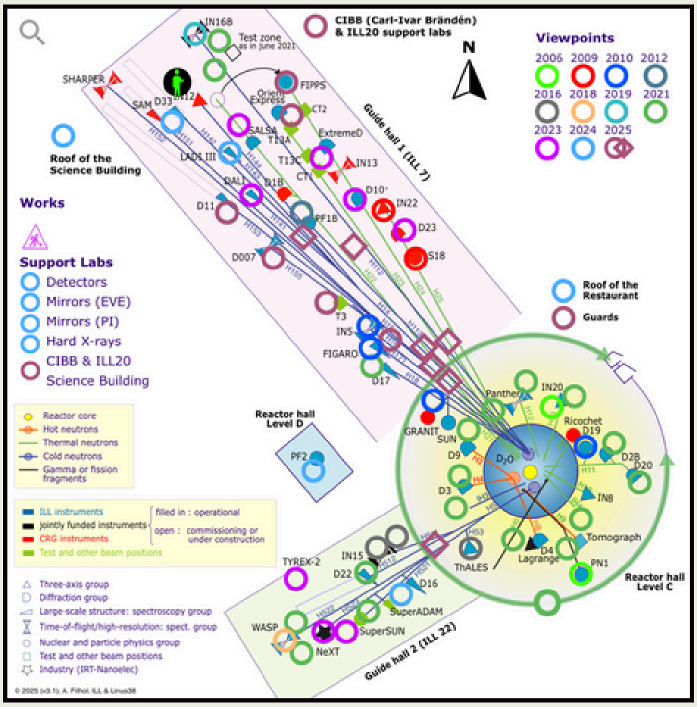

FIG 2: Instruments map for the research reactor at Institut Laue-Langevin (ILL), France. Here D stands for Diffraction instrument, IN stands for inelastic neutron scattering instruments etc. Each instrument shown here as circle, square or triangle has area more than 30 m^2. Image taken from ILL website given in the reference.

2. Neutron Scattering: A Window into the Structure and Dynamics of Matter

Neutron scattering is a fundamental experimental method in condensed matter physics, providing information about both the static and dynamic properties of materials. Neutrons interact with matter through nuclear forces and their magnetic moments, making them uniquely sensitive to both atomic nuclei and magnetic moments of electrons.

2.1. Diffraction vs. Spectroscopy

Neutron scattering experiments can broadly be divided into two categories:

- Diffraction experiments reveal static information: The arrangement of atoms and magnetic moments in a crystal lattice.
- Spectroscopy experiments provide dynamic information: How atoms or spins move and interact with time, such as phonons (lattice vibrations) and magnons (spin waves).

Both techniques rely on **momentum and energy conservation** principles. When a neutron with wave vector k_i and energy E_i interacts with a sample and scatters to k_f , E_f , the changes are given by:

$$Q = k_i - k_f, \qquad \hbar\omega = E_i - E_f$$

Here, is the **momentum transfer** and is the **energy transfer.**

For **diffraction,** the scattering is **elastic** $(E_i = E_f)$, and the condition for constructive interference follows **Bragg's Law:**

$$n\lambda = 2dsin\theta$$

where is the interplanar spacing of the crystal, λ is the neutron wavelength, and the θ scattering angle. Similar applies to x-day diffraction which is only sensitive to probe electronic clouds (atoms) and not the magnetic moments associated with it. Neutron diffraction gives the exact position of atoms and related information in crystals by interacting with nucleus; which not the case for x-rays.

For spectroscopy, scattering is inelastic, allowing measurement of excitations in the material, such as vibrations or magnetic fluctuations.

3. Anatomy of a Neutron Scattering Instrument

Despite differences in purpose, most neutron instruments share a common design based on four key components:

- **Monochromator:** Selects neutrons of a desired wavelength (or energy) from the white beam using Bragg reflection from a single crystal (Cu or Graphite).
- **Sample Stage:** It holds the material under study; may include cryostats, magnets, or pressure cells to control environmental conditions.
- **Analyzer:** Selects scattered neutrons of specific energy or momentum for detection.
- **Detector:** Records scattered neutrons and measures their intensity as a function of scattering angle or energy transfer.

This arrangement allows researchers to map the distribution of scattered intensity in reciprocal space, constructing detailed pictures of atomic or magnetic structures and excitations producing rigorous information about atomic and magnetic dynamics in materials relevant for technology applications.

4. Properties of Neutrons as Ideal Probes

The neutrons emerging from a reactor's beam port possess several defining physical properties:

- **Neutral charge:** Enables deep penetration into matter without significant absorption or surface sensitivity, unlike electrons or X-rays.
- **De Broglie wavelength:** Comparable to interatomic spacings (≈1 Å) for thermal neutrons, ideal for studying crystal structures.
- **Magnetic moment:** $\mu_n \approx -1.91\mu_N$ (~0.001 μB), allowing sensitivity to magnetic moments within materials.
- **Spin:** Makes neutrons sensitive to magnetic ordering and spin correlations.

After moderation, neutrons (>10^{15} at the beam hole) follow a Maxwell–Boltzmann energy distribution, peaking around 25 meV at room temperature, corresponding to a wavelength near 1.10 Å (FIG 3). This range makes them highly suitable for diffraction and inelastic scattering studies in solids.

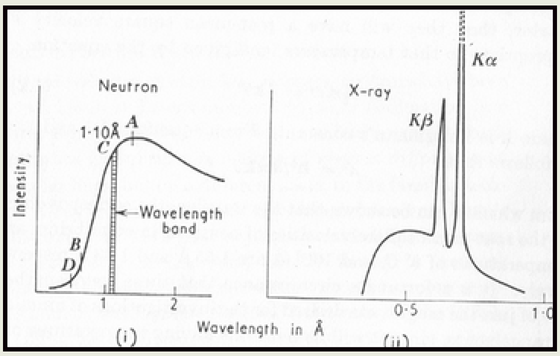

FIG 3. The intensity versus wavelength distribution (i) for the neutron beam emerging from a reactor, indicating the band of wavelength selected by a monochromator, is contrasted with the distribution (ii) from an X-ray tube which gives intense lines of 'characteristic' radiation.

5. Neutron vs. X-ray Diffraction: Complementary Insights

Property	Neutrons	X-rays
Nature of interaction	Short-range nuclear	Long-range electromagnetic
Dependence on atomic number (Z)	No simple trend; isotope-specific	Scattering ∝ Z
Angular dependence	No angular dependence	Decreases with scattering angle
Magnetic sensitivity	Yes (via magnetic dipole moment)	Limited (via resonant scattering)
Penetration depth	Deep (cm range)	Shallow (μm range)

These distinctions mean neutron diffraction excels at locating light atoms (e.g., hydrogen), distinguishing isotopes, and studying magnetic structures, while X-ray diffraction is more suited for electronic and heavy-atom contrast.

6. Magnetic Scattering of Neutrons

Although neutrons are electrically neutral, they possess an intrinsic magnetic dipole moment, which allows them to interact with internal magnetic fields in a material. Two main mechanisms contribute to neutron–electron magnetic interactions:

- Intrinsic spin dipole moment of electrons, arising from unpaired spins.
- Orbital magnetic fields produced by electron motion in atoms or solids.

This makes neutron scattering particularly powerful for studying magnetic materials, spin arrangements, and magnetic excitations. Depending on whether energy is transferred, scattering can be:

- **Elastic** → provides information on static magnetic order (ferromagnetism, antiferromagnetism, spin spirals).
- **Inelastic** → reveals spin dynamics, e.g., magnons, spin gaps, or fluctuations near phase transitions.

Figure 4 shows typical set-up for the triple axis spectrometer preset at the large scale neutron scattering facilities like, ILL, France, BARC, Mumbai, India etc.

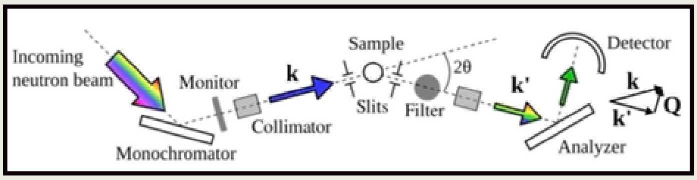

FIG 4: An typical set-up for the triple axis spectrometer to study the spin dynamics in magnetic materials.

7. Detection of Neutrons

Detecting neutrons is nontrivial since they carry no electric charge. Instead, detection relies on nuclear reactions that convert neutrons into charged particles detectable by conventional electronics. Common detector materials and reactions include:

- **^{3}He gas detectors:**

$$23He + n \rightarrow^3 H + p + 0.76MeV$$

- **BF_3 (boron trifluoride) detectors:**

$$510B + n \rightarrow^7 Li + \alpha + 2.3MeV$$

- **Scintillation detectors** using **^{6}Li** or **Gd** compounds for high efficiency.

The resulting charged particles (like ^{3}H and ^{7}Li) ionize the medium, and the produced electrical signals are amplified and counted to measure the neutron intensity.

8. Applications of Neutron Scattering

8.1 Condensed Matter and Materials Research

Neutron scattering is indispensable in determining crystal structures, phase transitions, magnetic ordering, and lattice dynamics. It provides unique insight into phenomena such as superconductivity, ferroelectricity, molecular dynamics, and magnetism.

8.2 Spintronics

In spintronics, the spin of the electron, rather than its charge, is used to store and manipulate information. Neutron spectroscopy enables direct observation of spin excitations, exchange interactions, and spin–orbit coupling, helping design new magnetic semiconductors and quantum materials for faster, energy-efficient devices.

8.3 Emerging Phenomenon: Altermagnetism

A recently discovered phenomenon — altermagnetism — bridges the gap between ferromagnetism and antiferromagnetism. Altermagnets exhibit compensated spin structures (zero net magnetization) but still possess spin-polarized electronic bands. Neutron diffraction and inelastic scattering can probe these subtle magnetic symmetries and the associated spin-dependent transport effects, guiding future spintronic and quantum computing applications.

8.4 Industrial and Biological Relevance

Beyond physics laboratories, neutron techniques find use in:

- Hydrogen storage and battery materials (locating light atoms),
- Residual stress analysis in engineering components,
- Soft matter and biomolecular structure (lipid membranes, polymers),
- Cultural heritage studies (non-destructive testing of ancient artifacts).

9. Conclusion

Neutron scattering stands as one of the most versatile and insightful probes in modern science. From the fission of uranium nuclei to the exploration of complex magnetic and quantum materials, neutrons have become a bridge between nuclear physics and real-world materials research.

Their unique ability to penetrate matter, distinguish isotopes, and probe both atomic and magnetic structures has made them indispensable for advancing fields like condensed matter physics, spintronics, and the newly emerging altermagnetic materials.

Facilities such as the ILL, France, continue to expand the frontiers of neutron science connecting the fundamental physics of the atomic nucleus to the technologies that shape our daily lives.

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Dnyaneshwar R. Bhosale *holds a Ph.D. in Physics (2019) through the collaborative research program between BARC, Mumbai and Savitribai Phule Pune University, Pune. He has accumulated over seven years of research experience (PhD + Postdoc) in neutron scattering, magnetic spectroscopy, and magnetic materials for spintronics applications, alongside five years of teaching experience at Cummins College of Engineering for Women, Pune.*

Currently, Dr. Bhosale is a Marie Skłodowska-Curie Actions (MSCA) Postdoctoral Scientist at the Jülich Centre for Neutron Science (JCNS), Forschungszentrum Jülich GmbH, Germany. His ongoing research expands into inelastic neutron scattering (INS) using both time-of-flight and triple-axis spectroscopy, with a focus on magnetic excitations, spin dynamics, and crystal-field modeling in complex oxide materials such as orthoferrites and garnets. He has conducted and analyzed experiments at several world-leading neutron facilities, including ILL (France), PSI (Switzerland), ISIS (UK), ANSTO (Australia), and BARC (India).

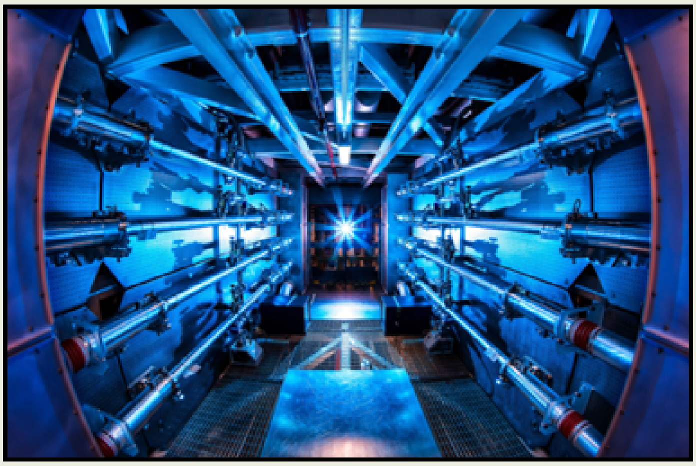
From Lab to Life: Cutting-Edge Nuclear Advances Revolutionizing Energy and Medicine

Sandeep Somvanshi
Department of Physics and Bernal Institute, University of Limerick, Ireland

"The release of atomic energy has not created a new problem. It has merely made more urgent the necessity of solving an existing one."
– Albert Einstein

Introduction

Nuclear physics, the study of atomic nuclei and their interactions, has long been a cornerstone of scientific progress. From unlocking the secrets of the universe's building blocks to powering modern society, this field continues to evolve rapidly. In recent years, particularly from 2023 to 2025, breakthroughs have accelerated, driven by technological innovations, international collaborations, and a renewed focus on sustainable energy solutions. This article explores key advancements in nuclear physics and highlights their practical applications in energy production, medicine, industry, and beyond. These developments not only push the boundaries of fundamental science but also address pressing global challenges like climate change and healthcare.



LLNL, National Ignition Facility Preamplifiers
(Source:https://www.scientificamerican.com/article/nuclear-fusion-lab-achieves-ignition-what-does-it-mean/)

Advancements in Nuclear Fusion

One of the most exciting frontiers in nuclear physics is fusion energy, where atomic nuclei combine to release vast amounts of energy-the process powering the sun. Unlike fission, which splits nuclei, fusion promises cleaner, virtually limitless power with minimal radioactive waste. A landmark achievement came from the National Ignition Facility (NIF) in the United States. Building on the 2022 ignition milestone, where more energy was produced from fusion than consumed by lasers, subsequent experiments in 2023 and 2024 refined this process. Researchers achieved repeated ignitions with higher energy yields, up to 3.15 megajoules net gain in a 2024 test. These advancements stem from improved laser technologies and target designs, incorporating advanced materials like diamond capsules to contain the plasma. Internationally, the ITER project in France made strides toward its first plasma in 2025, with enhanced magnetic confinement systems. Private ventures, such as those by Commonwealth Fusion Systems, demonstrated high-temperature superconductors that could make compact fusion reactors viable. In 2025, AI integration optimized plasma stability, reducing disruptions in Tokamak designs. These fusion breakthroughs are pivotal for practical applications. Fusion could provide base-load power without carbon emissions, supporting renewable energy grids. For instance, fusion-derived heat might enable hydrogen production for fuel cells, decarbonizing transportation and industry.

Advances in Nuclear Fission and Reactor Technologies

While fusion garners headlines, fission-the splitting of heavy nuclei like uranium-remains the backbone of nuclear energy. Recent years have seen a renaissance in fission technology, emphasizing safety, efficiency, and scalability. Small Modular Reactors (SMRs) represent a game-changer. These compact, factory-built units produce 300 megawatts or less, allowing flexible deployment in remote areas or grids. In 2023, NuScale Power's SMR design received final certification from the U.S. Nuclear Regulatory Commission, paving the way for construction. By 2025, projects like the UK's Rolls-Royce SMR and Canada's GE Hitachi BWRX-300 entered early deployment phases, with AI-driven monitoring enhancing operational safety.

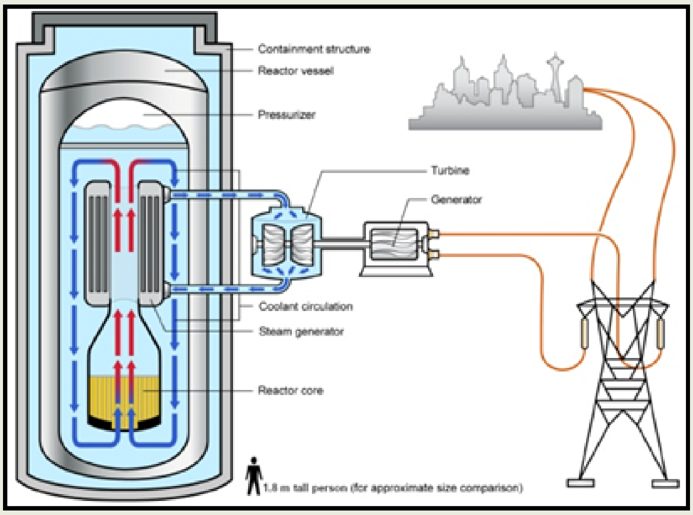
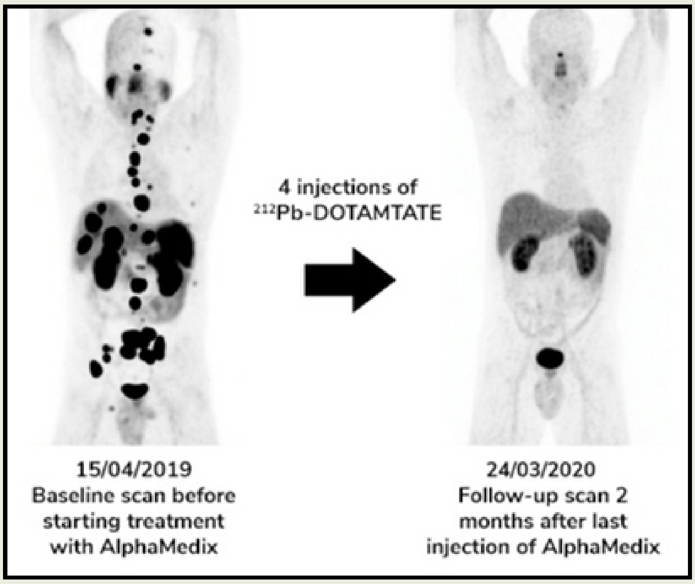


Illustration of a light water small modular nuclear reactor (SMR)

(Source:https://en.wikipedia.org/wiki/Small_modular_reactor)



Patient with metastatic neuroendocrine tumors included in the phase 1 clinical trial of AlphaMedix (^{212}Pb-DOTAMTATE), a drug currently being developed by Orano Med and RadioMedix.

(Source:https://www.oranomed.com/en/targeted-alpha-therapy)

Advanced reactors, such as Generation IV designs, incorporate molten salt or fast neutron technologies for better fuel utilization and waste reduction. The IAEA's 2025 Nuclear Technology Review highlights progress in neutron and gamma-ray detectors, enabling real-time monitoring that minimizes accidents. Additionally, experiments at Brookhaven National Laboratory's RHIC and the upcoming Electron-Ion Collider (EIC) have deepened understanding of quark-gluon plasma, informing safer reactor materials. Practically, these advancements bolster nuclear power's role in clean energy. Nuclear plants now integrate with renewables, providing stable output. In 2023, the Nine Mile Point station in New York began producing clean hydrogen via electrolysis, a model expanded globally by 2025. SMRs also support desalination in water-scarce regions, addressing climate-induced shortages.

Progress in Nuclear Medicine

Nuclear physics has revolutionized healthcare through radioisotopes and radiation technologies. Recent advancements focus on precision and personalization. Targeted Alpha Therapy (TAT) has emerged as a powerful tool against cancer. Alpha particles, with their short range and high energy, destroy tumor cells while sparing healthy tissue. In 2024, clinical trials of Actinium-225-based therapies showed remarkable results in treating metastatic prostate cancer, extending survival rates. The FDA approved new TAT drugs in 2025, building on Lutetium-177 successes. Advances in imaging include hybrid PET-MRI systems, enhanced by AI for faster, more accurate diagnostics. Research in nuclear astrophysics, using laser-driven experiments, has improved isotope production; ensuring supply chains for medical radioisotopes like Technetium-99m. Applications extend beyond oncology. Radiation therapy treats hyperthyroidism and blood disorders, while brachytherapy delivers localized doses for cancers. In agriculture, nuclear techniques sterilize pests and preserve food, reducing waste. Environmental monitoring uses tracers to track pollutants, aiding conservation efforts.

Other Emerging Applications

Nuclear physics influences diverse fields. In space exploration, radioisotope thermoelectric generators power missions like NASA's Perseverance rover, with 2025 advancements in Plutonium-238 production enabling longer voyages. Industrial applications include non-destructive testing of materials using neutron radiography, ensuring infrastructure safety. Archaeology benefits from carbon-14 dating, refined with accelerator mass spectrometry for greater precision. National security leverages nuclear forensics to trace illicit materials, while quantum computing explores nuclear spins for stable qubits.

Conclusion

The period from 2023 to 2025 marks a transformative era in nuclear physics, with fusion nearing viability, fission becoming smarter and medical applications saving lives. These advancements underscore nuclear science's potential to drive sustainable development, from clean energy to innovative therapies. As we face global challenges, continued investment in research-through facilities like EIC and ITER-will unlock further benefits. For students and enthusiasts, this field offers endless opportunities to contribute to a brighter future.

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TRIVIA

Do You Know ?

- **Fusion = the energy of stars, fission = energy of reactors**
  Fusion joins nuclei; fission splits them—two opposite processes, both incredibly powerful.

- **Radiation is older than Earth**
  Some radioactive elements formed in supernova explosions before our solar system existed

Ion-Matter Interactions: A Cornerstone of Nuclear Physics and Technology

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1. Introduction

The study of ion interactions with matter lies at the heart of nuclear physics, materials science, and modern accelerator-based applications. When energetic charged particles traverse a medium, they engage in complex processes with the atoms and electron clouds of the target material. These interactions determine how ions lose energy, how deeply they penetrate, and what modifications they induce within the material. Such fundamental knowledge has not only shaped our theoretical understanding of nuclear physics but has also fueled transformative technologies in semiconductors, medicine, metallurgy, and beyond.

This article presents an overview of ion–matter interactions, their governing mechanisms, and selected applications of ion accelerators, with an emphasis on their relevance to nuclear physics and multidisciplinary research.

2. Mechanisms of Ion Energy Loss

When an energetic ion enters a solid medium, it gradually loses its kinetic energy through collisions with both electrons and nuclei of the target atoms. The overall stopping power (S) is defined as the rate of energy loss per unit path length, expressed as $S = -dE/dx$. This energy dissipation can be broadly categorized into two mechanisms:

2.1. Electronic Energy Loss (Se):

At high energies (above ~1 MeV/amu), ions primarily lose energy via inelastic collisions with the electron cloud of the target atoms. These processes involve excitation and ionization of the target atoms. If the projectile velocity exceeds that of the valence electrons (~10^6 m/s), significant ionization occurs. At sufficiently high energies, ions may be stripped of all valence electrons, becoming fully ionized "bare" ions. This electronic stopping dominates the early stages of ion penetration.

2.2. Nuclear Energy Loss (Sn):

At lower energies (~10 keV/amu and below), elastic collisions with target nuclei dominate. This "hard-ball" scattering displaces atoms from their lattice positions, generating defects such as vacancies and interstitials. These displacements profoundly alter material properties, a principle exploited in ion-beam engineering. Nuclear stopping dominates near the end of the ion's range, where it eventually comes to rest and may be implanted within the material.

The balance between Se and Sn is energy-dependent: electronic stopping is stronger in the initial stages, while nuclear stopping dominates at the terminal trajectory. This interplay determines the **range**, **straggling**, and implantation depth of ions.

2.3. Ion Range and Straggling

The **range (R)** of an ion is the average distance travelled before it comes to rest. Due to the probabilistic nature of collisions, not all ions penetrate to exactly the same depth. Instead, their final positions follow a statistical distribution known as **range straggling**. Factors influencing the range include the mass and energy of the ions as well as the stopping power of the target material.

Ion beams are typically classified according to their energies:

- **Low-energy ion beams (LEIB):** 1–10 keV
- **Medium-energy ion beams (MEIB):** 10 keV–1MeV
- **Swift heavy ions (SHI):** >1 MeV

Each regime produces distinct material effects, from surface modifications in LEIB to deep lattice disorder and track formation in SHI.

2.4. Interaction Regimes

2.4.1. Low-Energy Ions:

At low velocities, ions interact strongly with target electrons, leading to partial neutralization. Subsequent elastic collisions dominate. Such beams are particularly useful for **surface modification** and **shallow implantation**.

2.4.2. Medium-Energy Ions:

In this range, continuous ionization and electron capture/recombination processes occur. Effective charge states of the ions fluctuate, described by Bethe's stopping theory. These beams are widely used in semiconductor doping.

2.4.3. High-Energy Ions:

At energies beyond 1 MeV/amu, ions become fully stripped of electrons, behaving as bare nuclei. Their interactions are dominated by long-range Coulomb forces and deep penetration. Swift heavy ions are crucial for **defect engineering, nuclear reaction studies, and track formation in polymers and dielectrics**.

3. Applications of Ion Accelerators

Ion accelerators—ranging from compact low-energy systems to large-scale synchrotrons— have become indispensable tools for both fundamental nuclear physics and applied sciences. Below are selected applications highlighting their multidisciplinary relevance:

3.1. Semiconductor Industry

Ion implantation revolutionized microelectronics by enabling precise doping of silicon wafers. Since the invention of the transistor in 1947, controlled ion-beam doping has allowed tailoring of conductivity and miniaturization of integrated circuits. Modern semiconductor fabs deploy thousands of ion accelerators annually to meet the demand for faster and more efficient devices.

3.2. Isotope Production

Accelerator-based nuclear reactions facilitate the generation of medical and industrial isotopes. By bombarding target nuclei with energetic ions, isotopes such as **Tl-201,I-123, and Ga-67**are produced for diagnostic imaging, while **C-11, N-13, O-15, and F-18** power positron emission tomography (PET) scans. Neutron-generating reactions (D–D, D–T) further broaden isotope synthesis pathways. This field exemplifies the fusion of nuclear physics with healthcare.

3.3. Hardening of Tools and Alloys

Ion implantation enhances surface hardness and wear resistance of engineering tools without compromising bulk toughness. Unlike conventional thermal treatments, ion implantation introduces controlled subsurface modifications, improving fatigue resistance, corrosion behavior, and dimensional stability. Applications range from surgical instruments to turbine blades.

3.4. Materials Science and Nanotechnology

Ion irradiation enables **defect engineering** in crystalline materials, **modification of optical properties in thin films**, and **nanoparticle synthesis**. By tuning ion mass, energy, and fluence, researchers can design novel materials with tailored conductivity, magnetism, or luminescence.

3.5. Biomedical Applications

Beyond isotopes, ion beams are central to **cancer therapy**. Proton and carbon-ion therapy exploit the Bragg peak phenomenon, where ions deposit maximal energy at a well-defined tissue depth, sparing surrounding healthy tissue. This has emerged as a cutting-edge alternative to conventional radiotherapy.

3.6. Nuclear Physics and Fundamental Research

Ion accelerators remain essential in probing nuclear structure and reactions. By colliding beams with targets, researchers investigate nuclear cross sections, resonance states, and astrophysical reaction rates. These studies provide insights into stellar nucleosynthesis and the origin of elements in the universe.

4 Broader Impacts and Future Directions

The interplay of electronic and nuclear stopping powers not only underpins accelerator science but also informs reactor physics, radiation shielding, and space mission design. In nuclear reactors, understanding ion interactions assists in predicting fuel behavior under irradiation. In space science, ion–matter interactions explain cosmic ray effects on spacecraft electronics and astronaut health.

Looking forward, several trends stand out:

- **Miniaturization of accelerators** for industrial and medical use.
- **High-precision ion-beam lithography** for next-generation microelectronics.
- **Multimodal ion–photon therapies** in oncology.
- **Quantum materials engineering** using ion implantation to introduce controlled defects.

The continued convergence of nuclear physics, materials science, and applied engineering ensures that ion–matter interaction research will remain at the forefront of scientific and technological progress.

Conclusion

The study of ion interactions with matter bridges fundamental nuclear physics and practical technology. From defining stopping powers and implantation depths to enabling semiconductor devices and medical isotopes, these processes highlight the far-reaching impact of nuclear physics in everyday life. As accelerator technology advances, ion beams will continue to offer new frontiers in both scientific discovery and societal benefit.

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Do You Know ?

- **Nuclear forces are the strongest forces in nature**
  They can overcome the immense electric repulsion between positively charged protons inside the nucleus.
- **A nuclear explosion is not a "chain reaction gone wild"**
  It requires extremely precise geometry and timing—reactors and bombs are fundamentally different.

Introduction to Medical Physics

Suraj Mirgal

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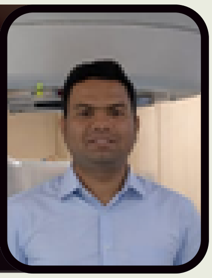

Introduction

Physics and Medicine have long shared a special partnership and it began in the late 19th century. The journey of medical physics truly started with two remarkable discoveries of X-rays discovered by Wilhelm Conrad Röntgen in 1895 and the radioactivity studied by Marie Curie and Pierre Curie. Röntgen's accidental discovery of X-rays opened a third eye to look inside the human body without surgery, while Madame Curie's extraordinary work on radioactive elements such as radium and polonium revealed foundation of both diagnosis and therapy. These two scientific revolutions laid the foundation for the entire field of medical physics.

In India, development of the medical physics field is done by Bhabha Atomic Research Centre (BARC) , Atomic Energy Regulatory Board (AERB) these institutes are responsible for education, research, and safety standards, helping the profession gain national recognition.

Roles and Responsibilities

A medical physicist is a healthcare scientist who blends physics, technology, and biology to improve diagnosis, treatment, and patient safety. Their primary responsibility as a medical physicist is to make sure that radiation is used in the right amount, at the right place, and in the safety of occupational staff and public.

Medical physicists can work in hospital in three departments like Radiotherapy, Nuclear medicine and Radio diagnosis.

Radiotherapy Department:

Above diagram shows typical work flow of the radiotherapy department in which Planning and patient specific quality assurance.

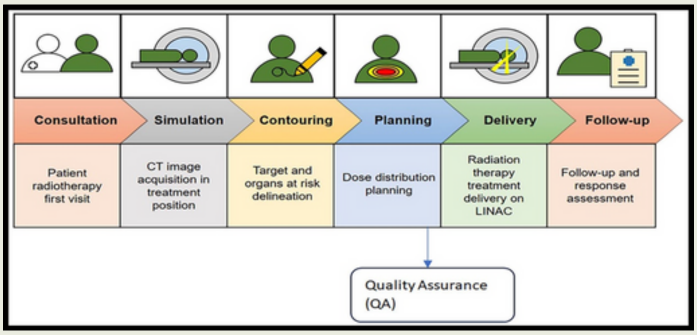

Image 1. Typical Workflow of Radiotherapy department

The Radiotherapy Department is a vital part of any cancer treatment center, dedicated to the use of ionizing radiation for Radiotherapy, also known as radiation therapy, involves the precise delivery of high energy radiation usually X-rays, gamma rays, or electron beams to destroy cancer cells while sparing surrounding healthy tissues.

Treatment planning in radiotherapy most important steps in which dose calculation done using Treatment Planning System (TPS) by help of various algorithm like Monte Carlo , Analytical Anisotropic Algorithm etc. .These algorithms simulates the transport and interaction of millions of radiation particles (photons or electrons) as they pass through different tissues of the patient's body, which is calculate on simulated CT .Whichever plan in finials by Radiation Oncologist then first step of medical physicist to do Patient specific quality assurance which ensure planned dose distribution created in the Treatment Planning System (TPS) is accurately delivered by the treatment machine (LINAC) for each individual patient.

Other important role such as commissioning of linear accelerators to maintain accuracy. The medical physicist or Radiological Safety Officer (RSO) ensures compliance with AERB safety guide line, performs radiation surveys, and maintains detailed dose and QA records.

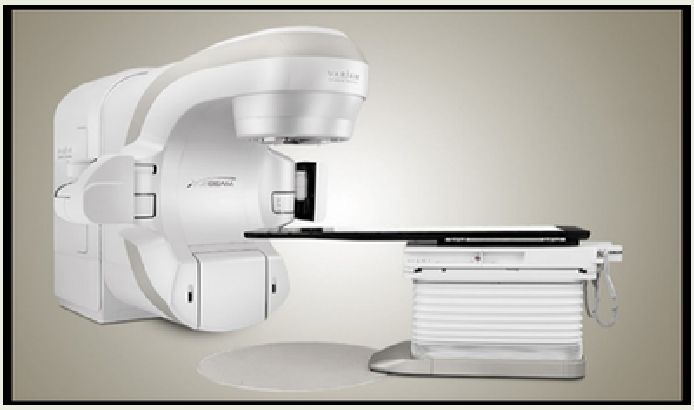

Image- 2 Linear Accelerator

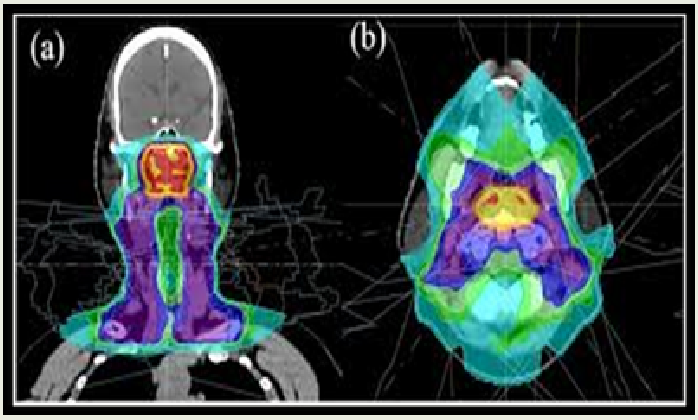

Image-3 Treatment Planning System (TPS)

Medical physicist responsible for provide technical and scientific training to radiation therapy technologists, medical residents, and students, ensuring that all staff understand the principles of radiation physics and safety.

Nuclear Medicine department

The Nuclear Medicine branch is a specialized branch of medical science that uses radioactive materials (radiopharmaceuticals) for the diagnosis and treatment of various diseases. Nuclear medicine provides functional and physiological information about organs, tissues, and cells.

While performing diagnostic procedure the small amounts of radioactive tracers are injected in to patients via orally, intravenously. These radioactive emit gamma rays or positrons, which are detected by imaging systems such as the Gamma Camera, SPECT (Single Photon Emission Computed Tomography), or PET (Positron Emission Tomography) scanners. The resulting images help physicians study organ function, detect cancer, evaluate heart , kidney functions. Along with imaging purpose radiopharmaceutical can use for therapeutic procedures, such as Radioiodine (I-131) therapy for thyroid disorders and Lutetium-177 or Yttrium-90 therapies for cancers.

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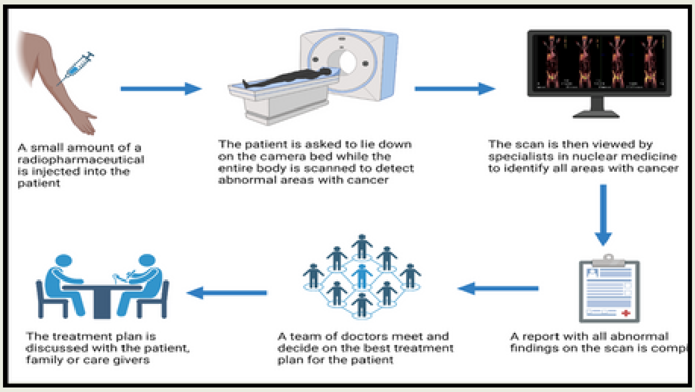

Image 4. Typical Workflow of nuclear Medicine department

Medical Physicist is responsible for keeping all instrument such as dose calibrator .physicist have to perform periodic survey, calculate dose due to administrated radiopharmaceutical. Nuclear medicine technologist is responsible to administer the radiopharmaceutical in to the patient.

Radiology Department

The Radiology Department is one of most important department in hospital which helps in diagnosis of disease by help of X ray . It employs technologies such as X-rays, CT (Computed Tomography) and Mammography to visualize internal organs and structures. Radiologists interpret these images to aid in accurate diagnosis and treatment planning. The department also focuses on image-guided procedures like biopsies and interventional radiology. Supported by technologists and medical physicists, the radiology department ensures accurate imaging, radiation safety, and optimal patient care through advanced imaging techniques and quality assurance.

Physicist in other radiation allied disciplines

In food irradiation and industrial radiography. a health physicist ensures the safe and controlled use of ionizing radiation. Radiation can use for to preserve food, eliminate pests, and reduce spoilage or contamination and in industry the use of radioactive sources or X-ray machines for non-destructive testing (NDT) of materials. Health physicist responsible for radiation safety program management, including shielding design, dose monitoring, and equipment calibration. The physicist verifies that radiation doses delivered to food products meet regulatory standards set by organizations such as the AERB, IAEA, and WHO. They monitor worker exposure, maintain safety records, and ensure proper storage and handling of radioactive sources. By maintaining safety and compliance, health physicists enable the effective and hygienic application of food irradiation technology.

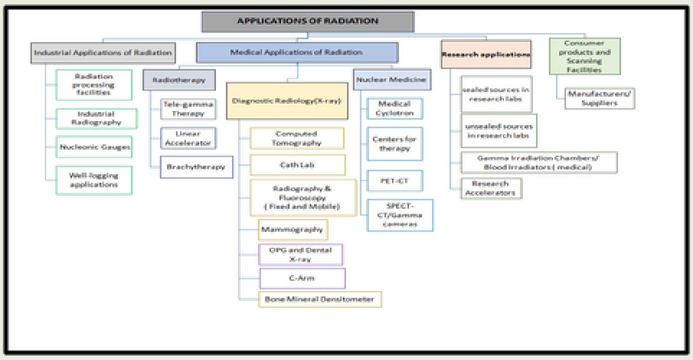

Image -5.Application of Radiation

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Evolution in an Atom

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Time is one of the greatest enigmas of nature, perhaps the most fundamental dimension of the universe. Humans, in their pursuit to tame it, have built sundials, sandglasses, pendulums. We schedule our lives in hours and minutes, celebrate birthdays in years, and live by alarms, dates, and deadlines — but even the finest human inventions pale in comparison to the timekeepers designed by Mother Nature.

Hidden deep inside matter lies the radioactive decay. Unlike our wristwatches that rust or our calendars that change every year, these nuclear clocks tick with consistency — unaffected by heat, pressure, or chemistry. They don't measure fleeting seconds; they measure millions and billions of years.

In spite of these incredible scales, most people remain unaware that the timeline of evolution has been written not by fossils alone, but by the atoms within them. They are silent, unstoppable, and astonishingly precise.

Ice Age Stories

Beneath the layers of ice and snow in Siberia, an enormous curve of ivory just lies buried. To the untrained eye, it is nothing more than the tusk of a woolly mammoth (Fig. 1) — a relic of an Ice Age giant. To zoologists, however, a tusk is a diary: growth rings reveal the seasonal stress, and wear patterns whisper of migrations across vast tundra. The zoologist finds what and how the creature lived; the physicist finds when it lived — in the mammoth's case, its tusks' composition is a precise chronometer.

The age of such fossils is measured through radiocarbon dating, using the **Carbon 14 (C-14)** isotope (effective up to tens of thousands of years). This radioactive isotope is continuously produced in the Earth's upper atmosphere. All living organisms constantly absorb both the stable C-12 and the unstable C-14 throughout their lives, maintaining a constant ratio that matches the atmosphere.

When the mammoth died, its tissues stopped exchanging carbon with the atmosphere. From that moment, the C-14 inside the tusk began to decay back into nitrogen (N-14) at a steady rate. The half-life of carbon 14 is 5,700 years, and using it for dating organic materials is highly effective and reliable for dating back to approximately 60,000 years ago, making it the perfect tool for Ice Age studies. By measuring how much C-14 remains today, scientists can calculate when the animal formerly lived — not in vague "ages ago," but in precise years. [1]

This precision showed, for example, that the last mammoths survived on Wrangel Island until 4,000 years ago – thousands of years later than previously thought. Each bone, tusk, or tooth becomes a ticking archive, transforming into a voice from the past.

Figure 1: The Woolly Mammoth (*Mammuthus primigenius*)

Tracing Humanity

From the frozen tundra of mammoths to the valleys of Ethiopia, these isotopes still uncover new chapters. Fossils — including dental remains and scattered skeletal remains — unearthed at theLedi-Geraru site revealed that early *Homo* species lived beside *Australopithecus*.

Using $^{40}Ar/^{39}Ar$ radiometric dating — a method based on the decay of K-40 into Ar-40 — researchers established precise ages for sediment layers between 2.78 and 2.59 million years ago. To determine this, they search for layers of **volcanic ash** that lie directly above and below the sedimentary layer containing the fossils — a technique called **bracketing**. This reshapes our understanding of human evolution. Rather than a single ancestral species giving rise to modern humans, the evidence points to a **diverse evolutionary landscape**, where multiple hominin species may have shared habitats, resources, and maybe even behaviors. Perhaps our ancestors coexisted far earlier than previously thought. [2]

By extending these dating techniques, we can move from studying early humans to uncovering the lives of creatures that roamed Earth millions of years before.

Deep Time Rulers

Deep into the Mesozoic Era, we rely on radioisotopes with exponentially longer half-lives.

Potassium-40 (K-40), a radioactive isotope found in volcanic layers — igneous rocks, decays slowly into argon-40 over hundreds of millions of years. By measuring this decay, geologists can determine the age of the rocks and, by extension, the creatures trapped within them.

Unlike the mammoth bones, dinosaur fossils are found in the sedimentary rock, but K-40 is primarily found in the igneous rock. These fossils can't be dated directly as the extreme heat required in the formation of the rock destroys any organic remains.

Scientists overcome this obstacle using the same principle of **bracketing**. Researchers establish the time frame, or "bookends," for the fossil layer trapped between them using the K-40 isotope. This method allows us to peer into eras when continents drifted, oceans shifted, and dinosaurs ruled, proving that the Geologic Time Scale (a system used to describe the timing and relationship of events in Earth's history) is calibrated by this consistent atomic process. [3]

The Oldest Clocks

Long before all this, life had already begun in its simplest forms. Microbes were the planet's first inhabitants, cycling nutrients, and laying the foundations for every ecosystem that would follow. Some of these microorganisms left behind stromatolites, layered structures preserved in ancient rocks, which stand as the oldest fossils on Earth.

With a half-life of over 4.5 billion years, Uranium-238 **(U-238)** decays so slowly that it is one of the longest-lived radioactive isotopes known. By measuring the ratios of uranium to its decay products in rocks that contain microbial fossils, researchers can pinpoint the very moments when life first began to flourish. These measurements allow us to look back billions of years, to a time when Earth's atmosphere lacked oxygen.

Yet, before any creature took its first step, there had to be a beginning—the initial spark of life. In 1953, two young scientists, Stanley Miller & Harold Urey, aimed to stimulate the conditions. In a simple glass flask, they sealed water, methane, ammonia, and hydrogen — gases thought to resemble the young Earth's atmosphere. Then they struck it with artificial lightning. Days later, the flask darkened, and within it appeared amino acids — the very molecules from which proteins, cells, and eventually all animals were built.

Through microbes, we can trace the earliest steps of evolution, from single-celled pioneers to the complex tapestry of life that would eventually include dinosaurs, mammals, and humans.

Stable Isotopes

While radioactive isotopes tell us ***when*** life existed, ***how*** organisms lived and interacted with their environments can be revealed by stable isotopes as these do not decay over time; instead, they are incorporated into tissues such as bones, teeth, shells, and even hair. These atoms chronicle the diets, migrations, and environmental conditions experienced by animals across millennia.

By analyzing the carbon isotope ratios in herbivore teeth or fossilized plant matter, scientists can reconstruct ancient diets and understand the composition of prehistoric ecosystems. On the other hand, variations in oxygen isotope ratios (preserved in bones & teeth) can indicate seasonal temperature changes or shifts in water sources. Fossilized teeth, for example, can show whether an ancient mammal roamed vast territories or remained in a small habitat. Even modern species carry these atomic traces, enabling scientists to study migration and diet in living animals with the same precision used for fossils.

Animals, past and present, are transformed into natural recorders of ecological and climatic history.

Atomic Microscopes: Peering Inside Time

The secrets of ancient life are no longer hidden in stone; they are read at the atomic level. Modern physics has given scientists extraordinary tools that allow them to probe fossils, bones, and even living tissues with unprecedented precision.

Synchrotrons, for example, generate ultra-intense X-ray beams capable of imaging microscopic structures without damaging the specimen. Using this technique, researchers have examined fossilized dinosaur embryos to see their developing bones, uncovering details about growth and development.

Neutron tomography offers yet another window into the past. It is a non-destructive imaging technique that uses slow-moving neutrons to penetrate materials and reveal internal structures based on their neutron absorption properties. Unlike X-rays, neutrons interact strongly with light elements such as hydrogen and lithium, making them ideal for studying fossils encased in dense matrices like calcareous concretions. This method allows researchers to visualize anatomical features—such as vertebral columns (Fig. 3)—without damaging the specimen, offering high-resolution insights into the morphology and preservation of ancient organisms. [4]

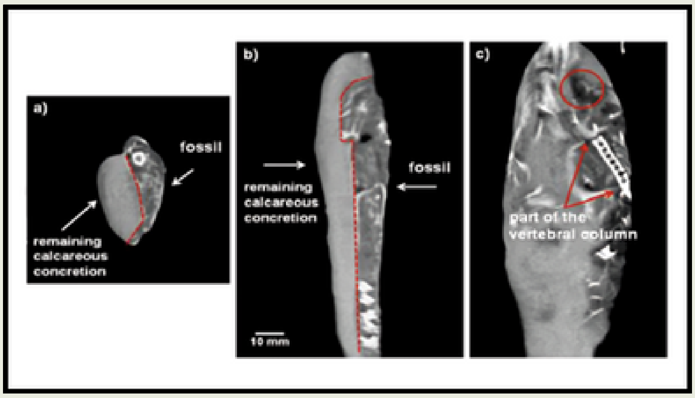

Figure 3: Neutron Tomography of Fossil Embedded in Calcareous Concretion. (Panels a–c show side, cross-sectional, and close-up views of a fossil preserved within calcareous concretion.) [4]

These tools turn fossils and biological specimens into living archives. Each atom carries information about evolution, climate, diet, and movement of the past.

Modern physics has transformed palaeontology and zoology into investigative sciences where the smallest particles reveal the largest stories—allowing humans to read the lives of creatures millions of years gone.

Conclusion

The consistency of the atomic nucleus and the slow, steady tick of radioactive decay make the entire evolution coherent. Every isotopic ratio tells a story, from the seasonal movements of birds to the grazing patterns of dinosaurs, and every atom is a witness to the cycles of life and the environment over time. Life itself becomes the ultimate archive with its undeniable time stamp.

The true power of this interdisciplinary union is its capacity to show us the entire story, from the exact moment the last great mammoth died to Miller and Urey's demonstration of the chemical spark of life.

In every bone and every cell, time is etched—and life itself becomes the ultimate witness to the passage of eons.

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Vajra Cipher: The Digital Armor of Atomic Dharma

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Abstract:

What if the biggest threat to nuclear safety isn't a missile but a malicious script? This article, Vajra Cipher[1]: The Digital Armor of Atomic Dharma[2], starts with the Stuxnet attack, the case where software was first used as a weapon against reactors. It takes a look at how digital security becomes the main defense for atomic energy. Then, we follow the development of safeguards, from AI-driven digital twins to quantum encryption. The article indicate that these technologies represent an Atomic Dharma: a digital responsibility where precise coding maintains the balance of creation itself.

[1] Vajra Cipher -used metaphorically to represent a resilient, multi-layered digital defense inspired by the Vajra.

[2] Atomic Dharma -used here to describe the ethical responsibility guiding nuclear cybersecurity.

I. The Silent Weapon of the Atomic Age:

In 2010, a stealthy weapon penetrated cyberspace: not a missile, but malicious code. Stuxnet breached Iran's Natanz nuclear site, inducing its centrifuges to self-sabotage while operators monitored deceiving displays. For the first time, humanity perceived software causing physical damage to the atom. Since then, boundaries between silicon and uranium have blurred; each reactor now operates within a network of digital control that makes it vulnerable despite its advancements. In this new era, firewalls have emerged into a modern **Vajra**, forged not by thunder but by the

Atomic Dharma, the sacred duty of ethical stewardship, upheld or betrayed. The verdict is clear: in this atomic era, cybersecurity has become the aegis of peace, ensuring the atom's obedience to human will.

II. Where Code Meets the Core

Modern nuclear facilities are now a hub of two once distinct but closely linked domains: **Information Technology (IT)** and **Operational Technology (OT)**. IT directs administrative networks and information, while OT manages fission physics, including valves, control rods, and feedback loops vital for a reactor's core. This union exposes new loopholes and affirms the need of the Vajra Cipher as the reactor core grows digital.

The problem isn't the data. It's the control. Uniting these two layers, which is supposed to simplify monitoring and maintenance, unveils a common attack surface. A breach that begins with an employee's inbox could end inside the reactor core. To address the vulnerability, implementing a structural partition is essential. Air-gapped systems keep crucial control networks isolated from external networks. This setup provides extra security to stop unauthorized access. Similarly, strict firewall rules restrict data traffic to authenticated, validated sources. These measures ensure that the **Atomic Dharma** is no longer protected solely by concrete and steel but guarded by code enforcing this digital separation.

III. The Building Blocks of Atomic Trust

The **Atomic Dharma**, our duty for safety, faces vulnerabilities as each attack targets something that, as humanity, we cannot afford to lose: **trust, information, or time**. The entire system remains intact until one of these pillars weakens.

- **Sabotage** targets anarchy. Operators have only seconds to respond; **time** becomes their most limited resource.
- **Espionage** thrives on information imbalance. It steals safety blueprints, leading to a lack of information for defenders. The 2019 Kudankulam breach was a malware precursor targeting administrative systems.
- **The insider threat** works from within, exploiting the most fragile resource: **trust**. Whether intentional or accidental, the human element 'trust' turns security into uncertainty.

Quantifying these threats would clarify the stakes. Loss of trust could erode confidence, costing nuclear facilities millions for regulatory penalties. Losing information from espionage could lead to damage recovery in millions and require months of investigative audits. The paramount commodity is time: a single zero-day instruction in OT can cause thermal hydraulic instability and produce catastrophic conditions within an hour.

Together, these influences wear down the meticulously designed safety margins. They shift a once stable balance into an uncertain state, link by link, breach by breach. The defense against this must be absolute: a Vajra Cipher designed to restore the core's integrity.

IV. The Armor Takes Shape

To restore stability to the Atomic Dharma, defense must be absolute, a layered Vajra Cipher built from the precision of computer science and insight of artificial intelligence.

Network segmentation is the first layer, partitioning the reactor's digital nervous system into isolated zones. This prevents a breach in one zone from reaching the core. This is reinforced by unidirectional gateways (data diodes), hardware protectors that allow data to flow outward for monitoring but prevent inward commands for control.

Beyond structural defenses, AI now manages areas that once required humans. Machine learning systems maintain dynamic digital twins of reactors, which are replicas that gain insights from each vibration, temperature change, and neutron pulse. When an attacker alters sensor readings, as Stuxnet once did, AI identifies the deception by analyzing its dynamics: its rhythm, latency, and patterns. This provides essential time for defenders to act and respond.

Some nuclear facilities have started using **blockchain-**

based Secure Update Ledgers. Every software patch that is critical to reactor operations, such as PLC (Programmable Logic Controller) firmware updates, is to be verified by multiple nodes before installation. Mere detection of even a single malicious instruction aborts the update process. This approach stops tampering by making unauthorized changes impossible to conceal.

Together, these technologies form a cognitive shield: a modern digital Vajra that ensures the atom aligns with human intent.

V. One Dharma, Many Defenders

In practice, **Atomic Dharma** means a unified philosophy of protection. Nations share cyber-threat intelligence, participate in coordinated incident-response simulations, and follow transparent reporting standards. It also involves following security standards, disclosing vulnerabilities, and matching digital safeguards with international safety standards. Concisely, it is the technical practice of choosing collaboration, clarity, and collective risk reduction instead of making decisions in isolation.

This interwoven defense cannot be achieved alone. Upholding the **Atomic Dharma** requires coordinated, worldwide action established by global organizations. The **International Atomic Energy Agency (IAEA)** sets global regulatory standards. Organizations such as the **US Department of Energy (DOE)** and **Cybersecurity and Infrastructure Security Agency (CISA)** impose steadfast security standards. In India, **CERT-In** monitors threats and addresses incidents like the Kudankulam malware attack.

Every simulated attack and shared intelligence report enhances the protection. The **Vajra Cipher** goes beyond just code and control representing an ethical commitment connecting engineers, scientists, and nations to protect the sanctity of atomic energy.

VI. Foresight Beyond Fear

As the globe unites for the common responsibility of Atomic Dharma, we gaze toward the future. Hope now lies in the next domain of digital protection, not defined by conflicts but by ethics.

Quantum encryption promises such a level of secure communication that even light cannot breach it. Any attempt to tamper with the information collapses the quantum state, exposing the intrusion. Earlier discussions in the first edition of *Bhoutiki Pradnya* have explored the expanding frontier of quantum technologies, from Prof. Sanket Gogte's *"Quantum Computing: The Bizarre Theory's Promise of a Powerful Regime of Computation"*, which introduced the fundamentals of quantum logic, to Yashvardhan Shukla's *"Quantum Warfare: The Next Frontier"*, which examined its strategic implications. Building on those foundations, quantum encryption now emerges as a core pillar of next-generation nuclear cybersecurity.

Ethical AI emerges as the guiding principle of automation, learning not only from data but from responsibility. For example, an ethical AI assistant might adjust access permissions during routine maintenance. Ensuring that only the right personnel can make changes to OT.

Across research centers, scientists are creating systems that can adapt faster than the challenges they confront. The future of nuclear cybersecurity is to be shaped by anticipation, reinforced by trust, and anchored in dharma (ethical discipline).

VII. The Silent Vow

The journey from the destructive code of Stuxnet to the protective shield of the Vajra Cipher reveals an axiom: the safety of the atom now relies on our command of code.

Cybersecurity has evolved into a **digital protective shield**, a partition that separates order from digital chaos. As technology advances, threats will also change, fueling a continuous digital arms race where each aggressive algorithm shall encounter a similar savvy defense.

In this new reality, computer science no longer stands beside global safety; it defines it. The precision of programming now upholds the operational integrity of the atomic process itself.

The era of purely concrete containment has ended. In the nuclear age, safety extends beyond walls; it lives within code, networks, and firewalls.

The ***Vajra Cipher*** persists as humanity's silent vow: to protect creation from the brilliance that could unravel it.

Acknowledgment:
This article was developed with the help of AI-based writing and visualization tools, OpenAI GPT-5 and Leonardo AI, to improve language and clarity. All interpretations, conclusions, and editorial decisions are original to the author.

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4. Online publications and news features discussing the link between computer science and atomic research.
5. Conceptual and creative refinements supported by AI-based tools (OpenAI GPT-5 and Leonardo AI).

Terminology Note:

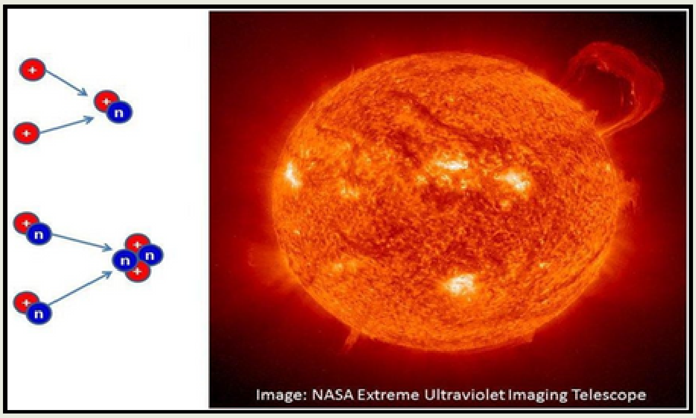
- ***Atomic Dharma*** *-used here to conceptually describe the ethical responsibility guiding nuclear cybersecurity.*
- ***Vajra Cipher*** *-used as a metaphor for a resilient, multi-layered digital defense system inspired by the Vajra.*

Quantum Tunneling in the Stars: The Secret Fire of the Universe

Mandira Koirala
Affiliation

The Sun's Impossible Flame

What if I told you that, by the laws of classical physics, **the Sun shouldn't even shine at all** ? Inside its blazing core, temperatures reach 15 million degrees far too low for hydrogen nuclei to fuse. The **Coulomb Barrier** between positively charged protons is simply too strong. Yet every second, the Sun turns millions of tons of hydrogen into helium, releasing light and warmth that make life possible. How? Through the most magical trick of quantum physics : **Quantum Tunneling.**



The Quantum Shortcut

In our everyday world, objects can't pass through walls. But in the quantum world, particles like protons are also **waves of probability**. When two protons collide, part of their wave ***leaks through*** the barrier giving a tiny chance that they'll merge instead of bounce apart. This chance is unimaginably small for one pair of protons but inside the Sun, with **10^{56} protons** trying every moment, enough succeed to keep our star glowing. That's quantum tunneling nature's way of letting the impossible happen.

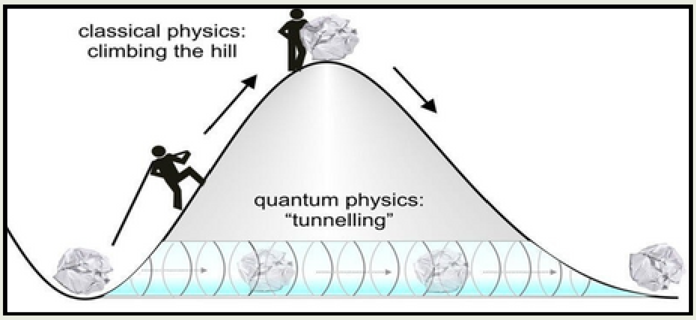
Fusion: The Miracle Within the Sun

When tunneling allows two protons to fuse, they form **deuterium**, releasing enormous energy in the process. Billions of these reactions occur every second, powering the sunlight that reaches Earth. Without tunneling, stars would remain dark, cold spheres and life would never exist. The universe shines because probability allows it to.

Stardust and Quantum Magic

The same process fuels all stars, forging heavier elements carbon, oxygen, iron, the very atoms in your body. So in a way, you and I are **made of stardust**, held together by quantum miracles. Each sunrise is a cosmic reminder that the universe runs not just on energy, but on ***chance***; a whisper from the quantum world saying:

"Even the impossible can shine."



Fun Facts

- Quantum tunneling was first used to explain radioactive decay.
- Without tunneling, stars would need to be 100 times hotter to burn.
- Every second, tunneling reactions in the Sun release energy equal to a billion nuclear bombs.

Beyond Standard Model with Neutrino

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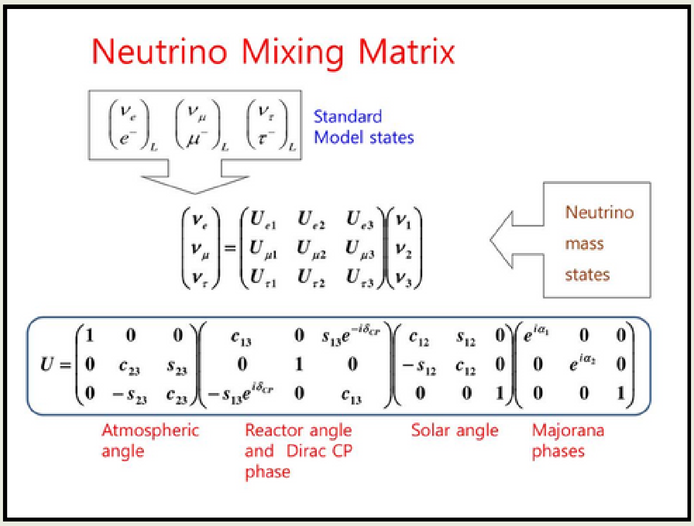
Conservation laws, confirmed by observations at accelerator experiments dictate that matter and antimatter always are produced in pairs which annihilate producing photons. This takes us to a very interesting conclusion that baryogenesis and leptogenesis should also produce equal amounts of matter and antimatter, which would mean that the universe should be filled with light because of annihilation of matter and antimatter. Well, we exist! so we know that this is not the case. Also, we know that our universe is matter dominant. Therefore a set of conditions are required to be met by any theory to explain the matter asymmetry in the universe which forces it to incorporate CP violation, indicating that physical laws are different for matter and antimatter. The present neutrino oscillation theory allows for CP violation through the Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix which gives the mixing of the neutrino flavor eigenstates.

The PMNS matrix is given as follows, The δ_{CP} term which is the difference in the oscillation probabilities of neutrinos and antineutrinos.

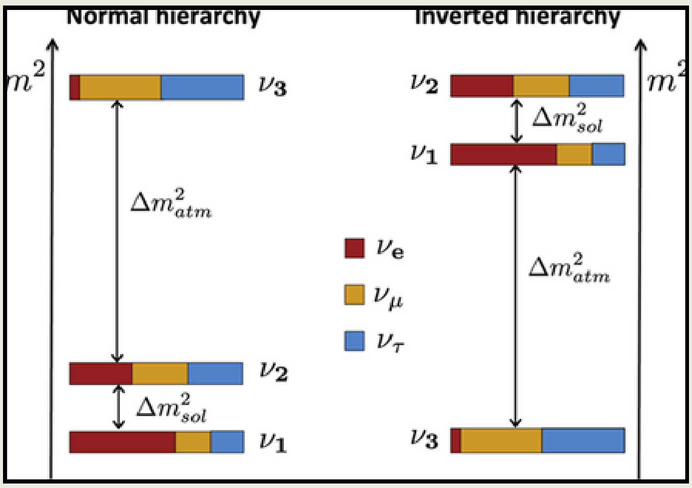
The Dirac Phase term allows for CP violation in neutrino reactions. The value of the term is yet to be determined experimentally. According to current experiments, the value is predicted to be near . While



uncertainties between different experiments exist, it strongly supports CP violation in the neutrino sector. The neutrino oscillation probability has a mass difference term in it.

$$P\left(\nu_e \rightarrow \nu_\tau\right) = \sin^2 2\theta \sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$

Therefore, neutrinos must have mass for them to oscillate between flavors. Since, the probability depends on the mass difference the mass hierarchy of the neutrinos is not known. The normal and inverse mass hierarchy are the most widely used ones. The present standard model does not explain where does the neutrino get its mass from, so several Beyond standard model extensions have been proposed to ascertain the mass mechanism for neutrinos. These BSM extension also allow for extra CP violating terms hence closing the gap between matter-antimatter asymmetry, some of them are discussed here.

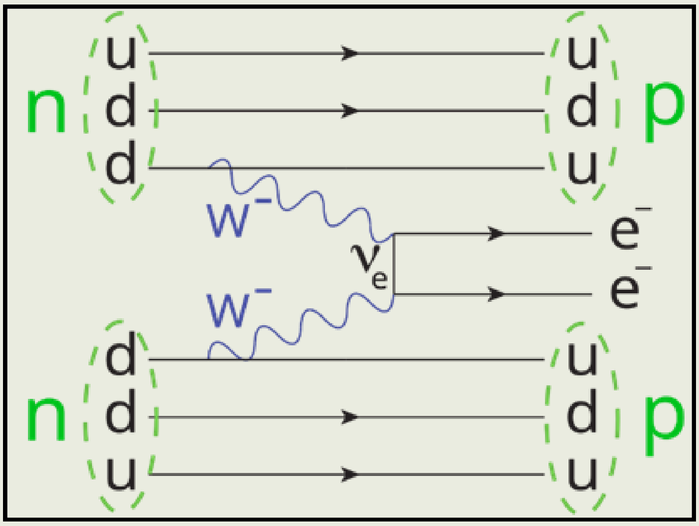


The seesaw mechanism is the most studied BSM extension to explain CP asymmetry and small neutrino mass. It explains the tiny non zero mass of the neutrino by adding a heavy neutrino to the standard model, to which the neutrino mass is inversely proportional.

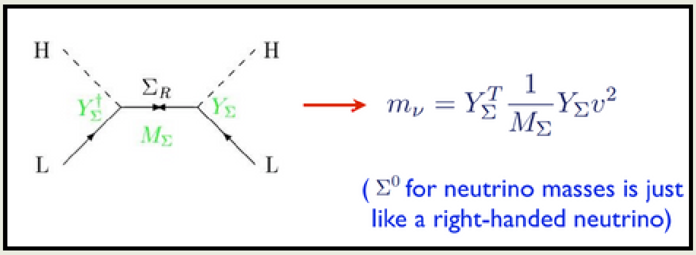
$$m_\nu \approx \frac{\left(m_D{}^2\right)}{M_R}$$

There are three types of seesaw models:

- **Type I:** It is the simplest of the three seesaw models. It adds a heavy right-handed sterile neutrino which interacts only with gravity which allows to study the unification of forces through this mechanism. The sterile neutrino is proposed to have mass independent of the Higgs through Majorana mass mechanism.
- **Type II:** It extends the SM by adding a charged Higgs triplet. The extension predicts neutrinos to be of Majorana type, this allows for neutrino less double beta decay (0νββ), in this model. This is an active experiment to confirm this model. Tata Institute of Fundamental Research, houses the TIN-TIN experiment (^{124}Sn based cryogenic bolometer to detect 0νββ) to be put in the proposed Indian Neutrino Observatory (INO). It also allows for lepton flavor violation also providing a channel to explain the lepton asymmetry through leptogenesis.



Here, two neutrons decay into two protons and electrons without any neutrino being emitted in the final state. The down quark converts into an up quark through weak W boson emission. The Majorana nature of neutrino in this model allows for the neutrino to be emitted and absorbed in the same process. This is disallowed in the SM due to the Dirac nature of neutrino.



Type III: Hypercharge-less heavy fermion triplet is added to Standard Model. The neutrino mass is generated through the exchange of a heavy neutral fermion triplet Σ^0. The fermion triplet is used analogous to the right-handed neutrino.

Everyday Nuclear Physics

Diganta Hazarika
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Prologue

First of all, I would quickly like to say how this article really came about. The invitation for articles for this Bhoutiki Pradnya edition came about a month ago. With the theme being Nuclear Physics and I being quite a novice in physics in general, my immediate and almost final thought was: there is hardly a way I will be able to contribute with an article to this edition. However, as soon as the semester exam got over, there was another push from one of the teachers for some contribution. But this time around, there was something which helped me coming up with an idea. It was the theme for the Physics Reel competition: Everyday Physics. That made me think: why not everyday nuclear physics?

Introduction

Generally, when we see some association of a certain subject to its use, it helps us appreciate the subject much better. And it is all the more important for domains like nuclear physics because they are something we find difficult to visualize the way we can with domains like mechanics, optics, electricity, magnetism, electronics etc. So, let's talk about the things in our regular life where nuclear physics plays a role (sometimes in the lead role and on other times behind the scenes).

Discussion

The Sun is our life. We (all the lifeforms) would not exist without the energy we receive from it. It is with the help of nuclear physics we are able to understand how the Sun is generating the vast amount of energy through transformation from hydrogen in plasma state to helium in a four steps proton-proton cycle. What is more interesting that there have been some ongoing attempts to generate energy using a similar process by scientists across the world. ITER is one such collaboration of 35 countries including India, making some significant progress over the last few decades. The process uses sea water, which is in abundant supply, to extract deuterium required for the fusion process. The extreme level of temperature (over 150 million ^{o}C) required for the plasma state is achieved using a combination of methods like Neutral Beam Injection, Ion Cyclotron Resonance Heating and Electron Cyclotron Resonance Heating. As no material can withstand such extraordinarily high temperature, strong magnetic fields are deployed to prevent the plasma touching the reactor walls. With this set up, ITER expects to produce clean energy equivalent to energy produced from approximately 300 litres of gasoline using just one litre of sea water.

Next thing to mention is the widely known energy generating nuclear reactors where highly radioactive raw materials (primarily Uranium-235) are used to produce vast amount of energy through nuclear fission. This technology has been there for quite a long time. However, there is very high risk associated with it due to the presence of such highly radioactive particles. We all know about the Chernobyl disaster that took place in 1986. In fact, because of the risk of such radioactive exposure, Germany has recently decommissioned all its nuclear reactors and moved heavily into solar and wind power generation. By the way, Germany is a key partner in the ITER project too. decommissioned all its nuclear reactors and moved heavily into solar and wind power generation. By the way, Germany is a key partner in the ITER project too.

Now, we will delve into the very significant nexus between nuclear physics and medical science, mostly around cancer treatment. There are actually quite a few to talk about. Let's browse through them one by one.

- We have heard about PET scan. PET stands for Positron Emission Tomography. PET scan is used to detect disease by showing the metabolic function of organs and tissues. The procedure goes like this.

1. A radioactive tracer (fluorodeoxyglucose) is injected into, swallowed by or inhaled by the patient.
2. The tracer gets absorbed by the cells that are comparatively more active especially the fast-multiplying cancer cells.
3. The tracer emits positrons which collide with electrons and get annihilated, thereby emitting gamma rays which get detected by the scanner.
4. A computer records the readings and displays these high metabolic activity spots in a 3-D image.

- Radiotherapy is another commonly heard term associated with cancer treatment. There are primarily two types of radiotherapy: External Beam Radiation Therapy
- (EBRT) and Internal Radiation Therapy (brachytherapy).neutrino by adding a heavy neutrino to the standard model, to which the neutrino mass is inversely proportional.

1. In EBRT, machines produce ionized radiation that is targeted to attack the DNA of the cancerous cell and thereby destroying them.
2. In Brachytherapy, radioactive sources are placed internally near the tumour, which start to destroy the cancerous cells.

- While the above two methods are conventional radiotherapy techniques, there is another kind of radiotherapy called Boron Neutron Capture Therapy (BNCT). It is a two-step process.

1. First the patient is given a not toxic boron containing drug intravenously. The drug then selectively accumulates in the tumour cells.
2. The affected areas are then irradiated with a beam of low energy neutrons which get captured by the boron compound resulting in fission. The fission releases high energy alpha particles and lithium nuclei that destroy the cancer cells from within.

Conclusion

In summary, although we do not talk about nuclear physics in our regular conversations all that much, it does affect our common life in so many ways. The idea of this article was to touch upon some of those at an introductory level to help evoke some curiosity in the readers. Hope this article is fruitful in accomplishing that idea.

The Role of Nuclear Physics in Advancing Space Exploration Technologies

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Nuclear physics opens new frontiers, even today, through better propulsion, power generation, and radiation protection - all keys to ambitious missions beyond Earth. As interplanetary and deep space missions become increasingly complex, new frontiers once unreachable are being enabled by the unique properties of nuclear reactions and materials.

Fundamentals of Nuclear Physics in Space

The field of nuclear physics investigates the structure and behaviour of atomic nuclei for the purpose of deriving useful energy from them. Nuclear reactions, such as fission (the splitting of heavy nuclei) and fusion (the combining of light nuclei), are favoured in space because of their very high energy density compared with chemical reactions. This energy is then converted more efficiently to electrical and propulsion forms that can enable longer and/or more robust missions where conventional solar power is impractical.

Power Generation: From Radioisotope Generators to Reactors

RTGs have powered such missions as Voyager, Cassini, and the Mars rovers. These devices generate power using the heat from radioactive decay (commonly plutonium-238). Operating for decades with no moving parts, RTGs are well-suited for small and uncrewed missions. For larger crewed missions and lunar or Martian outposts, researchers are developing small fission reactors that can produce from several kilowatts to megawatts of continuous power without depending on sunlight or local resources. Such reactors could operate for 10 to 15 years and can even extend this period.

Advanced Propulsion: Faster Journeys and Interplanetary Ambitions

Chemical rockets are powerful, indeed; however, they are restricted by fuel mass and efficiency. Nuclear thermal propulsion will use a fission reactor to heat hydrogen propellant. Nuclear thermal propulsion might reduce Mars mission duration by 25%, lowering the fuel requirements for a human mission and, at the same time, minimizing the length of time crews have to be exposed to cosmic radiation. NEP systems differ in that their power source - a fusion or fission reactor - generates electricity that in turn powers high-efficiency plasma or ion engines. Plasma rockets, including VASIMR and direct fusion drive, combine rapid transit with high efficiency, enabling human missions to Mars and robotic probes to the outer planets and beyond.

Radiation Protection: Safeguarding Astronauts and Equipment

Cosmic radiation in deep space represents a profound challenge. It is dominated by GCRs and solar energetic particles. Nuclear interaction of the GCRs with the materials of the spacecraft should be properly understood for shielding design and safety evaluation of the astronauts. Contemporary nuclear data and simulation models support risk assessment, radiation-hardened electronics design, and mission planning in respect of optimal exposure profiles. Material and magnetic shielding has been explored and researched, and in many cases, nuclear physics has contributed to the testing of new materials and forecasting secondary radiation effects.

Future Trends and Interdisciplinary Innovation

The scope of nuclear technology in India's space exploration, led by the Indian Space Research Organization (ISRO)s and the Bhabha Atomic Research Centre (BARC), is significant and strategic, primarily focused on enabling long-duration, deep space missions beyond the limits of solar power. This collaboration has already seen success with the use of Radioisotope Heating Units (RHUs) on the Chandrayaan-3 propulsion module to maintain instrument temperatures, a crucial first step. Building on this, the primary goal of current programs is the development of 100-watt Radioisotope Thermoelectric Generators (RTGs) which convert heat from radioactive decay into electricity, vital for missions to the Moon, Mars, and beyond where sunlight is insufficient. Furthermore, ISRO is actively researching advanced nuclear propulsion systems, including both nuclear thermal and nuclear electric concepts, which promise to drastically reduce transit times to Mars from months to mere days, thereby reducing risks for astronauts on future human missions. The future scope includes potential collaboration with Russia on a lunar nuclear power plant to support a sustained moon base, aligning with India's ambitious goal for a crewed lunar mission by 2040 and the broader objective of becoming a global power in space exploration.

Conclusion

Nuclear physics lies at the heart of a new era in space exploration, providing the means to power, propel, and protect the next generation of missions. As research in propulsion systems, compact reactors, and radiation mitigation advances, the prospect of sustainable human presence on the Moon and Mars, as well as the robotic exploration of the solar system, grows rapidly.

Father Of Indian Nuclear Physics - Dr. Homi Bhabha

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Dr. Homi Jahangir Bhabha (30th October 1909– 24th January 1966) was an Indian nuclear physicist who is also known as 'father of Indian nuclear programme'. He was builder of great institutions like TIFR, AEC, Trombay. A great scientist whose vision made India a nuclear power.

Bhabha was born into a wealthy parsi family and had an influential and cultured family. Because of his family his education was good as well as he had interest in music, art and gardening. Though he passed his Senior Cambridge Examination with honours at the age of fifteen, he was too young to join any college abroad. So, he enrolled in Elphinstone College. He then attended the Royal Institute of Science in 1927. The following year, he joined Gonville and Caius of Cambridge University. Where he did mechanical engineering due to his father's insistence. Later he wrote a letter to his father saying he had interest in physics and would like to pursue that. He mentioned that he can do better work in the field of physics than other. Bhabha's father agreed to it and also financed for his studies in mathematics. Bhabha sat the Mechanical Tripos in June 1930 and the Mathematics Tripos two years later, passing both with first-class honours. Bhabha worked at the Cavendish Laboratory while working towards his PhD degree in theoretical physics supervised by Ralph Fowler. At Zurich, Bhabha wrote his first paper in July 1933 with Wolfgang Pauli, which was published in the 'Zeitschrift fur physic' in October 1933. In 1933 he also published his first paper on the role of electron showers in absorbing gamma radiation.

The discovery of the Positron in 1932 and the formulation of Dirac's hole theory to explain its properties led to the creation of the field of high-energy physics. Bhabha made this field the focus of his career, publishing over fifty papers on the topic during his lifetime. He played a key role in the early development of quantum electrodynamics. Bhabha received his doctorate in nuclear physics in 1935 for his thesis titled "On cosmic radiation and the creation and annihilation of positrons and electrons". In 1935, Bhabha published a paper in the Proceedings of the Royal Society in which he first calculated the cross-section of electron-positron scattering. Electron-positron scattering was later named 'Bhabha scattering' after him.

Bhabha had returned to India for his annual vacation before the start of World War 2 in September 1939. War made him to be in India, where he accepted a post of reader in physics at the Indian Institute of Science in Bengaluru headed by Noble Laureate C.V. Raman. In 1940, the Sir Dorabji Tata trust supported his experimental cosmic ray physics research. Bhabha was made a Fellow of the Royal Society in 1941. And the following year he received the Adams Prize. Soon after receiving the Adams Prize, Bhabha was also made a Fellow of the Indian Academy of Sciences and President of the Physics section of the Indian Sciences Congress.

In 1940's he was waiting for war to get over so that he can continue his work in USA/UK with his fellow scientists. But later he decided to stay in India as here he got proper appreciation and financial support and he thought it's his duty to stay and work in India. In 1943, Bhabha wrote to J. R. D. Tata proposing the establishment of an institute of fundamental research. He wanted a school of physics which should be counted as world's best. This proposal with good strategy was kept infront of J.R.D. Tata that led to the establishment of Tata Institute of Fundamental Research (TIFR) in 1945.

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On 26 April 1948 Bhabha wrote to Jawaharlal Nehru, the then prime minister that a commission for atomic energy research should be established to make country powerful. He suggested that the commission should contain few people and report directly to prime minister for the safety of country. Atomic Energy Commission (AEC) was established on 10 August 1948. Nehru appointed Bhabha as the commission's first chairman. The three-member Commission included S. S. Bhatnagar and K. S. Krishnan.

Bhabha thought that technology development for atomic energy research in TIFR can no longer be carried out so he proposed to government to have separate laboratory for atomic energy research. For this purpose, 1,200 acres of land was acquired at Trombay from the Bombay Government. Thus, the Atomic Energy Establishment Trombay (AEET) started functioning in 1954. The same year, Bhabha was appointed the secretary of the Department of Atomic Energy (DAE) under the direct charge of the Prime Minister. Atomic Energy was established as a separate ministry.

Building a labrotary isn't enough a good nuclear power plan is important to make it work. In India thorium is available in ready to extract form and that is 500,000 tons. And uranium is less than 10th of this. Bhabha suggested that rather than uranium thorium can be used for nuclear program. The first generation of atomic power stations based on natural uranium can only be used to start an atomic power program. The plutonium produced by the first-generation of power stations can be used in a second-generation of power stations designed to produce electric power and convert thorium into U-233, or depleted uranium into more plutonium. The second generation of power stations may be regarded as an intermediate step for the breeder power stations of the third generation all of which would produce more U-238 than they burn in the course of producing power. This was Bhabha's three stage nuclear program.

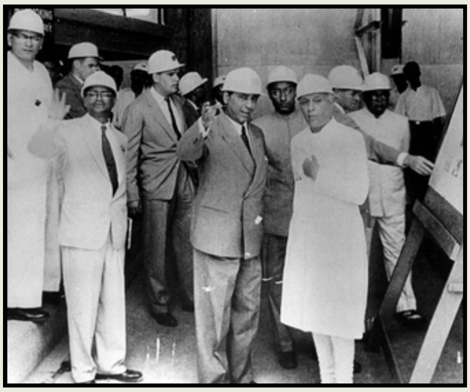
APSARA(1956): This was a one-megawatt "swimming pool" research reactor where India after Russia became the 2nd country in Asia to own this. Bhabha's friendship with sir John Cockcroft (a former colleague at Cavendish) helped us to get natural uranium fuel supplied by the UK. APSARA represented the first stage of Bhabha's plan, helping scientists in India to research experimentally rather than theoretically.

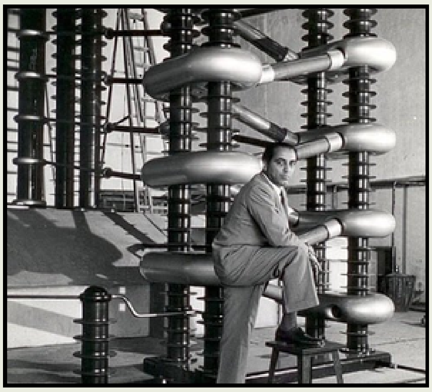
CIRUS (1960): A 40-megawatt reactor that was under agreement between India and Canada in 1956. Bhabha's friendship with W. B. Lewis (head of the Canadian Atomic Energy Agency) helped in securing the deal for the Canada India Reactor Utility Service (CIRUS). CIRUS became India's first good plutonium source which was also used in nuclear test in 1974. Bhabha ensured that nuclear fuel cycle should be indigenously made in India. CIRUS needed supply of heavy water therefore a heavy water plant was established in 1962 in Nangal. In 1961 Plutonium reprocessing plant was initiated by Bhabha in Trombay. Which got completed in 1964 and known as phoenix plant. It was used for extracting plutonium from used fuel. Pheonix helped India to produce plutonium in India itself.

The institutions that he founded are still great institutions, his ideas are still used in nuclear programs. One of the aspect that makes a country powerful and developed is nuclear power which would have not been possible in India without his contributions. Bhabha was first Indian to receive Adam's prize on his doctoral thesis in 1942. In 1948 he received Hopkins prize by Cambridge Philosophical Society. His major contributions were Compton scattering, R-process and in nuclear physics. He was nominated for the Noble prize for physics in 1951 and 1953–1956. He was awarded Padma Bhushan, India's third-highest civilian honour, in 1954.

Society of Edinburgh. He was elected a Foreign Honorary Fellow of the American Academy of Arts and Sciences in 1958, and appointed the President of the International Union of Pure and Applied Physics from 1960 to 1963. Bhabha received several honorary doctoral degrees in science throughout his career: Patna (1944), Lucknow (1949), Banaras (1950), Agra (1952), Perth (1954), Allahabad (1958), Cambridge (1959), London (1960) and Padova (1961). On24 January 1966 Bhabha was heading to Vienna Austria and his plane got crashed and he died. That day India lost one of his prominent scientists of India, a person who saw visions for India and made those visions come true. An article won't justify his intelligence and his contributions

Photos of Dr. Homi Bhabha





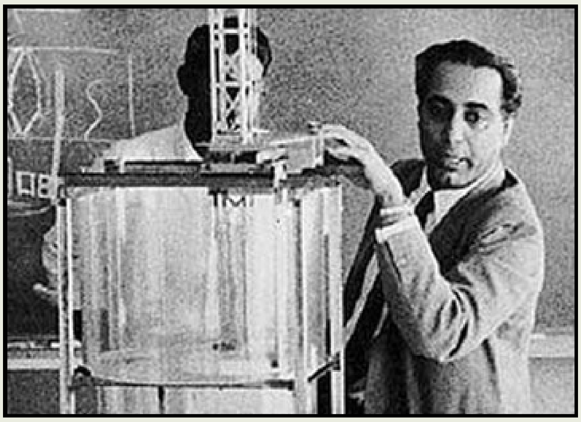


Image Courtesy: Respective Owner

BARC, Mumbai: The Core of India's Scientific Self-Reliance

Chanchal Agarwal
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001

Set against the lush hills of Trombay and the vast Arabian Sea, the Bhabha Atomic Research Centre (BARC) stands as far more than a scientific campus. It is the backbone of India's technological sovereignty. As the Department of Atomic Energy's premier multidisciplinary nuclear research institution, BARC has, over seven decades, driven India's transformation from a technology-dependent nation to a global force in nuclear science.

Genesis of a Vision

BARC traces its origins to January 1954, when Dr. Homi Jehangir Bhabha founded the Atomic Energy Establishment, Trombay (AEET). His conviction was bold and far-sighted: a newly independent India could only secure its future by mastering atomic science. After his untimely death in 1966, the institution was renamed in his honour.

Bhabha's emphasis on indigenous innovation continues to guide BARC's mission. In an era when nuclear knowledge was closely guarded worldwide, Indian scientists worked under severe isolation to develop everything from reactor engineering to plutonium reprocessing. This self-reliance ensured that India's nuclear programme remained resilient to external pressures and sanctions.

Research Reactors: The Technological Bedrock

At the heart of the Trombay campus lies a series of research reactors that have served as the foundation of India's nuclear capabilities. Commissioned in 1956, Apsara, Asia's first research reactor, pioneered pool-type reactor technology in the region. This was followed by Cirus in 1960, a Canada–India collaboration that later played a critical role in India's first nuclear test.

The commissioning of Dhruva in 1985 marked a defining moment in India's nuclear journey. Entirely indigenous in design and construction, Dhruva remains India's largest research reactor, providing the high neutron flux essential for advanced materials research and the large-scale production of medical radioisotopes. More recently, Apsara-U, an upgraded and fully indigenous version of the original reactor using Low Enriched Uranium, was commissioned in 2018, reflecting India's commitment to modern, proliferation-resistant technologies.

Architect of the Three-Stage Nuclear Programme

BARC is the scientific architect behind India's distinctive Three-Stage Nuclear Power Programme, conceived by Dr. Bhabha to harness the country's vast thorium reserves. The programme begins with Pressurised Heavy Water Reactors using natural uranium, progresses to Fast Breeder Reactors that generate more fissile material than they consume, and culminates in thorium-based systems designed for long-term sustainability.

By 2025, substantial progress has been achieved toward this final stage through the Advanced Heavy Water Reactor (AHWR), which aims to demonstrate the commercial viability of thorium fuel cycles and secure India's energy independence for generations.

Science in Service of Society

Beyond strategic and power-related technologies, BARC's contributions have deeply influenced Indian society. In agriculture, its radiation-induced mutation breeding programme has produced over 71 improved crop varieties, collectively known as Trombay Varieties, enhancing yield, disease resistance, and climate resilience.

Strategic and National Security Role

BARC's contribution to India's strategic autonomy is foundational. The centre provided the scientific and technical expertise behind the 1974 Smiling Buddha test and Pokhran-II in 1998. It also played a crucial role in developing the compact nuclear reactor for INS Arihant, completing India's nuclear triad and reinforcing national security.

Looking Ahead: 2025 and Beyond

As India advances through 2025, BARC is expanding its focus to Small Modular Reactors (SMRs), including the BSMR-200 and SMR-55, designed to supply clean energy and industrial process heat. Under the SHANTI Bill (2025), the centre is also leading efforts in High-Temperature Gas-Cooled Reactors to enable large-scale green hydrogen production, aligning nuclear science with global decarbonisation goals.

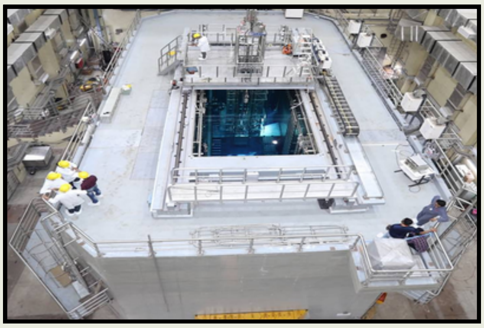
Forging Scientific Leadership

Founded in 1957, the BARC Training School remains one of India's most prestigious scientific institutions. Through its rigorous training of selected science and engineering graduates, it ensures a continuous pipeline of highly skilled Scientific Officers who sustain India's strategic and civilian nuclear programmes.

Conclusion

From its origins on marshy land in Trombay, BARC has evolved into a global scientific powerhouse. It exemplifies the strength of long-term investment in research and faith in indigenous capability. As India moves toward its vision of Viksit Bharat 2047, BARC continues to function as the quiet yet luminous engine of national progress—demonstrating that atomic energy, guided by wisdom and responsibility, can serve humanity at large.

Institute Images



Apsara Reactor

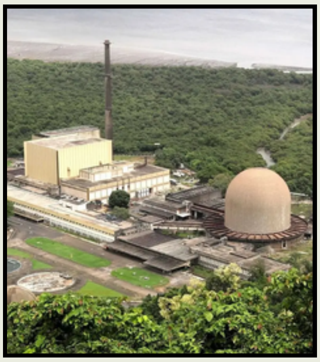
राष्ट्र की सेवा में परमाणु
भा प अ कें
BARC
ATOMS IN THE SERVICE OF THE NATION

Institute Logo

Dept of Atomic Energy

Campus

CIRUS Reactor



Main Building

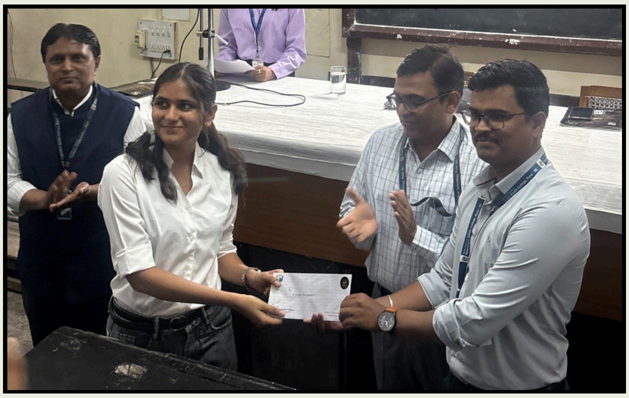
Image Courtesy: Bhabha Atomic Research Center

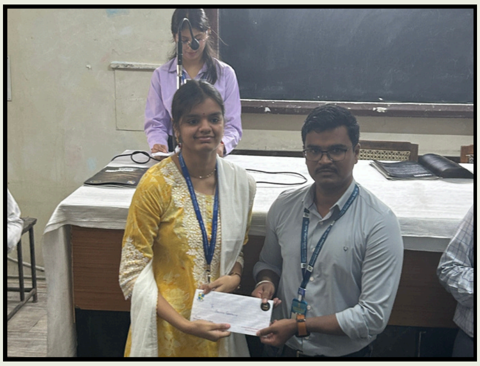
BHOUTIKI Pradnya 3rd Issue Release and Recognition Ceremony

Team BHOUTIKI

Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001

भौतिकी
— The Physics Club —





The **BHOUTIKI Pradnya 3rd Issue Release & Recognition Ceremony** was successfully organized to mark the release of the third issue of **BHOUTIKI Pradnya – Semiconductor Edition**. The event was graced by the esteemed presence of **Dr. Ajay Borkar Sir**, whose encouragement and guidance added great value to the occasion.

This special edition highlights the significance of semiconductors in modern technology and reflects the scientific curiosity, creativity, and dedication of the student contributors. During the ceremony, the third issue was formally released, celebrating another milestone in the journey of BHOUTIKI Pradnya.

The event also included the felicitation of contributors, acknowledging their hard work, intellectual effort, and enthusiasm in making the edition a success. The ceremony served as a motivating platform, inspiring students to continue exploring physics and contributing meaningfully to scientific outreach initiatives.

Tribute to Dr. Eknath Chitnis, Prof. Naresh Dadhich & Dr. James Watson

Rucha Joshi
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001

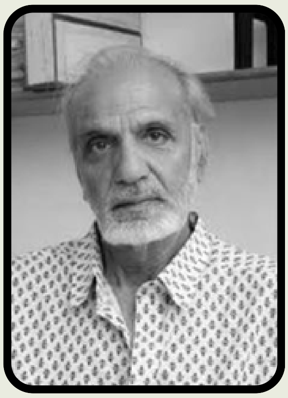
(1925 - 2025)

Dr. Eknath Chitnis

Dr. Eknath Chitnis, (25 July 1925 – 22 October 2025),a space scientist and former member secretary of INCOSPAR (Indian National Committee for Space Research), passed away in Pune at the age of 100, leaving behind a life marked by quiet dignity. He believed that science was not meant to stay confined to laboratories, but it was also meant to serve people and answer their questions. His early years at the Physical Research Laboratory (PRL) were devoted to understanding the invisible cosmic rays, where he designed Cerenkov Counters to detect high- energy particles streaming from space. This foundational work helped shape India's early efforts in nuclear and high-energy detection science.

What made Dr. Chitnis remarkable was not only his research but also his vision. He saw how the discipline of physics could shape technology, education, and a nation's overall growth. His scientific precision and leadership later guided the creation of the "Thumba" rocket launching station and the Satellite Instructional Television Experiment (SITE),both milestones in India's journey to self-reliance in space technology.

Dr. Chitnis's life reminds us that great innovation begins with curiosity and dedication. His story bridges the gap between pure science and its real-world impact, a reminder that every discovery has the power to uplift a nation.



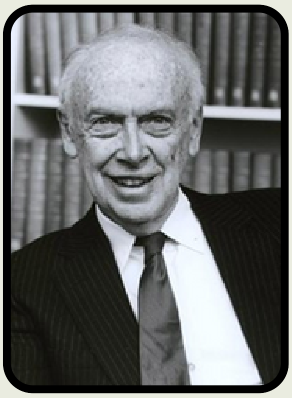
(1944 - 2025)

Prof. Naresh Dadhich

Prof. Naresh Dadhich (1 September 1944 – 6 November 2025) is a name that quietly commands respect in the world of theoretical physics, renowned for his profound work in general relativity, gravitation, black holes, and cosmology. He spent his final days in China, where he completed his journey at the age of 81. Through his research, he explored how space, time, and gravity intertwine, revealing the nature of singularities and those mysterious points where the existing laws of physics collapse. His work deepened our understanding of the universe at its most extreme, from black holes to neutron stars.

Moreover, his brilliance goes far beyond equations and theories. Prof. Dadhich is admired not just for his intellect but for his kindness. As a teacher, he has a rare gift of making the abstract feel alive and meaningful. To his students, lessons on gravity and spacetime were never just formulae, but stories about curiosity, beauty, and how everything in the universe stays connected.

Above all, Prof. Dadhich's legacy rests not only in his scientific contributions but also in the many students he encouraged to think boldly. His influence continues in every young mind he helped shape.



(1928 - 2025)

Dr. James Watson

Dr. James Watson (April 6, 1928 – November 6, 2025), an American molecular biologist who passed away in New York at the age of 97, leaves behind a legacy that has reshaped the way we understand life. Together with Francis Crick, he uncovered the double-helix structure of DNA, a discovery that revealed how our genetic story is written, preserved, and passed down through generations. It was a moment that changed the course of modern biology.

Watson's contributions went beyond this iconic discovery. He conducted pioneering research on gene regulation and the structure of chromosomes, helping shape the field of molecular genetics. He also co-founded the Cold Spring Harbor Laboratory, turning it into a center for cutting-edge research and education.

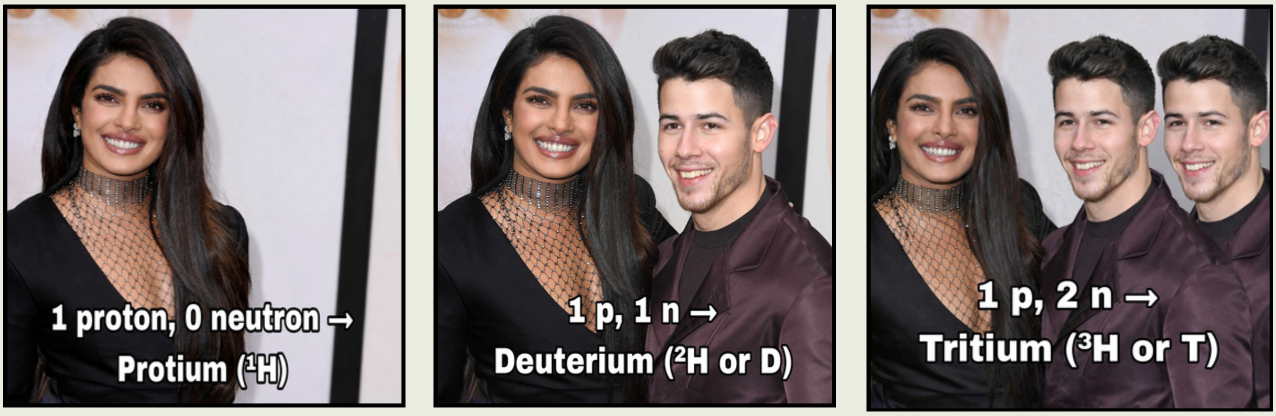
He became widely known to the public through his book "The Double Helix", which offered a personal glimpse into the excitement and challenges of scientific discovery. Through this and his lifelong dedication to science, his work continues to inspire curiosity, guide research, and highlight the remarkable ways of how much we can discover about the living world when we stay curious.

Do You Know ?

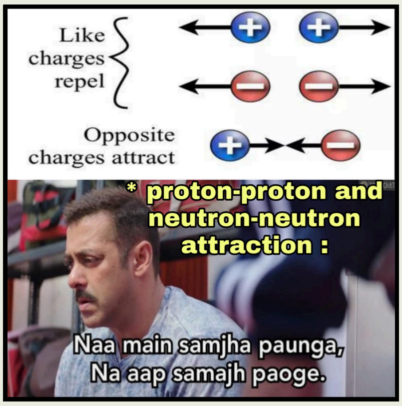
- Dr. Chitnis was a foundational figure in India's space program, working closely with Dr. Vikram Sarabhai in the early days of Indian space research.
- He helped establish the Indian National Committee for Space Research (INCOSPAR), which evolved into ISRO (Indian Space Research Organisation).
- Prof. Naresh Dadhich was a renowned Indian theoretical physicist specializing in classical & quantum gravity and relativistic astrophysics.
- He served as Director of the Inter-University Centre for Astronomy and Astrophysics (IUCAA) in Pune and later held the M.A. Ansari Chair in Theoretical Physics at Jamia Millia Islamia, Delhi.
- James Dewey Watson was an American geneticist and biophysicist, best known for co-discovering the double-helix structure of DNA with Francis Crick in 1953.
- This discovery revolutionized biology by revealing how genetic information is stored and replicated.
- For this breakthrough, Watson shared the 1962 Nobel Prize in Physiology or Medicine with Crick and Maurice Wilkins.

Physics Memes

Shubham Jadhav
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001



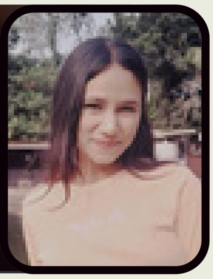
Hydrogen Isotopes

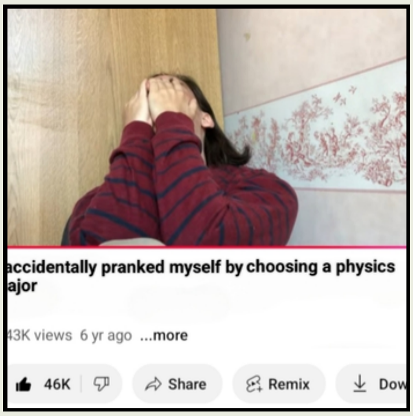


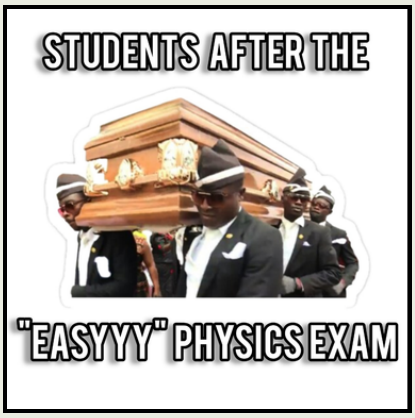
Strong Nuclear Force makes them attract

Physics Memes

Suhani Bistchatri, TYBSc Physics
Affiliation







Nobel Prize 2025 Public Talk by Dr. Siddharth Dhomkar - Jnana Prabodhini

Team BHOUTIKI
Department of Physics, MES's Nowrosjee Wadia College, Pune 411 001

Speaker: Dr. Siddharth Dhomkar, Assistant Professor, Department of Physics, IIT Madras
Venue: Auditorium, Jnana Prabodhini, Pune
Date & Time: Saturday, 22 November 2025, 6:30 PM
On Saturday, 22 November 2025, Jnana Prabodhini, Pune, organized a public lecture on the 2025 Nobel Prize in Physics. The talk was delivered by Dr. Siddharth Dhomkar, Assistant Professor in the Department of Physics at IIT Madras. The lecture attracted students, teachers, and science enthusiasts interested in recent developments in modern physics.

The 2025 Nobel Prize in Physics was awarded to John Clarke, Michel H. Devoret, and John M. Martinis for their pioneering experimental work on macroscopic quantum mechanical tunnelling and energy quantization in electrical circuits. Dr. Dhomkar began by revisiting the "Classical Crisis" of the late 19th century. He explained how classical physics, once thought to be complete, suffered a catastrophic breakdown when faced with phenomena like Black Body Radiation. He walked the audience through the mysteries of Atomic Spectra and Radioactivity, illustrating how these anomalies forced the transition from a continuous world to a "quantized" one.

The lecture then traced the evolution of quantum concepts, starting from the Double-Slit Experiment and Quantum Tunnelling, where particles defy physical barriers. Dr. Dhomkar expertly connected these theories to the discovery of Superconductivity, leading to the 2025 Nobel-winning work on Macroscopic Tunnelling and Quantum Circuits. He concluded this journey with the famous Schrödinger's Cat thought experiment, demonstrating that today, we are no longer just imagining cats that are both dead and alive; we are actually building "Schrödinger's Circuits" where billions of electrons act as a single quantum unit to power the future of computing.

In conclusion, Dr. Dhomkar spoke about India's growing contribution to quantum research through initiatives such as the National Quantum Mission. He encouraged students to view these Nobel Prize–winning discoveries as the starting point for future innovations in quantum computing, sensing, and secure communication. The lecture successfully connected fundamental physics with real-world applications and inspired the audience to explore the rapidly advancing field of quantum science.

Here's to the little girl who turned passion into purpose.

Riddhi Dhondkar was told the sky was the limit, yet she kept aiming beyond it. Every "impossible" became her fuel, every setback her strength. She studied with purpose, holding on to a dream bright enough to light her darkest nights. And then, one day, the universe whispered back…

We are proud to announce that Ms. Riddhi Dhondkar has been selected as a Prospective Astronaut Candidate (ASCAN) with Titans Space Industries Inc., Class of June 2030. She will begin her fully sponsored astronaut training next year under the guidance of veteran astronaut William McArthur.

Riddhi's journey began at Nowrosjee Wadia College, Pune, where she graduated Physics in 2022–23. She then pursued her Master's in Astrophysics at the University of Glasgow, further sharpening her vision of reaching the stars.

Her story is not just about breaking barriers it is about redefining them.

Mr. Anurag Mehta

Ms. Vidhi Baldota

Our department's bright students, Mr. Anurag Mehta and Ms. Vidhi Baldota had remarkable achievement at Avishkaar 2025. Their research poster, exploring the "Predictive Analysis of Human Vision through Biopotential Signals," impressed the Zonal level jury.

Their innovative work demonstrates a sophisticated approach to decoding visual processing, showcasing exceptional promise in the field of biophysics. We wish them the very best for the next stage (University and State Level) of the competition.

We take immense pride in congratulating our students who secured 2nd research funding from Nowrosjee Wadia College. Their dedication, innovative thinking, and consistent efforts have been recognized through this prestigious support. Receiving such funding at the student level is not only an encouragement for their individual projects but also a mark of the strong academic culture nurtured within our department.

These students have shown exceptional initiative in taking their ideas beyond the classroom and working towards real-world applications. Their achievement reflects both their commitment to research and the guidance of faculty mentors who have supported them throughout this journey. We believe that such milestones will inspire many more of our students to explore new frontiers in science and innovation, carrying forward the proud legacy of the department.

Mr. Yash Bundile

Ms, Vidhi Baldota

Mr. Anurag Mehta

IISc Winter School 2025: Exploring the Frontiers of Physics

From December 15th to 19th, 2025, students from our Department of Physics participated in the prestigious Winter School hosted by the Indian Institute of Science (IISc), Bengaluru. Titled "Recent Frontiers in Physics Research: Matter, Life, and Cosmos," this five-day immersion offered a high-level look at the future of scientific inquiry.

Diverse Academic Tracks

The program condensed years of complex research into accessible, expert-led sessions across several key domains:

Quantum Technology & Condensed Matter: Focused on the physics of 2D materials and the development of superconducting qubits for quantum computing.

Astrophysics & Cosmology: Explored the mysteries of the early universe, stellar evolution, and gravitational waves.

Soft Matter & Biophysics: Investigated how physical laws govern biological systems and complex fluids.

Plasma Physics & Photonics: Covered the dynamics of ionized gases and the manipulation of light-matter interactions.

Skill Development

Beyond theoretical lectures, students engaged in hands-on afternoon tutorials. These sessions focused on computational physics, data visualization for astrophysics, and Machine Learning applications in plasma research, providing them with the practical tools required for modern experimental science.

Impact

By interacting with world-class faculty at IISc, our students gained invaluable exposure to global research trends. This experience has equipped them with the clarity and technical foundation necessary to pursue advanced specializations in the fast-evolving landscape of 21st-century physics.

REVIEWS

Bhoutiki Pradnya, brought out by the Department of Physics of Nowrosjee Wadia College, is a noteworthy academic initiative that reflects the department's dynamism and commitment beyond classroom teaching. Bringing out such a well-structured and engaging magazine requires sustained effort, and the dedication of the faculty and students involved is clearly evident. The magazine succeeds in presenting Physics in a lucid and approachable manner, making scientific ideas accessible to a wider audience, including the common reader. This effort to popularise Physics without diluting its essence is particularly appreciable. The use of attractive and thoughtfully chosen section titles add to the readability and appeal of the magazine. Overall, Bhoutiki Pradnya is a valuable contribution to fostering scientific temper within the academic community.The Semiconductor Edition of BHOUTIKI Pradnya is an excellent and well-curated publication showcasing technical depth, creativity, and scientific enthusiasm.

It is both instructive and captivating due to its bilingual presentation, design, and coverage of a broad range of subjects, from semiconductor physics to astronomy and perception.

it is also suggested to add a section about research that has undergone peer review and add student research profiles or interactive QR codes.

-Prof. Dr. S. S. Boxwala Kale, Vice Principal & Head, Dept. of Mathematics, MES's Wadia College of Engineering, Pune

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-Prof. Ajay Borkar, MES's Wadia College of Engineering, Pune

The Bhoutiki Pradnya is a remarkable reflection of how science can inspire curiosity, creativity, and collaboration. Each article brings forth a unique perspective whether on nanotechnology, magnetism, or the physics of life making this issue both informative and engaging.

Overall, this is not just a magazine it's a platform that nurtures scientific thinking and communication among young physicists. Heartfelt congratulations to the Bhoutiki team for their hard work and for delivering such a high-quality, inspiring edition.

-Akansha Ashtankar, Smt. Kishoritai Bhoyar College of Pharmacy, Kamptee Nagpur

It has always been enjoyable to read the published "BHOUTIKI PRADNYA" (Volume-1, Issue-3) on semiconductor edition because of its intelligent articles and straightforward, approachable layout.

For both college students and others, it has been a genuine source of knowledge that has had an influence. The experience of writing my first article for this publication was amazing and enlightening.

I want to express my gratitude to the entire team for this opportunity, and in particular to Dr. Shashikant Shinde, who is the coordinator, for encouraging me to write a small piece of article on electrochemical sensors. During this occasion, I genuinely wish this magazine and many more congratulations.

-Chandrashekhar Ghorpade, Department of Physics, MES's Nowrosjee Wadia College, Pune