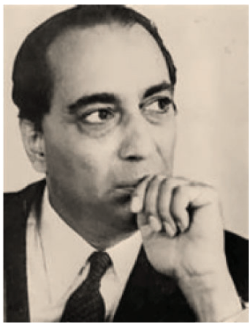
# TIFR at seventy-seven – in ceaseless pursuit of excellence

**S. Ramakrishnan***

Tata Institute of Fundamental Research, Mumbai 400 005, India

## An overview of TIFR

SEVENTY-SEVEN years after its foundation by Homi Jehangir Bhabha in 1945, the Tata Institute of Fundamental Research (TIFR), Mumbai, stands tall among Indian institutions devoted to pure science and claims a high international stature. It remains at the cutting edge of scientific progress in many and varied fields, from the abstractions of number theory to gravitational waves and elusive neutrinos, from lasers and quantum computation to the study of wildlife and living cells at the molecular level. This vast range of activities is driven by a single watchword – excellence – and a single motto – to take Indian science forward and make it a keystone of the nation's progress.



Almost from their inception, TIFR and the Department of Atomic Energy (DAE) have been inextricably involved together. The AEC, the Bhabha Atomic Research Centre (BARC) and the DAE itself were all, in a sense, incubated in TIFR, under the common direction of Homi J. Bhabha. Over the years, the mandate of DAE, viz. (i) to develop a nuclear power technology, (ii) to apply radiation and radioisotope technology for the larger benefit of the society and (iii) to pursue basic research in frontier areas in science and technology (S&T), has largely (though not wholly) been split between BARC and allied institutions for the first two points, and between TIFR and some other grant-in-aid research institutions for the third point. Of the latter class of institutions, TIFR, with its large footprint across the country, is the oldest and the largest. It has also been – and continues to be – the trend-setter for much of the fundamental research programmes in independent India, of which prime examples are the bringing of modern mathematics, computer science, accelerator-based high-energy physics, molecular biology, radio astronomy, string theory and satellite-based astronomy to the country. The research work by TIFR and other institutions of similar nature places DAE in a commanding position in the S&T establishment of the country. TIFR is spearheading DAE-funded national-level projects like the giant metrewave radio telescope (GMRT), the AstroSat and the Pelletron. The landmark discovery in 2016 of gravitational waves set up by coalescing black holes includes a pioneering computation from TIFR of the masses of the black holes. Even today, TIFR scientists are fulfiling DAE's mission by developing new technologies such as the use of particle detectors for weather monitoring, a large-scale study of the Indian monsoon and chemical absorbents for greenhouse gases. Even during the recent pandemic, it was TIFR scientists, with support from DAE, who took the initiative to conduct sero-surveys, which established the degree of herd immunity in the city of Mumbai, initially the worst-affected location in India.

The maximum amount of research work done at TIFR is in the physical sciences, at various scales ranging from small tabletop experiments to GMRT with a baseline as large as 25 km. The subjects of research involve practically the whole gamut of physics, including the most abstruse theoretical questions involving elementary particles and the Universe at large, studies of the cosmos using different parts of the electromagnetic spectrum, lasers and quantum optics, condensed matter systems ranging from soft matter to superconductors to novel materials like graphene, nuclear physics and its applications, and last, but not least, participation in some major international experiments like the LIGO experiment (gravitational waves), Large Hadron Collider (LHC) (the Higgs boson) and the planned Square Kilometer Array (SKA) (the largest-ever radio telescope).

Mathematics research has been a part of TIFR from its inception and today, TIFR mathematicians are working in number theory, topology, algebraic geometry, group theory and harmonic analysis, as well as in applied areas such as differential equations, fluid mechanics and probability theory. TIFR also carries out research in the theoretical areas of computer science, such as algorithms, complexity and information theory, as well as in machine learning and artificial intelligence. TIFR scientists also work on both theoretical and experimental aspects of quantum computation.

*e-mail: ramky07@gmail.com


In biological sciences, TIFR pursues research in areas like molecular biology, cell biology, genomics and systems biology, neuroscience, biophysics and bioinformatics, ecology and evolution, and offers an almost unique Master's programme in wildlife biology. Chemical sciences is a small but rapidly growing group in TIFR, where research is pursued in chemical physics, theoretical chemistry, biophysics, photochemistry, synthetic chemistry, biomolecular imaging, bio-inorganic chemistry, medicinal chemistry, materials chemistry and nanocatalysis with an underlying interdisciplinary approach.

Though initially conceived as a research institution, TIFR has played a pioneering role in scientific education and outreach in the country. From the late 1960s, TIFR built on the BARC Training School to create the first fully-fledged Graduate School in India, which later became DAE's first independent degree-granting body in 2002. Over the years, TIFR alumni have carried the DAE flag to almost of the institutions of higher education in the country, from Srinagar in the north to Thiruvananthapuram in the south, from Tezpur in the east to Jodhpur in the west. TIFR has perhaps the largest and most varied outreach programme in the country, to bring scientific ideas and scientific discoveries to the general public. It has made DAE a trendsetter in developing India's first internship programme purely for women students. TIFR also has a small but unique group of researchers studying science education and developing educational tools for science, mainly at the school and college level. This group also trains and mentors India's participation in the International Science Olympics, where the young participants bring back an impressive harvest of prizes every year.

TIFR's nerve centre is located at Mumbai, in the idyllic campus designed and developed by Bhabha himself. This main campus hosts three schools – Mathematics, Computer Science and Natural Sciences. The School of Natural Sciences is split into seven Departments dealing with respectively, astrophysics, biology, chemistry, condensed matter, high-energy physics, nuclear and atomic physics and theoretical physics. In addition, there is the National Centre for Radio Astrophysics at Pune, the National Centre for Biological Sciences (NCBS), a Centre for Applicable Mathematics (TIFR-CAM) and an International Centre for Theoretical Sciences (ICTS), all at Bengaluru and the relatively new second campus at Hyderabad (TIFR-H), which currently houses the TIFR Centre for Interdisciplinary Sciences. The Homi Bhabha Centre for Science Education (HBCSE) is located in Mumbai in a separate campus. TIFR also has field stations at Udhagamandalam, Tamil Nadu and Gauribidanur in Karnataka, Hanle in Ladakh and Pachmarhi in Madhya Pradesh. No other scientific institution has a comparable footprint across the country.

Some of the exciting science which is being done at the Mumbai campus and the different Centres of TIFR is described below.

## Mathematics and computer science

The TIFR School of Mathematics at Mumbai enjoys an international reputation second to none in India. In fact, an international review committee commented 'One could say that TIFR is the place that has created the mathematics of post-independence India.'

Some of the fields of mathematical research represented in the School today are: algebra, algebraic geometry, combinatorics, dynamics, ergodic theory, hyperbolic geometry, representation theory, number theory and automorphic forms and topology. Major contributions by the current faculty include those to moduli problems of vector bundles, theorems on modular forms, work on the third degree of the Lindelof hypothesis, realization of K-theory in terms of algebraic cycles and proof of the existence of Cannon–Thurston maps on hyperbolic manifolds – all of which have received international recognition.

Complementing the focus on research is the strong commitment of the School to education and dissemination of mathematical knowledge across the country. These include a flagship series of International Colloquia organized once every four years, which are usually attended by several Fields Medallists. A collaborative project with IIT Bombay – the National Centre for Mathematics – conducts a variety of activities, including mini courses and advanced lectures aimed at introducing young researchers around India to the latest developments.


TIFR-CAM is the culmination of a joint programme between TIFR and the Indian Institute of Science (IISc), Bengaluru, to focus on application-oriented mathematics.

The research here falls into three broad topics, viz. differential equations, probability theory and scientific computing, including established groups working on elliptic and hyperbolic partial differential equations (PDEs), control theory, geometric PDEs and inverse problems, as well as stochastic PDEs, the theory of Gaussian processes and their relationships with geometry, ergodic theory and dynamical systems, symbolic dynamics and related areas of statistical physics and probability, random polynomials, etc. and development of computational techniques for the above systems. Mathematical research is also carried out at ICTS where the topics of interest include, in addition to some of the above, dynamical systems, monsoon dynamics, differential geometry and higher category theory.

Ever since TIFR built India's first indigenous computer in the 1950s, computer science has been a thrust area in the Institute. The current School of Technology and Computer Science has today come to be recognized internationally for its expertise and high-quality, cutting-edge contributions in areas such as algorithms, complexity theory, cryptography, formal methods, financial mathematics, classical and quantum information theory, communications, machine learning, stochastic optimization and probabilistic computation. In recent times, the work of students and faculty from the School has been recognized at well-respected fora, winning the highly coveted best paper awards at prestigious conferences. Former students of the school populate the top academic institutions such as the IITs, IISc and NUS, as well as research laboratories, including Google, Qualcomm, GE, etc.

During the COVID-19 pandemic, faculty members from this School jointly with colleagues at IISc developed a world-class, city-scale, agent-based simulator for the study of non-medical interventions, using which projections were made to aid Mumbai in the gradual opening up from lockdown. The remarkably accurate projections were widely reported, and have guided the Mumbai city administration in its planning. Again, computer scientists in collaboration with biologists at the Institute, tied up with NITI Aayog, BMC and some other organizations and conducted a sero-survey in Mumbai in July as well as in August 2020. The results showed a high degree of prevalence in Mumbai, especially in the slums, and surprised the whole world as this was the first major city to show a very high degree of prevalence, suggesting that herd immunity may be achievable in the city in the not-too-distant future.

## Mathematical and theoretical physics

An international review committee visited the Department of Theoretical Physics (DTP) in Mumbai in 2018 and concluded, 'By the standards of US theoretical physics groups we rate the DTP subgroups as generally among the top 20 departments, with the string theory group in the top 10.'

The group which has drawn the highest praise works on topics such as string theory, general relativity, black-hole physics and the AdS–CFT correspondence. Major results from this group include, among others, construction of the KKLT–de Sitter solutions of string theory, discovery of fluid–gravity correspondence, proposal of conformal invariance as a guiding principle to find consistent string backgrounds, construction of black-hole solution in two-dimensional string theory, etc.

Another group works on similar subjects at ICTS, focusing on understanding scattering in anti-de Sitter space, the applications of this correspondence to cosmology and condensed matter physics and the deep problem of information loss in black holes.

Recently, the high-energy physics subgroup at Mumbai has demonstrated how to probe neutrino oscillations using terrestrial and astrophysical observations, and proposed novel signatures for new particles at detectors in collider experiments. Lattice QCD methods were developed to compute the properties of matter in the microseconds-old Universe. Large-scale computer simulations have predicted exotic subatomic particles like tetraquarks and pentaquarks – some of which have now been observed. A state-of-the-art data centre which can host up to a 10 Petaflop supercomputer has been constructed at the Balloon Facility, Hyderabad.

A relatively new and younger group at Mumbai studies cosmology, especially the microwave background, galaxy formation and dark matter. The relatively new subject of astrophysical and numerical relativity is being pursued at ICTS, having close links with the international LIGO project. It is this group that computed the masses of the coalescing black holes which provided the first signal for gravitational waves in 2016.


Last, but not least, is the group which works on condensed matter and statistical physics, focusing on a diverse array of many-body systems, either classical or quantum, in or out of thermal equilibrium, focusing on emergent phenomena in these systems. Recent results include the discovery of vacancy-induced, non-abelian, anyon magnetic moments in Kitaev's honeycomb model and vacancy-induced, fractional magnetic moments in some frustrated magnets, as well as the discovery of a new universality class of percolation phenomena with implications for diverse physical systems. Other work has led to predictions of the robustness of topological order in magnetically ordered Kitaev materials, an observable collective Higgs mode in disordered superconductors and a novel phase of frustrated antiferromagnets with singular ferromagnetic response. Finally, the recent discovery of an exact solution for the 'free energy' of a commonly studied non-equilibrium system provides a possible basis for a future theory of living matter.

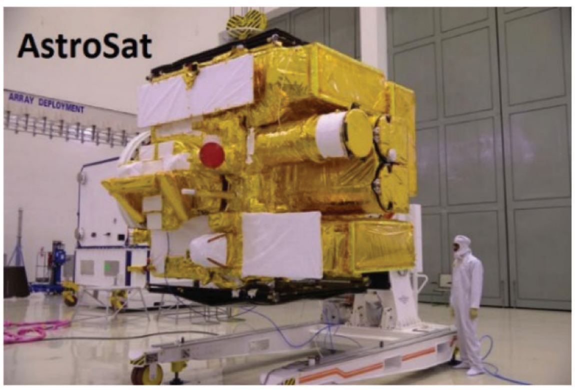
ICTS has also initiated a major research effort to understand the science of the Indian monsoon. An improved understanding can have a huge social and economic impact on the country. In fact, the effort of ICTS is unique and multidisciplinary, which combines the fundamental dynamics of the problem with data-driven mathematical modelling.

## Astronomy and astrophysics

TIFR has a rich history of pioneering activities in the fields of theoretical astrophysics, space-based astronomy and cosmic ray studies, and has been engaged in research in various areas of astronomy and astrophysics using theoretical and observational methods and in building several observing instruments spanning a large range of the electromagnetic spectrum.

The current focus of the theoretical astrophysics group includes topics in astero- and helio-seismology, astrophysics of compact objects, active galactic nuclei, gravitational wave astronomy, stellar dynamics and exo-planets. Members also focus on computational aspects that are relevant for analysing and interpreting large volumes of data from various national and international facilities. The group has successfully demonstrated the use of seismic techniques to study the motion of gas and magnetic fields in the interior of the Sun. The gravitational interaction and evolution of dense star clusters is an active area of research in the group. The current focus is on the processes that control the formation of a plethora of exotic stellar sources, including gravitational wave sources, X-ray binaries, blue stragglers, and recycled pulsars in these chaotic dynamical environments. Some members are part of the LIGO scientific collaboration and are contributing to the study of gravitational wave events.

The infrared astronomy group at TIFR is involved in near infrared (1–5 μm) and far infrared (100–200 μm) astronomy experiments to study star formation and other astrophysical phenomena. The group has developed two state-of-the-art near-infrared spectrographs and imagers, viz. TIRSPEC mounted at Hanle, Ladakh and TANSPEC mounted on the 3.6 m Devasthal Optical Telescope, Nainital. The experience and technical training gained are being used to indigenously develop a Multi-Object Near-Infrared Spectrometer (MOIS) at TIFR.




TIFR astronomers played a leading role in the AstroSat mission (2015), with all three major and pointing X-ray instruments built at the Institute. These instruments are soft X-ray telescope, large area X-ray proportional counters and cadmium–zinc telluride imager. Members of the Department of Astronomy and Astrophysics (DAA) also significantly contributed to the AstroSat UV/optical telescope.

The National Centre for Radio Astrophysics (NCRA), Pune, designed and built the GMRT near Pune in the 1990s. GMRT consisting of 30 antennas, 45 m in diameter, was and remains one of the most sensitive aperture-synthesis radio telescopes at its frequencies of operation. It was the first radio telescope in the world to use optical fibres for signal communication. The digital hardware combines, in real time, the astronomical signals of the antennas spread over 25 km, to synthesize a signal mimicking that of a single telescope 25 km across. The recently upgraded GMRT provides significantly more sensitivity than the original telescope, achieved through the replacement of all major components (except the antennas themselves) with state-of-the-art systems. This experience enables NCRA members to contribute to the upcoming SKA, the next generation radio telescope.

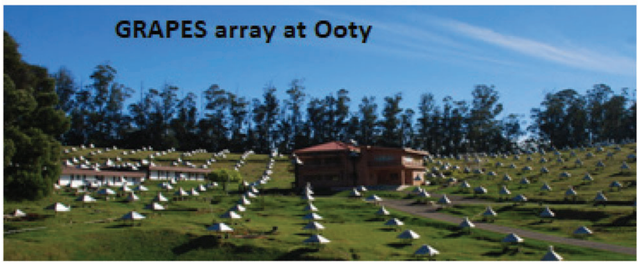

In 2020, GMRT was declared an 'IEEE Milestone in Engineering', being the third such honour for India, after the pioneering works of J. C. Bose and C. V. Raman.

## High-energy physics

High-energy physics, or the physics of elementary particles, is the oldest subject pursued in TIFR, being Bhabha's own area of specialization. Currently, the flagship programme of the Department of High Energy Physics at Mumbai is their participation in LHC at CERN, Geneva – the world's largest and most powerful facility to explore the Universe a few picoseconds after the Big Bang by studying science at the smallest length scales ($10^{-16}$ m). The host laboratory, CERN is an inter-governmental organization where India is an associate member state. Indian scientists play key roles in various aspects of the CERN facility. In 2012, the Higgs boson was discovered at the LHC by the ATLAS and CMS experiments, the latter including members from TIFR. The grid computing facility hosted by TIFR is a national contribution to the CMS experiment from India.


The Belle experiment at the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan provided the clinching experimental confirmation of charge-parity (CP) violation – a delicate asymmetry intimately connected to our existence. Its second phase – Belle II – aims to search for the next fundamental layer of physics by studying rare decays of unstable subatomic particles, namely beauty and charm mesons. The Belle group at TIFR continues to play a leadership role in this international project.

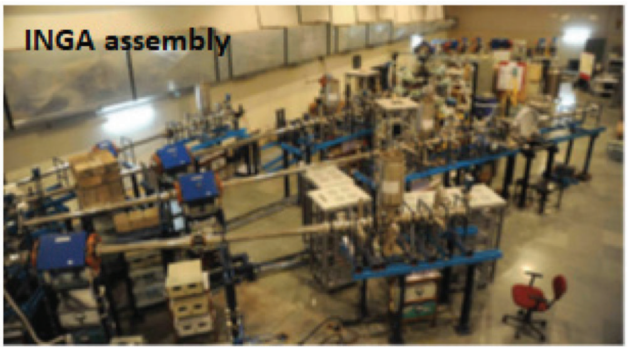
Studies and preparations for our own gravitational wave detector LIGO-India, at Hingoli, Maharashtra, are in progress. Since September 2008, the gamma-ray astronomy group at TIFR has been operating an array of seven telescopes called HAGAR at Hanle an altitude of 4.3 km. The main goal of this project is to detect gamma-ray emission with energies above 100 GeV originating from various classes of astronomical objects, particularly pulsars located in our galaxy and a class of active galactic nuclei (AGNs) on an inter-galactic scale.




The GRAPES-3 observatory of TIFR, located in the scenic hill town of Udhagamandalam is designed to study the most energetic particles in the Universe, i.e. cosmic rays. A unique aspect of the GRAPES-3 observatory is the in-house development of almost everything that is being used in this laboratory, including state-of-the-art detectors and cutting-edge electronics – at a cost just 10–20% of imported ones. One such example of the development is the high-quality plastic scintillators which are not only in the GRAPES-3 laboratory, but also in several national laboratories and institutions in the country. An accurate prediction of the arrival of solar storms from the ground is one of the future goals of the GRAPES-3 experiment.

## Nuclear physics

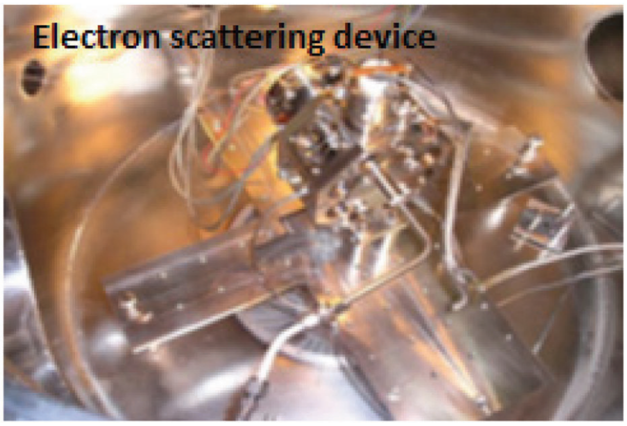
The Department of Nuclear and Atomic Physics at Mumbai prides itself on its philosophy of building new experiments in-house, often from scratch, and building and sustaining new facilities. At this point of time, the major facilities include a Pelletron–LINAC accelerator, an Indian National Gamma Array (INGA) detector array, an electron cyclotron resonance (ECR) ion source with 400 kV accelerator, and a rare-decay studies system. These facilities have enabled inter-departmental collaborations within TIFR, and several collaborations outside of TIFR within the country and abroad, leading to an ever-expanding national and international footprint of the Department. On the national front, the Department holds the leadership role in INGA and accelerator technology and in the international arena, as equal partners with GANIL (France) and GSI (Germany), Notre-Dame University, Rutherford Appleton Labs (UK), INFN (Italy) and other Universities such as Osaka, York, Hebrew and Pisa.




The scientific studies are broadly centred around nuclear reactions (fission and fusion), gamma spectroscopy of high angular momentum nuclei, nuclear shapes, the study of nuclei far from the stability line, giant dipole resonances, and so on. Theoretical studies are pursued on nuclear multifragmentation and relativistic hydrodynamics in the quark–gluon plasma. A unique programme pursued is of the hitherto unseen neutrinoless double-beta decay.

## Atomic, molecular and optical physics

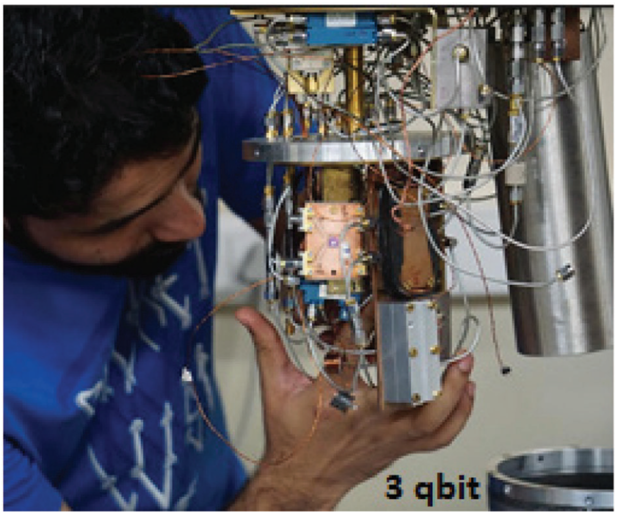
In atomic, molecular and optical physics, scientific activities in Mumbai encompass exploration of properties of atoms and molecules in the gas phase by collisions with fast and slow charged particles, understanding the local magnetic properties in the condensed matter systems using dopant atoms and ions, probing the free electron-induced chemistry in the condensed molecular films, exploration of the propagation of light in random (disordered) media, nano-optics and mesoscopic optics, as well as the intense, femtosecond laser interaction with matter in all forms – gaseous clusters, liquids, planar solids, solids with structured surfaces, and, finally investigation of the interactions of ultracold molecules with ions. Some of the scientific highlights of the recent past include, among other topics, the demonstration of turbulent giant magnetic fields in intense laser-produced dense plasmas, generation of neutral atom beams from the laser interaction with molecular clusters, ultrahigh energy electrons from the laser interaction with liquid drops, and very bright X-ray sources using tabletop lasers, which can be used for 3D tomography in the future.




At Hyderabad, particle acceleration, exploration of quantum electrodynamics and nuclear photonics using the upcoming petawatt laser facility are being jointly nurtured at the TIFR Centre for Interdisciplinary Sciences (TCIS). TIFR-H researchers have developed a novel fluorescence correlation spectroscopy set-up in order to investigate the early stages of aggregation of amyloid proteins. The laser physics laboratory has been studying lasers which can heat matter to convert it to a hot, dense plasma, with temperatures greater than that of solar cores. Using techniques to engineer the density and spatial profiles of plasmas, researchers have shown that it is possible to generate such plasmas using a comparatively lower-power terawatt laser.

## Condensed matter and materials science

The Department of Condensed Matter Physics and Materials Science (DCMPMS) at Mumbai is engaged in cutting-edge experimental research across a range of areas that include strongly correlated electron systems, semiconductors, nanotechnology and soft condensed matter. This includes a range of phenomena like superconductivity, magnetism, ferroelectricity and multiferroics. Currently, there is also focus on the technologically relevant research topics of semiconductor opto-electronics, soft matter, nanophotonics, nano-electro-mechanics and quantum computation. The scientists at TIFR employ a variety of synthesis techniques like crystal growth, MOVPE, ALD, PLD, RF/DC sputtering, arc/induction melting and have sophisticated characterization and measurement techniques like XRD, SEM, TEM, ARPES, XPS, optical (Raman, PL, THz), thermal, AFM, STM, SQUID, VSM, NMR and Mössbauer spectroscopy. Many of these state-of-the-art experimental facilities have been built in-house. TIFR has the largest cryogenic facility under R&D sector in India (1 lakh litres of helium per year) that supplies liquid helium and liquid nitrogen to various Departments of the Institute.




TIFR has initiated an ambitious project to build India's first superconducting, circuit-based quantum computer. The project is led by faculty from DCMPMS with a goal to build a 7-qubit quantum computer. In metamaterials research, the main focus is to design and nano-fabricate designed novel materials and study their intriguing properties to manipulate light at nanoscale. TIFR has developed pulsed laser-driven tera-Hertz (THz) source and detector technology with numerous designs. Another area is materials at the atomic scale to engineer novel quantum phenomena in solid-state systems. Research in 2D materials is likely to provide an understanding of the mechanism of high-temperature superconductivity, and is being addressed by making devices using a few unit-cell-thick high-$T_c$ superconductors and twisted bilayers of graphene. The possibility of very low dissipation modes of information transport like magnons and valley excitations is promising for new energy-efficient devices. Finally, developing quantum sensors that enable the detection of tiny forces, magnetic fields and electric fields; some of these can have medical applications.

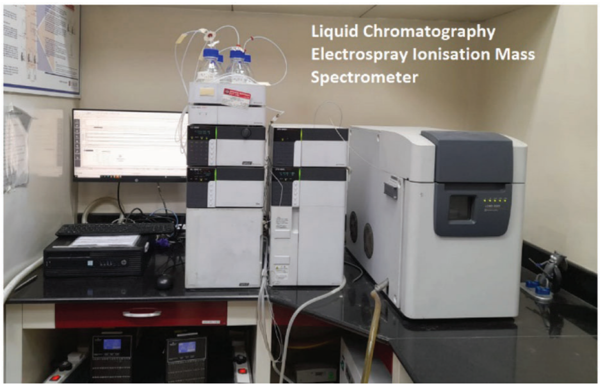
The soft condensed matter physics group has developed an optical tweezer-based technique to understand weakly adhering systems and works on novel experiments that centre on complex classical problems in 'everyday' materials like the elucidation of different aspects of rolling and sliding friction.

TIFR-H houses stellar research facilities and laboratories, which include a National Facility for High-field NMR, laser laboratory, state-of-the-art imaging facilities, low-temperature cryogen-free scanning tunneling microscope (STM), ultrahigh vacuum (UHV) cluster system, molecular beam epitaxy system, clean room facility for materials fabrication, scanning electron microscope (SEM), Raman microscope, workshop and a high-performance computing facility with a total capacity of 240 teraflops. The surface science and interface engineering group has been working towards developing viable options for futuristic energy storage. Researchers at TIFR-H have provided a completely novel framework within which one can extract conditions wherein stable, rigid, crystalline solids are possible.

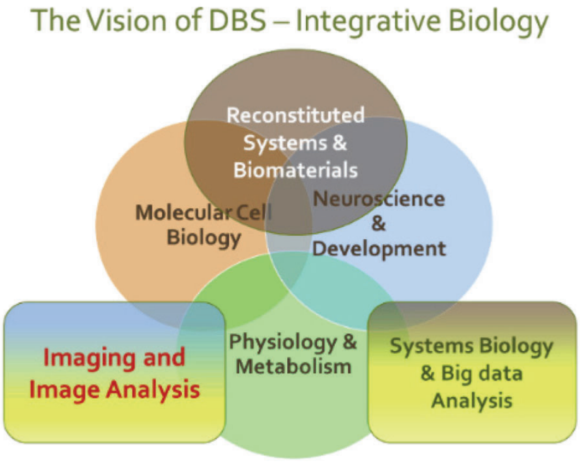
Condensed matter research at ICTS includes topics like anomalous heat transport in low-dimensional systems, quantum transport, stochastic many-particle systems, quantum many-body physics and the dynamics of integrable models.

## Chemical and biological science

The Department of Chemical Sciences (DCS) at Mumbai spans traditional areas of chemistry such as organic, inorganic, physical, analytical and biochemistry with an emphasis on interdisciplinary areas of research. Currently, scientists are exploring the link between living systems and the physical laws that govern Nature by studying systems of varying sizes. The laws that govern interactions in molecules are studied in isolated small molecules and the information gained is applied to design novel materials with exotic properties of value to chemical and solar-energy industries, and to medical applications. The research also includes efforts aimed at disease mechanisms, sensors for diagnostics and therapeutics, cheaper and cleaner synthesis of useful chemicals, materials for energy storage, energy harvesting and catalysis to combat climate change. The wide-ranging expertise in the DCS brings with it the ability to work on emerging interdisciplinary topics. These are constantly supported by core expertise in state-of-the-art experimental methodologies such as high-field NMR, ultrafast lasers, high-resolution mass spectrometry and single molecule methodologies.




Researchers at TIFR-H have been working towards developing viable options for futuristic energy storage, such as better catalysts for zinc–air batteries. The NMR group has made pivotal contributions in areas of biophysics, such as studying proteins in their native and functional state, for molecules responsible for Alzheimer's and Parkinson's diseases. They have also developed a novel fluorescence correlation spectroscopy set-up in order to investigate the early stages of aggregation of amyloid proteins. Similar pressing problems which lie on the intersection of biology and chemistry are also being investigated.




There is a great deal of overlap nowadays between research in chemistry and biology. In fact, today's biology is a highly interdisciplinary science that amalgamates ideas from many different fields, producing a new understanding of the physical nature of life's processes. The Department of Biological Sciences (DBS) at Mumbai, therefore, maintains a core biology activity and augments it with the interface areas. The research interests include intracellular transport and spermatogenesis, regulation of intracellular transports by kinesin-2, impact of the rate of stem-cell divisions on differentiation of its lineage; mechanisms of F-actin assembly at the plasma membrane; vesicle transport in *C. elegans* neurons, genetic mechanisms and signalling pathways in the developing brain, neurobiology of depression, cellular reorganization and dynamics, genetics of epidermis development, metabolism and physiology, cytokinesis in fission yeast, protein folding and secretion of chemical messengers, and molecular genetics of adaptive evolution. Significant contributions have been made in the areas of neurogenetics of taste and olfaction, identification of unique malarial antigens, origin of hippocampus in mammalian brain, lipid movement by molecular motors inside a cell, genesis and impact of early-life stress in brain, metabolic reprogramming by microRNA in liver and the origin of epithelial polarity in zebrafish.

NBCS has helped nucleate the Bangalore Life Science Cluster (BLiSC), which connects basic research to real-world impact. NCBS provides the fundamental science backbone, DBT-inStem undertakes translational biomedical research and the Centre for Cellular and Molecular Platforms (C-CAMP) incubates and supports over 100 biotech start-ups. NCBS provides a network of experimental facilities such as the Animal Care and Resource Centre, along with the National Mouse Research Resource and Fly Facility, which develops and sustains hundreds of transgenic model organisms, the backbone of modern biological research, as well as the National CryoEM Facility, the first of its kind in the country. This enables the Cluster to pursue ambitious, collaborative research programmes, such as the accelerator programme for discovery in brain disorders using stem cells (ADBS), in collaboration with NIMHANS, which seeks to understand the basis of psychiatric disorders in the Indian population.


The COVID-19 pandemic posed a challenge to researchers worldwide. NCBS and DBT-inStem rapidly set up a COVID-19 testing laboratory which tested over 90,000 samples in Karnataka within one year. Research on COVID-19 by NCBS faculty include *in silico* drug discovery, screens to identify compounds that inhibit viral replication, a COVID-19 biorepository, establishing organoid models for infection, development of novel sensitive tests and participation in a national consortium to sequence 1000 SARS-CoV-2 genomes. Scientists from TIFR-H also came up with a colour-based assay for visually detecting the presence of SARS-CoV-2 virus in 30 min developing an open-source, low-cost version of a sensitive fluorescence detector in a PCR machine, developing a low-cost, rechargeable N95 mask and a testing device to determine the quality of masks. In Mumbai, heat-based treatments for mask sanitization were developed at a time of great crisis and the liquid-nitrogen plan was temporarily repurposed to produce medical-quality liquid oxygen.

## Science education

The Homi Bhabha Centre for Science Education (HBCSE), TIFR, is a unique institution in the education sector in India. Unlike other education centres and departments which focus on general education, it has a specialized focus on science, technology and mathematics (STEM) education, thereby bringing together deep subject expertise both in science and education. Another unique feature of HBCSE not typically found in the education sector is the focus at all levels of education – primary, secondary and tertiary. These features also make the Centre unique in the science and technology space in the country, in being an interdisciplinary academic institution integrating humanities, social science and science disciplines.

Research and innovations by the Centre include inquiry-based and enactive approaches to STEM education, curricular strands in middle-school mathematics, design and technology education, environmental education, pedagogical content knowledge for teachers, collaborative online platforms for science learning, 'home-grown' model systems laboratories for undergraduate biology, etc.

The HBCSE is India's nodal centre for selection and training of Indian students for participation in the prestigious international olympiads in astronomy, biology, chemistry, junior science, mathematics and physics. Out of a total of 682 Indian students who have participated in these olympiads over the years, 92.7% have won medals with 29.3% winning gold medals. In 2018, the physics team (in picture) won all five gold medals.

## Graduate studies

TIFR has the status, under the University Grants Commission of a Deemed-to-be University, granting three degrees, i.e. Ph.D., M.Phil. and M.Sc. under five different subject boards, viz. mathematics, physics, chemistry, biology and science education. Of these, the main programmes are for Ph.D. and integrated M.Sc.–Ph.D.

Students are admitted to graduate studies in TIFR through an all-India screening test. A few students are also admitted through other nationwide screening tests, such as JEST, CSIR-NET and JGEEBILS. Selection takes place after conducting interviews of the shortlisted candidates. The success rate is about 1%.

Students admitted to the Integrated M.Sc.–Ph.D. programme have to go through 3–4 semesters of rigorous coursework at the M.Sc. level, with an early entry into research being provided by one-semester research projects. Their tenure at TIFR is supported by a generous stipend and contingency grants.

After completion of the doctoral work, a student must submit a synopsis of the work and defend it in an open seminar evaluated by an internal committee. If deemed adequate, the thesis can be written and it is then sent to two external examiners, one of whom conducts the thesis defence. Successful candidates are awarded their degrees by the Academic Council of TIFR.

## National facilities

The Pelletron LINAC Facility (PLF), set up as a collaborative project between BARC and TIFR, has been serving as a major facility for heavy-ion accelerator-based research in India since its commissioning in 1988. Several advanced experimental facilities have been established

here to pursue research in nuclear, atomic, condensed matter physics and in interdisciplinary areas. Several application-based research programmes like irradiation studies of food grains and devices for space applications have also been taken up. Research work in nuclear physics, the main thrust of PLF activities, covers areas of nuclear structure studies at high angular momentum and excitation energies, and the heavy ion reaction dynamics.

The National Balloon Facility (NBF) at Hyderabad is a unique facility in the world where the entire chain of balloon design, manufacture, launch, tracking and recovery is conducted indigenously. These balloons have various uses which include space astronomy, atmospheric sciences, monsoon studies, global warming and climate change mitigation, emergency communication during natural calamities, national border security and surveillance systems in inhospitable areas, zero-gravity tests on space components of ISRO, satellite pre-launch wind sounding at the ISRO launch pads, etc. NBF also provides balloons to various international groups for experiments and other launches.

## Outreach activities

There is increasing need for scientists to connect with the community at large and to share with them the excitements of scientific discovery and our deepening understanding of the natural world. To implement this, TIFR and all its Centres maintain a vigorous outreach programme with many aspects. At Mumbai, the flagship programmes are the National Science Day initiative, when a few hundred school children are brought to visit the Institute and see its laboratories. The ‘Chai and Why’ series of popular science lectures, organized jointly with the iconic Prithvi Theatre, have become a regular part of Mumbai’s cultural landscape. ICTS organizes a similar programme – ‘Kaapi with Kuriosity’ – at Bengaluru. An interactive programme called ‘Sawaal Jawaab’ is organized by TIFR-H. NBCS too has been active in promoting the National Mission on Biodiversity and Human Well-Being, IndiaBioscience and the Science Gallery Bengaluru.


At a more technical level, TIFR has been conducting the Visiting Students’ Research Programme (VSRP), a summer internship for Master’s students, for many years. HBCSE hosts the National Initiative on Undergraduate Studies, a two-week enrichment programme, where bright undergraduate students around the country are taught advanced topics. The School of Mathematics has started the Mumbai Math Circle, which gives high-school and college students and mathematics teachers a glimpse into some themes of fundamental and historical importance in mathematics.

Last, but not least is TIFR’s new ‘Vigyan Vidushi’ programme – a summer coursework only for women, which is designed to attract more women into the STEM disciplines. During 2020 and 2021, it was held totally online, but in 2022 it is planned to be held in person.

## Looking ahead

While it is difficult to predict specific happenings in the future, there is no doubt that science and scientific progress will come to play an increasingly important part in our daily life as the years go by. TIFR and all its scientists are fully committed to keeping up with the impact of new subjects of research and new challenges to bring them to society in general. Important programmes on the anvil are increased involvement in mega-science projects, opening a branch for undergraduate education and diversifying research into applied fields which would bring the benefits of science to the common populace. These and allied activities would be in consonance with Bhabha's dream of India's future and would further DAE's mandate in many ways, especially in nation-building and the furtherance of basic research.

Before concluding, I would like to thank colleagues across TIFR and all its Centres for their inputs in preparing this article.

doi: 10.18520/cs/v123/i3/451-460