Frontiers in Science & Cutting Edge Technologies: Physics Group in BARC

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Physics Group

Abstract

The Physics Group in BARC continues to pursue R & D programmes which are excellent and relevant to the DAE mandate. The Physics Group has an active basic research programme which spans a range of energy and length scales and includes a comprehensive study of matter at extremes. The indigenous development of technologies which include precision instrumentation, particle accelerators, synchrotron and neutron beam lines and high energy gamma ray telescope systems, is an intense activity of the group. The Physics Group also operates a number of national facilities for users from the DAE and universities for pursuit of frontiers in Physics.

Introduction

Right from inception of the DAE, the physics discipline has occupied a pride of place in the growth of atomic energy in the country. Over the years the Physics Group (PG) has contributed significantly to the various R & D programmes of BARC. The primary mandate of the PG continues to be pursuit of excellence in frontiers of physical sciences, spanning a wide dynamic range of length and energy scales, cutting across disciplines and investigation of matter at extremes of pressure and temperature. The PG programmes also include “directed basic research” and “applied research” in areas of relevance to the DAE. The scientific & technical personnel of PG are contributing to the operation and maintenance of national facilities like the 14 MV + SC Linac at TIFR, 6 MV FOTIA and PURNIMA fast neutron facility at Trombay, National facility for neutron beam research at DHRUVA, High energy gamma ray telescope TACTIC at Mt. Abu, Cosmic-ray neutron monitor at Gulmarg and Synchrotron beam-based set ups at INDUS, RRCAT, Indore. Further, the PG has a viable and sustained programme of indigenous development of detectors, crystals, sensors, beam line instrumentation, accelerator sub-systems, mass spectrometers, X-ray and neutron based imaging techniques, multilayer mirrors, sample analysis methodologies and these developments / services cater to the needs of many other units of DAE and also various divisions of BARC.

Currently the PG is taking a lead role in the development of the MACE gamma – ray telescope at Hanle and the state- of- the- art beam lines at INDUS, RRCAT, Indore. As a part of the Indian ADS programme, the PG is spearheading the design and development of Low Energy High Intensity Proton Accelerator (LEHIPA) and the PURNIMA fast neutrons coupled to a sub-critical U core. In addition, the PG is participating in several international programmes / performing / planning experiments at CERN – LHC, BNL(USA), GANIL(France), FAIR(GSI) , Fermi lab, ILL(Grenoble), PSI( Switzerland), Elletra( Italy). The PG is also actively involved in the setting up of the mega science project India-based Neutrino Observatory (INO) and the development of high intensity and high energy proton accelerator as a part of the Indian ADS programme. The S&T personnel of PG are contributing to HRDD / teaching activities at BARC Training school, Mumbai university – DAE Centre of Excellence in Basic Sciences at Mumbai university and BRNS programmes which strengthen the collaboration between the DAE and the teaching institutes.
In this article we shall summarise some of the highlights of the PG programmes under various heads - basic research, design and development, projects, O & M of facilities and services.

**Basic Research**

The basic research programmes in Physical Sciences involve investigation of phenomena which cover a range of energy scales, from eV to a few TeV and length scales, from a few fm to several light years. The basic motivation continues to be the understanding of the structure of matter and behaviour of matter at extreme conditions. The reaction mechanisms taking place in different time scales is another area of intense investigation. Both basic research and directed basic research programmes are being pursued.

In the area of astrophysics, the frontier areas are: discovery and measurement of high energy gamma ray emissions from the active galactic nuclei in particular, understand the origin and the acceleration mechanism of these high energy gamma-rays, establish connection between the phenomena of high energy gamma-ray emission and the energetic cosmic rays dominated by particles and finally bridge the gap between the ground based and the satellite based observations in terms of energy limits. Some of the recent observations include the flaring activity of extragalactic objects Mkn 421 and Mkn 501 with the TACTIC (TeV Atmospheric Cherenkov Telescope with Imaging Camera) at Mt. Abu.

Nuclear physics research is expanding in three directions: Study of nuclear matter at high energy and density and observation of phase changes (QGP, hadron interactions, structure and medium effects); shape evolution of the nucleus as a function of excitation energy and angular momentum (high spin spectroscopy and GDR); Investigation of the nuclei away from the line of stability to map the nuclear landscape (stable and weakly bound projectile induced fusion and fission reactions). Both the national (accelerator facilities at Kolkata, Delhi and Mumbai) and international facilities at BNL, CERN, GANIL and GSI are being used. A number of state-of-the-art detector arrays (like the charged particle detector array) have been built for these investigations. Fission fragment spectroscopy facility at CIRUS/DHRUVA is an unique facility in the country. A state-of-the-art Resistive Plate Chambers (RPC) detector lab has been set up for LHC and INO programmes.

In the area of Atomic and Molecular physics research, multiwavelength investigation ranging from UV to IR is a recurring theme of the investigations. Some of the recent programmes include: investigation of molecules which are of atmospheric and astrophysical interest. VUV spectroscopy of solids - lanthanide doped glasses and radiation treated solids is another activity. For VUV spectroscopy studies of exotic molecules, free radicals and molecular solids, the PG has developed a full scale Matrix Isolation Spectroscopy set up at INDUS in collaboration with IGCAR, Kalpakkam and RRCAT, Indore. Laser spectroscopy is an important activity which is relevant for isotope separation programme of the department. One of the recent programmes is on nano-photonics- photonic band gap materials and self assembled photonic crystals. Ion traps and quantum optics are other areas of interest.

A state-of-the-art matrix-assisted laser desorption ionization (MALDI) technique in combination with TOF mass spectrometer has been established, for the detection, identification and characterization of peptides, proteins, DNAs and clusters in the mass range 1 to 50000 Da. In the macromolecular crystallography investigations, three dimensional structures of proteins – HIV -1 protease, PhoK and PSP94 have been determined.

Design and development of materials with desired properties is an important programme of the PG. The preparation and the characterization of Nano-materials, functional materials and thin films and investigation of their properties under different temperatures and pressures is an intense activity of the PG. Organic field effect transistors and organic and dye sensitized solar cells are being developed. High efficiency (8%) dye sensitized solar cells have been recently produced. Growth of high mobility
Cobalt phthalocyanine films by molecular beam epitaxy technique is an ongoing programme. In the broad area of condensed matter physics, the research areas include: Diffusion in confined media, structures in magnetic nano-materials, mechanism of negative thermal expansion, structural evolution in protein solutions; mesoscopic structures in cement and SOFC materials, interfaces in magnetic multilayers, hydrogen bonding in novel ferroelectrics. The high pressure – static and dynamic pressure – investigations include study of magnetic and superconducting materials, low temperature spectroscopic studies, impedance and Hall coefficient measurements, shock studies with laser ablation, high strain rate dynamics in laser shocked materials, short pulse laser heating of shock compressed matter, hot electron transport in hot matter, characterization of targets for the maximum conversion efficiency used for the X-ray backlighter and time-resolved Raman spectroscopy of materials under laser driven shock. All these experimental programmes are supported by comprehensive and intense computational activity which has been an asset for the success of all the programmes of the PG. For a more comprehensive account of the ongoing basic research programmes, one may refer to the proceedings of the nuclear physics and solid state physics symposia and related theme meetings.

Design and Development

Some of the design and development activities have direct relevance to the nuclear power programme of our country. The PG has set up facilities to develop multilayer optical interference coatings for high power CW and pulse lasers in the wavelength region from deep UV to IR. The PG has expertise to make the Holographic transmission and reflection gratings. Further development of precision optical components and optical analytical instruments for various DAE programmes is another activity of the PG. Reactive electron beam PVD, co deposition PVD, ion beam sputtering, thermal evaporation are some of the techniques used for multilayer coatings.

A 10 meter long optical periscope has been designed and developed indigenously as an in-service inspection instrument for the visual inspection of Prototype Fast Breeder Reactor’s (PFBR) main vessel internals including components and equipment installed inside. This project has been successfully completed with the collaborative efforts of Applied Spectroscopy Division (ASD), Division of Remote Handling & Robotics (DRHR), Centre for Design & Manufacture (CDM) of BARC and Reactor Engineering Group (REG) of IGCAR, Kalpakkam (Fig.1). A few hundred pieces of catalytic recombiner cards have been developed for NPCIL for safe recombination of hydrogen and oxygen. Thermoelectric devices are being developed for CHTR and space programmes. PbTe and TAGS alloy-based devices operating at 500 deg C have been developed with an efficiency of 6%. SiGe with n and p type doping has been prepared for use in this programme. Bottle double decapper gadget

![Periscope for PFBR facility](image-url)
(Fig. 2) for handling bottles containing radioactive samples in hot cells to open the cap and pour the contents into reactants has been developed. It is compatible with the existing mechanism of tongs used in hot cell. The first units are in use in A3F and more are being made for KARP. A computerized and automated mechanical system that exposes biological cell samples to uniform and controlled doses of alphas from radioactive source- alpha irradiator - has been developed for Radiation Biology programme.

A large number of precision spectrometers have been designed, developed, installed and commissioned at various units of DAE, RMP, HWB and AMD. These instruments are continuously improved in performance and sensitivity to cater to the growing needs of the department. Development of portable gas chromatograph mass spectrometer for identification of chemical warfare agents, stable isotope ratio mass spectrometer and ion mobility spectrometer for explosive detection is underway.

One of the active areas of the PG is in the application of neutron and X-ray imaging techniques for nuclear energy, security and healthcare programmes. Both emission and transmission tomography techniques have been developed. The PG has developed an advanced digital imaging system using the flat panel technology. X−ray and neutron based phase contrast imaging technique is one of the recent advancements. Using neutron phase contrast imaging method it has been possible to quantify the presence of light elements in a matrix of heavy element (Fig.3). Neutron based tomography has been applied to various applications such as qualitative and quantitative evaluation of hydrogen in blistered zirconia tubes. It has also been possible to examine the fuel cladding using neutron tomography based technique.

Using X-ray-based phase contrast technique, it has been possible to characterize thin coatings (Fig. 4) of pyrocarbon, carbon composites, foams etc. The PG has developed an advanced digital imaging system using the flat panel technology.

To carry out high pressure studies at very high temperatures (~ few thousands K) a laser-heated diamond cell facility, employing a 100 W air cooled ytterbium fibre has been set up at Purnima laboratories at BARC (Fig. 5). A Helium cryostat has been installed for the measurement of transport and optical
properties of solids at high pressure and at low temperature. A facility for in-situ pressure measurements has also been developed.

As a part of the BARC contribution to the CMS detector upgrade at CERN, PG is developing RPC detectors (Fig. 6). While these RPCs are based on bakelite, similar RPCs being developed for the INO programme are made from glass. The RPC detectors are versatile and they can be also used for muon tomography programme as they can distinguish between different elements, like iron, lead and uranium.

Projects

The PG is spearheading the efforts to design and develop the next generation gamma–ray telescope, MACE (Major Atmospheric Cherenkov Experiment).

This will be located at Hanle at an altitude of 4200 m above sea level and is optimized for detection of gammas in the energy range 10 - 100 GeV. This is a national effort involving IIA, TIFR and SINP and is being executed with the active involvement of ECIL (Fig. 7).

A fast neutron facility based on D-D and D-T reactions is already in operation at PURNIMA, PG. It is proposed to couple the 14 MeV neutron source to a sub-critical U assembly (with BeO reflector and Polythene...
moderator) to carry out neutron multiplication and transport studies. The coupled operation of the accelerator and the sub-critical core is a forerunner to the ultimate ADS, a long term programme of the DAE (Fig. 8). Another flagship programme in which the PG is taking a lead role is the design and development of the LEHIPA (Low Energy High Intensity Proton Accelerator) which can serve as an injector of the high energy, high intensity accelerator (1 GeV, mAs) to be built as part of the Indian ADS programme. The LEHIPA consists of an ECR source, RFQ and DTL modules, high voltage power supplies, high power RF systems, precision temperature controlled LCW supply system and is designed to accelerate the protons up to 20 MeV with mAs intensity (Fig. 9). It is a challenging assignment and the project is planned for installation and commissioning at the basement of the Common Facility Building.

A project is underway to build a low energy heavy ion accelerator facility based on state-of-the-art high intensity, high charge state ECR ion source and RFQ modules. The ion source is capable of delivering beams ranging from H to U and U ions with charge states 33 and 34 have been demonstrated (Fig. 10).

Generation of quality manpower, particularly in accelerator physics and technology, is crucial for the future programmes of BARC / DAE. This is relevant in the context of DAE with an ambitious plan to use accelerators not only for multidisciplinary basic research but also for applications which will include healthcare, nuclear energy and national security.

The PG is responsible for development and commissioning of several state-of-the-art beam lines at INDUS Synchrotron at RRCAT. Currently work is progressing well on the following beam lines – Photoabsorption (PASS), Infra Red FTS, SAXS, Imaging, and protein crystallography. When completed in the next one year, the user community will be able to pursue R & D programmes exploiting these beam lines.

**O & M of facilities**

The S&T personnel of the Physics Group operate and maintain a number of national facilities. Amongst them, mention may be made of the TACTIC high moderator (moderator) to carry out neutron multiplication and transport studies. The coupled operation of the accelerator and the sub-critical core is a forerunner to the ultimate ADS, a long term programme of the DAE (Fig. 8). Another flagship programme in which the PG is taking a lead role is the design and development of the LEHIPA (Low Energy High Intensity Proton Accelerator) which can serve as an injector of the high energy, high intensity accelerator (1 GeV, mAs) to be built as part of the Indian ADS programme. The LEHIPA consists of an ECR source, RFQ and DTL modules, high voltage power supplies, high power RF systems, precision temperature controlled LCW supply system and is designed to accelerate the protons up to 20 MeV with mAs intensity (Fig. 9). It is a challenging assignment and the project is planned for installation and commissioning at the basement of the Common Facility Building.

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energy gamma ray astronomy facility at Mt. Abu (Fig. 11), the National facility for neutron beam research at DHRUVA (Fig. 12), Low Energy Accelerator Facility (LEAF) at BARC, the 14 MV Pelletron + Superconducting LINAC at TIFR (Fig. 13), the 6 MV FOTIA at BARC (Fig. 14) and the fast neutron facility at PURNIMA.

The Physics group has been instrumental in setting up several beam lines at INDUS for users: The ones which are operated mainly by the Physics group are: Photo-physics, Extended X-ray Absorption Fine Structure (EXAFS) (Fig. 15), Angle Resolved Photoelectron Spectroscopy (ARPES), Energy Dispersive XRD (EDXRD) with an option to study material at high pressure and High Resolution Vacuum Ultraviolet (HRVUV) (Fig. 16) which are used for atomic, molecular and condensed matter physics investigations.
spectrometers – TIMS (Fig. 17), PGMS, ICPMS (Fig. 18), QMS and D/H ratio mass spectrometer-have been designed and indigenously developed to meet the growing needs of the department of DAE in general and RMP, AMD, and HWB in particular. Over the years nearly, 25 mass spectrometers have been supplied to DAE users.

Powerful spectroscopic techniques (including PIXE, XRF) have been employed to characterize a large number of samples from different labs in DAE. Trace analysis of nuclear and detector grade material is being routinely carried out for various users. The Atomic Emission Spectroscopy, ICP-based technique and the Echelle Spectrometry are employed for this programme.

All these facilities are catering to a large body of users from the DAE and the universities.

Services

As part of the indigenous development of single crystals which are technologically important and of great relevance to DAE programmes, the Physics Group has a sustained programme of growing single crystals of different types. These include the laser (PbMoO$_4$, NaBi(WO$_4$)$_2$, Nd:YAG, Pb$_5$Ge$_3$O$_{11}$ and Li$_2$B$_4$O$_7$) and the detector (CsI(Tl) and LiF) materials. Silicon surface barrier semiconductor detectors of varying thicknesses (10 to 300 microns) and areas (50 to 250 mm sq) have been fabricated and supplied to the users. PG has a specialization in developing BF$_3$ and He$_3$ filled neutron proportional counters for many years and these have been employed successfully in our programme and also supplied to other users. The precision mass
The PG is playing a leading role in the newly created Nuclear Data Physics Centre of India (NDPCI), which coordinates the nuclear data activities of the country and also interfaces with international agencies like the IAEA.

Summary

To sum up, the Physics Group has been making sustained and significant contributions to the R & D programmes of DAE in general and BARC in particular. The PG continues to hold a leading position in the country, in the pursuit of basic research addressed to frontiers in physics. In addition the PG also has the mandate to run severed national facilities catering to a large user community. One may consider the present article as just an overview of some of the important programmes of the Physics Group. It is only a representative account and is in no way exhaustive. Needless to say that much of the success achieved by the PG in the various R & D programmes would not have been possible without the active involvement and constant cooperation of colleagues from other Divisions / Groups of BARC but also other units of the DAE.

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Forthcoming Symposium

**DAE – BRNS Interdisciplinary Symposium on Materials Chemistry**

The 4th DAE – BRNS Interdisciplinary Symposium on Materials Chemistry will be held at BARC, Mumbai, from Dec 11-15, 2012. It is being organized by the Society for Materials Chemistry & Chemistry Division, BARC. The scientific programme of the Symposium will cover the following topics: Nuclear materials, High purity materials, Nanomaterials and clusters, Carbon based materials, Surface chemistry and thin films, Materials for energy conversion, Magnetic materials and electroceramics, Catalysis, Soft condensed matter, Biomaterials and polymers.

**Important Dates**

- Last date for submission of abstract: Aug. 31, 2012
- Acceptance notification: Sept. 28, 2012
- Payment of registration fee: Oct. 31, 2012

For further details please visit the symposium website: [www.barc.gov.in/ismc-2012](http://www.barc.gov.in/ismc-2012) or contact:

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