PHYSICAL SCIENCES

Programme Code: PHYS04

Programme Outcome:

- Manpower development with the ability to apply basic concepts and methods in physics to research problems.
- Training of manpower to take up research in frontier areas of physics
- Building human resource in carrying out R&D in physical and nuclear sciences
- Training of manpower in working in interdisciplinary subjects with physics as one of the subjects

SUMMARY TABLE: BARC-HBNI PHYSICS PHD (JRF) COURSES

Sr. No	Course Code	Subject Title	Lecture + tutorials (Hrs)	Credits	Marks
A. FOUNDATION COURSES					
1.	01-PHYS04-005-F	Accelerator Physics	30	2	100
2.	01-PHYS04-006-F	Computational and Numerical Methods	30	2	100
3.	01-PHYS04-007-F	Reactor Physics	15	1	50
4.	01-PHYS04-008-F	Health Physics	15	1	50
5.	(By HBNI)	Research Methodology & Research Publication Ethics*	45	3	150
B. ADVANCED COURSES					
1.	01-PHYS04-010-A	Nuclear and Astrophysics	30	2	100
2.	01-PHYS04-011-A	Condensed Matter Physics	30	2	100
3.	01-PHYS04-012-A	Laser and Plasma Physics	30	2	100
C. ADVANCED EXPERIMENTAL TECHNIQUES					
1.	01-PHYS04-013-A	Experimental Techniques in Nuclear & Astrophysics	15	1	50
2.	01-PHYS04-014-A	Experimental Techniques in Condensed Matter Physics	15	1	50
3.	01-PHYS04-015-A	Advanced Experimental Techniques in Laser Physics	15	1	50
4.	01-PHYS04-017-A	Introduction to mega science projects	15	1	50
		Total	**285**	**19**	**950**

*** Research Methodology & Research Publication Ethics course is already approved and will be conducted by HBNI**

**** 1 Credit is equivalent to 15 contact hours of classroom teaching as per the new UGC guidelines.**

- **Course work for PhD (JRF) students**

  The course work consists of 5 Foundation courses (PHYS04.5 - PHYS04.8) including Research Methodology & Research Publication Ethics, 4 Advanced courses (PHYS04.10-PHYS04.13), and courses on Advanced experimental techniques as listed in Table-1. The topic 'Research Methodology & Research Publication Ethics' is explicitly included as a part of the course work as per the requirement of UGC and will be conducted by HBNI. Total classroom lecture hours including tutorials are 285.

  Total credits for the JRF coursework are 19 as per the requirement of HBNI for a PhD student. Detailed course structure for individual subjects is provided separately. Some specific issues are as follows:

- **Research Methodology & Research Publication Ethics**

  This course includes specific topics related to 'Research Methodology & Research Publication Ethics' which are not covered elsewhere in the syllabus. These include design, analysis and presentation of scientific projects, objectives and planning of research, literature survey, statistical methods, mathematical modeling, documentation and presentation, laboratory safety and research ethics. The course syllabus is already approved and will be conducted by HBNI.

SUMMARY TABLE: BARC-HBNI PHYSICS PHD (JRF) COURSES

Chief Coordinators:

Dr. Dimple Dutta (Email : dimpled@barc.gov.in)

Course Code	Course Name	Coordinator	Lecture hours	Credits
PHYS04.5	Accelerator Physics	Dr. S. V.L.S. Rao, IADD, BARC	30	**2**
PHYS04.6	Computational and Numerical Methods	Shri Nilay Bhatt, APSD, BARC	30	**2**
PHYS04.7	Reactor Physics	Dr. Anurag Gupta, RPDD, BARC	15	**1**
PHYS04.8	Health Physics	Dr. P. Ashokkumar, HPD, BARC	15	**1**
CYJRF-112	Research Methodology & Research Publication Ethics	Prof. Dipanwita Dutta and Prof. K.K. Swain	15	**1**
CYJRF-113	Research Publication and Ethics	Prof. Dipanwita Dutta and Prof. K.K. Swain	30	**2**
PHYS04.10	Nuclear and Astrophysics	Dr. S. Santra, NAS, BARC	30	**2**
PHYS04.11	Condensed Matter Physics	Dr. V. K. Aswal, SSPD, BARC	30	**2**
PHYS04.12	Laser and Plasma Physics	Dr. S. Ghorui, L&PTD	30	**2**
PHYS04.13	Experimental Techniques in Nuclear & Astrophysics	Dr. K. Mahata, NPD, BARC	15	**1**
PHYS04.14	Experimental Techniques in Condensed Matter Physics	Dr. Y. Kashyap, TPD, BARC	15	**1**
PHYS04.15	Advanced Experimental Techniques in Laser Physics	Dr. Asawari D. Rath, ATLAD, BARC	15	**1**
PHYS04.17	Introduction to mega science projects	Dr. D. Bhattacharya, A&MPD, BARC	15	**1**

A. FOUNDATION COURSES (5 courses, 8 credits)

01-PHYS04-005-F: Accelerator Physics (30 Lecture Hrs)

Coordinators: Dr. S. V.L.S. Rao, IADD, BARC
svlsr@barc.gov.in

Course Details:

- **Introduction to accelerators**
  History of accelerators; Applications of accelerators; Relativistic kinematics; Guided electromagnetic fields in waveguides and cavities; Transverse beam dynamics; Accelerator coordinates; Guide field; Dipole and Quadrupole Magnets; Hills equation and solution; Betatron oscillations; Twiss parameters; Matrix formulation; stable oscillations; FODO lattice; Chromaticity; sextupole magnets and dynamics aperture.
- **Longitudinal beam dynamics**
  Fields and forces; acceleration by time varying fields; relativistic equations; transit time factor; main RF parameters; synchronous particle; synchrotron oscillations; principle of phase stability; RF acceleration for synchronous and non-synchronous particles; small amplitude oscillations; Oscillations with Hamiltonian formalism.
- **Linear accelerators**
  Basic methods of linear acceleration; Fundamental parameters of accelerating structures; Energy gain in linear accelerating structures; Q, Shunt-impedance, transit-time factor; periodic accelerating structures; RFQ; DTL; advantages of superconducting cavities; TEM and TM superconducting cavities; spoke resonators and elliptic cavities.
- **Advanced topics**
  Introduction to space-charge effects, Envelope equation, Introduction to wake fields and collective instabilities, Non-linear dynamics in accelerators. Elements of microwave electronics for accelerators, Elements of magnet design.

Course Outcomes:

- Understand principles of coordination chemistry, solid-state structures, and crystallography.
- Gain hands-on knowledge of synthesis and characterization of inorganic materials.
- Explore structure–property relationships in solids and coordination compounds.
- Appreciate the role of metals in biological systems through bioinorganic chemistry concepts.

References:

1. An Introduction to Particle Accelerators, *E. J. N. Wilson*
2. An Introduction to the Physics of High Energy Accelerators, *D. A. Edwards and M. J. Syphers*
3. Principles of RF Linear Accelerators, *T.P. Wangler*
4. Accelerator Physics, *S.Y. Lee*
5. Theory of Charged Particle Beams, *M. Reiser*
6. Microwave Measurements, *E.L. Ginzton*
7. Lecture Notes on High-Current Beam Dynamics, *I. Hofmann*
8. Radio-frequency Quadrupole, *M. Weiss, CERN-PS/87-51*
9. RF Superconductivity for Accelerators, *Hasan Padamsee.*

01-PHYS04-006-F: Computational and Numerical Methods (30 Lecture Hrs)

Coordinators: Shri Nilay Bhatt, APSD, BARC
nilayb@barc.gov.in

Course Details:

- **FORTRAN90 programming language**
  Overview and basic concepts, data types, flow control, functions, arrays inputs/outputs, makefile, libraries. Introduction to Python programming

- **Numerical methods**
  Introduction and sources of computational errors, solution of non-linear equations (Root finding), solution of system of linear equations, numerical interpolation, numerical differentiation and integration, solution of differential equations, solution of partial differential equations. Diagonalization of a Matrix and finding eigen values and eigen vectors, Fourier transform, convolution and deconvolution of a numerical data.

- **Data analysis**
  Classification of errors, error propagation, basics of Monte Carlo techniques, data interpretation using Bayesian approach.

Course Outcomes:

- Understand principles of coordination chemistry, solid-state structures, and crystallography.
- Gain hands-on knowledge of synthesis and characterization of inorganic materials.
- Explore structure–property relationships in solids and coordination compounds.
- Appreciate the role of metals in biological systems through bioinorganic chemistry concepts.

References:

1. Computer Programming in Fortran90 & 95, *V. Rajaraman, Prentice Hall India Pvt.Ltd.*
2. Numerical Recipes, *W.H.Press, S.A.Teukolsky, W.T. Vellering and B.P. Flannery, CUP.*
3. Numerical Mathematical Analysis, *J. B. Scarborough (Oxford and IBH Publishing)*
4. Computer Oriented Numerical Methods, *V. Rajaraman*
5. Data Reduction and Error Analysis for the Physical Sciences, *P. R. Bevington and D. K. Robinson*
6. An Introduction to Error Analysis, *J.R. Taylor*

01-PHYS04-007-F: Reactor Physics (15 Lecture Hrs)

Coordinators: Dr. Anurag Gupta, RPDD, BARC
anurag@barc.gov.in

Course Details:

- **Basics of nuclear reactor**
  Basic concepts of nuclear energy, Classification of reactors, Characteristics of research, test and power reactors with examples, Brief overview of different reactor components

- **Neutron induced reactions and their energy behavior**
  Concepts of binding energy, Interaction of neutrons with matter, Microscopic cross-section, Energy dependence of nuclear cross-sections, Fast, resonance and thermal regions, 1/v law of neutron cross-section, Nuclear fission process, Liquid drop model, Critical energy for fission, Fissile, Fertile and fissionable materials, Fission products yield, Prompt and delayed fission neutrons, concept of 'ν' and 'η', Macroscopic cross-section, Mean free path, Reaction rate density, Energy release during nuclear fission, Fission rate and reactor power, Decay heat, Fission gammas

- **Reaction rates and measurement of reaction cross sections**
  Measurement of cross-sections– Activation and transmission methods, Overview of Measurement of partial cross-sections, Introduction to neutron time-of-flight experiments.

- **Steady state neutron transport equation**
  Definition of neutron flux and current, Fick's law and its validity, Neutron transport equation, Diffusion approximation, One speed neutron diffusion equation, Interface conditions, Diffusion coefficient, Diffusion length and extrapolation distance, Solution of diffusion equation for point source and plane source in non-multiplying medium.

- **Neutron multiplication and bare homogeneous reactor**
  Nuclear chain reaction, Multiplication factor, K-infinity and K-effective, Reactivity, Units of reactivity, Concept of criticality, Non-leakage probability, Bare homogeneous reactor - concepts of material and geometric buckling, Conditions for criticality, Four factor formula, Heterogeneous reactors. Neutron slowing down, Slowing down power/moderating ratio of moderators, Slowing down with spatial migration, Fermi age concepts, Migration length.

- **Time dependent neutron diffusion equation and reactor kinetics**
  Time dependent neutron diffusion equation, One group kinetic equation and its solution, Role of delayed neutrons, Prompt neutron life time, Reactor period, One dollar of reactivity, Prompt criticality. Xenon and Samarium poisons, Xenon loads, Variation of xenon load with power, Reactivity feedbacks of reactivity.

- **Reactor control and operation**
  Control rods, Reactor safety and shut-down mechanisms, Principles of reactor operation, Approach to criticality, Control rod worth measurement, Concepts of irradiation, Burn-up, Conversion and breeding.

Course Outcomes:

- Understand principles of coordination chemistry, solid-state structures, and crystallography.
- Gain hands-on knowledge of synthesis and characterization of inorganic materials.
- Explore structure–property relationships in solids and coordination compounds.
- Appreciate the role of metals in biological systems through bioinorganic chemistry concepts.

References:

1. Nuclear Reactor Engineering, Reactor Design Basics, *S. Glasstone and A. Sesonske*
2. Nuclear Reactor Engineering: Reactor Systems Engineering, *S. Glasstone and A. Sesonske*
3. Introduction to Nuclear Reactor Physics, *Robert E. Masterson, (CRC Press, 2017)*

4. Nuclear Reactor Physics, *Weston M. Stacey (Wiley, 2007)*
5. Fundamentals of Nuclear Reactor Physics, *Elmer Lewis (Academic Press, 2008)*

01-PHYS04-008-F: Health Physics (15 Lecture Hrs)

Coordinators: Dr. P. Ashokkumar, HPD, BARC
ashokkp@barc.gov.in

Course Details:

- **Introduction**
  Radiation sources, Uses of radiation sources, quantities and units, Natural and Induced radioactive sources, Units of radioactivity, Half-Life and Decay constant, Specific activity, Uranium-238 series and associated radioactivity; Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation/tissue weighting factors and their importance (with stress to use only SI units however old and new units' relation can be given), Exposure dose relationship.

- **Biological effects**
  Interaction of radiation with biological matter (DNA damages). Factors, which influence radiation damage of cell, Direct and indirect effects, Stochastic and Deterministic, Acute and Chronic doses – Examples, Radiation syndromes (Hematopoietic, GI and CNS) NVD, $LD_{50/60}$ -Threshold doses for radiation syndromes.

- **Radiation detection and measurement**
  Brief introduction on Charged particle interaction, ionization and excitation, Interaction of gamma radiation with matter: Photoelectric, Compton and pair production (not detailed); Neutron interaction and dose; Ionization chamber, proportional counter and GM counter working principle; HP instruments Alpha, Beta, Gamma and Neutrons; Buildup concept, shielding for alpha, beta, gamma and neutron sources, Shielding for mixed sources.
  Luminescence (theory & materials): Radiation dose measurement (Basics of dose measurements, different methods of radiation dose measurements, Importance and requirement of radiation dose measurements).

- **Radiation protection program**
  Types of exposure (occupational, medical and public), Exposure situations (Planned, Existing and Emergency, National and International regulatory bodies, their role and responsibilities). Latest Dose limits stipulated by these bodies, Dose limits observed in India, Radiation protection philosophy, Principles of radiation protection, Justification, Optimization and Dose Limits.

- **Occupational Radiation Protection**
  Radiation Safety Officer (RSO); Nature of duties and responsibilities of RSO/Health Physicist, Protection against internal and external exposure; Time, Distance and Shielding; Concept of ALI & DAC (with suitable problems); Modes of entry of radionuclides into the human body leading to internal exposure; Personnel monitoring, workplace monitoring, environmental monitoring. Surface contamination and air activity monitoring, and Criticality Safety; Dosimeters, TLDs, DRD (pocket dosimeters), alarm dosimeters CR-39 etc.; Bioassay, whole body counting and Liquid Scintillation Spectrometry (LSS) techniques (not in detail); Role of ESL in environmental monitoring; Radiotoxicity and classification of laboratories, design of laboratory for radioactive work.

- **Radiation Protection procedures**
  Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas, spill pack (contains gloves + absorbing paper), Decontamination techniques, Precautions during radioactive source storage and handling, Safety during transportation of radioactive sources, Transport index, TREM card, Radioactive waste classification and management.

- **Emergency Preparedness**
  Types of emergencies, emergency preparedness; Nuclear and radiological emergencies, RDD, IED, International Nuclear Events Scale (INES), Examples of nuclear and radiological accidents, and Iodine Prophylaxis.

Industrial Safety (Conventional): Basic Principles of industrial safety and industrial hygiene.

Course Outcomes:

- Understand principles of coordination chemistry, solid-state structures, and crystallography.
- Gain hands-on knowledge of synthesis and characterization of inorganic materials.
- Explore structure–property relationships in solids and coordination compounds.
- Appreciate the role of metals in biological systems through bioinorganic chemistry concepts.

References:

1. Introduction to Health Physics, *Herman Cember, 4th Edition (McGRAW-HILL, 2009).*
2. Physics for Radiation Protection, *James E. Martin, 2nd Edition (Wiley -VCH Verlag GmbH, 2006).*
3. IAEA Regional Basic Professional Training Course on Radiation Protection *(Course jointly organized by BARC and IAEA), October 26-December 18, 1998.*
4. Radiobiology for radiologists, *Eric J. Hall, 7th Edition, (Lippincott Williams & Lippincott, 2012).*
5. Accident Prevention Manual for Industrial Operation, *Vol. 2, National Safety Council, 11th Edition, (National Safety Council, USA, 1997).*

A.ADVANCED COURSES (3 courses, 6 credits)

01-PHYS04-010-A: Nuclear and Astrophysics (30 Lecture Hrs)

Coordinators: Dr. S. Santra, NAS, BARC
ssantra@barc.gov.in

Course Details:

i. **Nuclear Physics: (15 Lecture Hrs)**

- **Review of basic nuclear physics**
  Basic properties of nuclei, systematic of nuclear ground states (low lying states) properties, size, shape, electric and magnetic moment, nuclei away from the line of stability, isomers, nuclear decay, symmetries. Nuclear Forces: Phenomenological description of nuclear forces, deuteron problem, N-N scattering, microscopic description, meson theory of nuclear forces.

- **Nuclear structure**
  Multipole composition of radiation, transition matrix, selection rules for multipole transitions, collective and single particle excitations, shell and collective models, giant resonances, high spin states and shape deformations, relativistic mean field theory, Fermi gas model, weak interaction, beta decay, neutrino interaction and oscillations.

- **Heavy ion nuclear reaction studies around Coulomb barrier energies**
  Physical description of heavy ion interactions, heavy ion potentials, elastic scattering, optical potentials. Direct reactions: Inelastic scattering, theories on nuclear transfer reactions, Coupled channels effects. Fusion and fission reactions: Compound nucleus theory, statistical model analyses, Hauser-Feshbach analyses, fusion of heavy ions, fusion cross section around Coulomb barrier energies and channel coupling effects. Particle evaporation spectra and nuclear level densities, nuclear fusion-fission reactions, fission fragment mass and angular distribution, and fission time scale.

- **High energy interactions**
  Deep Inelastic Scattering, Nuclear reaction at Relativistic Heavy Ion Collisions, Quark Gluon Plasma (QGP) - a deconfined state, Signatures of QGP: Quarkonia, Jets, Energy loss; Equation of State; High Energy QCD in proton-nucleus interaction and ultra-peripheral collisions, Critical point.

References:

1. Introductory Nuclear Physics, *Kenneth S. Krane (Wiley, New York, 1988)*
2. Treatise on Heavy-Ion Science, *Vol. 2, 3, ed. D. A. Bromley*
3. Nuclear Structure (Vols. I and II), *A. Bohr and B. R. Mottelson (Benjamin, Reading, Massachusetts, 1969 and 1975)*
4. Theoretical Nuclear Physics, *A. de Shalit and H. Feshbach (Wiley, NY 1974)*
5. Nuclear Structure From A Simple Perspective, *R. F. Casten (Oxford University Press, 1990)*
6. Ultrarelativistic Heavy- Ion Collisions - *R. Vogt (Elsevier Science, Amsterdam, 2007)*
7. Introduction to High Energy Heavy Ion Collisions: *C. Y. Wong (World Scientific, Singapore,1994)*
8. Introduction to Relativistic Heavy-Ion Collisions: *L. Csernai (John Wiley, 1994)*
9. Quark Gluon Plasma 4: *Edited by R. C. Hwa and Xin-Nian Wang (World Scientific, Singapore, 2010)*

ii. **Astrophysics: (15 Lecture Hrs)**

- **Radiation Processes in Astrophysics**

Concepts of Radiative Transfer, radiation from accelerated charge, Bremsstrahlung, Thomson and Compton scattering, synchrotron radiation, thermal and non-thermal distribution of radiating particles, nonthermal synchrotron radiation, synchrotron-self-absorption, synchrotron and Compton cooling, hadronic process, neutral pion decay.

- **Basic definitions from Cosmology**
  Universe at large scales – Homogeneity and isotropy, distance ladder, Newtonian cosmology, expansion and redshift, Cosmological Principle, Hubble's law, Robertson-Walker metric,
- **Observable quantities**
  Luminosity and angular diameter distances, Horizon distance.
- **Particle Acceleration**
  First and second order Fermi acceleration, Particle acceleration in astrophysical shocks, evolution of particle distribution, kinetic equation, different cases.
- **Cosmic rays**
  Historical perspective, Cosmic ray spectrum, GZK cut, off, cosmic ray and neutrino.
- **Gamma-ray emission from Galactic sources:**
  Supernova remnants, pulsars, black hole x-ray binary systems.
- **Gamma-ray emission from extra-Galactic sources:**
  Seyfrert galaxies, blazars and gamma-ray burst.

Course Outcomes:

- Understand principles of coordination chemistry, solid-state structures, and crystallography.
- Gain hands-on knowledge of synthesis and characterization of inorganic materials.
- Explore structure–property relationships in solids and coordination compounds.
- Appreciate the role of metals in biological systems through bioinorganic chemistry concepts.

References:

1. Radiative process in astrophysics, Rybicki and Lightman, *John Wiley & Sons Inc, ISBN: 9780471827597, 0471827592*
2. High energy astrophysics, *M. Longair, Cambridge University Press, ISBN: 9780521756181, 0521756189*
3. Quasars and Active Galactic Nuclei, *Ajit K. Kembhavi and Jayant V. Narlikar, Cambridge University Press, ISBN: 9781139174404, (1999)*

01-PHYS04-011-A: Condensed Matter Physics (30 Lecture Hrs)

Coordinators: Dr. V. K. Aswal, SSPD, BARC
vkaswal@barc.gov.in

Course Details:

- **Crystal Structure**
  Crystal structure of materials, Space group and its application, Crystal structure determination, Powder diffraction, Single crystal growth (basics & methods) and characterization, Structure of disordered materials.

- **Phase Transitions and Critical Phenomenon**
  Equation of state, Phase transitions, Landau theory of phase transition, First and second order phase transitions, Critical exponent, Properties near critical points, Materials response under temperature, pressure and magnetic field.

- **Magnetism and Magnetic Materials**
  Fundamentals of magnetism, Multiferroics, Magnetoelectrics, Magnetostriction, Spintronics, Frustrated magnetism, Colossal magnetoresistance, Low dimensional quantum magnetism, Spin liquid.

- **Strongly Correlated Electron Systems**
  Metal-insulator transition, Charge and orbital ordering, Quantum phase transition, Quantum criticality.

- **Dynamics of Collective and Non-collective Excitations**
  Phonon dispersion. Stochastic Processes, Magnetic excitations.

- **Surfaces, Interfaces and Thin Films**
  Preparation and structure of thin films, Complex surfaces and interfaces, Thin film multilayer devices.

- **Soft Matter and Nanostructures**
  Constituents of soft mater, Structure and interaction, Soft Matter in Biology, Properties, synthesis and applications of nanomaterials.

- **Energy Materials**
  Types and sources of energy, Energy storage methods and devices, Solar cells, Fuel Cells, Thermoelectric power generation. Magnetic energy materials: Spin Seebeck effect, Magnetocaloric effect, and Permanent magnets.

Course Outcomes:

- Understand principles of coordination chemistry, solid-state structures, and crystallography.
- Gain hands-on knowledge of synthesis and characterization of inorganic materials.
- Explore structure–property relationships in solids and coordination compounds.
- Appreciate the role of metals in biological systems through bioinorganic chemistry concepts.

References

1. Solid State Physics, *N. W. Ashcroft and N. D. Mermin (Harcourt College Publishers, London, 1976)*
2. Quantum Theory of Solids, *C. Kittel (Wiley, 1987)*
3. Condensed Matter Physics, *M. P. Marder (John Wiley & Sons, 2010)*
4. Lecture Notes on Electron Correlation and Magnetism (Series in Modern Condensed Matter Physics), *P. Fazekas (World Scientific Publishing Company, 1999)*
5. Soft Condensed Matter, *R.A.L. Jones (Oxford University Press, 2002)*
6. Energy Materials, *D.W. Bruce, D. O'Hare and R.I. Walton (Editors) (Wiley, 2011)*
7. Renewable Energy Conversion, Transmission and Storage, *Bent Sørensen (Academic Press, 2007)*

01-PHYS04-012-A: Laser and Plasma Physics (30 Lecture Hrs)

Coordinators: Dr. S. Ghorui, L&PTD
sghorui@barc.gov.in

Course Details:

A. Basics of Laser Physics: (15 Lecture Hrs)

Introduction to Lasers, unique properties of lasers and their importance, coherence, laser spectrum and wavelengths, Wave nature of light, Heisenberg's uncertainty principle, concept of wave packet. Brief overview of energy levels and radiative properties of atoms, molecules, liquids and solids; Boltzmann distribution; Interaction of EM radiation with materials: spontaneous and stimulated emission, Einstein's coefficients, population inversion. Two level system, three / four level system, rate equation model. Working principle of lasers, stable laser resonator and laser cavity modes, threshold gain and threshold population inversion. Homogeneous and inhomogeneous broadening, spectral hole burning, spatial hole burning. Different Types of Lasers and their properties, Non-linear optical processes and materials, high harmonic generation, Techniques to narrow down laser line widths / increase pulse powers

References:

1. Laser Fundamentals, *W.T. Silfvast, Cambridge University Press 2004.*

B. Physics & Technology of Arcs: (15 Lecture Hrs)

- **Production of arcs and its characteristics**
  Ionization, Cathode processes, Penning effect, AC and DC break down, Paschen's law, Transition to Arc, Arc characteristics and required power supply features, Arc root movement and inherent instabilities.
- **Thermo-physical Properties of Arc Plasma**
  Partition function hierarchy, Specific energy and enthalpy from partition function, Non-equilibrium Saha equations, Determination of thermodynamic and transport properties from Chapman Enskog Approach.
- **Fluid Model of Arc Plasma**
  Fluid model from kinetic theory, Vlasov equation, Handling of collisional term, Conservation of charge, mass, momentum and energy from moments of Vlasov equation, Generalized Ohm's law, MHD equations, Application of fluid model.
- **Electromagnetic Interactions in Arcs**
  Arc root dynamics and instability, Modes and origin, Mutual interaction between arc current and magnetic field, Electromagnetic pumping, Retrograde motion, Skin depth, JxB thrust.
- **Applications of Arc Plasma Devices**
  Cutting, Plasma Spraying, Gasification, Nano-synthesis, EDM discharges, Pyrolysis and Extractive metallurgy, Thermo-chemical cathodes, Erosion scenario, Understanding arc plasma behavior in different torches.
- **Plasma Technology for Renewable Energy and Environment**
  Plasma for waste management, Waste to energy concept, Pyrolysis, gasification and incineration, Elements of plasma gasifier plants, Principles and operation.

Course Outcomes:

- Understand principles of coordination chemistry, solid-state structures, and crystallography.

- Gain hands-on knowledge of synthesis and characterization of inorganic materials.
- Explore structure–property relationships in solids and coordination compounds.
- Appreciate the role of metals in biological systems through bioinorganic chemistry concepts.

References:

1. Introduction to Plasma Technology: Science, Engineering and Applications, *John Ernest Harry (Wiley- VCH Verlag GmbH & Co, 2011)*
2. Plasma Technology Fundamentals and Applications, *M. Capitelli, and C. Gorse (Eds.) (Springer, 2012)*

C. Advanced Experimental Techniques (4 courses, 4 credits)

01-PHYS04-013-A: Experimental techniques in Nuclear and Astrophysics (15 Lecture Hrs)

Coordinators: Dr. K. Mahata, NPD, BARC
kmahata@barc.gov.in

Course Details:

- **Nuclear Physics**
  Interaction of radiation (heavy charged particles, electrons, gamma rays, neutron and neutrino) with matter, Radiation detectors, General characteristics of detectors: efficiency, resolution and timing properties.
  Gas detectors: Basic processes, ionization and charge multiplication. Ionization chamber, proportional counter, avalanche counter and Geiger Muller counter. Multi-Wire Proportional Counter (MWPC), Parallel Plate Avalanche Counter (PPAC), Time Projection Chamber (TPC) and Resistive Plate Chamber (RPC), Gas Electron Multiplier (GEM). Semiconductor detectors: Silicon detectors (surface barrier, PIN diodes, Li drifted silicon detectors), Germanium (HPGe and Clover) detectors, Compton suppression. Scintillation detectors: Inorganic and organic scintillators, photomultipliers, photodiodes, avalanche photodiodes. Miscellaneous detectors: Cryogenic detectors, thermal detectors, channeltrons and microchannel plates, hybrid detectors.
  Experimental techniques: Particle identification methods using (DeltaE-E) telescope, pulse shape discrimination, Cerenkov radiation technique, time of flight technique, magnetic spectrometers including recoil mass separator. Analog signal processing, Electronics modules for pulse processing: Preamplifiers, amplifiers, timing discriminators, Coincidence (fast and slow) techniques, Data acquisition systems (DAQ), Monte Carlo simulation of detectors to obtain efficiency, and Digital signal processing.
  Typical experimental setups using Strip detector array, Neutron detector array and Indian National Gamma Array (INGA) and other national and international facilities. Applied nuclear physics: Rutherford Back Scattering (RBS), Nuclear Reaction Analysis (NRA), Neutron activation Analysis (NAA), and Accelerator Mass Spectroscopy (AMS).

- **Astrophysics**
  - **Experimental techniques in various wavebands**
    History of telescopes, resolving power, angular resolution, energy resolution, current and future generation large optical telescopes, X-ray telescopes, gamma ray telescopes.

  - **Science with gamma, ray telescope:**
    Hadronic and leptonic emissions in astrophysical sources
    observational perspective, cosmic ray measurement using VHE experiments, indirect detections of dark matter, estimation of extra, galactic background light using VHE observations, test on photon-ALP oscillation and violation of Lorentz invariance.

  - **Extensive Air Shower (EAS) and Cherenkov radiation**
    Radiation length, critical energy, development of gamma, ray and hadron generated EAS, Cherenkov radiation: spectral distribution, threshold energy, emission angle, Cherenkov light pool and pulse duration, lateral distribution of Cherenkov light for gamma, ray and hadron. Imaging atmospheric Cherenkov telescopes: Features of Cherenkov telescopes: trigger threshold, flux sensitivity and cosmic ray background rejection, imaging technique, data analysis techniques for

Cherenkov telescopes.

- **Cosmic rays and related experiments**
  Cosmic ray experiments: historical perspective, Cosmic ray spectrum, GZK cut off, Hillas plot
- **Description of various astrophysical sources**
  supernova remnants, pulsars, active galactic nuclei, gamma ray bursts etc. and their observational results, Spectral Energy Distribution, multi-messenger observations.
- **Astronomical techniques**
  Astronomical Coordinate system: Horizon, Equatorial and Galactic coordinate system; Magnitude of stars and different distance measurement techniques used in astronomy.
- **Experimental techniques in various wavebands**
  History of telescopes, resolving power, angular resolution, energy resolution, current and future generation large optical telescopes, X-ray telescopes, gamma-ray telescopes.
- **Science with gamma-ray telescope**
  Observational perspective, indirect detections of dark matter, estimation of extragalactic background light using VHE observations, test on photon- ALP oscillation and violation of Lorentz invariance.
- **Extensive Air Shower (EAS) and Cherenkov radiation**
  Radiation length, critical energy, development of gamma-ray and hadron generated EAS, Cherenkov radiation: spectral distribution, threshold energy, emission angle, Cherenkov light pool and pulse duration, lateral distribution of Cherekov light for gamma-ray and hadron.
- **Imaging atmospheric Cherenkov telescopes**
  Features of Cherenkov telescopes: trigger threshold, flux sensitivity and cosmic ray background rejection, imaging technique, data analysis techniques for Cherenkov telescopes, features of MACE telescope

Course Outcomes:

- Understand principles of coordination chemistry, solid-state structures, and crystallography.
- Gain hands-on knowledge of synthesis and characterization of inorganic materials.
- Explore structure–property relationships in solids and coordination compounds.
- Appreciate the role of metals in biological systems through bioinorganic chemistry concepts.

References:

1. Radiation Detection and Measurement, *G.F. Knoll, 4th edition (John Wiley & Sons, New York, 2010)*
2. Techniques for Nuclear and Particle Physics Experiments, *W.R. Leo, 2nd Edition. Springer International Student Edition (Narosa Publishing House, New Delhi, 1995)*
3. Very high energy gamma, ray astronomy, *T.C. Weekes, CRC Press (old -Institute of Physics Publishing), ISBN: 9780750306584, (2003)*
4. Astronomy with Your Personal Computer: *Petter Duffett-Smith, Cambridge University Press, ISBN: 9780511564888, (1990)*
5. Extragalactic background light and the gamma ray opacity of the universe, *E. Dwek and F. Krennrich, Volume 43, 2013, Pages 112-133*

01-PHYS04-014-A: Experimental Techniques in Condensed Matter Physics (15 Lecture Hrs)

Coordinators: Dr. Y. Kashyap, TPD, BARC
yskashyap@barc.gov.in

Course Details:

- **X-rays and Neutron Scattering**
  X-rays vs. neutron scattering, Neutron scattering facilities and instrumentation.
- **Synchrotron Radiation**
  Basics of synchrotron radiation, Beam lines and techniques.
- **Spectroscopy Techniques**
  Basics of atomic and molecular spectroscopy, Raman, FTIR, EPR, NMR, FMR, Mössbauer spectroscopy, Impedance spectroscopy, UV-Vis absorption techniques and applications.
- **Microscopy techniques**
  Optical microscopy, Scanning probe microscopy, Electron microscopy; Techniques for electronic, magnetic, electrical transport, thermal transport, and calorimetric properties.
- **Imaging Techniques**
  Overview of different imaging techniques; X-ray, neutron and synchrotron based imagining techniques. Detectors and Sensors: Single crystal scintillators and applications, X-rays and neutron gas detectors, Development and application of gas sensors.

Course Outcomes:

- Understand principles of coordination chemistry, solid-state structures, and crystallography.
- Gain hands-on knowledge of synthesis and characterization of inorganic materials.
- Explore structure–property relationships in solids and coordination compounds.
- Appreciate the role of metals in biological systems through bioinorganic chemistry concepts.

References:

1. Introduction to the Theory of Thermal Neutron Scattering*, G. L. Squires, Cambridge University Press (1978).*
2. Theory of Thermal Neutron Scattering, *S. W. Lovesey, Clarendon Press (1984).*
3. Neutron Scattering in Condensed Matter Physics, *A. Furrer, J. Mesot and T. Strässle, World Scientific (2009).*
4. An Introduction to Synchrotron Radiation: Techniques and Applications, *P. Willmott (John Wiley & Sons, 2011)*
5. Inorganic Scintillators for Detector Systems: Physical Principles and Crystal Engineering, *Paul Lecoq, Alexander Gektin, and Mikhail Korzhik (Springer, 2017).*
6. Fourier Transform Infrared Spectroscopy (2ed), *Peter R. Griffths & James A. de Haseth*
7. Modern Raman Spectroscopy: A practical Approach. (2ed), *Ewen Smith & Geoffrey Dent*

01-PHYS04-015-A: Advanced Experimental Techniques in Laser Physics (15 Lecture Hrs)

Coordinators: Dr. Asawari D. Rath, ATLAD, BARC
asawarim@barc.gov.in

Course Details:

- **Significance of high-resolution laser spectroscopy, Designing an experiment**
  Different types of atomic/molecular sources, Laser-atom/molecule interaction, Detection Techniques – light/ions, detectors, Designing an experiment.
- **High resolution spectroscopic techniques**
  Emission, Absorption, RIS, LIBS, LIF, etc.
- **Applications in fundamental and applied areas**
  Nuclear investigations through atomic spectroscopy, Multiphoton ionization of atoms /molecules, selective excitation /ionization, isotope separation, trace analysis, etc., Manipulation of atoms/molecules using Lasers – laser cooling, optical tweezers. Other advanced topics (e.g. STIRAP, FEL-spectroscopy, Laser-atom interaction in high intensity regime)

Course Outcomes:

- Understand principles of coordination chemistry, solid-state structures, and crystallography.
- Gain hands-on knowledge of synthesis and characterization of inorganic materials.
- Explore structure–property relationships in solids and coordination compounds.
- Appreciate the role of metals in biological systems through bioinorganic chemistry concepts.

References:

1. Laser Spectroscopy: Basic Concepts and Instruments, *W. Demtroder, 2nd Edition (Springer Verlag, 1996)*
2. Atomic Physics, C.J. Foot, Oxford Master Series in Atomic, Optical and Laser *Physics (Oxford University Press 2008)*

01-PHYS04-017-A: Introduction to Mega Science Projects (15 Lecture Hrs)

Coordinators: Dr. D. Bhattacharya, A&MPD, BARC
dibyendu@barc.gov.in

Course Details:

i. **Introduction (1 Lecture)**

ii. **Gamma-ray Astronomy Major Atmospheric Cherenkov Experiment (MACE) and Cherenkov Telescope Array (CTA): 2 Lectures**
Details of imaging atmospheric telescope MACE built by BARC, presently operational at Hanle, Ladakh. The physics goals and engineering challenges; CTA, an upcoming experiment consisting of array of multiple telescopes and the international collaboration; Physics goals of CTA experiment and the present status of the collaboration.

References:

1. Introducing the CTA concept, *Acharya et al, Astroparticle Physics, 2013, v. 43, pg. 3*
2. Science with the Cherenkov Telescope Array, *by The CTA Consortium, World Scientific, ISBN: 978-981-3270-08-4*

iii. **Neutrino and LHC Physics: 2 Lectures**
Standard model of particles and interactions, Weak interactions and neutrinos, Sources of neutrinos, Cosmic ray interactions in atmosphere, Neutrino oscillation phenomena, Interactions of neutrino with matter (charged and neutral current processes, quasi-elastic and deep inelastic scattering). Strong interactions, Quark Gluon Plasma, Electro-Weak interactions, Higgs mechanism and discovery of Higgs particle at LHC; Compact Muon Solenoid (CMS) and A Large Ion Collider Experiment (ALICE) at CERN, Super Kamiokande detector, SNO experiment, India-based Neutrino Observatory, ISMRAN and CEνNS experiments.

References:

1. Neutrino Astrophysics, *J.N. Bahcall, (Cambridge University Press, Cambridge, England, 1989).*
2. Massive Neutrinos in Physics and Astrophysics, *R. N. Mohapatra and P. B. Pal, (3rd Ed. World Scientific, 2004)*
3. The Neutrino Matrix, *APS Multidivisional Study Group report (2004).*
4. A plastic scintillator array for reactor based anti-neutrino studies: *D. Mulmule, S. P. Behera, P. K. Netrakanti, D. K. Mishra, V. K. S. Kashyap, V. Jha, L. M. Pant, B. K. Nayak, A. Saxena,Nuclear Inst. and Methods in Physics Research, A 911 (2018) 104–114*
5. Introduction to Elementary particles: *David Griffiths*
6. An Introduction to the standard model of particle physics: *W. N. Cottigham*
7. Ultrarelativistic Heavy Ion collisions: *R Vogt*

iv. **Accelerators (Proton Improvement Plan-II, LHC): 2 Lectures**
High intensity, high energy and high luminosity accelerators, Goals and challenges, RF superconductivity, RF Sources, SCRF cavity technology, Kapitza resistance, Lorentz force detuning, Quench design, Cavity qualifications, Magnet lattice of high intensity accelerators, Minimizing beam dispersion, Kicker magnets, Solenoid and Quadrupole focusing lenses, Compensation of cavity Quadrupole and skew quadrupole field, design of superconducting magnets for accelerators, Significance of strength of magnetic field in synchrotrons, Rutherford cables, NbTi and Nb3Sn based

superconducting magnets, challenges with development of Nb3Sn SC magnets, superconducting dipole and Quadrupole magnets.

References:

1. PIP-II Reference Design Report, *V1.00, June 2015, Fermi National Accelerator Laboratory*
2. Advanced Accelerator Magnets for upgrading the LHC, *Luca Botturaet. al., IEEE/CSC & ESAS European Superconductivity News Forum, No. 19, January 2012*
3. RF linear accelerators, *Thomas P. Wangler*
4. Superconducting Magnets, *M. N. Wilson*
5. RF Superconductivity: Science, Technology and Applications, *Hasan Padamsee*

v. Synchrotron Radiation and X-ray Free Electron Lasers: 2 Lectures

Fundamental principles of generation of synchrotron radiation and X-ray free electron lasers along with various exotic properties of the emitted radiation. Glimpses of various (2nd and 3rd generation) synchrotron sources and X-ray free electron laser facilities in the world. Details about Indian Synchrotron source (Indus-1 & Indus-2) and various material characterization techniques available including their underlying principles and related instrumentations.

References:

1. Synchrotron Radiation: Basics, Methods and Applications, *Editors: Mobilio Settimio, Boscherini Federico, Meneghini Carlo Springer, 2015*

vi. Neutron Scattering in Large Facilities Challenges and Scope: 2 Lectures

A brief introduction to neutron scattering for condensed matter research, Indian and global perspective, High flux neutron sources for neutron scattering and radiography, reactor and spallation Sources. Different experimental facilities for insight into structure and dynamics, Description of a few selected state of the art neutron instruments, Selected examples and scientific outcome highlighting the novelty of large-scale neutron scattering facilities and their role in understanding various types of materials including magnetic materials, crystalline and amorphous materials, thin films and nano-structured materials, Description of a few selected state of the art neutron instruments highlighting the physics of large scale structures in soft matter, phonons and stochastic dynamics in solids and soft matter.

References:

1. Neutron scattering in condensed matter, *A. Furrer, J. Mesot, T. Strässle (world Scientific), DOI: https://doi.org/10.1142/4870*
2. Neutron Scattering - Applications in Biology, Chemistry, and Materials Science, *Edited by Felix Fernandez-Alonso, David L. Price, Experimental Methods in the Physical Sciences, vol 49, 2017, DOI: https://doi.org/10.1016/B978-0-12-805324-9.09989-1*
3. Neutron scattering facilities in Europe - Present status and future perspectives, *Ed. Colin Carlile and Caterina Petrillo url: https://www.esfri.eu/sites/default/files/NGL_CombinedReport_230816_Complete%20document_0209 - 1.pdf*

vii. International Thermo-Nuclear Experimental reactor (ITER): 2 Lectures

Nuclear Fusion, Lawson Criterion, magnetic confinement in Tokamak and ITER Fusion reactor, High magnetic field Superconducting magnets technology (Nb3Sn based Toroidal coil, Central solenoid and NbTi based Poloidal coils) to confine, shape and control plasma in ITER. Electron Cyclotron and Ion Cyclotron based heating sources for Plasmas viz. High-power Klystrons, Gyrotrons, Accelerator based Neutral Ion beam generation and alternative plasma heating source. Indian Participation and R&D related to Test Blanket Modules (TBM) for breeding Tritium to enable sustainable energy generation.

References:

1. The ITER Superconducting magnet programme, Workshop on Accelerator Magnet superconductors *(WAMS 2004), CERN/AT 2005-007(MAS)*
2. Fusion Physics, *Mitusur Kikuchi, Karl Lackner, Minh Quang Tran, IAEA, 2012*
3. Tokamaks, *D. J Campbell and John Wesson, International Series of Monographs on Physics*
4. The ITER Design, Plasma Physics and controlled fusion, *Vol. 44, 519*

viii. Introduction to advanced energy systems and Gen-IV Reactor concepts: 2 Lectures

Introduction to Gen-IV reactor concepts, Innovative reactor design concepts in India and world-wide, High temperature reactors, Molten salt reactor concept, Design challenges in physics simulations, Long life cores, Use of advanced fuels, Fuel utilization aspects.

Course Outcomes:

- Understand principles of coordination chemistry, solid-state structures, and crystallography.
- Gain hands-on knowledge of synthesis and characterization of inorganic materials.
- Explore structure–property relationships in solids and coordination compounds.
- Appreciate the role of metals in biological systems through bioinorganic chemistry concepts.

References:

Following link can be considered for introduction to MSRs and HTRs

HTRs: *https://web.mit.edu/pebble-bed/Presentation/HTGR.pdf*

MSRS: *https://inis.iaea.org/collection/NCLCollectionStore/_Public/44/078/44078357.pdf*