

# PHYSICAL SCIENCES

*Programme Code:* PHYS00

*Programme Outcome:*

- To provide DAE with a manpower trained in the nuances of Nuclear Science & Technology in Physical Sciences
- Building strong foundation in the area of physical and nuclear sciences
- Expose the young students to state-of-the art experimental techniques
- Teach fundamental aspects pertaining to latest developments in the field of physical and nuclear sciences
- Understanding the role of engineering sciences in DAE programmes
- PGD (00) PHYSICAL SCIENCES: BARC
- Understating the role of engineering sciences in societal and strategic programmes

The syllabus for the physics discipline is intended to train the OCES Physics trainees on several special topics (Core courses) relevant to BARC advanced technologies, in addition to Foundation courses, Research orientation & Lab courses, Elective courses and a Mini project

## DETAILED COURSE STRUCTURE

(Notation: \* Tutorials, \$ Lab courses)

Foundation Courses					
Sr. No	Course Code	Subject Title	Hours (T)	Credits	Marks
1	01-PHYS00-501-F	Mathematical Physics	28 + 4*	2	150
2	01-PHYS00-502-F	Quantum Mechanics	28 + 4*	2	150
3	01-PHYS00-503-F	Statistical Physics	28 + 4*	2	150
4	01-PHYS00-504-F	Electromagnetic Theory	28 + 4*	2	150
5	01-PHYS00-505-F	Computational Physics	28 + 4*	2	150
6	01-PHYS00-604-F	Nuclear Physics	28 + 4*	2	150
7	01-PHYS00-607-F	Condensed Matter Physics	28 + 4*	2	150
<b>Total Foundation</b>			<b>196+28*</b>	<b>14</b>	<b>1050</b>
Core Courses					
Sr. No	Course Code	Subject Title	Hours (T)	Credits	Marks
1	01-PHYS00-601-C	Reactor Physics & Technology	28 + 4*	2	150
2	01-PHYS00-602-C	Electronics	28 + 4*	2	150
3	01-PHYS00-603-C	Astrophysics	(14 + 2*) Hrs	1	75
4	01-PHYS00-605-C	Atomic, Molecular & Laser Physics	28 + 4*	2	150
5	01-PHYS00-606-C	Plasma Physics & Technology	28 + 4*	2	150
6	01-PHYS00-608-C	Accelerator Physics & Technology	28 + 4*	2	150
7	01-PHYS00-609-C	Health Physics and Radiation Detectors	28 + 4*	2	150
<b>Total Core</b>			<b>182+26*</b>	<b>13</b>	<b>975</b>
Research Orientation and Lab Courses					
Sr. No	Course Code	Subject Title	Hours (T)	Credits	Marks
1	01-PHYS00-610-L	Engineering Drawing & Workshop Practices	15	1	75
2	01-PHYS00-611-L	Research Methodologies	8	NA	0
3	01-PHYS00-612-L	Methods of Experimental Physics	32	2	150
4	01-PHYS00-613-L	Experiments at BARC labs	75\$	3	200
<b>Total Orientation &amp; Lab</b>			<b>55+75\$</b>	<b>6</b>	<b>425</b>
Electives and Mini-Project					
Sr. No	Course Code	Subject Title	Hours (T)	Credits	Marks
1	01-PHYS00-701-728-E	Elective 1	20 + 4*	1	100
2	01-PHYS00-701-728-E	Elective 2	20 + 4*	1	100

3	01-PHYS00-751-PR	Mini Project	130\$	3	300
<b>Total Electives and Mini Project</b>			<b>40+ 8*+130\$</b>	<b>7</b>	<b>500</b>
<b>Total ( Lecture + Tutorial + Lab )</b>			<b>473+62*+205\$</b>	<b>40</b>	<b>2950</b>

<b>Viva Voce</b>	
<b>Subject Title</b>	<b>Marks</b>
Viva Voce	200

\* Tutorials, \$Lab hours

Courses: (A) Foundation Courses, (B) Core Courses, (C) Research Orientation and Lab Courses, (D) Electives and Mini-project, (E) Viva Voce

<b>Grand Total</b>				
<b>Subject Title</b>	<b>Course Code</b>	<b>Total Hours</b>	<b>Total Credits</b>	<b>Total Marks</b>
All subjects (A-E)	01-PHYS00-501-C to 01-PHYS00-751-PR	740+	40	3150

Total Contact Hrs=740 (Lecture=473 + Tutorial=62 + Lab=205)

## ELECTIVE COURSES UNDER DIFFERENT SUBGROUPS

Elective Courses In General Physics					
Sr. No	Course Code	Subject Title	Hours (T)	Credits	Marks
1	01-PHYS00-701-E	Special topics in Mathematical Physics	20 + 4	1	100
2	01-PHYS00-702-E	Quantum computing and quantum information science	20 + 4	1	100
3	01-PHYS00-703-E	Chaos and Nonequilibrium Statistical Mechanics	20 + 4	1	100
4	01-PHYS00-704-E	Nonlinear Dynamics	20 + 4	1	100
5	01-PHYS00-705-E	Advanced Computational Physics	20 + 4	1	100
6	01-PHYS00-706-E	Stochastic Physics	20 + 4	1	100
7	01-PHYS00-707-E	Python and its application to Machine Learning	20 + 4	1	100
8	01-PHYS00-708-E	Introduction to Mega Science projects	20 + 4	1	100
Elective Courses In Nuclear And Accelerator Physics					
9	01-PHYS00-709-E	Selected Topics in Nuclear Physics	20 + 4	1	100
10	01-PHYS00-710-E	Advanced accelerators and related technology	20 + 4	1	100
11	01-PHYS00-711-E	Introduction to Neutrino Physics	20 + 4	1	100
12	01-PHYS00-712-E	High Energy Astrophysics	20 + 4	1	100
Elective Courses In Atomic, Laser & Plasma Physics					
13	01-PHYS00-713-E	Synchrotron Radiation and its Applications	20 + 4	1	100
14	01-PHYS00-714-E	Quantum Optics, atom optics and Technology	20 + 4	1	100
15	01-PHYS00-715-E	Advanced Photonics	20 + 4	1	100
16	01-PHYS00-716-E	High Power Lasers and Applications	20 + 4	1	100
17	01-PHYS00-717-E	Computational Electrodynamics	20 + 4	1	100
18	01-PHYS00-718-E	Nonlinear Plasma Theory	20 + 4	1	100
Elective Courses In Condensed Matter Physics					
19	01-PHYS00-719-E	Modelling and Simulations in Condensed Matter Physics	20 + 4	1	100
20	01-PHYS00-720-E	Organic Semiconductor Devices	20 + 4	1	100
21	01-PHYS00-721-E	Single Crystal Growth and Devices	20 + 4	1	100
22	01-PHYS00-722-E	Advanced Magnetism and Superconductivity	20 + 4	1	100
23	01-PHYS00-723-E	Neutron as a Probe of Condensed Matter	20 + 4	1	100
24	01-PHYS00-724-E	Structure and Crystallography of Biomolecules	20 + 4	1	100
Elective Courses In Reactor Physics					

25	01-PHYS00-725-E	Advanced Reactor Physics and Computational Methods in Neutron Transport problems	20 + 4	1	100
26	01-PHYS00-726-E	High Energy Density Physics: Theory	20 + 4	1	100
27	01-PHYS00-727-E	High Energy Density Physics: Experimental	20 + 4	1	100
28	01-PHYS00-728-E	Nuclear Data Physics for Advanced Nuclear Applications	20 + 4	1	100

## COORDINATOR

### Chief Coordinators:

Meenakshi Sunder (Email : [msunder@barc.gov.in](mailto:msunder@barc.gov.in))

## CORE COURSES COORDINATOR

Course	Coordinators	Email
Mathematical Physics	Dr. Subir Bhattacharyya, ApSD	subirb@barc.gov.in
Quantum Mechanics	Dr. D. Bhattacharyya, A&MPD	dibyendu@barc.gov.in
Statistical Physics	Dr. V.K. Aswal, SSPD	vkaswal@barc.gov.in
Electromagnetic Theory	Dr. Raghwendra Kumar, TPD	raghav@barc.gov.in
Computational Physics	Shri N.G. Bhatt, ApSD	nilayb@barc.gov.in
Nuclear Physics	Dr. S. Santra, NPD	ssantra@barc.gov.in
Condensed Matter Physics	Dr. Subhankur Mitra, SSPD	smitra@barc.gov.in
Reactor Physics & Technology	Dr. Anurag Gupta, RPDD	anurag@barc.gov.in
Electronics	Shri Rohit Chandak	rohitc@barc.gov.in
Astrophysics	Dr. K.K. Yadav, ApSD	kkyadav@barc.gov.in
Atomic, Molecular & Laser Physics	Dr. Aparna Shastri, A&MPD	ashastri@barc.gov.in
Plasma Physics & Technology	Dr. S. Ghorui, L&PTD	sghorui@barc.gov.in
Accelerator Physics & Technology	Dr. Rajni Pande, IADD	rajnip@barc.gov.in
Health Physics and Radiation Detectors	Dr. Shaswati Sen, TPD & Dr. S. Anand, HPD	shash@barc.gov.in & sanand@barc.gov.in

Engineering Drawing & Workshop Practices	Shri Kavindra Pathak, EmA&ID	kpathak@barc.gov.in
Research Methodologies	Dr. S. Santra, NPD	ssantra@barc.gov.in
Methods of Experimental Physics	Dr. Debasis Sen, SSPD	debasis@barc.gov.in
Experiments at BARC labs	Dr. S. Santra, NPD	ssantra@barc.gov.in

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## Course work for Training School Officers (OCES)

The course work structure is divided into 7 foundation courses (A1-A7), 7 core courses (B1-B7), 4 research orientation and laboratory courses (C1-C4) and 2 elective courses (D1, D2) and a mini-project (D3), as given in Table-1. The topic 'Research Methodology' is explicitly included as a part of the course work (C2) as per the requirement of UGC. Total lecture hours are 473, with additional 62 hours for tutorials, 75 lab hours for experiments at different labs (C4) and about 140 lab hours spread over 7 weeks for a mini project (D3).

Total credits for the OCES coursework are 40. As per the requirement of HBNI, completion of only 18 credits is required for a PhD student. Detailed course structure for individual subjects is provided separately.

Some specific issues are as follows:

### ***Research Methodology***

This course includes specific topics related to 'Research Methodology' 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 modelling, documentation and presentation, laboratory safety and research ethics.

### ***Mini Project***

The Mini Project (D3) needs to be carried out upon completion of the second trimester concurrently with the elective courses.

### ***Elective Courses***

The elective courses are organized under five broad categories as mentioned in Table-2. This grouping has been done to help trainees/Ph.D students in selecting elective courses that will allow them to obtain advanced training required for the R&D work to be carried out in the division or for the doctoral programme.

### ***Viva Voce***

An overall Viva Voce examination will be carried out at the end of each semester based on all the subjects taught in that Semester.

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# FOUNDATION COURSES

## 01-PHYS00-501-F: Mathematical Physics (28 + 4\* Hrs)

Coordinators: **Dr. Subir Bhattacharyya, ApSD**  
[subirb@barc.gov.in](mailto:subirb@barc.gov.in)

### Course Details:

- **Symmetries and groups**  
Point groups, Abelian and non-Abelian groups, characters, representations of simple groups, Lie groups, symmetric groups, braid group
- **Functions of a complex variable**  
Analytic and multi-valued functions, Cauchy residue theorem and complex integration, Riemann surfaces, applications to fluid mechanics and quantum mechanics.
- **Ordinary differential equations (ODE)**  
Linear and nonlinear first-order equations, classification of ODEs, linear independence and Wronskian, singular points, Frobenius series solutions for second-order differential equations, Green function, system of ODEs, phase portraits, hyper-geometric and confluent hyper-geometric equations, relation with special functions.
- **Partial differential equations**  
Classification, characteristics, method of integral transforms, Green functions for Poisson equation, diffusion equation, wave equation, Helmholtz equation
- **Integral equations**  
Fredholm, Volterra, Abel integral equations, solutions by Liouville-Neumann, Fredholm method, Hilbert-Schmidt theory, Sturm-Liouville problems

### Course Outcomes:

- Understand and apply mathematical techniques for describing and deeper understanding of physical systems.

### References:

1. Groups and Symmetry: A Guide to Discovering Mathematics, D. W. Farmer (Universities Press, 1998).
2. Mathematical Methods in Physics, J. Mathews, R. L. Walker (Addison-Wesley, 1971).
3. Advanced Mathematical Methods for Scientists and Engineers, C. M. Bender, S. A. Orszag (Springer, 2010).
4. Elements of Green's Functions and Propagation, G. Barton (Clarendon Press, 1989).
5. Mathematical Methods for Physicists, Seventh ed., G. B. Arfken, H. J. Weber, F. E. Harris (Elsevier, 2013).
6. Fundamentals of Mathematical Physics, E. A. Kraut (McGraw-Hill, 1967).

**01-PHYS00-502-F: Quantum Mechanics (28 + 4\* Hrs)****Coordinators: Dr. D. Bhattacharyya, A&MPD**  
**dibyendu@barc.gov.in****Course Details:**

- **Formalism**  
Postulates of quantum mechanics; Representation of a state as a vector in Hilbert space; Scalar products; Dirac's bra and ket notation, Schwarz's inequality; Uncertainty relation as a consequence of Schwarz's inequality and the concept of minimum uncertainty states; State representation, quantum mechanics in coordinate and momentum space representations and their relationship.
- **Quantum Dynamics**  
Schrodinger and Heisenberg pictures, The Schrodinger equation and elementary solution in 1-dimension; Free particle and wave packet, phase and group velocities, completeness; Particle in a well/box, density of states; Simple Harmonic Oscillator potential; Tunneling - reflection and transmission coefficients; Angular Momentum and Spin: Angular momentum algebra; Addition of angular momentum.
- **Quantum Mechanics in 3-dimension**  
Free particle in 3-d; Particle in central potential; Hydrogen atom; Virial theorem, Feynman-Hellmann theorem.
- **Identical Particles**  
Two particle systems; Pauli's principle, Fermions and Bosons; Spin of an electron, Multiparticle quantum states, Entanglement.
- **Approximation methods**  
WKB quantization method, expression for transmission coefficient; Time-independent perturbation theory for non-degenerate as well as degenerate Hamiltonians; Variational method; Time-dependent perturbation theory, Fermi golden rule.
- **Collision theory**  
Born series and approximations, Partial wave analysis, Need for complex potentials, Analytic properties of S-matrix and dispersion theory.

**Course Outcomes:**

- Understand and apply principles of Quantum mechanics for understanding the physical systems in quantum realm.

**References:**

1. Introduction to Quantum Mechanics, D. J. Griffiths
2. Quantum Mechanics, B.H.Bransden and C.H.Jochain.
3. Principles of Quantum Mechanics, P.A.M. Dirac
4. Modern Quantum Mechanics, J.J.Sakurai
5. Quantum Mechanics, E. Merzbacher.
6. Quantum Mechanics (Non-relativistic Theory), L.D. Landau and E.M. Lifshitz
7. Principles of Quantum Mechanics, R. Shankar

**01-PHYS00-503-F: Statistical Physics (28 + 4\* Hrs)**

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

**Course Details:**

- **Background**  
Revision of main results of thermodynamics
- **Formalism**  
Introduction to micro-canonical, canonical and grand canonical ensembles with examples for each, derivation of Fermi-Dirac and Bose-Einstein distribution for a quantum ideal gas, Specific heat of a degenerate Fermi gas, Black body radiation, Bose-Einstein Condensation.
- **Phase transitions**  
Introduction to phase transitions, notion of continuous and discontinuous transitions, Landau Theory Mean field and Gaussian fluctuations.
- **Monte Carlo Techniques and applications**  
Introduction to Monte Carlo methods, Metropolis algorithm, Application to numerical integration, application to Ising Model.
- **Applications**  
BBKGY equations, Vlasov equation, Saha ionization formula, Statistical nuclear physics
- **Irreversible processes**  
Master equation, Brownian motion and Langevin equation, Fluctuation-Dissipation theorem and calculation of friction constant

**Course Outcomes:**

- Understand and apply statistical methods for describing the classical and quantum particles in various physical systems and processes.

**References:**

1. Statistical Mechanics, K. Hunag, 2nd Edition (Wiley, 1987)
2. Statistical Mechanics, R. K Pathria, 2nd Edition (Butterworth-Heinemann, 1996)
3. Fundamentals of statistical and thermal physics, F. Reif, 1st Indian Edition (Levant Books, 2000)
4. Principles of Condensed Matter Physics, P M Chaikin and T C Lubensky, 1 st paperback Edition (CambridgeUniversity Press, 2000)
5. Reports on Progress in Physics 60, 487 (1997), K Binder
6. Saha Equation, Hale Bradt, (soft copy available)
7. Saha and his Formula, G. Venkataraman, 1 st Edition (Universities Press India Ltd., 1995)
8. Statistical Models for Nuclear Decay, A. J. Cole (IOP Publishing Ltd, 2000).
9. Treatise on Heavy Ion Science, R. Stokstad, Ed. D. A. Bromley (Plenum, New York, 1985), Vol. 3, p. 83.

**01-PHYS00-504-F: Electromagnetic Theory (28 + 4\* Hrs)****Coordinators: Dr. Raghendra Kumar, TPD**  
**raghav@barc.gov.in****Course Details:**

- **Electrostatics**  
Maxwell's equations, Laplace & Poisson equations, Boundary value problems in macroscopic media involving use of special functions, multipole expansion.
- **Magnetostatics**  
Maxwell's equations, Vector potential, Coulomb Gauge, Magnetic scalar potential, Laplace & Poisson equations in magnetic media, Boundary value problems involving use of special functions and multipole expansion.
- **Electrodynamics**  
Maxwell's equations, vector and scalar potentials, Lorentz gauge, Conservation laws, wave equation, Poynting's theorem and conservation of energy and momentum of electromagnetic field, Plane electromagnetic wave and wave propagation, interaction of radiation with matter, radiation from a localized source, Electric dipole radiation.
- **Wave guides and resonant cavities**  
Fields at the surface of a conductor, eddy currents, skin depth and surface resistance, modes in a rectangular waveguide, energy flow and attenuation in a wave-guide.
- **The special theory of relativity**  
Transformation of fields under Lorentz transformations, introduction to the four-vector formalism of electrodynamics, radiation by moving charges - Liénard-Wiechert potentials.

**Course Outcomes:**

- Gain knowledge in understanding the principles and dynamic phenomena of electromagnetism that occur in the case of time-varying sources (local charges and currents). Equips the students with the necessary mathematical knowledge for a detailed and accurate description of these phenomena and for solving related problems.

**References:**

1. Classical Electrodynamics, J. D. Jackson
2. Introduction to Electrodynamics, D. J. Griffiths
3. Foundations of Electromagnetic Theory, J. R. Reitz, F. J. Milford, W. Christy
4. Modern Electrodynamics, A Zangwill (Cambridge University Press)

**01-PHYS00-505-F: Computational Physics (28 + 4\* Hrs)****Coordinators: Shri N.G. Bhatt, ApSD  
nilayb@barc.gov.in****Course Details:**

- **Computer Programming**  
Introduction to Linux, Programming in Fortran, Introduction to Python programming, Concepts of classes and objects. Introduction to C and Parallel Processing, Hands on experience at the computer, Data plotting using programs such as gnuplot.
- **Numerical Methods**  
Errors in Numerical Methods, Data Statistics & Curve Fitting, Interpolation and Extrapolation, Integration of Functions, Solution of System of Linear Equations, Solution of Nonlinear Equation or Root Finding, Solution of Ordinary Differential Equations, Solution of Partial Differential Equations, Solution of Integral Equations. Diagonalization of a Matrix and finding eigen values and eigen vectors, Fourier transform, convolution and deconvolution of a numerical data.
- **Project Assignments**  
Various realistic physics problems to be solved using numerical algorithms coded into programs to be run on the computer, Introduction to artificial intelligence.

**Course Outcomes:**

- Gain knowledge in basic concepts in computational & numerical skills and apply them for understanding and describing complex physical systems.

**References:**

1. Computer Programming in FORTRAN 90 and 95, V. Rajaraman (Prentice-Hall of India Private Limited, 2006).
2. Upgrading to FORTRAN 90, C. Redwing (Springer-Verlag New York, 1995).
3. C: The Complete References, H. Schildt (McGraw-Hill, 1987).
4. Computer programming in C, V. Rajaraman (Prentice-Hall of India Private Limited, 1994).
5. C++ : The Complete References, H. Schildt (Tata McGraw-Hill, 2003).
6. Numerical Recipes – The Art of Scientific Computing : W. H. Press, S. A. Teukolsky, W. T. Vetterling and B. P.Flannery (Cambridge University Press, 1996).
7. Numerical Algorithms: Computations in Science and Engineering, E. V. Krishnamurthy and S. K. Sen (EastWestPress, 1986).
8. Numerical Methods for Engineers - A Programming Approach, D. V. Griffiths & I. M. Smith (Chapman and Hall,2006).
9. Numerical Methods for Scientists and Engineers, H. M. Antia (Birkhauser, 2002).

**01-PHYS00-604-F: Nuclear Physics (28 + 4\* Hrs)**

**Coordinators: Dr. S. Santra, NPD**  
**ssantra@barc.gov.in**

**Course Details:**

- **Background**  
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 resonances.
- **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.
- **Nuclear reactions**  
Definition of cross-sections, phase shifts, low energy behavior and astrophysics, compound nucleus theory, optical model, statistical model, direct reactions, heavy ion reactions and fission, semi-classical methods and applications, nuclear astrophysics.
- **High energy nuclear physics**  
Fundamental particles and forces with Feynman diagrams, Relativistic Kinematics, Dirac equation, Scattering in QED, Symmetries, Lepton-Nucleon Scattering, Form factor, Quarks and Gluons and Quantum Chromo Dynamics (QCD), Experiments at particle colliders and underlying theory, Relativistic Heavy Ion Collisions and Quark Gluon Plasma (QGP), dark matter & dark energy.
- **Applied nuclear physics**  
Rutherford Back Scattering (RBS), Nuclear Reaction Analysis (NRA), Neutron Activation Analysis (NAA), Accelerator Mass Spectrometry (AMS), muon-Tomography, medical/ industrial/ agriculture applications of Radioisotopes.

**Course Outcomes:**

- Understand the properties and structure of nuclei, nuclear reaction mechanisms and their role in formation of universe consisting of different elements.

**References:**

1. Introductory Nuclear Physics, Kenneth S. Krane (Wiley, New York, 1988).
2. Introductory Nuclear Physics, Samuel S.M. Wong (Wiley Interscience).
3. Basic Ideas & Concepts in Nuclear Physics, K. Heyde (3 rd Ed. Taylor & Francis 2004).
4. Particles and Nuclei, B. Povh, K. Rith, C. Scholz and F. Zetsche, 5th Edition (Springer 2006).
5. Introduction to Elementary Particle Physics, E. Griffiths (Wiley, New York 1987).
6. Introduction to High Energy Heavy Ion Collisions, Cheuk-Yin Wong (World Scientific).

## 01-PHYS00-607-F: Physics of Materials and Surfaces ( Renamed as Condensed Matter Physics) (28 + 4\* Hrs)

Coordinators: **Dr. Subhankur Mitra, SSPD**  
[smitra@barc.gov.in](mailto:smitra@barc.gov.in)

### Course Details:

- **Background**  
Nature of Bonding in Condensed Matter, Symmetry, crystalline structure and classification, 2D and 3D lattice types, symmetry tables, constraints on physical properties by symmetry, Glasses and Amorphous systems, diffraction for structure studies, phase transitions in condensed matter.
- **Sample Preparation methods**  
Bulk single crystals and bulk poly-crystals, nano-particles, clusters, selfassembled, alloys, ceramics, polymers and molecular crystals.
- **Lattice vibrations and phonons**  
Debye model, dynamical matrix, acoustic and optical branches, outline of experimental techniques, like neutron inelastic scattering, Raman and Brillouin scattering; special features in phonon spectra like softening, Kohn anomaly, etc.
- **Transport Properties of Solids**  
Thermal and electrical transport, Magneto-transport, Hall Effects, Diffusion in Solids.
- **Electron states**  
Independent particle picture and periodic boundary conditions, metal-insulator-semiconductor bands, Fermi surface, relation to many electron system and total energy, exchange-correlation terms, relation to experiments like photoemission, optical absorption, etc.
- **Magnetism**  
Magnetic materials, types of magnetic ordering and interactions, principles of adiabatic demagnetization and cooling, magnetic domains, linearized spin waves in ferromagnets.
- **Superconductivity**  
Meissner effect, energy gap, London equation, type-I and type-II superconductors, vortices, tunnelling junctions, outline of modern superconductivity theories, new superconducting materials.
- **Semiconductors**  
Intrinsic and extrinsic semiconductors, p-n junction and its applications, heterostructures and semiconductor superlattices. Physics principles of energy devices.
- **Dielectrics and Ferroelectrics**  
Dielectric relaxation and loss, ferroelectric and related materials, comparison with ferromagnets.
- **Introduction to surface structures**  
Difference between bulk and surfaces. Surface-driven physical phenomena. Different types of surfaces, surface symmetry, concept of surface free energy, stability and reactivity, surface reconstructions & relaxation, Surface processes: Physisorption and chemisorptions,
- **Growth of controlled surfaces**  
Concept of vapour pressure, Condensation, nucleation and growth of a surface / thin films, Different modes of surface growth and factors affecting it, Preparation of controlled surfaces and associated phenomena: Importance of vacuum in growth of controlled surfaces, Physical vapor deposition (thermal evaporation, electron beam, laser ablation, DC, RF & magnetron sputtering, molecular beam epitaxy) and chemical vapor deposition.
- **Surface characterization**

(i) Concept of surface sensitive characterization (ii) Determination of structure and morphology (iii) Estimation of roughness, thickness and density (iv) Composition determination of a surface / thin films.

**Course Outcomes:**

- Able to formulate basic models for electrons and lattice vibrations for describing the physics of crystalline materials; and understand band structure and electrical/optical properties, magnetism, superconductivity and surface structure of a material.

**References:**

1. Solid State Physics, N.W. Ashcroft and N.D. Mermin (Saunders College,1976)
2. Introduction to Solid State Physics, C. Kittel 8th edition (Wiley, 2004)
3. Solid State Physics, A.J. Dekker (Macmillan India Limited, 2000)
4. Physics of Surfaces and Interfaces, H. Ibach(Springer, 2006)
5. Handbook of thin films technology, Leon I Maissel and ReinhardGlang (McGRAW HILL, 1970)
6. Materials Characterization Introduction to Microscopic and Spectroscopic Methods Leng Y. (Wiley 2008)

## CORE COURSES

### 01-PHYS00-601-C: Reactor Physics and Technology (28 + 4\* Hrs)

**Coordinators: Dr. Anurag Gupta, RPDD**  
[anurag@barc.gov.in](mailto:anurag@barc.gov.in)

#### *Course Details:*

- **Basics Neutron Physics Concepts**  
 Neutron-nuclear interaction cross sections, Reaction rate density, macroscopic cross section. International Nuclear Data files & processing for reactor application. Fission Process: Fissile and Fertile nuclides, Critical energy
- **Steady State Neutron Transport Equation**  
 Definition of neutron flux, current and sources, Neutron Transport equation: Differential & integral forms, Diffusion approximation, One speed neutron diffusion theory, Boundary conditions, Source-sink problem, Sub-critical reactors with flux independent source, K-infinity, four factor formula, Critical reactor and concept of K
- **Homogeneous Reactor**  
 Space dependence of neutron flux. Flux shape in different geometries, Slab/cylinder/spherical reactor, Geometric and material, buckling. Diffusion length, reflected slab, reflector savings.
- **Slowing Down and Energy Dependence**  
 Elastic scattering, Inelastic scattering, Anisotropy, average energy loss per neutron, Concept of lethargy. Fermi age theory, age of neutron, Logarithmic energy decrement, Slowing down spectra, Slowing down in hydrogen, Definition of resonance integral, Shape of thermal neutron: Maxwell spectrum.
- **Resonance Absorption**  
 Resonance cross sections, Resolved and unresolved region, Spatial and energy selfshielding, Concept of potential scattering cross section, Doppler broadening of resonance. Multi-group Diffusion Theory: Energy group and group fluxes, Flux weighted group constants, One group theory for thermal neutrons, Two group theory, Two group two region model core with reflector.
- **Reactor Kinetics**  
 Time dependent diffusion equation, Point kinetics, Prompt neutrons, Delayed neutron precursors, Reactor period, period versus reactivity, In hour formula, One group delayed neutrons, One dollar of reactivity, Prompt criticality.
- **Reactor Control**  
 Cold start-up, Hot power operation, Temperature loads, Effects of burnup and fission products. Function of control rods. Theory of control rods, Xenon load during operation, Xenon iodine concentrations after shutdown, Xenon override, Xenon poison out condition, Samarium poisoning. Temperature coefficient of reactivity, Density temperature coefficient.
- **Experimental reactor physics aspects**  
 Approach to criticality in different reactors, Low power experiments for validation of reactor physics evaluations - subcritical and critical experiments, Experimental determination of reactivity coefficients, General methods of flux measurement - foil/wire activation methods, Spectrum unfolding, Differential measurements for reaction rates, Dynamic methods for reactivity evaluation - power run-down experiments and period measurements; Process parameter measurements using neutronics - Coolant flow measurement with  $^{16}\text{N}$  gamma signals, Delayed neutron and noble gas
- **Nuclear Fuel Cycles**  
 Uranium-Plutonium, Uranium-Thorium. Brief Description of Nuclear Reactors like PHWRs, AHWR, VVER, HTR and FBR. Brief discussion of Accelerated Driven Subcritical System (ADSS)

**Course Outcomes:**

- Understand the basic principle of nuclear power generation and physics design of a reactor.

**References:**

1. The Elements of Nuclear Reactor Theory, Samuel Glasstone and M.C.Edlund, (Van Nostrand, 1952).
2. Nuclear Reactor Theory, Lamarsh J.R., (Addison-Wesley, 1966).
3. Nuclear Reactor theory, Duderstadt and Hamilton, (Wiley, 1976).
4. Nuclear Reactor Engineering, Glasstone and Sesonske, (Reprint CBS Publishers, 2004)
5. The Physical Theory of Neutron Chain Reactors, Weinberg A. M. and Wigner E.P., (Chicago Press, 1958).
6. Nuclear Reactor Theory, Bell and Glasstone (Van Nostrand Reinhold Co., 1970).
7. Physics of Nuclear Reactors, Jakeman D. (American Elsevier, 1966).
8. Physics of Nuclear Reactors, Garg, FerozAhemad and Kothari L.S. (Tata McGraw Hill,1986).
9. Nuclear Reactor Physics, Weston M. Stacey, (Wiley, 2001).

**01-PHYS00-602-C: Electronics (28 + 4\* Hrs)**

**Coordinators: Shri Rohit Chandak**  
**rohite@barc.gov.in**

**Course Details:**

- **Digital Electronics**

Number system, Boolean algebra, Logic gates and Truth tables, logic family concept -static and dynamic, TTL/ECL/CMOS logic specification, fan-in/fan-out, power dissipation in logic families. Combinational Logic Circuits: Adders, subtractor, Decoder, Multiplexer, De-Multiplexer, K-map for realizing up to four variable Boolean function, Seven segment display driver.

- **Sequential Logic Circuits**

Flip-Flops, Block diagram of sequential circuits, Finite State Machines (FSM), Moore and Mealy FSM models, Counters, Shift Registers, Kmap for sequential circuits, meta-stability in logic circuits, Semiconductor memories static/dynamic.

Basics of Computer Organization

Principle of Operation of a simple microprocessor circuit along with its Memory; Peripheral and Input-Output circuit; Block diagram of computer mother board. Computer communications & interfacing: Data transfer - Serial and Parallel, Synchronous and Asynchronous. Salient features of PCI/PCIe, RS232, LVDS, USB and introduction to Ethernet & LWIP; Digitizer, graphical user interfacing methods.

Introduction to Programmable Logic Devices

PAL, PLD, CPLD and FPGA; Overview of Hardware Description Language VHDL/Verilog; Design tools and process for design using programmable logic devices; introduction to logic resolution.

- **Analog Electronics**

Basic concepts

Introduction to semiconductor physics-mobility, resistivity, law of mass action, doping band gap, concept of decibels dB.

Overview of Electronic Devices and Circuits

Diodes, Transistors, FETS and MOSFET with small signal models, intrinsic gain, Feed-back theory, Miller's theorem, classes of amplifier, gain /phase margin, noise in devices.

Linear Integrated Circuits

Characteristics of OP AMP, Applications of OP AMP using feedback theory, Comparator, Schmitt trigger, Window detector, Phase lock loop.

Power Supplies

Linear and Switch Mode Power Supplies, High Voltage and Power supplies.

Data Converters

Dynamic and static specification of ADC/DAC, SNR, SFDR, effective no of bits , DNL/INL Sampling Theorem, noise shaping, Analog to Digital Converters types , Digital to Analog Converters types, Sample and Hold, peak detector Circuits.

**Course Outcomes:**

- Understand how an analog signal is processed through different electronics modules and converted to digital signals, stored in memory and transferred to another device.

**References:**

1. Fundamentals of Microelectronics, Behzad Razavi. Wiley
2. Digital Design , M Morris Mano Person
3. Electronic Principles, A. P. Malvino, 7th Edition (Tata McGraw-Hill Publishing)
4. Digital Computer Electronics A. P. Malvino Jerald Brown McGraw Hill

**01-PHYS00-603-C: Astrophysics (14 + 2\*) Hrs**

**Coordinators: Dr. K.K. Yadav, ApSD**  
**kkyadav@barc.gov.in**

**Course Details**

- **Introduction to Astrophysics and Astronomy**  
Celestial sphere, coordinate system, time References, cosmicrays, multi-wavelength observations.
- **Astrophysical Objects**  
Stars, clusters, galaxies, x-ray binaries, pulsars, supernova remnants, active galactic nuclei etc.
- **Non Thermal Universe**  
Cosmic-ray spectrum and composition, Cosmic emissions at keV-TeV energies, first order and second order Fermi acceleration, diffusive shock acceleration.
- **Experimental Techniques in Astronomy**  
Gas filled detectors, solid state detectors, satellite based experiments, ground based experiments, extensive air showers, simulation studies, atmospheric Cherenkov technique.
- **Fundamentals of Radiative Transfer**  
Electromagnetic spectrum, radiative flux, specific intensity and its moments, basic equations of radiative transfer, Bremsstrahlung, synchrotron and inverse Compton process, proton-proton collision, neutral pion decay, proton-photon interaction.
- **Theory of Accretion**  
Spherical accretion, Eddington luminosity, disc accretion and its basic equations, equations for structure of discs and their standard solution.
- **Jets and Outflows**  
Microquasars, Blazars and Radio Galaxies, radiation emission from jets, Doppler boosting, Lorentz transformations, observed spectra and spectral models.

**Course Outcomes:**

- Able to identify and explain the properties of different astrophysical objects, learn experimental techniques to study them, understand the fundamentals of radiative transfers, theory of accretion and jets & outflows.

**References:**

1. High Energy Astrophysics, Vol 1 & 2, M.Longair (Cambridge University Press, 2004).
2. Very High Energy Gamma-Ray Astronomy, Trevor Weekes (IOP Publishing, 2003).
3. Radiative Processes in Astrophysics, G.B.Rybicki and A.P.Lightman (John Wiley & Sons, 1979).
4. Accretion Power in Astrophysics, J.Frank, A.King, D.Raine (Cambridge University Press, 2003).
5. Note: First four topics (with first three References) constitute the regular 15 lecture course (See Table-1) while
6. all the topics together constitute the 30 lecture course (see Table-3).

**01-PHYS00-605-C: Atomic, Molecular and Laser Physics (28 + 4\* Hrs)**

**Coordinators: Dr. Aparna Shastri, A&MPD**  
**ashastry@barc.gov.in**

**Course Details:**

- **Atomic Physics**
  - **Background**  
Revision of basic concepts, atomic structure, energy levels and spectra of hydrogenic atoms.
  - **Multi-electron atoms**  
Central field approximation, fine structure (spin-orbit coupling, LS and jj coupling schemes), nuclear effects (hyperfine structure & isotope shifts); Rydberg and autoionizing levels. Interaction of atoms with radiation: Semi-classical treatment of interaction of radiation with atoms, selection rules, effect of external fields (Zeeman, Stark effect), spectral line broadening
  - **Spectroscopy using X-rays**  
Interaction of X-rays with matter and basic phenomenon of photoelectron emission and back scattering, X-ray absorption spectroscopy, electron spectroscopy and X-ray fluorescence.
- **Molecular Physics**
  - **Diatomic Molecules**  
Born Oppenheimer approximation; Rotational, vibrational, electronic structure and spectra of diatomic molecules, selection rules and intensities of spectral lines, molecular orbital theory, radiative and nonradiative transitions.
  - **Polyatomic Molecules**  
Introduction to rotational, vibrational and Raman spectra of polyatomic molecules. Molecular symmetry and group theory: Point groups, character tables and selected applications to spectra of polyatomic molecules.
- **Laser physics**
  - **Theory of Optical Resonators**  
Resonator modes, Stability criterion, Gaussian beams and their propagation.
  - **Principles of laser oscillation**  
Pumping mechanisms, Rate equation for three/four level laser systems, Population inversion, Gain coefficient and threshold population inversion, Gain clamping, Single mode and multimode oscillations, Spatial and spectral hole burning.
  - **Intense and ultra-intense lasers**  
Techniques for generation of short laser pulse, Q-switching and mode-locking including active/passive schemes, Chirped pulsed amplification.
  - **Types of Lasers**  
Solid state lasers- Nd:YAG, Ti:S; Gas and metal vapour Lasers, Dye lasers, Semiconductor lasers and Diode pumped solid state lasers.
  - **Non-linear Optics**  
Classical theory of nonlinear response, Wave propagation in nonlinear media, Three wave mixing– Second harmonic generation, Phase matching condition, Sum and difference frequency generation, Optical parametric oscillator and amplifiers.
- **Laser based atomic & molecular spectroscopy/applications**

- **Laser spectroscopy**  
Atomic/molecular beam and vapour sources; Doppler-limited spectroscopic techniques: absorption, fluorescence, opto-galvanic spectroscopy; Doppler-free laser spectroscopy: Saturated absorption spectroscopy. Multi-photon and multi-step processes and spectroscopy: Multistep Resonance excitation/ionization, Multi-photon absorption/ionization.
- **Applications of laser spectroscopy**  
Trace analysis, Laser isotope separation, Laser cooling and trapping

**Course Outcomes:**

- Understand the role of atoms and molecules in the structure and properties of mater. Describe different types of atomic and molecular spectra with and without external field.

**References:**

1. Atomic Physics, C.J. Foot, Oxford Master Series in Atomic, Optical and Laser Physics (Oxford University Press 2008).
2. Physics of Atoms and Molecules, B.H. Bransden and C.J. Joachain, 2nd edition (Pearson Education India)
3. Fundamentals of Molecular Spectroscopy, C.N. Banwell and E.M. McCash, 4thEdition, (Tata McGraw Hill, 2010).
4. Modern Spectroscopy, J.M. Hollas, 4thEdition (Wiley India Pvt. Ltd)
5. Symmetry and Spectroscopy, An Introduction to Vibrational and Electronic Spectroscopy, D.C. Harris and M.D. Bertolucci (Dover publications).
6. Laser Fundamentals, W.T. Sylfvast, 2nd Edition (Cambridge University Press, 2004).
7. Photonics, Ralf Menzel, 2nd Edition (Springer, 2007).
8. Laser Spectroscopy Basic Concepts and Instrumentation, W. Demtröder, 3rd Edition (Springer-Verlag 2003).
9. X-Ray Absorption: Principles, Applications, Techniques of EXAFS, SEXAFS and XANES, edited by D.C. Konigsberger and R. Prince (Wiley, New York, 1988).

**01-PHYS00-606-C: Plasma Physics and Technology (28 + 4\* Hrs)**

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

**Course Details:**

- **Introduction to Plasma**

Plasma in nature and laboratory, the fourth state of matter, thermal and non-thermal plasmas, cold atmospheric plasma, APPJ, fusion plasma, inertial and magnetic confinements, collective and single particle behaviour, charge neutrality, spatial and time scales, plasma temperature, plasma emission, Debye shielding and Debye length, plasma frequency, plasma parameters, plasma criteria, plasma sheath and plasma as a dielectric medium, propagation of electromagnetic waves in plasma.

- **Basic processes in plasmas**

Ionization mechanism in plasma, Saha ionization equation, concept of CTE, LTE and PLTE plasma, basic processes, ionization scenario in monatomic and molecular gases, recombination, diffusion, mobility, ambipolar diffusion. Collisional scenario, large angle and small angle scattering in plasma, collision frequency.

- **Plasma Theory**

Plasma orbit theory, ExB drift, magnetic mirror concept, reflection criteria, plasma kinetic theory, Klimontovich equation, plasma kinetic equation, Vlasov equation, solution of Vlasov equation, electrostatic waves in plasma, dispersion relation, Langmuir waves in plasma, dispersion relation for Langmuir waves, Landau damping, introduction to fluid theory of plasmas, single & multi fluid approximations, conservation laws, MHD equations.

- **Plasma production**

Basic processes for plasma production, ionization by electron collision, positive ions, photons, cathode processes, effect of contaminants, Penning effect, DC and AC breakdown in gases, Townsend mechanism, Paschen law, glow to arc transition.

- **Plasma diagnostics**

Plasma diagnostic techniques, optical emission spectroscopy for species identification and plasma temperature, in-flight particle velocimetry and particle temperature measurement in plasma jet, principles of enthalpy probe, voltage probe, Langmuir probes, fast imaging, Signal and image analysis techniques for plasma instability.

- **Fusion plasma**

Concept of fusion, regimes of fission and fusion, thermonuclear reaction in stars, controlled thermonuclear fusion, ignition and breakeven, magnetic and inertial confinement, fusion reactions, cross sections, radiative processes in plasmas, energy loss, Lawson criterion, emission of X rays and neutrons, fusion plasma diagnostics.

- **Plasma applications**

Potential of thermal and non-thermal plasma for material processing. Unique aspects, plasma based surface coatings, nano-synthesis, spheroidization, novel material synthesis, melting, cutting, welding, waste management, application in nuclear, space and semiconductor industries, biomedical application of APPJ.

**Course Outcomes:**

- Describe basic concept of plasma, its physical parameters and applications. Describe basic processes in plasma and associated theory and solve simple plasma physics problems.

**References**

1. Plasma Physics: An Introductory Course, Ed. R.O. Dendy (Cambridge University Press 1995)

2. Introduction to Plasma Physics (Plasma Physics Series) by R.J. Goldstan, P. H. Rutherford (Institute of Physics, 1995)
3. Principles of Plasma Physics, N.A. Krall and A. W Trivelpiece (McGraw Hill, 1973)
4. Introduction to Plasma Theory, D.R. Nicholson, (Wiley, 1992)
5. Principles of Plasma Diagnostics by I.H. Hutchinson (Cambridge University Press, 2002)
6. Thermal Plasma Diagnostics, A.A. Ovsyannikov (Cambridge International Science Publishing, 2001)
7. Inertial Confinement fusion, J.J. Dudesrstadt and G.A. Mosses, (Wiley, 1982)
8. Fusion: An introduction to the Physics and Technology of Magnetic Confinement Fusion, W. M. Stacy (Wiley, 1984)
9. Industrial Plasma Engineering, J. Reece Roth (IOP Publications, 2000)

**01-PHYS00-608-C: Accelerator Physics (28 + 4\* Hrs)**

**Coordinators: Dr. Rajni Pande, IADD**  
**rajnip@barc.gov.in**

**Course Details:**

- **Basic Accelerator Physics**

Introduction to accelerators; basic concepts; types of accelerators. Limitations of DC accelerators, acceleration using time varying fields, principle of successive acceleration, isochronism, concept of phase. General equations of motion in a combined electric and magnetic field, in Cartesian co-ordinate system; in cylindrical co-ordinate system; beam rigidity; relativistic expressions. Concept of magnetic field index; introduction of focusing forces in magnets; transverse focusing (betatron) oscillations; expression for vertical betatron frequency; expression for horizontal betatron frequency; weak focusing principle; stop bands. Tunes and resonances in betatron oscillations; imperfection resonances; sum and difference resonances; non-linear resonances; tune diagram; working point of an accelerator; general design of a cyclic accelerator. Linear beam optics, beam transport systems: drift spaces, bending magnets, quadrupole lenses; solenoidal lens. Matrix techniques in beam optics; first-order transfer matrix of drift space, dipole, quadrupole; quadrupole doublet; aberrations; second order transfer matrix; matching and design of beam transport systems. Phase-space ellipse; beam emittance; Liouville's theorem; emittance matching, Twiss parameters; Strong focusing principle; analysis of betatron frequencies using matrix technique; condition for strong focusing; lattice design; Momentum compaction; longitudinal stability, phase (synchrotron) oscillations; synchrotron frequency. Physics of synchrotron radiation sources; spectrum of emitted radiation; Schwinger's expressions; brilliance of a source; critical wavelength; energy lost by an electron per revolution; total power radiated; number of photons emitted in a given bandwidth.

- **Introduction to RF Linacs**

Guided waves in waveguides and cavities; TE and TM modes; cut-off frequency. Generation of an electric field in the loaded cavity; damping of waves; dispersion relations; frequency evaluation; application to the different types of linacs including travelling and standing wave types. Transit time factor and the energy gained in a linac. Longitudinal stability; stability criteria; separatrix; synchronous oscillation with small and large amplitudes; longitudinal wave vector; time period; phase damping; acceleration through  $v=c$  traveling wave linac and damping phenomena; acceleration conditions therein; Transverse stability in linacs; stability criteria; impulse due to radial field; focal strength of a radial defocusing impulse, phase advance and stability in linacs. General ideas of Q value; power loss; surface resistance; shunt impedance, etc; room temperature structures; superconducting (SC) cavities; general advantages of SC cavities over room temperature ones; breakdown mechanisms in SC cavities; Linac structures: Radiofrequency Quadrupole linac, DTL, CCDTL, CCL, IH linac, CH linac; Introduction to Space charge effects; Linear space charge and KV envelope equations; Applications: Accelerator Driven Systems. High power DC electron accelerators: Principles of HV generation (CW generator, Van de Graaff principle and its modifications, Marx generator, tandem accelerator principle), Industrial DC electron accelerators.

**Course Outcomes:**

- Understand working principles and design concepts of different accelerators and their applications in industry and research in basic and applied sciences.

**References:**

1. Introduction to Accelerator Physics, Arvind Jain
2. An Introduction to Particle Accelerators, E. J. N. Wilson
3. An Introduction to the Physics of Particle Accelerators, M. Conte & W.W. Mac Kay
4. Principles of Charged Particle Acceleration, Stanley Humphries
5. Particle Accelerator Physics (Vol 1 and Vol 2), Helmut Widemann

6. The Physics of Particle Accelerators, An Introduction, Klaus Wille
7. Principles of RF Linear Accelerators, T. P. Wangler
8. Electron Beam Technology, S. Shiller, U. Heisig and S. Panzer
9. Handbook of Accelerator Physics and Engineering, A. Chao, M. Tigner

**01-PHYS00-609-C: Health Physics and Radiation Detectors (28 + 4\* Hrs)**

**Coordinators: Dr. Shaswati Sen, TPD & Dr. S. Anand, HPD**  
**shash@barc.gov.in & sanand@barc.gov.in**

**Course Details:**

- **Part-I: Nuclear and Radiation Detectors**

- **Interaction of radiation with matter**

Energy loss of heavy charged particles in matter: Electronic stopping power (Bohr and Bethe-Bloch formulae), Cherenkov radiation; Energy loss of electrons and positrons: Electronic stopping and energy loss by Bremsstrahlung radiation; Interaction of photons: Photoelectric absorption, Compton scattering and pair production; Electromagnetic shower in high energy photon and electron interaction with matter; Interaction of Neutrons: elastic scattering, radiative capture, positive Q-value reactions such as (n,p), (n, $\alpha$ ), (n,fission) and hadron shower production at high energies.

- **Radiation detectors**

General characteristics of detectors: efficiency, response in energy, time, position and corresponding resolutions, recovery time or count rate handling capability, Gas detectors: Basic processes, Q-V characteristics as a function of primary ionization, charge multiplication; Ionization chamber, proportional counter, avalanche counter and Geiger Muller counter; Large area Multi-Wire Proportional Counters (MWPC), PPAC; Semiconductor detectors: Silicon detectors (surface barrier, PIN diodes, Li drifted silicon detectors), Germanium detectors (planar and cylindrical geometry), Photovoltaic cells, charged coupled devices; Scintillation detectors: Inorganic and organic scintillators, photomultipliers, photodiodes, avalanche photodiodes; Compton suppressed high purity germanium detectors for high-resolution gamma spectroscopy; Miscellaneous detectors: Cryogenic detectors, thermal detectors, channeltrons and microchannel plates, plastic track detectors, hybrid detectors.

- **Experimental techniques**

Electronics modules for pulse processing: Preamplifiers (charge, voltage sensitive), amplifiers (spectroscopy or high resolution, fast and timing filter), timing discriminators (leading edge and constant fraction types), gate and delay generators, coincidence (fast and slow) units, linear gate and stretchers, scalers and rate dividers, Single Channel Analyzer (SCA), Time to Amplitude Converter (TAC), Analog to Digital Converter (ADC), Charge to Digital Converter (QDC), Time to Digital Converter (TDC), Multi Channel Analyzer (MCA), computer based data acquisition systems (DAQ). Particle identification methods, dE-E telescope, pulse shape discrimination, Cherenkov radiation, time of flight technique, magnetic spectrometers including recoil mass separator, Monte Carlo simulation of detectors.

- **Part-II: Health Physics**

- **Introduction**

Radiation sources, Uses of radiation sources, quantities and units: Natural and artificial radioactive sources, Units of radioactivity, Half-Life and Decay constant, Specific activity, Definition of various dosimetric terms and units- Radiation exposure, Absorbed dose, Equivalent dose, Effective dose, their units, concept of radiation & tissue weighting factors and their importance (with stress to use only SI units however old and new units –X unit, Roentgen, Gray, Sievert, rad, rem etc. - and relation should 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, LD50/60, LD50/30 -Threshold

doses for radiation syndromes.

- **Radiation detectors and monitoring Instruments**

Brief (not detailed) introduction on interaction of charged particle, gamma and neutron radiation with matter. HP instruments basic operating principles of (a) Gas filled (b) Scintillation and (c) Semiconductor detectors. Instruments used for monitoring Alpha, Beta, Gamma and Neutrons; Shielding for alpha, beta, gamma and neutron sources; Shielding for mixed sources; Calibration requirement of radiation monitoring instruments; Thermo Luminescent Dosimeter (TLD), Pocket dosimeters, GM survey meter, Teletector, Contamination monitor, CAM, AGM, Portal exit monitor,

- **Framework of Occupational Radiation Protection**

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

- **Occupational Radiation Protection**

Radiation Safety Officer (RSO). Nature of duties and responsibilities of RSO/Health Physicist; Principles of radiation protection; External radiation exposure; Control of external exposure-Time, Distance and Shielding; Internal exposure, Concept of ALI & DAC (with suitable problems); Routes of intake of radioactive material into the human body leading to internal exposure; Control of internal exposures, personnel protective equipment (PPE); Bioassay, whole body counting and Liquid Scintillation Spectrometry (LSS) techniques (not in detail).

- **Workplace monitoring**

Personnel monitoring (Dosimeters, TLDs, DRD, pocket dosimeters, alarm dosimeters, CR-39 etc.); Area monitoring (Ambient radiation dose rate, Surface contamination and Air activity monitoring); Environmental release monitoring (Role of ESL in environmental monitoring).

- **Radiation Protection procedures**

Procedures followed in radiation work places, work permits, zoning concept, contamination control methods and rubber areas; Decontamination techniques; Precautions during radioactive source storage and handling, Protective equipments; Radio toxicity & classification of laboratories; FH, GB, Hot cell, General containment Principles; Criticality hazards and control; Safety during transportation of radioactive materials; Transport index, TREM card; Radioactive waste classification and management.

- **Emergency Preparedness and Management**

Classifications of accidents, International Nuclear Events Scale (INES); Types of emergency, emergency preparedness; References and Guidance levels in radiation emergencies.

- **Principles of Industrial Hygiene and Safety**

Hazard, Risk, Occupational exposure limits- PEL, TLV, TLVTWA, TLV-STEL, TLV-C, Hazard control, Industrial Safety, Accident, Injury On Duty, First Aid Injury, Disabling Injury, Frequency Rate, Severity Rate, Injury Index, Fire Hazard, Classification of fires Class A, Class B, Class C and Class D, Flammable Liquids, explosive limits LEL and UEL, Flammable gases, Ignition temperature.

### **Course Outcomes:**

- Gain basic knowledge of different types of radiations, doses, shielding, health effects and safety

### **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. Introduction to Health Physics, Herman Cember, 4th Edition (McGRAW-HILL, 2009)
4. Physics for Radiation Protection, James E. Martin, 2nd Edition (Wiley-VCH Verlag GmbH, 2006)
5. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by BARC and IAEA), October 26-December 18, 1998
6. Nuclear Radiation Detection, W.J. Price, 2nd Edition, (McGRAW-HILL, 1964)
7. Radiobiology for radiologists, Eric J. Hall, 7th Edition, (Lippincott Williams & Lippincott, 2012)
8. Accident Prevention Manual for Industrial Operation, Vol. 2, National Safety Council, 11th Edition, (National Safety Council, USA, 1997).
9. Radiation protection for nuclear facilities safety manual no. AERB/NF/SM/O-2 (Rev. 4).
10. Radiation Protection Manual for BARC Facilities, BSC Safety Manual No. BSC/SM/2020/3 Rev.-0, BARC Safety Council, (2020)

# RESEARCH ORIENTATION AND LAB COURSES

## 01-PHYS00-610-L: Engineering Drawing and Workshop Practices (15 Hrs)

Coordinators: Shri Kavindra Pathak, EmA&ID  
kpathak@barc.gov.in

### Course Details:

- **Overview of Engineering Drawing:**

Drawing Instruments, Standards and Codes: Introduction; Drafting Instruments-Drawing board, T-square, Set-square, Compass, Dividers, Scales, French curves and Drafting machines; Various Indian and International standards and codes related to drafting. Sheet Layout and Sketching: Sheet layout; Sheet sizes; Scales and scale drawing. Types of drawing: Assembly drawing- General assembly drawing, Schematic assembly drawing, Exploded assembly drawing; Sub assembly drawing; Part drawing; Production drawing; Drawing for manual and catalogue. Lines, Lettering and Dimensioning: Introduction; Types of lines; Types and sizes of letter; Dimensioning- Types, Terms and notations, Placing of dimensions, Unit of dimensioning, general rules and practical hints on dimensioning. Orthographic Projection: Introduction, principle of projection; Methods of projection, Orthographic projection, Planes of projection, First angle projection, Third angle projection, B.I.S. code of practice and conventions employed. Sectional Views: Introduction; Cutting plane line; Types of sectional views- Full section, Half section, Partial or broken section, Revolved section, Removed section and Offset section; Sectioning conventions; Hatching or section lines and conventions of section lines. Tolerances, Limits and Fits: Introduction; Linear and angular tolerances; Tolerance zone – limits and deviations; Tolerance sizes, Standard tolerance grades; Geometric tolerances; Classification of fits – Clearance, Transition and Interference; System of fits – Hole basis and Shaft basis. Surface Parameters: Surface texture; Surface irregularities; Surface roughness assessment methods; Roughness grades –symbols, values and grade numbers; Principle reasons for controlling the surface texture; Factors affecting the surface roughness; Disadvantages of excessive roughness; surface roughness achievable from different manufacturing process.

- **Computer Aided Drafting**

Introduction; Benefits and limitations of CAD; Hardware and software of CAD system; AutoCAD–Brief introduction; Drawing environment, layout and sketching; How to access commands; Getting help; Starting a drawing-Existing drawing & New drawing; Basic settings – Units, Scale, Limits, Grids, & Snap; Elements of drawing- Line, Multi-line, Rectangle, Polygon, Curve, Circle, Donut, Points, Sketch, Spline, Ellipse, Hatch & Fill; Object Properties - Line type, Colour and Layer; Undoing mistakes; Drawing accurately; Viewing and Editing commands– Zoom, PAN, Move, Align, Rotate, Copy, Mirror, Array, Offset, Trim, Extend, Chamfer, Fillet and Erase; Text; Dimensioning and Printing / Plotting of drawing. Brief introduction of Solid modelling software and its command.

- **Threads and fasteners**

Introduction; Parts of threads; Forms of threads; Single and multiple start threads; LH & RH threads; Brief introduction of bolts, studs, screws, plain & spring washers, set screw and split pin. Type of weld joints, weld joint details in drawings, BOM (bill of material) in drawing, Designation of standard components like fasteners (nuts, bolts, screws, studs etc.), circlips, washers, split pin etc., as per IS standards.

- **Overview of Workshop Practices**

- **Manufacturing Process**

Introduction, and Classification of manufacturing process- Machining, Joining and Forming.

- **Metal Cutting using machine tools**

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Introduction; Theory of metal cutting; Process of metal cutting; Single point and Multipoint cutting tools; Tool signature; Machine References system; Commonly used metal cutting machines, its parts and related operations / processes viz. Turning, Drilling, Boring, Milling, Shapers, Planer, Grinding etc. Unconventional machining operations: Introduction; Various types of machines and its operations viz. AJM, USM, ECM,EDM, EBM, and LBM.

▪ **Metal Cutting using hand tools**

Introduction; Various types of hand tools, its parts and related machining operations viz.saws, Files, Hand drills, Taps, and Reamers.

▪ **Metal Forming**

Introduction; Various types of forming tools, its parts and related forming process viz. Rolling, Bending, Spinning and Drawing.

▪ **Joining Methods:**

Introduction; Various metal joining tools and related processes viz. Soldering, Brazing and Welding; Various types of demountable joints, flanges and coupling.

▪ **Brief introduction on inspection:**

Visual, dimensional and Non-destructive examination of welds (NDE)- MPI, LPI, UT & RT

**Course Outcomes:**

- Introduce advanced experimental techniques in proposing experimental investigations in the frontiers of physics.

**References:**

1. Engineering Drawing Practice for Schools & Colleges (SP 46:2003), Bureau of Indian Standards.
2. Geometrical and Machine Drawing, N.D. Bhatt, V.M. Panchal, (Charotar Publishing House, Anand 2000).
3. Manufacturing Science, A. Ghose, A. Mallik (Tata McGraw Hill, 1997).

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**01-PHYS00-611-L: Research Methodology (8 Hrs)****Coordinators: Dr. S. Santra, NPD**  
**ssantra@barc.gov.in****Course Details:**

Definition and importance of research, Importance of selection of research problems, Basic and applied research; a few examples, Planning, execution, Safety and safe practices in research, Literature survey, Data collection, Presentation, Interpretation, Errors in experimental data and their estimation, Data analysis, Fitting of suitable and realistic model to the data. Least square methods and parameter estimation, Error on fitting parameters, Scientific report/paper writing, Research ethics; awareness of plagiarism and other scientific misconducts, Awareness of different types of publications, Reputed journals and Predatory journals

**Course Outcomes:**

- Introduce advanced experimental techniques in proposing experimental investigations in the frontiers of physics.

**References:**

1. Research methodology for science, M.P. Marder (Cambridge University Press 2011).
2. Essentials of Research Design and Methodology Geoffrey Marczyk David DeMatteo David FestingerJohn Wiley & Sons, Inc. 2005
3. How to write and Publish a Scientific Paper, Robert A. Day and Barbara Gastel (Greenwood, 2016).
4. How to Research, Loraine Blaxter, Christina Hughes and Malcum Tight (Open University Press, 2006).
5. The Craft of Scientific Writing, Michael Alley, (Springer, 1996).
6. A Student's Guide to Methodology, Peter Clough and Cathy Nutbrown (Sage Publications, 2012).

**01-PHYS00-612-L: Methods of Experimental Physics (32 Hrs)**

**Coordinators: Dr. Debasis Sen, SSPD**  
**debasis@barc.gov.in**

**Course Details:**

- **Experimental Techniques in Condensed Matter Physics**

Neutrons, X-rays and electrons based techniques: Neutrons, X-rays and electrons as probes for characterization of condensed matter; Complementarity of the three probes; Basic properties of these three probes and comparison of their interaction with matter.

Raman & Infrared spectroscopy in condensed matter.

Neutrons from research reactors and spallation sources, Scattering length and Scattering length density, Various kinds of elastic and in-elastic scattering experiments using neutrons, Kinematic constraint

Laboratory and Synchrotron based X-ray sources, Properties of synchrotron radiation, Synchrotron X-ray beam lines: Basic components, Different experimental techniques at X-ray synchrotron.

Practical examples towards use of neutrons, X-ray and electron based experiments for various applications and solving fundamental problems in condensed matter physics.

Overview of Atomic force microscopy, Scanning electron microscopy and Transmission Electron microscopy.

Techniques for measuring transport (thermal & electrical) and magnetic properties (Faraday balance, Vibrating Sample magnetometer, SQUID, A.C. Susceptibility, Torque magnetometry).

**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. Griffiths & James A. de Haseth
7. Modern Raman Spectroscopy: A practical Approach. (2ed), Ewen Smith & Geoffrey Dent
8. An Introduction to Synchrotron Radiation: Techniques and Applications, P. Willmott (John Wiley & Sons, 2011)
9. Synchrotron Radiation Production and Properties, Philip John Duke (Oxford, 2000)

- **B. Experimental techniques in Laser and plasma Physics**

Manipulation of atoms/molecules using Lasers – laser cooling, optical tweezers. Other advanced topics (e.g. Free Electron Laser-spectroscopy, Laser-atom interaction in high intensity regime).

Doppler spectroscopy & beyond, Frequency modulation techniques.

Boltzmann technique for plasma temperature and density determination from line broadening mechanisms, Langmuir probe technique, techniques for characterization of plasma instability, Plasma physical vapour deposition and chemical vapour deposition, plasma spray coating,

### 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).
3. Physics of Fully Ionized Gases" by Lyman J Spitzer (2013)
4. Plasma Science, From Fundamental Research to Technological Applications, National Research Council; Plasma Science Committee (1995)

### ▪ C. Vacuum and low temperature Techniques for Physics experiments

Definition of Vacuum, Importance of Vacuum for various experiments, Flow Regimes in vacuum systems, Line Conductance, Calculation of pump-down time, Pumps and their ranges: Rotary vane pumps, Diffusion pumps, Ion pumps, Cryo-pumps, Sorption pumps, Gettering pumps, Achieving ultra-High vacuum (UHV), Vacuum Gauges for various ranges of vacuum: Vacuum gauges, Vacuum valves, Design of vacuum systems, Leak detection.

Requirement of Low Temperature techniques for Physics experiments, Methods for Production of Low temperature, Cryogenic handling and safety, Types of Insulations and super-insulation, Low temperature thermometry, Temperature control methods and PID control, Cryogenic Liquid level measurements, Design of small scale laboratory cryostats: Material selection criteria, their properties, safety measures.

### Course Outcomes:

- Introduce advanced experimental techniques in proposing experimental investigations in the frontiers of physics.

### References:

1. Handbook of Vacuum Technology, Second Edition, Author / Editor: Karl Jousten
2. Publication year: 2016, Publisher: Wiley-VCH Verlag GmbH & Co. KGaA, ISBN: 978-3-527-41338-6
3. Modern Vacuum Physics, Author / Editor: Austin Chambers, Publication year: 2005, Publisher: CRC Press LLC. ISBN: 0-8493-2438-6
4. A User's Guide to Vacuum Technology, Third Edition, Author / Editor: John F. O'Hanlon, Publication year: 2003, Publisher: John Wiley & Sons, Inc. ISBN: 978-0-471-27052-2
5. Handbook of Vacuum Science and Technology,
6. Author / Editor: Dorothy M. Hoffman, Bawa Singh and John H. Thomas, III, Publication year: 1998  
Publisher: Academic Press, ISBN: 978-0-12-352065-4

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## ELECTIVE COURSES IN GENERAL PHYSICS

### 01-PHYS00-701-E: Special topics in Mathematical Physics (20 + 4 Hrs)

Coordinators: Meenakshi Sunder  
msunder@barc.gov.in

#### *Course Details:*

- **Difference equations**  
Homogeneous linear difference equations (constant-coefficient equations, linear independence, initial and boundary-value problems, Euler equations, generating functions, eigen value problems); Inhomogeneous linear and nonlinear difference equations
- **Local analysis**  
Singular points, local behaviour of solutions at irregular singular points of homogeneous linear equations, inhomogeneous linear equations, asymptotic relations, asymptotic series, approximate solutions of nonlinear differential equations, nonlinear autonomous systems, singular points of difference equations and local behaviour of solutions, regular and singular perturbation theory, perturbative eigen value problems
- **Global analysis**  
Boundary layer theory (examples, mathematical structure, simple boundary layer problems), Multiple scale analysis (resonance and secular behaviour, formal theory, examples), Floquet theory of stability, Mathieu equation, Fermi-Pasta-Ulam problem

#### *Course Outcomes:*

- Learn about a few special topics in mathematical methods- difference equations, local analysis and global analysis.

#### **References**

1. Advanced Mathematical Methods for Scientists and Engineers, C. M. Bender, S. A. Orszag (Springer, 2010).

**01-PHYS00-702-E: Quantum computing and quantum information science (20 + 4 Hrs)****Coordinators: Meenakshi Sunder  
msunder@barc.gov.in****Course Details:**

Number of lectures: 25

- **Basic concepts: (5 lectures)**  
density operator, qubits, Bloch sphere, bipartite systems, Schmidt decomposition, entanglement, quantum erasure, Hughston-Jozsa-Wootters theorem, fidelity, distance measures, von Neumann model of measurement, generalized measurements, quantum channels, information and entropy, multi-partite systems and entanglement, entanglement entropy, CHSH Bell inequality, teleportation, polar decomposition, singular value decomposition, relative states
- **Quantum dynamics and measurement: (5 lectures)**  
measurement statistics, positive operator valued measurements, quantum operations, quantum channels, open quantum systems, Master equations, noise, decoherence, qubits as noise spectrometers
- **Computation and complexity: (8 lectures)**  
classical circuits, universal gates, complexity measures, reversible classical computation, quantum circuits, quantum parallelism, quantum gates and controlled operations, universal quantum gates, Deutsch-Jozsa algorithm, Grover's algorithm, quantum Fourier transform, phase estimation, order finding, period finding, factorization (Shor's algorithm)
- **Error detection and correction: (4 lectures)**  
basic ideas, origin of error-correcting codes, finite geometries, from classical error-correction to Shor's nine qubit code, quantum error correction
- **Circuit quantum electrodynamics: basic ideas and experimental implementation (3 lectures)**

**Course Outcomes:**

- Understand fundamental concepts of quantum information including qubits, density operators, entanglement, entropy, quantum measurements, and Bell inequalities.
- Analyze quantum measurement, noise, and open system dynamics using POVMs, quantum channels, decoherence, and master equations.
- Design and analyze quantum circuits and algorithms, including universal gates, Deutsch–Jozsa, Grover's algorithm, QFT, phase estimation, and Shor's algorithm.

**01-PHYS00-703-E: Chaos and Non-equilibrium Statistical Mechanics (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

- **Introduction**  
Laws of mechanics and the law of large numbers, Boltzmann ergodic hypothesis, Gibbs' mixing hypothesis, problems in modern non-equilibrium statistical mechanics
- **Boltzmann and Liouville equation**  
Derivation, H-theorem, Kac ring, diffusion, BBGKY hierarchy, Poincare recurrence theorem, Birkhoff ergodic theorem, mixing systems, distribution functions
- **Green-Kubo formulae**  
Linear response theory, van Kampen's objections, Green-Kubo formula for diffusion
- **Canonical perturbation theory**  
Resonances, classical perturbation theory, adiabatic perturbation theory, secular perturbation theory, applications
- **Near-integrable systems**  
KAM stability, three-body problem, applications to celestial mechanics, plasma physics
- **Nonlinear maps**  
Baker map, Boltzmann equation for Baker map, Bernoulli sequences, irreversibility, Arnold cat map, Kolmogorov-Sinai entropy, Pesin's theorem, Markov partitions, Frobenius-Perron equation
- **Open systems**  
Smale horseshoe, escape-rate formalism, thermodynamic formalism for chaos, transport coefficients, deterministic diffusion, Sinai-Ruelle-Bowen measures, entropy, Gallavotti-Cohen fluctuation formula
- **Dynamical foundation of Boltzmann equation**  
Lorentz gas, Sinai formula, Lorentz-Boltzmann equation

**Course Outcomes:**

- Learn about Chaos and non-linear statistical mechanics involving Boltzmann and Liouville equation, Green-Kubo formulae, nonlinear maps, open systems and dynamical foundation of Boltzmann equation

**References:**

1. An introduction to chaos in non-equilibrium statistical mechanics, J. R. Dorfman (Cambridge University Press, 1999).
2. Chaos, scattering, and statistical mechanics, P. Gaspard (Cambridge University Press, 1998).

**01-PHYS00-704-E: Nonlinear Dynamics (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

Introduction to dynamical systems

Flows and maps, fixed points, linearization of vector fields, canonical forms, invariant sub-spaces and classification of equilibria, phase portrait.

Bifurcations: Saddle-Node, Transcritical, Pitchfork and Hopf Bifurcation.

Hartman-Grobman theorem, Stable Manifold Theorem, Center Manifold Theorem, Manifolds in simple 2 and 3 dimensional systems.

Index theory, Lyapunov functions and stability analysis, Limit cycles, Poincaré-Bendixson Theorem.

Gronwall's inequality, the Variational Equation, exploring neighbourhoods, Lyapunov exponents, Monodromy matrix, strange attractors

1-d maps, linear stability of fixed points and higher order fixed points, chain rule, Lyapunov exponent, bifurcation diagram, finding period-orbits in 1-d maps

2-d maps, Linearization, the Henon map, Poincaré surface of section

Symbolic dynamics, Sensitivity to initial conditions, Chaos, Partitions, Transition matrix, The Invariant density, Entropies, Smale Horse shoe.

Fractals in dynamical systems, cantor sets, box-counting, correlation and information dimension, generalized dimensions.

Hamiltonian Dynamics, complete integrability and ergodicity, Area preserving mappings, KAM theory.

**Course Outcomes:**

- Learn about instabilities and chaos of periodically forced nonlinear oscillators, bifurcations and chaos in laboratory-scale systems, control and synchronization of nonlinear phenomena, experiments and numerical projects

**References:**

1. S. Strogatz, "Nonlinear Dynamics And Chaos"
2. K.T. Aligood, T.D. Sauer, J.A. Yorke, "Chaos: An Introduction to Dynamical Systems"
3. M. Tabor, "Chaos and Integrability in Nonlinear Dynamics: An Introduction"
4. P. Cvitanovic et. al. "Chaos: Classical and Quantum" available as a webBook at <http://chaosbook.org/>
5. M. Hirsh, S. Smale and R. Devaney "Differential Equations, Dynamical Systems and an Introduction to Chaos"
6. L. Perko, "Differential Equations and Dynamical Systems"

**01-PHYS00-705-E: Advanced Computational Physics (20 + 4 Hrs)****Coordinators: Meenakshi Sunder  
msunder@barc.gov.in****Course Details:**

Scientific Programming: Introduction to Computer Programming, Familiarization with Linux and WINDOWS, Computer arithmetic, High Level languages, FORTRAN, PYTHON & C statements and implementation on PCs, Introduction to parallel programming using Message Passing interface (MPI), Sample assignments to write programs for scientific computation. Numerical Methods: Solution of non-linear system of equations. Curve fittings of given data.

Numerical integration Solution of linear systems and eigenvalue problems. Solution of ordinary and partial differential equations, Monte Carlo Methods. Introduction to machine learning methods. Physics problems and solutions based on scientific programming: Scattering by a central potential, Partial wave solution of quantum scattering, A Schematic shell Model, Thermodynamics of many particle system s, (molecular dynamics, deterministic method), Optimization methods, Neutron transmission through a shield ( Monte Carlo Method). Multidimensional Monte Carlo integration, importance sampling random walk methods, The approach to equilibrium (Monte Carlo method), Microcanonical ensemble, Canonical ensemble and Metropolis algorithm.

**Course Outcomes:**

- Learn different programming languages and able to solve physics problems using advanced computer programming and/or Monte-Carlo simulation.

**References:**

1. Numerical Recipes in Fortran, W.H. Press et.al., (Cambridge Univ. Press, 1992)
2. Numerical Methods for Engineering Application, J.H. Ferziger, (John Wiley, 1998)
3. The Monte Carlo Method, I.M. Sobolov (MIRPublishers,1971).
4. An Introduction to Computer Simulation Methods, H.Gould and J.Tobochnik, Part-1&2 (Addision-Wesley, 1988)
5. Computational Physics, S.E. Koonin (Addision Wesley, 1986)
6. Theoretical Physics on the Personal Computers, E.W.Schmidt et.al (Springer-Verlag,1988).
7. A high-bias, low-variance introduction to Machine Learning for Physicists. Physics Repots Vol 810, pages 1-124, 2019.

**01-PHYS00-706-E: Stochastic Physics (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

- **Classical theory of Brownian Motion**

Langevin's Formulation: Motion of a particle in a fluid; Continuum theory of viscous drag; Molecular fluctuations- resolution into mean and fluctuating force; Langevin's equation for a free particle; Force correlations and ensemble averaging; Approach to equilibrium; fluctuation dissipation theorem; implications; Stochastic motion of a harmonically bound particle. Random-walk Model: Markov process; Simple Markovian random walks; position distribution using Fourier transforms; Levy flights; asymptotic law of root mean square displacements; continuous time random walks; random walk with memory; Monte-Carlo techniques of random walk simulations. Passage to Differential equation: Concept of Transition probability; Constraints on moments; Integral formulation; Derivation of phase space Fokker-Planck equation (FPE); special solutions. Diffusion approximation: Moments Equations of FPE; Closure problem; Reduction to diffusion equation; Discussion on boundary conditions.

- **Nucleation and Coagulation theory:**

Homogeneous nucleation theory: Thermodynamics of phase equilibrium; Free energy of a spherical drop; concept of critical size; Free energy barrier; cluster size distribution; detailed balancing; derivation of nucleation rate-Becker-Doring theory; Zeldovich Factor; Lifshitz-Slosov theory; Experimental studies on homogeneous nucleation rates; multi-component and ion-induced nucleation.

Mathematical theory of coagulation: Onset of irreversibility post nucleation; The absorption condition; Derivation of formulae for Kernels; Smoluchowski's formulation of colloid coagulation; Integro-differential formulation; scaling theory; self-preserving distributions; Classification of Kernels; Gelation condition; numerical approaches; Practical examples in aerosols. Escape over barrier: Transition state theory; Kramer's rate formula.

- **Growth Models**

Aggregation theory: fractal concepts; compact and fractal aggregates; mathematical and statistical fractals; Ballistic Aggregates; Eden clusters. Fractal aggregates: Diffusion limited growth; Mullins-Sekerka instability; Diffusion Limited Aggregate (DLAs); Witten-Sanders Model; spectral, walker and chemical dimensions; Current state of understanding of DLAs; Cluster-cluster aggregation Model; Relation to coagulation problem; dynamic scaling theory. Numerical simulation techniques: Lattice and off-lattice simulations; Monte- Carlo techniques.

**Course Outcomes:**

- Learn about classical theory of Brownian motion, nucleation and coagulation theory and growth models

**References**

1. Stochastic problems in Physics and Astronomy, S. Chandrasekhar, Rev. Mod. Phys. 15,1-89 (1943).
2. Noise and fluctuations: An Introduction, D.K.C. MacDonald (Wiley 1962).
3. The Fokker-Planck Equation, H Risken, ed. H. Haken, (Springer-Verlag 1984)
4. Wonderful world of random walks, E.W. Montrol and M.F. Shlesinger in Studies in Statistical mechanics, Vol XI:Eds. E.W. Montrol and J.L. Lebowitz (Elsevier1984).
5. Homogeneous Nucleation Theory, F.F. Abraham (Academic 1974).
6. Nucleation, A.C. ettemoyer (Ed.) (Marcel Dekker, 1969).
7. Homogeneous nucleation theory and Experiment: A survey, J.L. Katz, Pure and Appl. Chem. 64, 1661 - 1666 (1992).
8. Nucleation theory, D.T. Wu in Solid-state Physics: Advances in Research and Applications 50, 37 (1997).
9. A general mathematical survey of the coagulation equation, R.L. Drake, in International Reviews in

Physics and Chemistry, Vol.3, Eds. G.M. Hidy and J.R. Brock (Pergamon 1972).

10. The effect of coalescence on the surface area of a coagulating aerosol, W. Koch and S.K. Friedlander, *J. Colloid & Interface Sci.* 140, 419 (1990).
11. Kinetics of clustering in irreversible aggregation, M.H. Ernst in *Fractals in Physics*, (Eds.) L. Pietronero and E. Tossatti, (North Holland 1986).
12. Diffusion limited aggregates—a kinetic critical phenomenon, T.A. Witten and L.M. Sander, *Phys. Rev. Lett.* 47, 1400 (1981).
13. *Fractal growth phenomena*, T. Vicsek (World Scientific 1989).
14. Scaling of kinetically growing clusters, M. Kolb, R. Botet and R. Jullien, *Phys. Rev. Lett.* 51, 1123 (1983).
15. *Kinetics of aggregation and gelation*: F. Family and D.P. Landau, (North-Holland 1984).

**01-PHYS00-707-E: Python and its application to Machine Learning (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:****PART-I: Python language and physics computations (11 Lectures)**

- **Why to learn python? (1 Lecture)**  
Introduction to python and the Object-Oriented Programming (OOP), Comparison of different high level computer languages (e.g., Fortran, C and C++) with python. Why has python become so popular even for scientific computing?
- **Setting up python (1 Lecture)**  
Python installation and setting up environment in Windows and Linux. Use of spyder, IPython and jupyter notebook.
- **Basic python (3 Lectures)**  
Python object types, numbers, strings, lists, arrays, dictionaries, tuples, files, I/O handling. Statements and syntax, expressions, loops, iterations. Basic functions, arguments, recursive functions, modules, module packages. Introduction to class and OOP, Error & exceptions handling.
- **Advanced python (2 Lectures)**  
Data structure and data handling using Pandas. Efficient array handling using Numpy and HDF5. Scientific computing and problem solving using Scipy. Integrating Fortran/C++ code with python.
- **Data visualization & GUI (2 Lectures)**  
Seaborn, pyplot and matplotlib; Introduction to python GUI toolkit–PyQt/wxPython.
- **Instrumentation programming with python (2 Lecture)**  
RS-232, TCP/IP Ethernet, USB, RS-485, and IEEE-488 GPIB communications.

**PART-II: Introduction to Machine Learning(ML) (11 Lectures)**

- **Introduction (1 Lecture)**  
Introduction to Artificial Intelligence (AI) with motivation from ample examples and research problems.
- **Mathematical foundations (3 Lectures)**  
Linear Algebra, basic probability theory using frequentist and Bayesian approach, maximum likelihood. Optimization using gradient descent methods and its variants. Bias/variance trade-off.
- **Machine learning in Python (3 Lectures)**  
Introduction to scikit-learn, classification, support vector machine (SVM). Linear and logistic regression, K- means clustering. Supervised and unsupervised learning.
- **Introduction to Deep Neural Networks (4 Lectures)**  
Introduction to Tensorflow/Keras. XOR gate, back-propagation algorithms. Convolutional neural networks (CNNs). Recurrent neural networks (RNNs).
- **Case studies/projects**  
A glimpse of various physics based problem solving using deep learning. Medical diagnostics using machine learning algorithms. Bragg peak analysis using deep learning. Recognizing handwritten digits with MNIST database.

**Course Outcomes:**

- Develop proficiency in Python programming for physics and scientific computing, including data handling, visualization, instrumentation control, and object-oriented programming.

- Apply machine learning techniques using Python to solve real-world and physics-based problems, including regression, classification, clustering, and optimization.
- Understand and implement deep learning models (CNNs, RNNs) using TensorFlow/Keras for case studies in physics, medical diagnostics, and pattern recognition.

**References:**

1. Learning Python by Mark Lutz (OREILLY)
2. Pattern Recognition and Machine Learning by C. M. Bishop (Springer)
3. Machine Learning by T. Mitchell (McGraw Hill)
4. Pattern Classification by Richard O. Duda, Peter E. Hart and David G. Stork (Wiley Interscience, US)
5. Deep learning by Ian Goodfellow, Yoshua Bengio, Aaron Courville (MIT Press)

**01-PHYS00-708-E: Introduction to Mega Science Projects (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

Introduction (Course Coordinator): 1 Lecture

- **A. Gamma-ray Astronomy : Major Atmospheric Cherenkov Experiment (MACE) and Cherenkov Telescope Array (CTA) :4 Lectures**

Details of imaging atmospheric telescope MACE built by BARC, presently operational at Hanle, Ladakh. The physics goals and engineering challenges will be discussed in the course. CTA, an upcoming experiment consisting of array of multiple telescopes and 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

- **B. Neutrino and LHC Physics 4 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, quasielastic 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 CE $\nu$ NS 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. Cottingham
7. Ultrarelativistic Heavy Ion collisions : R Vogt

- **C. Accelerators (Proton Improvement Plan-II, LHC) 3 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 Nb<sub>3</sub>Sn based

superconducting magnets, challenges with development of Nb<sub>3</sub>Sn SC magnets, superconducting dipole and Quadrupole magnets.

### References:

1. PIP-II References Design Report, V1.00, June 2015, Fermi National Accelerator Laboratory
2. Advanced Accelerator Magnets for upgrading the LHC, Luca Bottura et. 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

#### ▪ D. Synchrotron Radiation and X-ray Free Electron Lasers 3 Lectures

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

### References :

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

#### ▪ E. Neutron Scattering in Large Facilities: Challenges and Scope 3 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](https://www.esfri.eu/sites/default/files/NGL_CombinedReport_230816_Complete%20document_0209-1.pdf)

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▪ **F. International Thermo-Nuclear Experimental reactor (ITER) :3 Lectures**

Nuclear Fusion, Lawson Criterion, magnetic confinement in Tokamak and ITER Fusion reactor. High magnetic field Superconducting magnets technology (Nb<sub>3</sub>Sn 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

▪ **G. Introduction to advanced energy systems and Gen-IV Reactor concepts :3**

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 the physics goals, experimental techniques, and major results of modern high-energy and astroparticle experiments, including gamma-ray astronomy (MACE, CTA), neutrino physics, and LHC experiments (CMS, ALICE), along with their underlying particle interactions and detector principles.

**References :**

Following link can be considered for introduction to MSRs and HTRs:

1. HTRs: [https://web.mit.edu/pebble bed/Presentation/HTGR.pdf](https://web.mit.edu/pebble%20bed/Presentation/HTGR.pdf)
2. MSRS: [https://inis.iaea.org/collection/NCLCollectionStore/\\_Public/44/078/44078357.pdf](https://inis.iaea.org/collection/NCLCollectionStore/_Public/44/078/44078357.pdf)

# ELECTIVE COURSES IN NUCLEAR AND ACCELERATOR PHYSICS

## 01-PHYS00-709-E: Selected Topics in Nuclear Physics (20 + 4 Hrs)

Coordinators: Meenakshi Sunder  
msunder@barc.gov.in

### Course Details:

- **Brief introduction to heavy ion fusion reactions**  
General features, Energy dependence at low energy, Limitation at high energy
- **Decay of the compound nucleus and the statistical model analysis**  
Bohr hypothesis and Hauser-Feshbach evaporation model, Optical model, Transmission coefficients, Nuclear level densities (NLD)
- **Particle evaporation spectra and nuclear level densities**  
Evaporation spectra of neutron and charged particles, Experimental measurements, Extraction of NLD from evaporation spectra
- **Electromagnetic decay of excited nuclei**  
Electromagnetic interaction in nuclei – a brief introduction, Single particle and collective gamma transition
- **Brief introduction to giant resonances in nuclei**  
Giant resonances – definition, Energy and width systematic, Macroscopic and microscopic description – brief treatment, Giant Dipole Resonance (GDR) in deformed nuclei
- **Giant Dipole Resonance in excited nuclei**  
Brink-Axel hypothesis, GDR on excited states in proton capture reactions, GDR in hot nuclei formed in heavy ion reactions
- **Properties of GDR from high energy gamma spectra using statistical model**  
Inclusion of GDR emission in statistical model, Measurement of high energy gamma spectra – detectors, experimental procedures, Extraction of GDR information from measured spectra using statistical model, Shape evolution and fluctuation of hot rotating nuclei
- **Experiments with radioactive Ion Beams (RIB) and future directions**  
Production of RIB – different methods, GDR in exotic nuclei

### Course Outcomes:

- Learn about theoretical tools and techniques of advanced nuclear physics research areas and topics of current interest.

### References:

1. Treatise on Heavy-Ion Science, Vol. 2, 3, ed. D. A. Bromley
2. Nuclear Structure (Vols. I and II), A. Bohr and B. R. Mottelson (Benjamin, Reading, Massachusetts, 1969 and 1975)
3. Introductory Nuclear Physics, S.S.M. Wong (Prentice Hall of India, 1990)
4. Theoretical Nuclear Physics, A. de Shalit and H. Feshbach (Wiley, NY 1974)

**01-PHYS00-710-E: Advanced accelerators and related technology (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

- **Proton and Heavy Ion Accelerators**

Recent development in DC Accelerators, Linacs, Cyclotrons, Synchrotrons etc., Positive and negative ion sources, High Current Accelerators, Introduction to ADS Systems, Linacs for ADS. Superconducting accelerator structures, Gigawatt Pulsed Power and Industrial Electron Accelerators: Electron emission processes and technology of cathodes, Electron gun design and related areas. Gigawatt to Terra-watt power pulsed electron guns, HPM generation, Flash X Ray generation and applications. DC and RF Industrial Electron Accelerators-

- **Novel accelerators**

Introduction to Fixed Field Alternating Gradient (FFAG) Accelerators, Cyc-linac, Combination of high intensity cyclotron with high frequency linac, Linac for Image Guided Hadron Therapy (LIGHT), Dielectric Wall Accelerators (DWA), CYCLADS: Innovative Cyclotron for Nuclear Waste Transmutation, Portable & compact accelerators for Medical therapy/ Medical research / Art studies / NDT, Proton & Carbon gantries with novel superconducting solutions.

- **Radio Frequency (RF) Systems:**

RF systems and components, Wall plug efficiency of accelerator, High efficiency RF systems, transmission lines, RF coupling, RF field stabilization techniques, diagnostic RF instruments, RF interference, energy recovery techniques.

- **Beam Diagnostics**

Introduction, measurement and monitoring of particle accelerator beam parameters. Diagnostic instruments for beam parameters, e.g. beam intensity, beam position, beam transverse distribution beam emittance etc., Beam loss estimation method, ways to monitor the longitudinal and energy distribution.

**Course Outcomes:**

- Learn about proton and heavy ion advanced accelerators, Giga-watt pulsed power & industrial accelerators, beam dynamics and design of advanced accelerators.

**References:**

1. Introduction to Accelerator Physics, Arvind Jain (Macmillan India 2007)
2. Electron Beam Technology, S. Schiller (John Wiley & Sons Inc 1982)
3. Industrial Electron Accelerators and Applications, E.A. Abramyan (Springer 1988)
4. Accelerator Physics, 2nd ed., S.Y. Lee (World Scientific, 2004)
5. Free Electron Lasers, C. A Brau, (Academic Press, Oxford, 1990)
6. V. Smaluk, Particle Beam Diagnostics for Accelerators: Instruments and Methods, V D M Verlag Dr. Müller, Saarbrücken 2009.
7. D. Brandt (Ed.), Beam Diagnostics for Accelerators, Proc. CERN Accelerator School CAS, Dourdan, CERN- 2009-005 (2009).
8. P. Strehl, Beam Instrumentation and Diagnostics, Springer-Verlag, Berlin 2006.
9. M.G. Minty and F. Zimmermann, Measurement and Control of Charged Particle Beams, Springer-Verlag, Berlin 2003.
10. Microwave devices and Circuits, S.Y. Liao, ISBN 81-297-0004-2

11. Foundations for Microwave Engineering, R E Collins
12. Electronics and Radio Engineering, F.E. Terman
13. Foundations of vacuum science and technology, edited by J.M. Lafferty, ISBN-13: 978-0471175933
14. Handbook of Vacuum Science and Technology, 1st Edition, Dorothy Hoffman Bawa Singh John Thomas, III, Hardcover ISBN: 9780123520654, eBook ISBN: 9780080533759
15. A Users Guide to Vacuum Technology, 3rd Edition, John F. O'Hanlo

**01-PHYS00-711-E: Introduction to Neutrino Physics (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

(The course is intended to introduce the basics of neutrino physics. By the end of the course it is hoped that one will be able to appreciate the intense activity worldwide in this field. A brief exposition of a non-invasive method of monitoring fissile materials using neutrinos will also be given.)

- **Neutrino Physics**

Neutrinos and their discovery, Weak decays such as nuclear beta decay, Higher order processes such as double beta decay in nuclei, Discovery experiments of neutrinos, Neutrino sources: Stellar (including the sun and supernovae), atmospheric, natural radioactivity, reactors and particle accelerators (5 Lectures + 1 Tutorial).

- **Fundamental properties and interaction of neutrinos**

Fundamental properties of neutrinos, spin, helicity, magnetic moment etc., Fundamental interactions of neutrinos.

- **Interactions of neutrino with matter**

charged and neutral current processes, quasielastic and deep inelastic scattering (5 Lectures + 1 Tutorial).

- **Neutrino oscillations:**

Two flavour oscillations in vacuum and matter, three flavor oscillations, More than three flavors oscillation, Matter effects on neutrino oscillation (5 Lectures + 1 Tutorial).

- **Some key experiments in neutrino physics:**

Solar and atmospheric neutrino detection, Indian Neutrino observatory (INO) experiment, Reactor Neutrino experiments, Sterile neutrino searches, Coherent elastic neutrino scattering experiments (5 Lectures + 1 Tutorial).

**Course Outcomes:**

- Able to appreciate the intense activity worldwide in the field of neutrino physics. Get a brief exposition of a non-invasive method of monitoring fissile materials using neutrinos.

**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. Active-sterile neutrino mixing constraints using reactor antineutrinos with the ISMRAN setup : S. P.Behera, D. K. Mishra, and L. M. Pant, Physical Review D 102, 013002 (2020).

**01-PHYS00-712-E: High Energy Astrophysics (20 + 4 Hrs)****Coordinators: Meenakshi Sunder  
msunder@barc.gov.in****Course Details:**

- **Introduction to Astrophysics and Astronomy**  
Celestial sphere, coordinate system, time References, cosmic- rays, multi-wavelength observations.
- **Astrophysical Objects**  
Stars, clusters, x-ray binaries, pulsars, supernova remnants, active galactic nuclei etc. Non Thermal Universe: Cosmic-ray spectrum and composition, Cosmic emissions at keV-TeV energies, first order and second order Fermi acceleration, diffusive shock acceleration.
- **X-ray and Gamma-ray emission**  
Observed spectra from galactic and extragalactic sources, bremsstrahlung, synchrotron and inverse Compton scattering, IC spectra from optically thin and thick sources, electron-positron pair physics, thermal electrons and radiation, non-thermal electrons and radiation, gamma-rays from proton- proton and proton-photon interactions.
- **Theory of Accretion**  
Spherical accretion, Eddington luminosity, disc accretion and its basic equations, a alpha prescription of viscosity, equations for structure of discs and their standard solution.
- **Jets and Outflows**  
Micro-quasars, Blazars and Radio galaxies, radiation emission from jets, Doppler boosting, Lorenz transformations, observed spectra and spectral models.
- **Experimental Techniques in Astronomy**  
Satellite based experiments, ground based experiments, extensive air showers, simulation studies, atmospheric Cherenkov technique.

**Course Outcomes:**

- Able to identify and explain the properties of different astrophysical objects, learn experimental techniques to study them, understand the fundamentals of radiative transfers, theory of accretion and jets & outflows.

**References**

1. High Energy Astrophysics, Vol 1 & 2, M.Longair (Cambridge University Press, 2004).
2. Very High Energy Gamma-Ray Astronomy, Trevor Weekes (IOP Publishing, 2003).
3. Radiative processes in Astrophysics, G. B. Rybicki and A. P. Lightman (John Wiley and Sons, 1979).
4. Accretion Power in Astrophysics, J. Frank, A. King, D. Raine (Cambridge University Press, 2003).

# ELECTIVE COURSES IN ATOMIC, MOLECULAR, LASER AND PLASMA PHYSICS

## 01-PHYS00- 713-E: Synchrotron Radiation and its Applications (20 + 4 Hrs)

Coordinators: Meenakshi Sunder  
msunder@barc.gov.in

### Course Details:

- **Physics of Synchrotron radiation**  
Physics of production of Synchrotron Radiation (SR), important equations and relations, properties and advantages of SR as a light source, components of storage rings, bending magnet radiation, radiation from insertion devices (undulators and Wigglers) & free electron lasers. Overview of the Indus-1 and Indus-2 storage rings.
- **Beam lines and Instrumentation**  
Optical design of SR beam lines, special requirements in different energy regions (VUV, Soft-X-ray, Hard X-Ray, IR); Types of monochromators, mirrors, gratings, detectors, vacuum systems, electronics etc.
- **Experimental Techniques using SR**  
Introduction to various SR based experimental techniques: Spectroscopy (VUV, soft X-ray/hard X-ray absorption spectroscopy, photoelectron spectroscopy, IR, terahertz, etc); Scattering (X-ray Diffraction, reflectivity, small angle, inelastic scattering); Imaging (X-ray imaging, X-ray/IR Microscopy, Lithography); Special techniques utilizing the polarization or time structure of SR. Overview of beam lines and facilities at the Indus-1 and Indus-2 synchrotron radiation sources.
- **Atomic, Molecular & Cluster Physics using SR**  
Basic principles and experimental considerations for SR based (VUV-soft X-ray) studies of atoms and molecules; Probing highly excited, auto-ionizing, Rydberg and super- excited states; Study of photon induced processes in atoms, molecules, radicals and clusters (photo-ionization, photo-dissociation, fluorescence) using techniques like photo-absorption/fluorescence spectroscopy, TOF mass spectrometry, photoelectron spectroscopy (including ZEKE, MATI), coincidence techniques, velocity map imaging (VMI).

### Course Outcomes:

- Learn about the basic of production of Synchrotron radiation, beam line instrumentation and experimental techniques to study atomic, molecular and cluster physics

### References

1. Synchrotron Radiation: Production and Properties, Oxford Series on Synchrotron Radiation 3 Philip John Duke, (Oxford, 2008).
2. Soft X-Rays and Extreme Ultraviolet Radiation; Principles and Applications, David Attwood (Cambridge University Press, 1999).
3. An Introduction to Synchrotron Radiation: Techniques and Applications, Philip Willmott (Wiley & Sons Ltd. 2011).
4. Vacuum Ultraviolet Spectroscopy, J.A. R. Samson and D.L. Ederer (Elsevier, 1999).
5. Handbook on Synchrotron Radiation, Volume 1A: Ernst-Eckhard Koch (Ed.) (North Holland, 1983).
6. Handbook on Synchrotron Radiation, Volume 2: Vacuum Ultraviolet and Soft X-ray Processes: G.V. Marr (Ed.) (North Holland, 1987).
7. Imaging in Molecular Dynamics: Technology & Applications; Benjamin J Whitaker (Cambridge University Press, 2003).

**01-PHYS00-714-E: Quantum Optics, atom optics and Technology (20 + 4 Hrs)****Coordinators: Meenakshi Sunder  
msunder@barc.gov.in****Course Details:**

- **Coherent spectroscopy**  
Transition from Doppler to sub-Doppler to natural line width to sub-natural linewidth, theory and practice of sub-natural line width spectroscopy, frequency modulation spectroscopy, atomic frequency stabilization techniques, error signals and stability, Quantum interference spectroscopy and application to advance technology.
- **Quantum theory of light-atom interaction**  
Lindbald master equation, two-level atom, three level atom.
- **Atom traps and quantum degenerate gas:**  
Laser cooling and trapping of atoms, Sub-Doppler cooling techniques, Thermometry at ultra-low temperature, ultra-cold quantum gases, Bose-Einstein condensation, Fermionic condensate, Optical lattice, Atom interferometry.
- **Ion traps:**  
Techniques of ion-traps (Paul trap, linear quadrupole trap etc)
- **Physics with trapped atoms and ions:**  
Ultra-precision measurements of atomic parameters and fundamental constants, quantum jumps and parity violation in atoms/ions.

**Course Outcomes:**

- Learn about quantum theory of radiation, light atom interaction, ultra-cold atoms, quantum degenerate gases, and elements of atom optics and quantum information.

**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).
3. Laser Cooling and Trapping, H.J. Metcalf and P. van der Straten, (Springer 1999).
4. Optically Polarized Atoms, M. Auzinh, D. Budker, and S.M. Rochester, Oxford University Press (2014).

**01-PHYS00-715-E: Advanced Photonics (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

- **Review of wave optics**  
wave-particle duality concepts and experiments, Maxwell's equations, wave equation for light. Light propagation in conducting and non-conducting medium, sources of light, characteristics of light (coherence and polarization), light in bulk materials.
- **Basics of lasers**  
emission and absorption of light, Einstein coefficients, population inversion, threshold condition, laser beam characteristics and parameters, Optical micro resonators and their applications.
- **Fiber and non-linear optics**  
Reflection and refraction at plane wave interface, total internal reflection, TE and TM polarization modes in optical waveguides, step index and graded index fibers, fiber in optical communication, fiber amplifiers and fiber lasers. Non-linear optics of materials, when and how non-linear response arise, dispersion relations, phase matching conditions, second and third harmonic non-linear optical effects, frequency mixing, Kerr effect and electro-optics effect. Applications of non-linear optics
- **Introduction to nanophotonics**  
Optical materials from bulk to nano-scale, why nano-photonics, light scattering mechanism in nano-scale structures, optics of quantum dots, nano-plasmonic crystals, surface plasmons, Fermi-Golden rule, photon density of states, different approaches to fabricate nano-photon structures, application of nano-photonics, Up-conversion nano-particle and their applications
- **Meta-materials**  
What are meta-materials, classes of materials and their exotic properties, photonic band gaps, origin of band gap, spontaneous emission in photonic band gap, nano-photonics switching, experimental realization of photonic crystals, different characterization techniques.

**Course Outcomes:**

- Learn the basics of LASER, fibre and non-linear optics, and get exposed to nano-photonics and meta-materials.

**References**

1. Optics, E. Hecht and A. R. Ganesan, (Pearson, 2008)
2. Laser Fundamentals, W. T. Silfvast, (University Press, 1996)
3. Nanophotonics, P. N. Prasad, (John Wiley & Sons, 2004)
4. Photonic Crystals: Molding the flow of light, J. D. Joannopoulos, S. G. Johnson, J. N. Winn and R. D. Meade, (Princeton University Press, 2008)
5. Nanophotonic Materials: Photonic Crystals, Plasmonics and Metamaterials, Editor(s): R. B. Wehrspohn, H.- S. Kitzerow, K. Busch, (John Wiley & Sons, 2008)

**01-PHYS00-716-E: High Power Lasers and Applications (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

The objective is to develop understanding and experience about the high power lasers and applications.

- **Module I: BASIC LASER PRINCIPLES:**

Recapitulation of Laser theory, Fundamentals of laser beam properties, Modified Optical properties, Laser output – its characteristics, Nonlinear Optical Processes.

- **MODULE II: LASER SYSTEMS:**

High power laser systems -Focusing optics -Steering optics Mechanisms -Overview of industrial lasers -CW and pulsed -Q-switched (ns pulses) and Mode locked.(ps, fs pulses) CVL, Nd:YAG- and Nd:Glass lasers, DPSS lasers, fiber lasers, Gas lasers, excimer-, dye-, X-ray and free-electron lasers; Semiconductor lasers, High power Single Mode Lasers.

- **MODULE III: APPLICATIONS OF HIGH POWER LASERS:**

Laser Applications in material processing and manufacturing; 3D-printing, marking, drilling, cutting, welding, hardening and manufacturing; Laser Doppler velocimetry, LIDAR, PIV, laser spectroscopy, LIF, LIBS, LIS, Bio- medical applications of lasers, Laser tweezers and applications, laser applications in defence. Application of lasers in data storage, communication and information technology, Laser applications in optical metrology, Surface profile and dimensional measurements.

- **Module IV: ULTRA HIGH INTENSE LASERS:**

Ultra-short pulse amplification, Chirped pulse amplification (CPA), regenerative amplifiers, Laser diagnostics: Short pulse – Autocorrelator, FROG (frequency resolved optical gating), SPIDER (spectral phase interferometry for direct electric field reconstruction), High intensity laser interaction with materials, Basic phenomenology of High intensity effects, production and acceleration of charged particles, laser induced nuclear reactions, X-ray lasers, Laser fusion.

- **Module V: LASER HAZARDS AND SAFETY MEASURES**

Types of hazards, hazards to eyes and skin, Maximum Permissible Exposure (MPE), Classification of lasers, from the point of view of hazards, safety measures, NOHD, buffer zone, laser safety measures.

**Course Outcomes:**

- Learn about non-linear optical processes, Laser dynamics and pulse generation, ultra-short pulse generation, amplification & compression and their applications.

**References:**

1. Principles of Lasers, O Svelto and D C Hanna, 4th Edition, Plenum Press 1988.
2. Solid State Laser Engineering, WKoehner, Springer Series in Optical Sciences, 6th Revised and Updated edition, Springer 2006.
3. Laser Electronics, J T Verdeyen, 3rd Edition Printice Hall 1995.
4. 'High Power Laser Applications', Reddy J.F., Academic Press, 1977.
5. Laser Fundamentals, William T Sifvast, Cambridge University Press, 2004.
6. Lasers , A E Sigman, Mill Valley 1986.
7. Fundamentals of Photonics, Saleh and Teich, John Wiely and Sons,

**01-PHYS00-717-E: Computational Electrodynamics (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

- **Overview of computational electrodynamics**  
A brief introduction to available numerical techniques for different kind of problems in Electrodynamics: Finite difference, Finite element, Method of moments, Spectral method, and Frequency and Time domain treatment. Different types of boundary conditions: perfectly conducting and magnetic boundaries, open/radiation boundary. (2 Lectures)
- **Numerical methods for Electrostatics/Magnetostatics: (12 Lectures)**  
Solution of Laplace and Poisson equation: a) Finite difference method: Gauss Siedel and Multi-grid Method b) Spectral method: Application to solve Poisson equation.c) Finite Element Method (FEM): Discretization of computational domain, Element types, Equation forms, adaptation strategies, Application of FEM to solve Laplace and Poisson equation. d) Boundary Element Method (BEM): Introduction to BEM, application to solve Laplace and Poisson equation. Truncation of computational domain in finite difference method using different types of open boundary conditions; Change in finite difference scheme for curved boundaries in regular orthogonal mesh.
- **Project work**  
To write a program based on finite difference method to solve Laplace equation with curved boundaries.
- **Electromagnetics: (8 Lectures)**  
Finite Difference Time Domain (FDTD); Yee algorithm to solve Maxwell equation; Finite Difference Frequency Domain (FDFD) method; Different schemes for truncation of computational boundary in FDTD: Mur, Liao and Perfectly Matched Layer; Tracking charged particle motion in a given electromagnetic field: Boris method.  
Schemes to deposit charge and current densities (generated due to presence of charged particles) on the Yee grid in FDTD. Self consistent evolution of charge and field: Particle-in-Cell (PIC) method. Parallelization of PIC code: OPENMP, MPI and GPU based approach.
- **Project work**  
Application of FDTD method to solve dipole antenna problem in free space; Application of PIC in Plasma and intense charged particle problems.

**Course Outcomes:**

- Apply computational electrodynamics methods (FDM, FEM, BEM, FDTD, PIC) to numerically solve electrostatic, magnetostatic, and electromagnetic field problems, including boundary conditions, particle–field interactions, and practical physics applications through programming and projects.

**References**

1. Plasma Physics via Computer Simulation, C. K. Birdsall, A. B. Langdon (McGraw-Hill, 2004).
2. Computer Simulation Using Particles, R.W Hockney, J.W Eastwood (CRC Press, 1989).
3. Electromagnetic Simulation using the FDTD Method, D. M. Sullivan (IEEE Press, 2013)
4. Numerical Techniques in Electromagnetics, Matthew N.O. Sadiku (CRC Press, 2009)
5. The Finite-Difference Time Domain Method for Electromagnetics, K. S. Kunz, R. J. Luebbers (CRC Press, 1993).
6. Introduction to Electrodynamics, D. J. Griffith (Prentice-Hall, 2012).
7. Classical Electrodynamics, J. D. Jackson (Wiley, 1998)
8. Introduction to Plasma Physics, F. F. Chen (Plenum Press, 1974).

**01-PHYS00-718-E: Nonlinear Plasma Theory (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder**  
**msunder@barc.gov.in**

**Course Details:**

- **Basics**  
Revision of linear theory, including Langmuir waves, ion-acoustic waves, Alfvén waves, waves from local pulsed source, Cerenkov emission and Kelvin wakes, wakes in ion-acoustic waves, Vlasov equation, Chandrasekhar equation, cold plasma waves, Landau damping.
- **Nonlinear waves**  
beams of non-interacting particles, ordinary progressive waves, waves in weakly dispersive media, Korteweg de Vries equation (KdV), solitons, Analytical solution of the KdV equation, Ion-acoustic wave overturn
- **Nonlinear wave-wave interaction**  
Three wave processes, dispersion laws and decay spectra, triads, Manley-Rowe conservation laws and nonlinear superposition, analogy with Euler equations for rigid bodies, resonant interactions between plasma waves, many-wave interaction in random phase approximation, nonlinear explosive instability, Interaction of low-frequency waves with high-frequency waves, plasma turbulence, kinetic equation and instabilities.
- **Wave-particle interaction**  
Statistical preliminaries, Random phase approximation, quasi-linear diffusion equation in two and three dimensions, single and many waves, quasi-linear theory of some instabilities, non-resonant wave-particle interaction, effect of transverse waves on ions, quasi-linear theory of Alfvén wave turbulence.
- **Nonlinear wave-particle interaction**  
Electron plasma oscillation turbulence, nonlinear theory of the drift instability, and the effect of thermal fluctuations. Nonlinear Landau Damping, Particle Trapping, The Wave Kinetic Equation, Kolmogoroff Turbulence, MHD Turbulence - An Exact Solution - The Wave Interactions - The Goldreich-Sridhar Theory.

**Course Outcomes:**

- Learn about non-linear waves, non-linear wave-wave interaction and wave-particle interaction.

**References**

1. Nonlinear Plasma Theory, R. Z. Sagdeev and A. A. Galeev (W. A. Benjamin Inc., New York, 1969).
2. Plasma physics for astrophysics, R. M. Kulsrud (Princeton University Press, 2004).
3. Plasma turbulence, B. B. Kadomtsev (Academic Press, 1965).
4. Nonlinear resonance analysis, E. Kartashova (Cambridge University Press, 2010).
5. Reviews of Plasma Physics, vol. 7, Ed. M. A. Leontovich (Consultants Bureau, 1979).

# ELECTIVE COURSES IN CONDENSED MATTER PHYSICS

## 01-PHYS00-719-E: Modeling and Simulations in Condensed Matter Physics (20 + 4 Hrs)

Coordinators: Meenakshi Sunder  
msunder@barc.gov.in

### Course Details:

- **Basics**  
Modeling in different domains: Continuum, Mesoscopic, Atomistic and Quantum descriptions, Setting up a computer experiment: Starting structure and dynamics length and time scales
- **Electronic structure Theory**  
Many-body Schrodinger Equation, Born-Oppenheimer approximation, Hartree-Fock theory and Slater Determinants, Density Functional theory(DFT), Thomas-Fermi and Exchange and Correlation(and different xc types)
- **Methods of Solution**  
Basis sets: Gaussian and Plane Wave, Analytic gradients and Hessians, The potential surface, Geometry optimization.
- **First Principles MD**  
Born-Oppenheimer Molecular Dynamics, Car-Parrinello Molecular Dynamics (CPMD), Mermin functional and Free Energy MD (FEMD).  
Studies of phase transitions, thermodynamic properties and melting at extreme conditions of pressure and temperature.
- **Lattice dynamics calculations**  
Microscopic to Macroscopic: From phonon spectra to thermodynamic properties.
- **Classical Molecular Dynamics simulations in soft condensed matter**  
Diffusion, phase transition, hydrogen bond interactions, self-assembled aggregates.

### Course Outcomes:

- Learn about electronic structure theory and modelling & simulations using Monte Carlo and Cluster Molecular dynamics

### References

1. Electronic Structure – Basic Theory and Practical Methods, Richard Martin (Cambridge University Press, 2004).
2. Electronic Structure Calculations for Solids and Molecules, Jorge Kohanoff (Cambridge University Press, 2006).
3. Computer Simulation of Liquids, M P Allen and D J Tildesley (Oxford Science Publications, 1989).
4. The Art of Molecular Dynamics Simulations, D C Rapport (Cambridge University Press, 2004).
5. Ab Initio Molecular Dynamics - Basic Theory and Advanced Methods, Dominik Marx and Juerg Hutter (Cambridge University Press, 2009).
6. Dynamics of perfect crystals, G. Venkataraman, L.A. Feldcamp and V.C. Sahni (MIT Press, Cambridge, 1975).
7. Phonons: theory and experiments, P. Bruesch (Springer-Verlag Berlin, Heidelberg, New York; 1982)

**01-PHYS00-720-E: Organic Semiconductor Devices (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

- **Introduction to organic semiconductors**

Organic materials: bonding, hybridization, conjugation and origin of semiconducting properties, Comparison of inorganic and organic semiconductors, types of organic semiconductor: molecular and polymeric, donor and acceptor materials, molecular ordering, light absorption and emission, different charge carriers and excitations, charge carrier injection: organic metal contacts and interfaces, charge transport models: tunnelling, Schottky, Poole-Frankel, space charge limited conduction, variable range hopping etc.

- **Organic thin films and their characterization**

Preparation techniques: Thin/thick film: Drop casting, doctor blading, spin casting, screen printing, inkjet printing, chemical polymerization, electrochemical polymerization and interfacial polymerization, physical vapour deposition, Monolayer/multilayer: Self-assembly, Langmuir- Blodgett and electrografting.

- **Characterization techniques**

Spectroscopic techniques: UV/Vis, Raman spectroscopy, Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy, Auger electron spectroscopy, electron energy loss spectroscopy (EELS) etc. Structure and surface analysis techniques: X-Ray diffraction (XRD), low-energy electron diffraction (LEED), SEM, TEM, AFM, NSOM, confocal microscopy and contact angle measurements. Thickness measurements: X ray reflectivity (XRR), ellipsometry and profilometer. Electrical characterization: current-voltage measurement and impedance analysis.

- **Organic devices**

Molecular electronics: Basic concepts of molecular electronics, making contact to single molecule molecular and self-assembled monolayer, molecular rectifiers, molecular resonant tunnel diodes, molecular memory, molecular transistors. Organic electronics: Fabrication and characterization of organic field effect transistors and organic light emitting diodes. Organic solar cells: Solar spectrum, interaction of photons with materials, solar cell operational parameters, bulk hetero-junction polymer solar cells, small molecule based solar cells and dye sensitized solar cells. Organic gas sensors: Gas sensors and their necessity, interaction between toxic gases with organic films, fabrication and characterization of chemi-resistive gas sensors.

**Course Outcomes:**

- Learn about the techniques of preparation of organic thin films and their characterization, molecular electronics, organic electronics, organic solar cells and organic gas sensors.

**References**

1. Molecular and Organic Electronics Devices, D.K. Aswal and J.V. Yakhmi (Nova Science, USA, 2010)
2. Organic Electronics: Materials, Processing, Devices and Applications, Franky So (CRC Press, 2010)

**01-PHYS00-721-E: Single Crystal Growth and Devices (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

- **Introduction**  
History, importance, applications and scope of single crystals and related devices.
- **Transportation, nucleation, growth and thermodynamics**  
Phase diagram, material synthesis and characterization of synthesized materials. Transportation of reactants to the growth surface. Absorption at the growth surface and nucleation (first order phase transformation) thereafter. Growth of nucleus (minimization of Gibbs free energy due to interplay of entropy and enthalpy).
- **Single crystal growth techniques**  
Growth from the liquid-phase From melt, Czochralski growth technique, Bridgman, Float Zone, From solution: TSSG (top seed solution growth), Aqueous solution growth, Growth from vapour phase: PVD, MBE, Thermal evaporation technique, Electron-beam evaporation technique, CVD, MOCVD
- **Characterization**  
Crystallography: Symmetry operations and crystal structure determination (single crystal XRD). Orientation and topography (Laue back reflection method). Crystal defect analysis: Point defects, Dislocation lines, Sub-grain boundaries. Defect formation during single crystal growth. Electronic structure and Electrical properties: Band structure (theory and first principle calculations). Electrical and thermal conductivity. Luminescence properties: Photoluminescence process, Thermo-luminescence process, Scintillation process
- **Specific single crystals and related devices**  
Scintillator / phosphor single crystals: Doped alkali halides, CsI:Tl, NaI:Tl, LaBr<sub>3</sub>:Ce etc, Doped and undoped Oxide, LBO, LSO, BGO, YAP etc, Gamma detectors, TL readers. Optical Window: Fluorides, Sapphire, Solid state laser crystals: YAG, Sapphire, Double tungstates, Laser cavity (diode pumped), Non-linear crystals: KDP, BBO, LBO etc, Second harmonic generation, SAW devices, Ferroelectric crystals: BaTiO<sub>3</sub>, LiTaO<sub>3</sub> etc, Remote temperature sensors, Semiconductor crystals: Si, Ge, GaAs etc. Superconductors: YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub>, Bi<sub>2</sub>Sr<sub>2</sub>CaCu<sub>2</sub>O<sub>8+x</sub> etc.

**Course Outcomes:**

- Learn about the techniques of single crystal growth, their characterization and applications

**References**

1. Crystal Growth Technology: From Fundamentals and Simulation to Large-scale Production, Hans J. Scheel, Peter Capper (John Wiley & Sons, 2011).
2. Kinetic Processes: Crystal Growth, Diffusion, and Phase Transitions in Materials, Kenneth A. Jackson (John Wiley & Sons, 2010).
3. Bulk Crystal Growth of Electronic, Optical and Optoelectronic Materials, Peter Capper (John Wiley & Sons, 2005).
4. Handbook of crystal growth, Govindhan Dhanaraj, Kullaiyah Byrappa, Vishwanath Prasad (Springer, 2010).
5. Fundamentals of Solid State Engineering, M. Razeghi (Springer, 2009).
6. Luminescence, Cees Ronda (John Wiley & Sons, 2008).
7. Thermoluminescence of Solids, S. W. S. McKeever (Cambridge University Press, 1988).
8. Springer Handbook of Electronic and Photonic Materials, Safa Kasap, Peter Capper (Springer, 2006).
9. Elements of X Ray Diffraction, Bernard Dennis Cullity, Stuart R. Stock (Prentice Hall, 2001).

**01-PHYS00-722-E: Advanced Magnetism and Superconductivity (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

- **Magnetism**  
Types of phase transitions- first and second order; Examples of magnetic and superconducting phase transitions
- **Type of magnetic exchange interactions**  
Direct exchange, Indirect exchange, Super exchange, Double exchange, RKKY exchange, D-M interaction, Dipolar interaction, etc.
- **Classification of magnetic systems**  
Diamagnetism, paramagnetism, ferromagnetism, ferrimagnetism, antiferromagnetism, super-paramagnetism, spin-glass, cluster spin-glass, metamagnetism, modulated spin structures, etc.; Magnetic ordering under external perturbations such as magnetic field, pressure, ion irradiation, quenched disorder, etc
- **Low dimensional magnetism**  
1D, Quasi-1D, 2D, and Quasi-2D magnetic lattices; spin dimensionality; Magnetic correlations in low-dimension: spin-liquid state, spin-nematic state, quantum paramagnet; quantum phase transition; Spin excitations: spinwaves, magnons, spinons.
- **Spintronics**  
Magneto-caloric effect; Giant magnetoresistance (GMR) and colossal magnetoresistance (CMR); Magnetic nanoparticles, molecular magnetism
- **Superconductivity**  
Thermodynamics of Superconductors; London Theory—A phenomenological approach to understand Superconductivity; Application of London theory – Electrodynamics of Superconductors; Ginzburg – Landau Theory Origin of vortex state, vortex structure, flux pinning; Josephson effect, Co-existence of superconductivity and magnetism Neutron scattering in magnetism and superconductivity

**Course Outcomes:**

- Learn about magnetism, magnetic exchange interaction, spintronics and superconductivity.

**References**

1. Magnetism- Principles and Applications, Derek Craik (Wiley, New York 1995) BARC TRAINING SCHOOL-MUMBAI: COURSE WORK SYLLABI-2014 101
2. Magnetism in the Solid State: An Introduction, Peter Mohn, 2nd Edition (Springer, 2005)
3. Introduction to Superconductivity, M. Tinkham (Dover Publications, 1996)

**01-PHYS00-723-E: Neutron as a Probe of Condensed Matter (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

(The short-range strong interaction of neutron with matter and its inherent magnetic moment of neutron make neutron scattering a unique probe in condensed matter research. The other important advantage of neutrons over other forms of radiation in the study of structure and dynamics on a microscopic level are they are uncharged, which allows them to penetrate the bulk of materials. They interact via strong nuclear force with the nuclei of the material and the scattering cross section varies randomly between various elements and even between isotopes. This allows one to observe light atoms such as hydrogen in the presence of heavier ones and distinguish neighbouring elements in the periodic table easily. One can exploit isotopic substitution and contrast variation methods. Matching wavelength and energy of thermal neutron to the lattice spacing and excitations in condensed matter makes it an indispensable tool to both study structure and dynamics. Over and above neutron has a magnetic moment that suits to study magnetic structures and the fluctuations and excitations of spin systems.)

- **Why neutron scattering?**

basic properties of neutron; Basics principles of Neutron Scattering, Neutron scattering cross section, correlation functions, coherent and incoherent scattering, Principle of detailed balance, magnetic scattering, polarized neutron.

- **Neutron sources**

Reactor and spallation sources, Moderation of neutrons.

- **Structural study by Diffraction**

Cross section, structure factors, Scattering of neutrons by atoms, Diffraction by crystals and polycrystals, Extinction and absorption, Experimental technique for diffraction, Principles of magnetic scattering, Investigation of magnetic materials, Diffraction by gases, amorphous materials and liquids.

- **Small-Angle Neutron Scattering**

Scattering from general Two Phase Systems, Scattering from Fractal Aggregates, Nuclear vs. Magnetic Scattering, Small-Angle Neutron Scattering Instrumentation (Experimental Aspects, Data Treatment), Analysis of Small-Angle Neutron Scattering Data (Model Independent Analysis, Model Dependent Analysis, Contrast Variation), Applications (Nano-materials, Colloids, Biological Systems, Porous and Fractal Structures)

- **Neutron Reflectometry**

Theoretical aspects of neutron reflectivity from Stratified Media, specular reflectivity from thin films and multi-layers, description of Rough Multi-layers, Reflectivity on Non-Magnetic Systems, Neutron Reflectivity on Magnetic Systems, Polarized Neutron Reflectometry on Magnetic Systems, instrumental setup for neutron reflectivity, OffSpecular (diffuse) reflectivity

- **Dynamics in condensed matter**

Deterministic: Basic Lattice Dynamics and Neutron Inelastic Scattering: Theoretical lattice dynamics (LD): Debye model, dynamical matrix, acoustic and optical branches. One phonon scattering, phonon dispersion relations: mono-atomic and diatomic crystals, Incoherent scattering: phonon density of states, Coherent scattering. Stochastic (Diffusion): Theoretical formalism of quasi-elastic neutron scattering (QENS), self and distinct vanHove correlation functions. Different kinds of motions and contributions to scattering law, different model for translation motion: continuous diffusion, jump diffusion and localized translational diffusion. Different models for rotational motions: continuous rotational diffusion on a circle, jump rotation among N equivalent sites on a circle and isotropic rotational diffusion on a surface of a sphere.

Instruments and methods for quasi-elastic neutron scattering, general aspects of data analysis, examples

of QENS studies.

**Course Outcomes:**

- Learn about neutron scattering, crystal structure study using neutron diffraction technique, neutron reflectometry and dynamics in condensed matter.

**References**

1. Neutron Diffraction, G. Bacon (Clarendon, Oxford 1975)
2. Thermal Neutron Scattering, P.A. Egelstaff (Academic Press)
3. Theory of Thermal Neutron Scattering, W. Marshall and S.W. Lovesey, (Clarendon, Oxford 1971)
4. Thermal Neutron Scattering, G.L. Squires, (Cambridge University Press, 1978)
5. Methods in Experimental Physics, Vol. 23 (eds. D.L. Price, Kurt Skold), (Academic Inc.USA 1987)
6. Neutron scattering in condensed matter, A. Furrer, J. Mesot, T Strässle (world Scientific)
7. Methods of Experimental Physics Ed. D.L. Price and K. Sköld P 99:Neutron Sources J.M. Carpentar and W.B. Yelon,(Academic Press)
8. Topics in Current Physics, Vol 6 ‘Neutron Diffraction’ H. Dachs (Springer)
9. Structure Analysis by Small-Angle X-Ray and Neutron Scattering, L.A. Feigin and D.I. Svergun (Plenum Press, New York, 1987)
10. Neutron, X-Ray and Light Scattering, P. Lindner and T. Zemb (North-Holland, Amsterdam, 1991)
11. Neutron Scattering from Polymers, J.S. Higgins and H. Benoit (Clarendon, Oxford, 1994)
12. Analysis of Small-angle Scattering Data from Polymeric and Colloidal Systems: Modelling and Least-squares Fitting, J. S. Pedersen, Advances in Colloid and Interface Science 70, 171-201 (1997).
13. Small-angle Scattering Studies of Biological Macromolecules in Solution, D.I. Svergun and M.H.J. Koch, Reportson Progress in Physics 66, 1735–1782 (2003).
14. X-ray and Neutron Reflectivity: Principles and Applications, Daillant, J., Gibaud, A. (Eds.), Lect. Notes Phys. 770 (Springer, Berlin Heidelberg 2009),
15. Theory of reflection of electromagnetic and particle waves, Lekner, J. (Martinus Nijhoff, Dordrecht, (1987) 188
16. Coherent inelastic Scattering in lattice dynamics, B Dorner, (Springer 1982)
17. Methods of Experimental Physics, Vol 23, Part A, Ed. D.L. Price and K. Sköld P 369: Lattice Dynamics.
18. Quasi-elastic Neutron Scattering, M. Bee (Adam-Hilger, Bristol, 1988)
19. Single Particle rotations in Molecular Crystals, W. Press, (Springer, Berlin, 1981)

**01-PHYS00-724-E: Structure and Crystallography of Bio-molecules (20 + 4 Hrs)****Coordinators: Meenakshi Sunder  
msunder@barc.gov.in****Course Details:**

Brief introduction to structure and functioning of a bacterial and eukaryotic cell; Introduction to important molecular components of the cell; Methods of recombinant protein production, purification; Introduction to three dimensional structures of proteins and nucleic acids; Computational and experimental methods of determining 3D structures; Macro-molecular crystallisation and crystal characterization; X-ray sources and diffraction, Methods of diffraction data collection, data processing; Phase problem and methods for solving the phase problem; Crystallographic refinement,

Electron density maps, Structure-based drug design; Laboratory experiments: a) High-throughput crystallization, b) Crystal mounting, diffraction data collection and processing, and c) Interpretation of electron density maps d) Structure validation

**Course Outcomes:**

- Learn about the computational and experimental methods of determining 3D structures in protein and nucleic acid, macromolecular crystallisation and characterization, diffraction data collection and data processing

**References**

1. Structure Determination by X-ray Crystallography, 4th ed., Mark Ladd and Rex Palmer, (Kluwer Academic/ Plenum, New York, 2003).
2. Crystallography Made Crystal Clear, A Guide for Users of Macromolecular Models, 3 rd ed., Gale Rhodes(Complementary Science Series, 2006) .
3. Protein Structure and Function, Gregory A Petsko and Dagmar Ringe (Blackwell Science and Sinauer Associates,2004).
4. Biomolecular Crystallography: Principles, Practice, and Application to Structural Biology, Bernhard Rupp, (Garland Science; 1st edition, 2009)

# ELECTIVE COURSES IN REACTOR PHYSICS

## 01-PHYS00-725-E: Advanced Reactor Physics and Computational Methods in Neutron Transport problems (20 + 4 Hrs)

Coordinators: Meenakshi Sunder  
msunder@barc.gov.in

### Course Details:

- **Neutron Transport theory**  
Various formulations of neutron transport theory, Integro-differential equation, Integral equation, surface integral equation, invariant imbedding theory, Transport equations for special geometries, Spatial discretisation and energy discretisation
- **Solution of transport equation**  
PN method (Plane and curved geometries), Discrete ordinates method (Plane and curved geometries, Quadrature sets), Collision probabilities methods Collision probability method in 1-D and 2-D geometries, Interface current method, Characteristics method, Discrete ordinates methods in 1-D, 2-D and 3- D geometries. Diamond differencing scheme. Diffusion approximation, Finite Difference method, nodal methods
- **The Monte Carlo method**  
Random numbers: methods of generation and properties, Methods for sampling distributions, Mechanics of particle transport, Source and criticality problems, Errors, Variance reduction
- **Reactor Dynamics**  
Point kinetics equations, Stability Analysis, Linear Stability theory, Routh's stability criterion, Root-Locus method, Nyquist plot, Non-linear stability analysis, Space dependent reactor Dynamics and related topics, Accident analysis for thermal and fast reactors
- **Solution of time dependent transport equation**  
Differencing of time dependent transport equation, Point kinetic equations, Space-time kinetics, Adiabatic approximation. IQS; explicit and implicit time differencing methods
- **Solution of the fuel depletion equations**  
Formalism of the detailed burnup chain, Formulation of fuel depletion equations, production-destruction of actinides and fission products, branching ratios , Solution of the burnup equations, Constant flux and constant power approximations. Solution for decay heat and other potential reactor applications

### Course Outcomes:

- Learn about neutron transport theory, numerical methods for solution of the multi-group neutron diffusion equation, reactor dynamics and reactor noise and its applications

### References

1. Nuclear Reactor Theory, G.I.Bell and S. Glasstone, Van Nostrand (1970).
2. Computational Methods of Neutron Transport, E.E.Lewis and W.F. Miller, (Wiley, 1984) and ANS (1993).
3. Nuclear Reactor Analysis, A.F. Henry,(MIT Press, 1975).
4. Numerical Methods of Reactor Analysis, M. Clark and K.F. Hansen,(Academic Press, 1964).
5. Nuclear Reactor Physics, Weston M. Stacey, (Wiley, 2001)
6. Computing Methods in Reactor Physics, editor, H.Greenspan et al, Gordon and Breach, 1968
7. Dynamics of Nuclear Reactor Dynamics, D.L.Hetrick, ANS
8. A primer for the Monte Carlo Method, IYYA, M. Sobol, CRC Press (1994)

9. Random Processes in Nuclear Reactors, M.M.R. Williams, Pergamon

10. Particle Transport Simulation with the Monte Carlo Method L.L.Carter and E.D.Cashwell, Report TID-26607, (1975)

**01-PHYS00-726-E: High Energy Density Physics: Theory (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

(This course is intended for those interested in acquiring basic knowledge in the physics of matter existing at extreme thermodynamic conditions as occurring in inertial confinement fusion, high velocity impact processes, interior of planets, astrophysical systems, etc.)

- **Introduction to High Energy Density Physics (HEDP)**

Definition and parameters, Basic processes involved. Properties of HEDP matter (Equation of State and Opacities): Polytrropic gases, Thermodynamics of condensed matter, Thomas-Fermi model, Gruneisen EOS, High pressure EOS of solids, Global EOS model, Ionization Balance from the Saha Equation, Ion sphere model, Thermodynamics of ionizing plasmas, Radiation opacities and emissivities, Rosseland and Planck means.

- **Hydrodynamics and shock waves**

Conservation equations in Euler and Lagrange formulation, Compressible and incompressible flow of fluids, Shock and Rarefaction waves, Rankine - Hugoniot relation, Shock impedance, Static and dynamic pressures, Isentropic compression, Hugoniot elastic limit.

- **Radiation transfer and Radiation hydrodynamics**

Types of interaction between radiation and matter, Radiation transfer equation, Equilibrium diffusion limit, Marshak Waves, Nonequilibrium diffusion and three- temperature model, Radiation matter coupling, Radiation hydrodynamic equations, Radiation driven mass ablation.

- **Hydrodynamic Instabilities**

Rayleigh–Taylor, Richtmyer–Meskov & Kelvin–Helmholtz Instabilities, Fluid- dynamics description, Stabilization effects of viscosity, density gradients, adiabatic shaping.

- **Physics of Inertial Confinement Fusion**

Fusion reaction and reaction rates, Radiation losses, Alpha heating, Thermo-nuclear burn and fuel burn up, Ignition schemes, Energy gain, Direct and indirect drive inertial fusion. Laboratory techniques for generating HED matters: Diamond Anvil Cell, Gas gun, High explosives, Lasers, X-rays, Electron and Ion beams, High Current and Magnetic field drives.

Simulation perspective and codes, EOS and opacity libraries.

**Course Outcomes:**

- Learn about hydrodynamic and shock wave, equation of state and radiation opacities, radiation hydrodynamic instabilities and inertial confinement fusion.

**References**

1. Physics of shock Waves and High temperature Hydrodynamic Phenomena, Vol-I &II, Ya. B. Zel'dovich and Yu. P. Raizer, Academic Press, 1966.
2. High-Energy-Density-Physics – Fundamentals, Inertial Fusion and Experimental Astrophysics, R. Paul Drake, Springer Verlag, 2006
3. The Physics of Inertial Fusion – Beam Plasma Interaction, Hydrodynamics, Hot Dense Matter, S. Atzeni, J. Meyer-ter-Vehn, Oxford Science Publication, 2004.
4. The equations of radiation Hydrodynamics, G. C. Pomraning, Dover Publication, 2005

**01-PHYS00-727-E: High Energy Density Physics: Experimental (20 + 4 Hrs)**

**Coordinators: Meenakshi Sunder  
msunder@barc.gov.in**

**Course Details:**

- **Physics of High Energy Density Effects in Matter**

Tensor representation of strain and strain. Linear and non-linear waves, ideal shock wave; Rankine Hugoniot relations, Shock representation in x-t and p-up plane, p-x and p-t plots, entropy and temperature under shock compression. Interaction of Shock waves, reflection of shock wave from rigid boundary etc. Development of rarefaction waves, interaction involving rarefactions, Negative pressures/isentropic compression in materials.

- **Energy Storage Systems, Energetic Materials and Applications**

Various Types of Energy Storage Systems and their Characteristics. Ideal detonation (ZND model); Chapman Jouget (CJ) pressure and density; detonation interaction. Concept of reaction zone; effect of diameter on detonation velocity, detonation failure diameter, effect of density/temperature. Initiation, critical energy fluence, run distance versus pressure, impact or thickness and diameter effect on impact initiation. Wave shaping and lens design. Single stage gas gun, two stage light gas gun, propellant gun; electric gun and, rail gun. Ultra high magnetic field and magnetic pressures using flux compression generators. Pulse radiation, lasers and particle beams. Z-pinch, Gas-Puff and Plasma Focus devices for Thermo-nuclear Fusion.

- **Diagnostic Techniques and Data Interpretation**

Measurement of shock velocity; particle velocity and stress history; shock temperature, sound velocity behind shock front; shock overtaking experiments. Velocity measurement using Displacement, VISAR, Fabry-Perot interferometers. Macroscopic measurements in shock compressed materials. Inductive Loops, Rogowski Coil, Voltage Dividers, Faraday Rotation. Visible and x-ray spectroscopy, Faraday cup, Thomson Parabola, X-ray, Ion and Neutron Imaging. Determination of equation of state, Hugoniot elastic limit, phase transition pressure and spall from experimental data. Ab-initio calculations for determination of isotherm, Hugoniot and phase transition pressures for interpreting the experimental shock wave data.

**Course Outcomes:**

- Learn about the physics of high energy density effects in matter, energy storage systems, energetic materials and applications, diagnostic techniques and data interpretation.

**References**

1. Physics of High Energy Density, G. E. Duvall (Academic Press, 1971).
2. High Pressure Shock Compression of Solids, J. R. Asay and M. Shainpoor (eds) (Springer-Verlag, 1993).
3. Explosive Engineering, P. W. Cooper (Wiley-VCH, 1996).
4. Pulsed High Magnetic Fields, H. Knoepfel (North Holland Publishing Co. 1970).

## 01-PHYS00-728-E: Nuclear Data Physics for Advanced Nuclear Applications (20 + 4 Hrs)

Coordinators: Meenakshi Sunder  
msunder@barc.gov.in

### Course Details:

- **Introduction to nuclear physics data**  
Types of Nuclear data, Variation of cross section with energy, Simple nuclear interactions theory, Measurement and model based predictions, Transmission experiment for total cross section, measurement of differential scattering cross section, Time-of-flight method, sources of errors in measurement, Optical model, Statistical model etc., exposition to SAMMY, EMPIRE. Training in online retrieval of data using Indian Mirror Website: [www-nds.indcentre.org.in](http://www-nds.indcentre.org.in).
- **Representation of nuclear data**  
General purpose and special purpose ENDF libraries, Sub libraries for neutron, photon and charged particle interactions, Radioactive decay data, Fission product yields, formats and procedures, Tabulated and parametric representations in ENDF, Mathematical formalisms for Resonance representation viz. , single and multi-level resonance formalisms, Rieche-Moore, R-Matrix formalism, Breit- wigner formalism, interpolations schemes.
- **Nuclear data processing**  
Steps for processing evaluated data, linearization, resonance reconstruction, tolerances, Doppler broadening, , importance of target temperature for Thermal scattering data, Group averaging, PREPRO code systems, SIGACE package.
- **Multi-grouping:**  
Multi-grouping techniques, Energy groups and limits, considerations for grouping, weighting functions: flux and current weighting, self-shielding, anisotropy and Legendre moments, group-to-group transfer cross sections, GROUPIE/GROUPR, transport cross section, group collapsing , Photon production cross section, Photo-atomic interaction cross sections, GAMINR, activation cross sections, coupled neutron-gamma cross section sets, Continuous energy data for Monte Carlo codes (ACER), Nuclear data for ADSS applications (MATXSR).
- **Concept of critical facility**  
AHWR CF, Difference between critical facility and actual reactors, ICSBEP criticality benchmarking, Illustrations with benchmarking of KAMINI, PURNIMA-I and PURNIMA-II in the US-DOE ICSBEP International Handbook.
- **Exposure to Error Propagation and sensitivity studies**  
Variance-Covariance error matrix in nuclear data, Propagation of errors in assessment of uncertainty margins. Philosophy and mathematics of adjustment of cross sections to fit integral data from critical experiments.

### Course Outcomes:

- Learn about nuclear physics data, representation of nuclear data, nuclear data processing, multi-grouping, concept of critical facility and exposure to error propagation and sensitivity studies.

### References

1. Handbook of Nuclear Engineering, DanGabrielCacuci (Springer 2010).
2. The Elements of Neutron Interaction Theory, Foderaro, Anthony Haroldde(MIT Press 1971).
3. Handbook of nuclear reactor calculations, Vols I-III, Ed. Yigel Ronen (CRC Press 1986).
4. ENDF-6 Formats Manual (2010), <http://www.oecd-nea.org/dbdata/data/manual-endf/endf102.pdf>
5. Manual of Nuclear model code EMPIRE ([http://www-nds.iaea.org/empire218 /manual.pdf](http://www-nds.iaea.org/empire218/manual.pdf))
6. Special Issues on Evaluated Nuclear Data File ENDF/B-VII.0, J.K.Tuli, Nuclear Data Sheets, Vol-107

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(2006).

7. ENDF/B Preprocessing codes, Cullen, D. E., (IAEA-NDS-39, Rev. 10, 2000)  
<http://www.nds.iaea.org/public/endl/prepro/DOCUMENT/PDF/Overview.pdf>
8. Methods of steady-state reactor physics in nuclear design, Stamm'ler, and R. J. J., Abbate, M. J., (Academic press, London., 1983).
9. See: <http://www-nds.indcentre.iaea.org.in/~wlup/> WIMS Library Update Project. WLUP.
10. Proc. of the workshop on Nuclear Reactors,- Physics, design and Safety, Eds. A. Gandini, S. Ganesan and J.J.Schmidt,(IAEA publication, 1994).
11. WIMS-D Library Update, Leszczynski, F., LópezAldama, D. and Trkov, A.(STI/PUB/1264, ISBN 92-105006-2. IAEA, 2007)
12. Theoretical Nuclear Physics, John Markus Blatt and Victor Frederick Weisskopf (Wiley and Sons 1952).

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## NON-SUBJECT ASSIGNMENTS

### 01-PHYS00-PY591: Viva Voce

#### *Course Details:*

In addition to the formal assessment carried out by the method of written examinations, a viva voce examination is also conducted in each semester. The objective of the examination is to assess the grasp of the basic concepts in the courses covered and also to examine the aptitude of the student to apply the knowledge gained in the individual subjects to establish linkages and solve problems across the various domains.

#### *Course Outcomes:*

- Assessment of capabilities to apply to solve real life.

### 01-PHYS00-PY592: Experiments

#### *Course Details:*

Short experimental projects, each about one week's duration, using different facilities or instruments available at different divisions of BARC are intended to provide acquaintance to the availability of the advanced experimental techniques which may become useful during their research work.

#### *Course Outcomes:*

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### 01-PHYS00-PY593: Mini Project

#### *Course Details:*

The Mini-Project is prescribed as an integral part of the training school curriculum. It is carried out in the third trimester on completion of the foundation and core courses and has a duration of 7 weeks. The principle objective of carrying out a Mini Project is to provide a hands-on experience to the trainee of working in an ongoing project of the Department. If feasible, the mini project is linked to the M.Tech. Project and the future work profile of the trainee, thus providing a meaningful synergy between the training, M Tech Project and work profile of the trainee. The experience gained in formulating and executing a scientific/technical problem and the possible pathways to its solution serves as value addition to the training provided. Interactions with senior scientists/technologists during the project work provides useful insights into the methodologies of research, development and deployment adopted by the BARC scientists and technologists. The trainee compiles a project report highlighting the scope, methods and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300Marks, out of which 225 Marks being awarded by the expert committee and 75 Marks by the respective guide.

#### *Course Outcomes:*

- Understanding and Documentation skills.
- Enhancing Skill Set for handling real life problems.