Ph.D. PHYSICAL SCIENCES

Programme Code: PHYS04

Programme Outcome:

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

FOR PH.D. STUDENTS FROM 2024–2025 ONWARDS

[Ref.: HBNI/RO/6/2024/297, dt. 06-March-2024]

I. For the students enrolling with a 4-year BS (Research) / M.Sc / M.A. / M.C.A. or equivalent degree, a minimum **18 credits** is required towards partial completion of credit requirements for Ph.D. programme.

II. A minimum of **12 credits** is required for the students who have successfully graduated from **BARC Training School** on or before 2006 or having **PGDSE or M.E. / M.Tech. / M.Sc(Engg.) / M.Phil. / D.M. / M.Ch. / M.V.Sc / M.Pharm. / M.D.** or equivalent degree.

[Ref.: HBNI/RO/6/2024/261 dt. 28-Feb-2024]

III. For students joining after **M.Sc. or Four-year graduate program**, the minimum number of credits requirement for the Ph.D. programme is **18 (12+6)*** credits
(15 Hrs of Class / 30 Hrs of Laboratory work = 1 Credit).

Doctoral students should obtain the mandatory 18 credits within the first two years to stay in the Ph.D. programme including a **"Research and Publications Ethics"** course as notified by UGC Vide D.O.F.1-1/2018 (Journal/Care) in 2019 and a **research methodology course**.

*12 credits from Course Works and 6 credits from Project Works or Course Works

HBNI APPROVED COURSE CONTENTS

Any courses as recommended by Doctoral Committee from the list 1 to 22.

COURSE DETAILED STRUCTURE

S. No.	Course Code	Name of Course	Course Type	L-T-P	No of Lectures (One hour each)	Credit
1	03-PHYS04-007-E	Numerical and Mathematical Scientific Programming and Computing Methodologies	E	25-0-10	35	3
	03-PHYS04-007-P (Practical)	Computing Methodologies (Practical)		10-0-10	10	
2	03-PHYS04-001-E	Mathematical Methods in Science and Engineering	E	30-0-0	30	2
3	03-PHYS04-004-E	Electromagnetic Theory	E	30-0-0	30	2
4	03-PHYS04-003-E	Laser Physics and Technology	E	30-0-0	30	2
5	03-PHYS04-005-E	Accelerator Physics and Beam Diagnostics	E	30-0-0	30	2
6	03-PHYS04-006-E	Reactor Physics and Safety	E	30-0-0	30	2
7	03-PHYS04-011-E	Vacuum Physics and Technology	E	30-0-0	30	2

8	03-PHYS04-008-E	Basic Solid State Physics and Material Science	E	30-0-0	30	2
9	03-PHYS04-012-E	Quantum Mechanics	E	45-0-0	45	3
10	03-PHYS04-001-L / 002-L / 003-L	Laboratory Experiments (Lasers, Electronics, Accelerators)	L	0-0-72	-	2
11	03-PHYS04-002-E	Magnet Physics and Technology	E	30-0-0	30	2
12	03-PHYS04-010-E	Physics of Semiconductor Quantum Structures	E	30-0-0	30	2
13	03-PHYS04-004-E	Plasma Physics and Technology	E	30-0-0	30	2
14	03-PHYS04-005-E	Instrumentation for Material Characterization	E	30-0-0	30	2
15	03-PHYS04-003-E	Statistical Physics	E	30-0-0	30	2
16	03-PHYS04-002-E	Advanced Accelerator Physics	E	30-0-0	30	2
17	03-PHYS04-001-E	Advanced Optics	E	30-0-0	30	2
18	03-PHYS04-011-E	Fiber Optics and Fiber Sensors	E	30-0-0	30	2

19	03-PHYS04-008-E	Advanced Course on Atom-Photon Interactions	E	30-0-0	30	2
20	03-PHYS04-006-E	Advanced Beam Dynamics	E	30-0-0	30	2
21	03-PHYS04-007-E	Course on Bio-Photonics	E	30-0-0	30	2
22	03-PHYS04-009-E	Concepts in X-Ray Physics	E	30-0-0	30	2
23	03-PHYS04-013-C	Research Methodology, Research & Publications Ethics	C	30-0-0	30	2

The course on "Research Methodology, Research & Publications Ethics" is compulsory for all the students.

** In addition, courses offered by other CIs/OCCs/NPTEL/Swayam and Institutes and Universities having MoUs with HBNI may be opted as per HBNI ordinances.*

COURSE CO-ORDINATORS

Name of Course	Coordinators	Email	Contact
Numerical and Mathematical Scientific Programming and Computing Methodologies	Dr. Ajit Upadhyay / Dr. J. Patil	ajitup@rrcat.gov.in / jpatil@rrcat.gov.in	0731-244-2396 / 0731-248-8971
Computing Methodologies (Practical)			
Mathematical Methods in Science and Engineering	Dr. Ajit Upadhyay	ajitup@rrcat.gov.in	0731-244-2396
Electromagnetic Theory	Dr. Anand Moorti	moorti@rrcat.gov.in	0731-244-2022
Laser Physics and Technology	Dr. Ajit Upadhyay	ajitup@rrcat.gov.in	0731-244-2396
Accelerator Physics and Beam Diagnostics	Dr. K. K. Pant	kkpant@rrcat.gov.in	0731-244-2814
Reactor Physics and Safety	Dr. K. P. Singh (BARC)	kpsingh@barc.gov.in	-
Vacuum Physics and Technology	Shri D. P. Yadav	dpyadav@rrcat.gov.in	0731-244-2835
Basic Solid State Physics and Material Science	Dr. M K Chattopadhyay	maulindu@rrcat.gov.in	0731-244-2829
Quantum Mechanics	Dr. Haranath Ghosh	hng@rrcat.gov.in	0731-244-2123
Laboratory Experiments (Lasers, Electronics, Accelerators)	Dr. Sunil Verma	sverma@rrcat.gov.in	0731-244-2901
Research Methodology, Research & Publications Ethics	Dr. V. B. Tiwari	vbtiwari@rrcat.gov.in	0731-248-8356
Magnet Physics and Technology	-	-	-

Physics of Semiconductor Quantum Structures	Dr. Pankaj Misra	pmisra@rrcat.gov.in	0731-248-8374
Plasma Physics and Technology	Dr. Anand Moorti	moorti@rrcat.gov.in	0731-244-2022
Instrumentation for Material Characterization	Dr. Sunil Verma	sverma@rrcat.gov.in	0731-244-2901
Statistical Physics	Dr. H. N. Ghosh	hng@rrcat.gov.in	0731-244-2123
Advanced Accelerator Physics	-	-	-
Advanced Optics	Dr. Sunil Verma	sverma@rrcat.gov.in	0731-244-2901
Fiber Optics and Fiber Sensors	Dr. Om Prakash	oprakash@rrcat.gov.in	0731-244-2472
Advanced Course on Atom-Photon Interactions	Dr. Ajit Upadhyay	ajitup@rrcat.gov.in	0731-244-2396
Advanced Beam Dynamics	-	-	-
Course on Bio-Photonics	Dr. S K Majumder	shkm@rrcat.gov.in	0731-248-8982
Concepts in X-Ray Physics	Dr. Gurvinderjit Singh	gjit@rrcat.gov.in	0731-244-2903

COURSE SYLLABUS

03-PHYS04-007-E Numerical and Mathematical Techniques and Scientific Programming and Computing Methodologies

(Lectures: 35 Hrs, Lab: 20 Hrs)

Coordinators: Dr. Ajit Upadhyay
ajitup@rrcat.gov.in

Course Details:

- **Numerical Methods**

  - **System of Linear Algebraic Equations:**
    Direct methods – Gauss elimination and Gauss Jordan methods; iterative methods – Jacobi, Gauss-Seidel and Successive over relaxation (SOR) methods; eigenvalue problem.

  - **System of Nonlinear Equations:**
    Newton-Raphson and Secant methods; roots of polynomials, synthetic division of polynomials, and Baristow method.

  - **Interpolation, Extrapolation, Error and Regression Analysis:**
    Types of errors their analysis.

  - **Numerical Integration:**
    Newton-Cotes, Gauss quadratures, trapezoidal, Simpson's 1/3 and 3/8 rule; numerical differentiation – forward, backward and central difference quotient.

  - **Differential Equations:**
    Solution of ordinary differential equations; solution of partial differential equations; fast Fourier transformation.

  - **Statistical Distributions:**
    Poisson and Gaussian distributions; Monte Carlo simulation, pseudo random numbers, and central limit theorem.

- **Finite Element Method (FEM)**

  - **Introduction:**
    Basic concepts of finite element method, application of finite element method, finite element method versus classical methods, finite element method versus finite difference method, and advantage of finite element method.

  - **Integral Formulations for Numerical Solutions:**
    Variational method, collocation method, subdomain method, weighted residual methods, Rayleigh-Ritz method, Galerkin's method, and least square method.

  - **Elements, Nodes, and Co-ordinate Systems:**
    Introduction, element shapes, nodes, nodal unknowns, and coordinate systems.

- **Shape Functions:**
  Introduction, polynomial shape functions, convergence requirement of shape function, and derivation of shape functions.
- **Introduction to Stiffness (Displacement) Method:**
  Definition of the stiffness matrix, derivation of the stiffness matrix, assembly of the total stiffness matrix, properties of the global stiffness matrix.
- **Application of Finite Element Method in Heat Transfer Problem:**
  Fundamentals, one dimensional finite element formulation, and problems.
- **Fundamentals of Computers:**
  Computer architecture, application of computers, input and output devices, latest processors, desktop PC and servers.
- **Networking Basic:**
  TCP/IP, DNS, Internet, and Intranet.
- **Operating System Basic:**
  Linux, windows, shell programming, and CLI, vi, multithreading, multituser, multitasking, hyper threading, file permissions, and ssh.
- **Fundamentals of programming:**
  Algorithm, flow charts, high-level languages like Fortran and C, and steps for creating a simple program.
- **Introduction to C Programming Language:**
  Program structure, header files, basic data types, variables, and declarations.
- **Operators and Declarations in C:**
  Relational, logical, increment, and decrement operators. Expressions and precedence of operators. Input and output operations, control statements, iterative loops, arrays, and pointer.
- **Overview of Scientific Computing:**
  Languages and compilers and scientific libraries.
- **Overview of Trends and Techniques:**
  Sequential, parallel computing, cluster and grid computing.
- **Architecture Taxonomy:**
  Traditional architecture, Flynn's classical taxonomy, SISD, SIMD, MISD, and MIMD Models.
- **Steps for Creating a Parallel Program:**
  Decomposition of the program, communication, computations, and composing the results. Parallel example-array processing.

Course Outcomes:

- Upon completion of this course, students will be proficient in applying numerical methods, finite element analysis, and computational techniques to solve complex engineering and scientific problems, utilizing tools like iterative solvers, programming languages (C, Fortran), and parallel computing methods for efficient problem-solving and modeling.

References:

1. "Numerical Methods for Engineers with Personal Computer", *S. C. Chapra and R. P. Canale*
2. "Numerical Analysis", *R. L. Burden and J. Douglas Faires*
3. "An Introduction to Numerical Analysis", *K. E. Atkinson*
4. "Numerical Method", *E. Balagurusamy*
5. "Numerical Methods for Engineers", *D. V. Griffiths and I. M. Smith*
6. "Data Reduction and Error Analysis for the Physical Sciences", *P. R. Bevington and D. K. Robinson*
7. "Finite Element Analysis", *S. Krishnamurthy*
8. "Introduction to the Finite Element Method", *Desai and Abel*
9. "An Introduction to the Finite Element Method", *J. N. Reddy*
10. "Concepts and Applications of Finite Element Analysis", *R. D. Cook*
11. "Finite Element Modeling for Stress Analysis", *R. D. Cook*
12. "Finite Elements and Approximation", *O. C. Zienkiewicz and K. Morgan*

2. 03-PHYS04-001-E Mathematical Methods in Science and Engineering

(30 Lectures Hrs)

Coordinators: Dr. Ajit Upadhyay
ajitup@rrcat.gov.in

Course Details:

- **Complex Analysis:**
  Analytic functions, Cauchy-Riemann conditions, Cauchy integral theorem, Laurent expansion, conformal mapping, singularities, calculus of residues, evaluation of definite integrals, Principal value of integrals, Analytic continuation, Dispersion relation, The Method of Steepest Descent.

- **Linear Vector Spaces, Matrices and Tensors:**
  Real and complex linear vector spaces, Scalar product, Dual vectors, Cauchy-Schwartz Inequality, Metric Spaces, Linear Operators and their algebra, Linear independence of vectors, Eigen values and Eigen vectors, Representation of Linear Operators, Matrix algebra, Symmetric, Skew-symmetric, Orthogonal, Hermitian, Skew-Hermitian and Unitary matrices, Change of basis, Tensors in real vector space, Tensor functions, Rotations, Invariant subspaces.

- **Function Space, Orthogonal Polynomials and Integral Transform:**
  Metric properties of the space of continuous functions, Lebesgue integral, The Reisz-Fisher Theorem, Expansions in orthogonal functions, Hilbert space, The Weiestrass theorem, Classical orthogonal polynomials, Laplace and Fourier Transforms.

- **Ordinary and Partial Differential Equations:**
  Review of ordinary differential equations, Introductions to partial differential equations, classification of partial differential equations, boundary and types of partial differential equations, Green's function technique for solving differential equation, Introduction to difference equations, Introduction of Geometric methods for analysis of nonlinear differential equations.

- **Group Theory:**
  Basic introduction, Representations of groups, Symmetry and degeneracy, Lie groups and Lie algebras, The orthogonal group in three dimensions, A few representative applications in classical and quantum physics.

Course Outcomes:

- Upon successful completion of this course, students will be able to apply advanced mathematical concepts—including complex analysis, linear vector spaces, functional analysis, differential equations, and group theory—to analyze and solve theoretical and applied problems in physics, engineering, and related scientific disciplines.

References:

1. Mathematics for Physicists, *P. Dennery and A. Krzywicki*
2. Mathematical Methods in Classical and Quantum Physics, *T. Dass and S. K. Sharma*
3. Mathematical Methods for Physicist, *G. Arfken*
4. Mathematical Methods for Scientists and Engineers, *Donald A. McQuarrie*
5. Ordinary Differential Equations, *V. I. Arnold*
6. Advance Engineering Mathematics, *Erwin Kreyszig*

3. 03-PHYS04-004-E Electromagnetic Theory

(30 Lectures Hrs)

Coordinators: Dr. Anand Moorti
moorti@rrcat.gov.in

Course Details:

- **Electrostatics:**
Electrostatic field in matter, Laplace equation and the uniqueness theorems, variational approach to solutions of the Laplace and Poisson equations. Formal solution of electrostatic boundary value problems with Green function. Method of relaxation for 2D electrostatic problems, method of images, separation of variables and special functions, Application of finite element method in solving electromagnetic problems.

- **Electromagnetic Wave:**
Wave equation and its solutions, plane waves, Gaussian beams, pulse propagation in material media, dispersion relations, Fresnel's laws of reflection and refraction, total internal reflection and evanescent waves. Negative refractive index.

- **Wave-guides, Resonant Cavities and Optical Fibers:**
Hollow metallic waveguides, dielectric waveguides, optical fibers, resonant cavities, and elements of microwave transport line.

- **Radiation by Moving Charges:**
Lienard-Wiechert potentials and fields, power radiated by an accelerated charge, Larmor's formula, and angular distribution of emitted radiation, Characterization of synchrotron radiation. Lorentz transformation of electromagnetic fields.

Course Outcomes:

- Upon completion of this course, students will be able to analyze and solve advanced electromagnetic problems involving electrostatics, wave propagation, waveguides, radiation mechanisms, and modern applications using analytical, numerical, and computational techniques.

References:

1. Electromagnetic Theory, *D. J. Griffith*
2. Classical Electrodynamics, *J. D. Jackson*
3. Soft X-rays and Extreme Ultraviolet Radiation: Principle and Applications, *D. T. Atwood*
4. Microwave Devices and Circuits, *S. Y. Liao*

4. 03-PHYS04-003-E Laser Physics and Technology

(30 Lectures Hrs)

Coordinators: Dr. Ajit Upadhyay
ajitup@rrcat.gov.in

Course Details:

- **Basic Formalism:**
  Spontaneous and induced transitions, Einstein's approach, A and B coefficients, conditions for light amplification and oscillations, and characteristics of laser light. Homogeneous and inhomogeneous broadening of the transitions, spectral narrowing in a laser, gain saturation, spatial and spectral hole burning and their consequences, Lamb dip spectroscopy and its applications.

- **Propagation of Optical Beams:**
  Propagation of optical beams in free space and in dielectric slab waveguides, Hermite-Gaussian beam modes, and ABCD law for Gaussian beam propagation.

- **Optical Resonators:**
  Optical resonators, concept of cavity modes, resonators with spherical mirrors. Resonance frequencies of optical resonators, losses in optical resonators, stable/unstable resonators, Kirchhoff's diffraction treatment for transverse modes.

- **Methods For Obtaining Population Inversion:**
  Optical pumping, coherent and incoherent pumping, one- and two-photon processes, pumping geometries, pump sources, electrical pumping by discharge in gases, excitation mechanisms, chemical pumping, and gas dynamic pumping.

- **Laser Dynamics:**
  Laser oscillation, three and four level lasers, rate equation modeling, power in laser oscillators, optimum output coupling low- and high-loss regimes, multimode laser oscillation and mode locking. Different techniques of mode locking. Relaxation oscillations, cavity dumping and Q-switching. Techniques of Q-switching. Pulse compression techniques for ultrashort pulse generation. Spectral control of laser output, tunability of output frequency, single frequency operation, and frequency stabilization.

- **Physics and Technology of Specific Laser Systems:**
  Solid state lasers, vibronic lasers, semiconductor diode lasers, diode pumped solid state lasers, fiber lasers, dye lasers, atomic and molecular gas lasers, chemical lasers, excimer lasers, free electron lasers. Measurement of parameters of a laser system.

- **Nonlinear Optics:**
  Crystal optics, electro-optic effect, wave propagation in nonlinear media, phase matched second harmonic generation, optical parametric oscillator, two-photon absorption, stimulated Raman scattering.

Course Outcomes:

- Upon successful completion of this course, students will be able to understand, analyze, and apply the principles of laser physics, optical beam propagation, resonator theory, laser dynamics, specific laser systems, and nonlinear optical phenomena for advanced research and technological applications.

References:

1. Laser Fundamentals*, W. T. Silfvast*

2. Laser Electronics*, J. T. Verdeyen*
3. Lasers, *A. E. Siegman*
4. Quantum Electronics*, A. Yariv*
5. Laser Physics and Technology, Proc. of the school on Laser Physics and Tech., *Eds. P. K. Gupta, R. Khare*
6. Nonlinear Optics, R. W. Boyd
7. Elements of Nonlinear optics, *P. N. Butcher and D. Cotter*

5. 03-PHYS04-005-E Accelerator Physics and Beam Diagnostics

(30 Lectures Hrs)

Coordinators: Dr. K. K. Pant
kkpant@rrcat.gov.in

Course Details:

- **Introduction:**
  Motion under electric and magnetic fields. DC and RF acceleration. Relativistic kinematics, Brief history and review of particle accelerators.
- **Synchrotron/Storage Rings:**
  Accelerator magnets – dipole, quadrupole and sextupole magnets. Synchrotron expansion method. Equation of motion, betatron oscillations, weak and strong focusing, transfer matrices, beam stability, twiss parameters, motion of particles with momentum deviation, momentum compaction, and chromaticity. Magnetic field errors, closed orbit distortion and its correction, resonances – integer and half integer, beam acceleration, synchrotron oscillations, phase stability, transition energy, beam emittance, Liouville's theorem, single turn injection, H-injection, and fast extraction.
- **Beam Transfer Lines:**
  FODO cells, quadrupole triplet, phase space matching, emittance dilution.
- **Synchrotron Radiation Sources:**
  Synchrotron radiation, radiation damping, quantum excitations, equilibrium beam emittance, and beam lifetime.
- **Linear Accelerators:**
  DC accelerators, various types of RF accelerators, EM mode in a simple structure, Q-factor, shunt impedance, transit time factor, filling time, energy gain, dispersion curve, TW and SW accelerators, and beam dynamics in LINACs.
- **Cyclotrons:**
  Basic principle of cyclotron, resonance condition, orbit stability, limitations of classical cyclotrons, AVF cyclotrons, injection, central region, extraction, time structure, energy resolution, and beam emittance.
- **Microtrons:**
  Classical microtrons, basic equations, and Racetrack microtrons.
- **Beam Diagnostics:**
  Physical principles, charge collection, secondary emission, ionization, fluorescence, scintillation, capacitive pick up, magnetic pick up, wall current, synchrotron radiation detection, and optical transition radiation.

Course Outcomes:

- Upon completion of this course, students will be able to understand, analyze, and apply the principles of particle accelerator physics—including beam dynamics, accelerator components, radiation mechanisms, and beam diagnostics—to design, operate, and evaluate modern accelerator systems for research and technological applications.

References:

1. Particle Accelerator Physics, *Helmut Wiedemann, Springer*
2. Introduction to Accelerator Physics, *Arvind Jain, Macmillan India*

3. CERN Accelerator School Proceedings, *Fifth General Accelerator Physics Course, 1992 (Available online)*
4. The principles of circular accelerators and storage rings, *P. J. Bryant and K. Johnsen, Cambridge University Press*
5. Principles of RF linear accelerators, *T. Wangler, John Wiley and Sons*
6. Collective phenomenon in synchrotron radiation sources, *S. Khan, Springer*
7. Physics of collective beam instabilities in high energy accelerators*, A. Chao, John Wiley and Sons*

6. 03-PHYS04-006-E Reactor Physics and Safety

(30 Lectures Hrs)

Coordinators: Dr. K. P. Singh (BARC)
kpsingh@barc.gov.in

Course Details:

- **Health Physics:**
  Radiation sources – radioisotopes, natural and manmade sources, radioactive series, reactors, accelerators, radiation facilities, solid, liquid and gaseous activity. Control measures – time, distance, decay, shielding, administrative control, radioactive discharge, waste disposal, and exposure control.

- **Interaction of Radiation with Matter:**
  Interaction of light and heavy charged particles, photons, and neutrons. Interaction of high energy charged particles, electromagnetic cascade, and Hadronic cascade.

- **Radiation Quantities, Units, and Regulatory Recommendations:**
  Dosimetric quantities, Exposure, absorbed dose, equivalent and effective dose, committed dose, ALI, DAC, ICRP, AERB, and dose limits.

- **Biological Effects of Radiation:**
  Somatic and genetic effects, stochastic and deterministic effects, and LD30/50.

- **Detection of Radiation:**
  Ionisation chamber, proportional counters, GM tubes, scintillation detectors, semiconductor detectors, thermos-luminescent dosimeters, direct reading dosimeters, neutron detectors, BF_3 and He tubes, Rem-meters, CR-39 foils, pulsed radiation detection. Low and high energy radiation detection.

- **Reactor Physics:**
  Introduction to nuclear energy – fission and fusion, interaction of neutrons with matter, fission process and energy release, fission cross-section, fissile and fertile materials. Chain reaction, neutron cycle and lifetime, criticality and classical four-factor formula. Thermal and fast systems, slowing down of neutrons, conversion and breeding of fissile materials, concept of neutron flux and current, neutron diffusion theory, critical size and mass, reflected systems and reflector saving, heterogeneous systems. Reactor kinetics, reactivity and importance of delayed neutrons, reactivity changes and coefficients, fission product poisoning, control devices, uranium and thorium fuel cycles and enrichment processes.

- **Accelerator Safety:**
  Types of accelerators, prompt and residual radiation, source terms, radiation hazards, radiation safety systems, shielding, radiation monitoring, non-ionizing radiation safety, RF and MW safety, magnetic field safety, ozone safety, safety at synchrotron radiation beam lines, spallation neutron sources, and accelerator driven sub-critical systems.

Course Outcomes:

- Upon successful completion of this course, students will be able to understand, evaluate, and apply principles of radiation physics, reactor physics, and accelerator safety to assess radiation hazards, ensure regulatory compliance, and implement effective radiation protection and safety measures in nuclear and accelerator facilities.

References:

1. Nuclear Reactor Engineering *Vol-1, Samuel Glasstone and Sesonske*
2. Health Physics, *Herman Cember*
3. Radiation Detection & Measurement, *G. F. Knoll*
4. Atoms, Radiation & Radiation Protection, *James Turner*
5. Physics for Radiation Protection, *James Martin*
6. Radiological Safety Aspects of the Operation of Electron Accelerators, *IAEA Technical Report Series No. 188*
7. Radiation Protection for Particle Accelerator Facilities, *NCRP Report No. 144*
8. Radiological Safety Aspects of the Operation of Proton Accelerators, *IAEA Technical Report Series No.* 283
9. A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators Nuclear Technology, *A. Sullivan*

7. 03-PHYS04-011-E Vacuum Physics and Technology

(30 Lectures Hrs)

Coordinators: Shri D. P. Yadav
dpyadav@rrcat.gov.in

Course Details:

- **Vacuum Theory:**
  Definitions – throughput, conductance, pumping speed etc. Pressure equations, mean free path, monolayer formation time. Units of vacuum, pressure regions in vacuum.

- **Vacuum Systems and Components:**
  Vacuum pumps – rotary pumps, dry pumps, turbo-molecular pump, titanium sublimation pump, non-evaporable getters, and sputter ion pump. Vacuum gauges – capacitance gauge, Pirani, thermocouple gauges, BA gauge, Penning gauge, partial pressure gauge. Flanges and seals, vacuum valves and feed through.

- **Vacuum System Design and Development:**
  Design considerations, sources of gas load (vaporization, thermal desorption, diffusion, permeation, electron and ion stimulated desorption etc.). Materials, fabrication techniques and leak detection. Processing to achieve ultra-high vacuum.

Course Outcomes:

- Upon completion of this course, students will be able to understand, design, and evaluate vacuum systems by applying vacuum theory, selecting appropriate pumps and gauges, and implementing material, fabrication, and processing techniques to achieve and maintain high and ultra-high vacuum environments for scientific and industrial applications.

References:

1. Handbook of Vacuum Science and Technology, *Ed. Dorothy M. Hoffman, Bawa Singh, John H. Thomas III and John H. Thomas III*
2. Vacuum Technology – *3rd edition, A. Roth*
3. A User's Guide to Vacuum Technology – *July 4, 2003, John F. O'Hanlon*
4. Vacuum Engineering Calculations, *Formulas, Armand Berman*
5. Vacuum Technology – CERN Accelerator School, *CERN*

8. 03-PHYS04-008-E Solid State Physics and Material Sciences

(30 Lectures Hrs)

Coordinators: Dr. M K Chattopadhyay
maulindu@rrcat.gov.in

Course Details:

- **Atomic Structures of Crystals:**
  Crystal systems, choice of unit cell and symmetry consideration, Bravais lattice: 2D, 3D and symmetry operations; reciprocal lattice; structure determination by scattering; structure factor, concept of Ewald sphere; types of bonding in solid.

- **Lattice Dynamics and Thermal Properties:**
  Classical vibration in one and three dimensions, quantum theory of harmonic crystal: quantization, energy and momentum conservation; specific heat: Einstein, Debye model and beyond (correction from actual phonon dispersion curve); thermal conductivity: effect of phonon scattering and mean free path, graphene, carbon nanotube and polymer; thermal expansion: effect of anharmonic oscillator model; negative thermal expansion, Grüneisen parameter.

- **Free Electron Model:**
  Drude model, relaxation time approximation, electrical conductivity of metal, Wiedemann-Franz law, Hall effect, Seebeck effect, thermoelectric effect. Quantum theory of free electron gas (Sommerfeld model of metal), density of states, specific heat and thermal conductivity of metal.

- **Electronic Band Structure of Solids:**
  Bloch theorem, free electron and tight binding electron approximations for band structure, concept of holes and effective mass, electronic properties of selected crystals, optical properties.

- **Electron-Electron Interaction:**
  Hartree and Hartree-Fock equations, density functional theory, electronic properties and phase diagram of homogeneous electron gas, and Fermi liquid theory. (5)

- **Electronic States at the Surface:**
  Work function, contact potential, thermionic emission, Electronic surface levels, Topological insulator. (3)

- **Magnetism:**
  Quantum Theory of diamagnetism and paramagnetism, magnetism of free electron gas, Pauli paramagnetism and Landau diamagnetism. Quantum mechanics of interacting magnetic movements. Origin of ferromagnetism and anti-ferromagnetism; Stoners model of ferromagnetism. Direct indirect, and super exchange. Order-disorder transition in magnetism.

- **Dielectric properties of materials:**
  Polarization mechanisms in dielectrics, dispersion in dielectric material; principles of piezoelectricity, transducers and energy harvesting materials; pyroelectricity and ferroelectricity. (4)

Course Outcomes:

- Upon successful completion of this course, students will be able to understand, analyze, and apply the principles of solid-state physics—including crystal structure, lattice dynamics, electronic band theory, electron interactions, surface states, magnetism, and dielectric properties—to explain and predict the physical behavior of materials and their technological applications.

References:

1. Solid State Physics, *N. W. Ashcroft and N. D. Mermin*
2. Condensed Matter Physics, *M. P. Marder*
3. Solid State Physics, An introduction to the Principles of Materials Science, *H. Ibach and H. Luth*
4. Atomic and Electronic Structure of Solids, *E. Kaxiras*
5. Dielectric Phenomena in Solids: With Emphasis on Physical Concepts of Electronic Processes, *Kwan-Chi Kao*

9. 03-PHYS04-012-E Quantum Mechanics

(45 Lectures Hrs)

Coordinators: Dr. Haranath Ghosh
hng@rrcat.gov.in

Course Details:

- **Mathematical Background and Postulates:**
  Illustrations and application of postulates by using simple two-level systems and two-slit interference experiment.
- **Quantum Mechanics of Composite Systems:**
  N-particle system, identical particles, symmetrization and antisymmetrization postulates, concept of density matrix, properties of density matrix, pure and mixed states.
- **Symmetry:**
  Symmetries in quantum mechanics, space and time translation, time reversal symmetry and parity invariance. Rotational invariance, angular momentum, spin, and addition of angular momenta.
- **Approximate Methods:**
  Variational methods, Wentzel-Kramers-Brillouin (WKB) method, time-independent perturbation theory, time dependent perturbation theory, adiabatic and sudden approximations, Fermi-Golden rule.
- **Scattering Theory:**
  Born approximation, partial wave analysis, two particle scattering.
- **Relativistic Quantum Mechanics:**
  Klein-Gordon equation, Dirac equation, electron spin, and positron.
- **Advanced Topics:**
  Entangled state, EPR paradox and Bell's inequality.

Course Outcomes:

- Upon successful completion of this course, students will be able to understand and apply advanced concepts of quantum mechanics—including composite systems, symmetries, approximation methods, scattering theory, relativistic quantum equations, and quantum entanglement—to analyze and solve fundamental problems in modern physics.

References:

1. "Principle of Quantum mechanics", *Ramamurthy Shankar*
2. "Quantum Mechanics, Vol. I and II", *C. Cohen-Tannoudji, B. Liu, F. Laloë*
3. "Modern Quantum Mechanics", *J. J. Sakurai*

10. 03-PHYS04-001-L, 03PHYS04-002-L, and 03PHYS04-003-L

Laboratory Experiment: (72 Lab Hrs)

Coordinators: Dr. Sunil Verma
sverma@rrcat.gov.in

Course Details:

A. EXPERIMENTS ON LASERS

Sr. No.	Title
1	Measurement of spectrum of diode/ LED Laser using spectrograph
2	Measurement of Time-Bandwidth Product of an ultra-fast pulse
3	Measurement of spectral responsivity of semiconductor detectors
4	Characterisation of laser beam parameters
5	Testing figure of an optical surface using phase shifting Fizeau Interferometer
6	Study on characteristics of all-fiber Yb-doped CW and Q-switched fiber laser
7	Studies on the fiber grating based temperature sensor
8	Saturated absorption in atomic vapour: Doppler broadening, natural line width, power broadening
9	Parametric study of a XeCl Excimer Laser
10	Pulsed laser ablation of metals in liquids – for nanoparticles synthesis
11	Synthesis of Ag nanoparticles using Nd:YAG pulsed laser irradiation

B. EXPERIMENTS ON ELECTRONICS

Sr. No.	Title
1	Study of stepper motor, DC motor drive and position feed-back, pico motors (piezo actuators), DC motor drive for precision motion control
2	Characterization of Data Converters (ADC and DAC)
3	Familiarization with Digital Control System Concepts
4	Application of digital image processing for beam profile measurement

5	Study of CC/CV buck converter and analysis of output current stability in CC mode
6	Ab *initio* Study of Electronic Band Structure of Solids – Semiconductor Versus Metal
7	Study of different transducers and their interfacing
8	G.U.I. software familiarization and applications
9	Study of flash lamp and measurement of flash lamp current and Ko factor
10	Characterization of RF Components
11	Fast current transformers: study and measurement of response

C. EXPERIMENTS ON ACCELERATORS

Sr. No.	Title
1	Electrical resistivity measurement on metallic sample at low temperature
2	Parametric studies of magnetic materials and operating point of magnets
3	Measurement of specific outgassing rate of materials
4	Experimental determination of the attenuation co-efficient of different absorbers to known gamma photon energy
5	Gamma ray spectroscopy using High Purity Germanium detector (HPGe)
6	Electron emission from LaB6 cathode and its characterization
7	Study on detuning compensation of superconducting RF cavity and tuner characterization at room temperature
8	Sensitivity Measurement of a Residual Gas Analyser / Residual Gas Analyser as a leak detector
9	Determination of Cooling Power of cryo-cooler
10	Proton ion source: Operation & experimental studies
11	XRF using radioactive source
12	Calibration of cryogenics sensors

Course Outcomes:

- Upon completion of this laboratory course, students will be able to design, perform, and analyze experiments in lasers, electronics, and accelerator physics, developing hands-on skills in measurement techniques, instrumentation, data acquisition, and interpretation to support research and applications in modern photonics, electronics, and particle accelerator systems.

03-PHYS04-002-E Magnet Physics and Technology

(30 Lectures Hrs)

Coordinators: -
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Course Details:

- **Origin of Magnetism:**
  Classical and quantum concepts, magnetic moments, angular momentum and quantization of angular momentum.
- **Classification of Magnetism:**
  Diamagnetism, paramagnetism, ferromagnetism, anti-ferromagnetism, and ferrimagnetism.
- **Role of Magnets in Accelerators:**
  Dipole, quadrupole, sextupole, and combined function magnets, DC and fast cyclic magnets, septum magnets, and kicker magnets.
- **Fundamentals of Magnet Design:**
  Magnetic circuit, dipole, quadrupole, sextupole and higher order multipole magnets and coil design, B-H curve.
- **Application of Magnetic Materials in Accelerators:**
  Materials for DC magnets: low field magnets, high field magnets, permanent magnets, and shielding.
- **Materials for AC Magnets:**
  Silicon steels, laminated Ni-Fe alloys, and ferrites. Numerical methods for magnet simulation; computer code and related mathematical formalism, methods of optimization, multipole expansion, Fourier representation of magnetic fields.
- **Magnet Technology:**
  Fabrication procedures, tolerances, and economic issues. Methods of magnetic field measurements: magnetic induction, search coil, Hall probe, and nuclear magnetic resonance.
- **Superconducting Magnets:**
  Basic concept of superconducting magnets, magnet geometries for dipole magnets, superconducting materials, need for twisted composite conductors, hot spot temperature, current densities, quench, training of magnets and persistent switch.
- **Geodesy and Alignment of Accelerators:**
  Introduction, survey and alignment as applicable to accelerators and its requirement. Position sensitive elements and their typical tolerances for alignment, fiducial references and adjustment system, fiducial posts and targets, and techniques of fiducialisation. Features of support elements and their adjustments during alignment.
- **Network and Alignment Procedure:**
  Defining coordinate systems, control networks, survey procedure, data adjustment and error analysis.
- **Survey and Alignment Instruments and Tooling:**
  Electronic theodolite, optical level, laser interferometer, distinvar, inclinometer, offset meter etc. Different

types of targets and sensors.

Course Outcomes:

- Upon completion of this course, students will be able to understand, design, and analyze magnetic systems and accelerator alignment procedures, including the use of magnetic materials, magnet technologies, superconducting magnets, and precision survey and alignment techniques to ensure accurate operation of particle accelerators.

References:

1. Iron Dominated Magnets, *Jack T. Tanabe*
2. Synchrotron Radiation Sources – *A Primer, Herman Winick*
3. Iron Dominated Electromagnets, Design, Fabrication, Assembly Measurements, *Jack T. Tanabe*
4. Conventional Magnets, Proceedings of CAT-CERN Accelerator School, *Nov. 1993, Page 23, "Neil Marks"*
5. Classical Electrodynamics, *J. D. Jackson*
6. Superconducting Magnet Systems, *H. Brechna*
7. Physics of Magnetism, *S. Chikazumi*
8. Soft Ferrite its Applications, *E. C. Snelling*
9. Permanent Magnet Materials Their Applications, *Peter*
10. Modern Ferrite Technology, *Alex Goldman*

03-PHYS04-010-E Physics of Semiconductor Quantum Structures

(30 Lectures Hrs)

Coordinators: Dr. Pankaj Misra
pmisra@rrcat.gov.in

Course Details:

- **Introduction to Semiconductor Nanostructures:**
  Review of condensed matter and semiconductor physics, scientific and technological significance of nanostructures and mesoscopic structures, characteristic length scales for quantum phenomena, energy states of carriers in free space of different dimensionality, effect of quantum confinement on carrier energy states, density of states for semiconductors of reduced dimensionality, key ideas on effect of quantum confinement in electronic properties, transport phenomenon and interaction of photons with materials, and applications of nanostructured semiconductors.

- **Growth of Semiconductor Nanostructures:**
  Homo and hetero epitaxial growth, nucleation and nucleation kinetics, strain in lattice mismatched systems, pseudomorphic growth and critical thickness, growth modes: Volmer–Weber (VW) or island growth, Frank–van der Merwe (FM) or planar growth and Stranski–Krastanov (SK) nucleation and growth, fundamental and principle physical and chemical vapor deposition methods: pulsed laser deposition, molecular beam epitaxy, chemical vapor deposition, atomic layer deposition, sputtering. Bandgap engineering and growth of quantum well structures, key issues in growth of quantum wires, quantum dots and super lattices, fundamental characteristics of semiconductor nanostructures.

- **Properties and Characterizations of Semiconductor Nanostructures:**
  Optical processes in low dimensional semiconductors: excitons, free carriers and defect level induced optical transitions, optical phonons and polaritrons. Basic principles and key issues of optical spectroscopy techniques for nanostructured semiconductors: absorption, reflection, photoluminescence, photoluminescence excitation and surface photovoltage spectroscopy. Transport in semiconductor nanostructures: conductance, resonant tunneling, hot electrons; transport in magnetic field, semi-classical and quantum approach, Aharonov–Bohm effect, Shubnikov–de Haas effect, introduction to quantum Hall effect. Principles of application of devices based on semiconductor nanostructures: photodetectors, lasers, resonant tunneling diodes and solar cells etc.

Course Outcomes:

- Upon completion of this course, students will be able to understand, analyze, and apply the principles of semiconductor nanostructures—including their growth, quantum confinement effects, transport and optical properties, characterization techniques, and device applications—for research and technological innovation in nanoelectronics and photonics.

References:

1. Material Science of Thin Films: Deposition Structures, *Milton Ohring*
2. Solid State Electronic Devices, *Jaspreet Singh*
3. Physics of Low-Dimensional Semiconductors, *Davies John H.*
4. Semiconductor Devices Design, *Jaspreet Singh and Umesh K Mishra*
5. Semiconductor Materials, *B. G. Yacobi*
6. Semiconductor Nanostructures, *Ed. D. Bimberg*
7. Semiconductor Optoelectronics: Physics Technology, *J. Singh*

03-PHYS04-004-E Plasma Physics and Technology

(30 Lectures Hrs)

Coordinators: Dr. Anand Moorti
moorti@rrcat.gov.in

Course Details:

- **Basic Plasma Physics:**
  Definition of plasma, concept of temperature, Debye shielding, plasma parameter, criterion for plasma, variety of plasmas.
- **Plasma Behaviour:**
  Single particle motion in electric and magnetic fields, collisions, plasma as fluid, kinetic approach.
- **Waves in Plasmas:**
  Dielectric function, plasma oscillations, electromagnetic equations, dispersion relations.
- **Methods of Plasma Production:**
  Electrical discharge, ohmic heating, RF heating, plasma production by lasers and particle beams, Tokamak plasma, Z-pinch, Theta pinch.
- **Plasma Processes:**
  Ionization, recombination, plasma equilibrium.
- **Radiation from Plasmas:**
  Emission processes, spectral characteristics.
- **Plasma Diagnostic Methods:**
  Density and temperature diagnostics using plasma radiation.
- **Plasma Heating by Laser Beams:**
  Propagation of laser beam in plasmas, inverse Bremsstrahlung, resonance absorption, parametric processes, second harmonic generation, filamentation, self-focusing.
- **Laser Plasma Interaction at Ultrahigh Intensities:**
  Ultrahigh intensity parameters, multi-photon ionization, tunnel ionization, above threshold ionization, high harmonic generation.
- **Applications of Laser-plasma:**
  Electron acceleration, x-ray lasing, inertial confinement fusion and fast ignition.

Course Outcomes:

- Upon completion of this course, students will be able to understand, analyze, and apply the principles of plasma physics—including plasma behavior, waves, production, diagnostics, and laser-plasma interactions—for advanced research and applications in fusion, particle acceleration, and high-intensity laser technologies.

References:

1. Introduction to Plasma Physics and Controlled Fusion Volume 1: Plasma Physics, *Francis F. Chen*
2. Fundamentals of Plasma Physics*, 3rd Ed., J. A. Bittencourt*, *Springer*
3. Principles of Plasma Spectroscopy, *Hans R. Griem*

4. Principles of Plasma Diagnostics, *I. H. Hutchinson*
5. The Physics of Laser Plasma Interactions, *W. L. Kruer*
6. Short Pulse Laser Interaction with Matters: *An Introduction, P. Gibbon*

03-PHYS04-005-E Instrumentation for Material Characterization

(30 Lectures Hrs)

Coordinators: Dr. Sunil Verma
sverma@rrcat.gov.in

Course Details:

- **Concept of Noise in Electrical Measurements:**
  Sources of noise, noise spectrum. Low signal DC voltage and current measurements, measurement system designing, problems in low signal measurements: ground loops, noise pickup, thermo-electric EMF, electromagnetic interference etc.

- **Resistance and Impedance Measurement Techniques:**
  Resistance and impedance measurement techniques.

- **Lock-in Detection:**
  Principles with mathematical derivation; analog vs. digital lock-in amplifiers.

- **Measurement of Pulsed Electrical Signals:**
  Measurement of pulsed (nano seconds) electrical signals, RC and LR delays in circuits.

- **High Frequency Measurements:**
  High frequency (RF) electrical signal detection and resonant perturbation techniques for studying material properties.

- **Time Dependent Measurements:**
  Time dependent measurement (nano seconds): boxcar, detection of ultrafast optical signals (pico seconds, femto seconds): pump-probe techniques, Streak camera and its working principle.

- **Accurate temperature measurement** (cryogenic to high temperature, radiation environment, high magnetic field environment).

- **Magnetic Measurement:**
  Vibrating sample magnetometer, SQUID. Basics of spectroscopy: Monochromators, spectrographs.

- **Energy and wavelength dispersion techniques in spectroscopy** (specifically in the x-ray region).

- **Spectroscopy in the IR region**, FTIR.

- **Introduction to Photon Detectors:**
  Photodiodes, photomultiplier tubes, proportional counters, CCD.
  Uncertainties in measurements, with specific cases.

- **Software Related Aspects:**
  Fourier transform, windowing and software based noise reduction in signal. Sampling theorem and its effect on the data: aliasing.

- **Computer based data acquisition:**
  Interface buses (LAN, LXI, USB, GPIB, RS-485, 232), PC based data acquisition (IPC, PCI, Compact PCI, PCI Express, PXI), introduction to LabVIEW, image acquisition hardware (GigE Vision, Cameralink, CoaXpress).

Course Outcomes:

- Upon completion of this course, students will be able to understand, design, and implement precise measurement techniques for electrical, optical, magnetic, and thermal signals—including noise management, high-frequency and time-resolved measurements, spectroscopy, photon detection, and computer-based data acquisition—enabling accurate characterization of physical systems in advanced research and technology applications.

03-PHYS04-003-E Statistical Physics

(30 Lectures Hrs)

Coordinators: Dr. H. N. Ghosh
hng@rrcat.gov.in

Course Details:

- **Classical and Quantum Statistical Mechanics:**
  Introduction, postulates, microcanonical, canonical and grand canonical ensembles, partition and grand partition functions and their properties.
- **Ideal Bose Gas:**
  Introduction, chemical potential, equation of state and thermodynamic properties, system of phonons, system of photons, Bose-Einstein condensation, Bose-Einstein condensation in dilute atomic gases, and superfluidity.
- **Ideal Fermi Gas:**
  Introduction, equation of state and thermodynamic properties of degenerate Fermi gas. Neutron stars, conduction electrons in metals, and cold Fermi atomic gases.
- **Phase Transition:**
  Mean-field theories, symmetry, order parameters, break-down of mean-field theories, critical phenomena and renormalization group.
- **Non-equilibrium Phenomena:**
  Elementary ideas, irreversibility, study of Brownian motion, random walk model, Langevin force equation, fluctuation-dissipation theorem, Fokker-Planck equation, Glauber dynamics.

Course Outcomes:

- Upon completion of this course, students will be able to understand, analyze, and apply the principles of classical and quantum statistical mechanics—including ensembles, ideal Bose and Fermi gases, phase transitions, and non-equilibrium phenomena—to explain and predict the thermodynamic and transport behavior of physical systems.

References:

1. Fundamental of Statistical and Thermal Physics, *F. Reif*
2. Statistical Mechanics, *R. Pathria*
3. Statistical Mechanics, *K. Huang*

03-PHYS04-002-E Advanced Accelerator Physics

(30 Lectures Hrs)

Coordinators: -
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Course Details:

- **Ion Sources:**
  Emission processes and Child Langmuir Law, positive and negative ion sources, atomic and molecular phenomena in ion sources, beam extraction and transport.
- **Proton and Heavy Ion Accelerators:**
  Introduction to acceleration of protons and heavy ions, RFQ, different type of cavities/accelerating structures, including SCRF, and introductory beam transport.
- **Instabilities in Linear Accelerators:**
  Basics of beam instabilities, short- and long-range instabilities.
- **Other Topics:**
  FEL, Linac based synchrotron sources, laser plasma acceleration, and ADS.

Course Outcomes:

- Upon completion of this course, students will be able to understand and apply the principles of ion sources, proton and heavy ion acceleration, beam transport, and accelerator instabilities, as well as advanced concepts such as free-electron lasers, laser-plasma acceleration, and accelerator-driven systems, for research and technological applications in particle accelerators.

03-PHYS04-001-E Advanced Optics

(30 Lectures Hrs)

Coordinators: Dr. Sunil Verma
sverma@rrcat.gov.in

Course Details:

- **Fundamentals of Geometric and Wave Optics:**
  Concepts of wave front and phase, complex representation of electromagnetic wave, image formation and spatial resolution, optical path and spatial coherence, monochromatic and temporal coherence, optics design and wave front aberrations, basics of interference and diffraction, intensity due to two beam interference, contrast/visibility of fringes.

- **Fourier Optics:**
  Concept of Fourier Transform and far field diffraction, concept of spatial filtering, amplitude and phase filters in spatial frequency domain, image processing, optical correlations in spatial and temporal domains, principles of phase shifting techniques and phase un-wrapping.

- **Modern Optical Instruments:**
  Basics of Michelson, Fabry-Perrot, Mach-Zehnder, Fizeau, Twyman-Green, and lateral shear interferometer; concept of coherence and white light interferometry, scanning white light interferometer (SWLI), Sagnac cyclic interferometer, Shack-Hartmann wave-front sensor, Nomarsky Microscope, basics of diffraction gratings and spectrometers, modern optical instrumentation like electron-Optics (photo-cathodes) and introduction to streak cameras, Doppler velocimetry and Velocity Interferometer System for Any Reflector (VISAR), use of spatial light modulators for amplitude and phase modulation, phase correcting mirrors.

- **Surface imperfections and ISO 10110 standard:**
  Definitions of surface form, parallelism, scratch and Dig and RMS roughness; their measurements using surface profilometers, white light confocal microscopy, Nomarsky microscopy and scatterometers.
  Super resolution and measurements for overcoming diffraction limits:
  Introduction to Scanning near field optical microscopy (SNOM).

- **Optical coatings:**
  Introduction, electromagnetic theory of dielectric coating, anti-reflection coating, beam splitters, neutral density filters, high-reflection mirror coatings, edge filters, bandpass interference filters, deposition of optical thin film multilayer coatings, infrared optical coatings, characterization of coatings.

Course Outcomes:

- Upon completion of this course, students will be able to understand, analyze, and apply the principles of geometric, wave, and Fourier optics—including optical instrumentation, interferometry, surface metrology, super-resolution techniques, and optical coatings—for the design, characterization, and optimization of advanced optical systems.

References:

1. Introduction to Fourier Optics, *Joseph W. Goodman*
2. Handbook of Optical Design (Optical Science and Engineering), *Daniel Malacara*
3. Encyclopedia of Optical Engineering, *Ronald G. Driggers (Editor)*
4. Laser Resonators and Beam Propagation, *Norman Hodgson and Horst Weber*
5. The Physics and Technology of Laser Resonators, *Denis Hall*
6. Optical Interferometry, *P. Hariharan*

7. Theory and Practice of Scanning Optical Microscopy, *Colin Sheppard*
8. Wave Optics and its Applications, *R. S. Sirohi*
9. Optical Thin Films and Coatings – From Materials to Applications, *Ed. Angela Piegari and François Flory*

03-PHYS04-011-E Fiber Optics and Fiber Sensors

(30 Lectures Hrs)

Coordinators: Dr. Om Prakash
oprakash@rrcat.gov.in

Course Details:

- **Fiber Optics:**
  Optical fiber basics, single mode fiber, multi-mode fiber, step index fiber, graded index fiber, double-cladded fiber, microstructured fiber, modes in optical fiber, dielectric slab wave guide, propagating modes of the symmetric slab waveguide, odd even TE modes, characteristics of modes, TM hybrid modes, characteristic equations, mode cutoff conditions, ray optics explanation of modes in a dielectric slab waveguide, basic equations, physical constraints in round optical fibers, the fields in the core cladding, boundary conditions, linearly polarized modes, power distribution in optical fiber.

- **Characteristics of Optical Fiber:**
  Losses in optical fiber: intrinsic impurity absorption loss, waveguide scattering loss, macrobending loss, coupling splicing loss; dispersion in optical fiber, group velocity dispersion, material dispersion, waveguide dispersion, polarization mode dispersion, dispersion management in optical fiber.

- **Fiber Optic Components and Devices:**
  Directional couplers, coupled mode equations, power transfer characteristics, transfer matrix of a coupler, super modes of a coupler, effect of fiber dispersion, optical isolator, and optical circulators.

- **Nonlinear Fiber Optics:**
  Nonlinearities in optical fiber, Kerr nonlinearity, self-phase modulation, self-focusing, cross phase modulation, four wave mixing, stimulated Brillouin scattering, stimulated Raman scattering. Ultra short pulse propagation, derivation of nonlinear Schrödinger equation (NLSE), ultra-short pulse propagation through fiber, soliton, simulation Gaussian pulse. Effect of gain loss on pulse propagation, interplay of dispersion, nonlinearity gain.

- **Optical Fiber Gratings:**
  Photosensitivity, defects in the optical fiber, photosensitivity of doped fibers, photosensitization methods for optical fiber, refractive index modulation in the optical fiber, methods of fiber grating writings e.g. phase mask based, interferometry, point by point; Types of fiber gratings such as uniform Bragg grating, long period grating, tilted fiber Bragg grating, chirped fiber grating, Type-IIa fiber grating, Type-II fiber grating, Type-Ia fiber grating etc., properties of laser sources used for fabrication of fiber gratings, Optical theory of fiber Bragg, tilted and long period gratings, mode coupling, reflection and transmission spectra.

- **Optical Fiber Sensors:**
  Principle of fiber optic sensor, classification of fiber optic sensor, sensing region, optical modulation mechanism, fiber grating sensors, principle of sensing, fiber designs for sensing, single point sensing, multi-point/distributed sensing, measurement of temperature with FBG, measurement of strain with FBG, measurement of pressure with FBG, FBG wavelength temperature compensation techniques, chirped grating sensor, long period grating sensor, evanescent field refractive index sensor, FBG based refractive index sensors, tilted FBG based refractive index sensors, LPG based refractive index sensors, sensors based on surface plasmon resonance (SPR), Raman, Brillouin and Rayleigh scattering based fiber sensors.

Course Outcomes:

- Upon completion of this course, students will be able to understand, analyze, and apply the principles of optical fibers—including fiber structures, propagation characteristics, nonlinear effects, fiber gratings, and fiber-optic sensors—for the design, characterization, and implementation of advanced fiber-optic communication and sensing systems.

References:

1. Introduction to Fiber Optics, *Ghatak and Tyagrajan*
2. Applications of Nonlinear Fiber Optics, *G. P. Agrawal*
3. Fiber Optics, Physics and Technology, *B. P. Palitschke*
4. Fiber Bragg Gratings, *Raman Kashyap*
5. Fiber Optic Sensors: Fundamentals and Applications, *D. A. Krohn*
6. Fiber Optic Sensors, Shizhuo Yin, Paul B. Ruffin, *Francis T. S. Yu*

03-PHYS04-008-E Advanced Course on Atom-Photon Interactions

(30 Lectures Hrs)

Coordinators: Dr. Ajit Upadhyay
ajitup@rrcat.gov.in

Course Details:

- **Interaction of Light with Matter:**
  Hamiltonian description, multipolar approximation, review of the time dependent perturbation theory, concept of transition amplitude, semiclassical theory of a two-level atom coupled to a single mode radiation field, density matrix, optical Bloch equations, semi-classical laser theory.
- **Coherent Effects:**
  Coherent population trapping (CPT), electromagnetically induced transparency, laser without population inversion, mechanical effects of light and its application in laser cooling and trapping.
- **Quantum Field:**
  Quantization of electromagnetic field, interaction of quantized radiation. With matter, Jaynes–Cummings model, quantum dissipative processes, atom in the vacuum field and spontaneous emission, resonance fluorescence.
- **Elementary Theory of Coherence:**
  Quasi-probability distribution functions, classical light and non-classical light, coherent state, squeezed state and its experimental realization, atom-photon and atom-atom entanglement, multiparticle entanglement, entanglement in Quantum Information Processing.
- **Interaction of Atom with Intense Light Field:**
  Virtual absorption and multiphoton ionization, generalized Fermi-Golden rule, above threshold ionization, Volkov state and KFR theory, high harmonic generation, Floquet theory, many-body correlation effects and non-perturbative field effects, and S-Matrix theory.

Course Outcomes:

- Upon completion of this course, students will be able to understand, analyze, and apply the principles of light–matter interaction, coherent and quantum effects, quantized electromagnetic fields, and strong-field phenomena, enabling them to study and design systems for quantum optics, laser physics, and quantum information processing.

References:

1. Quantum Optics, *M. O. Scully and M. Suhail Zubairy*
2. Elements of Quantum Optics, *Pierre Meystre and Murray Sargent*
3. Laser Physics, Murray Sargent, *Marlan O. Scully and Willis E. Lamb*
4. Photon and Atoms: Introduction to Quantum Electrodynamics, *C. Cohen-Tannoudji, J. Dupont-Roc, G. Grynberg*

03-PHYS04-006-E Advanced Beam Dynamics

(30 Lectures Hrs)

Coordinators: -
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Course Details:

- RMS envelope equation, beam matrix approach, concept of stationary states for beam distribution functions.
- Transverse beam dynamics in a solenoid, Busch emittance, transverse and longitudinal beam dynamics in RF field, Panofsky–Wenzel theorem and its applications, wakefields and impedances in linear accelerators.
- Emittance growth mechanisms and approximate techniques to estimate the emittance growth, beam halo. Bunch compressors and coherent synchrotron radiation (CSR), emittance growth due to CSR.
- Beam dynamics with ion trapping and electron clouds.
- Coupling of electromagnetic power to RF cavities, beam loading and its implications, Slater perturbation theorem and its applications.
- Computational methods in accelerator physics, symplectic integration, Lie Algebraic methods.

Course Outcomes:

- Upon completion of this course, students will be able to understand, analyze, and apply the principles of beam dynamics—including transverse and longitudinal motion, emittance growth, wakefields, beam–cavity interactions, and computational methods—for the design, optimization, and operation of particle accelerators.

References:

1. Theory and Design of Charged Particle Beams, *Martin Reiser*
2. RF Linear Accelerators, *Thomas P. Wangler*
3. Advanced Beam Dynamics, Bruce Carlsten and Steve Russell, a course Offered at US Particle Accelerator School, Univ. of California, 2005.
4. Computational Methods in Beam Dynamics, Robert Ryne, a course offered at US Particle Accelerator School, Univ. of California, 2005.
5. Advanced Accelerator Physics Course, CERN Accelerator School Proceedings, CERN-95-06-V1-V2.
6. Neutralization of Accelerator Beam by Ionization of the Residual Gas, *Y. Baconnier, A. Poncet and P. F. Tavares, Lecture notes, CERN.*

03PHYS04-007-E Course on Bio-Photonics

(30 Lectures Hrs)

Coordinators: Dr. S K Majumder
shkm@rrcat.gov.in

Course Details:

- **Introduction:**
  Scope of bio-photonics, interaction of light with cells and tissues: absorption, scattering and depolarization of light.
- **Basics of Biology:**
  Cell structure and organization, structure and function of biomolecules, metabolism and energetics. General methods for biophysical and biochemical analysis, mechanism of cell death.
- **Light Propagation in Tissues:**
  Rayleigh and Mie scattering, multiple scattering and propagation of light in tissues, radiative transport and diffusion approximation, effect of boundary conditions, numerical approaches for determining irradiance at surface and interior of scattering objects, techniques for determination of optical properties of biological samples.
- **Optical Imaging Through Turbid Medium:**
  Trade-off between resolution and depth of imaging, use of spatial filtering, polarization gating and time-gating for optical imaging, high resolution imaging using coherence gating, Optical coherence tomography (OCT) and diffuse optical tomography.
- **Optical Spectroscopy for Biomedical Diagnosis:**
  Elastic scattering spectroscopy for disease diagnosis, fluorescence and Raman spectroscopy for diagnosis.
- **Optical Techniques for Micro-manipulation:**
  Optical tweezers and micro-beams, radiation pressure and force on microscopic objects, gradient and scattering force, applications of optical tweezer.
- **Optical Microscopy: Recent Developments:**
  Contrast methods in optical microscopy, techniques for single molecule imaging, scanning laser microscopy, multi-photon microscopy and near-field techniques.
- **Optical Methods for Bio-sensing Applications:**
  Surface plasmon resonance-based sensors, quantum dots and functionalized nanoparticles as biosensors, approaches for label-free sensing, opto-fluidics and lab-on-chip approach.
- **Effect of Light on Biological Tissue:**
  Basic principles of photobiology, photo-acceptors, action spectra and light induced signaling mechanisms, light effect based on endogenous photosensitizers, use of exogenous photosensitizers for photodynamic therapy and Photo anti-microbial therapy, biological effects of narrow bandwidth light.

Course Outcomes:

- Upon completion of this course, students will be able to understand and apply the principles of light–tissue interaction, optical imaging, spectroscopy, microscopy, and photonic manipulation for biomedical diagnosis, therapy, and biosensing applications.

References:

1. Biomedical Photonics Handbook, *Editor-in-Chief Tuan Vo-Dinh*
2. Optical Tweezers: Methods and Applications, *Ed. Miles J. Padgett, Justin Molloy, David McGloin*
3. Introduction to Biophotonics, *Paras N. Prasad*

03PHYS04-009-E Concepts in X-Ray Physics

(30 Lectures Hrs)

Coordinators: Dr. Gurvinderjit Singh
gjit@rrcat.gov.in

Course Details:

- **X-ray and Their Interaction With Matter:**
  X-ray waves and photons, sources of X-rays, X-ray scattering from an electron and atom, refractive index including absorption, coherence, Kramer–Kronig relationship.
- **Refraction and Reflection of X-rays:**
  Refraction and phase shifting in scattering, Snell's law and Fresnel equation in X-ray region, reflection from homogeneous slab and multilayers, rough interfaces and surfaces, examples of refractive and reflective X-ray optics and curved mirrors.
- **Kinematical Diffraction and Resonant Scattering:**
  Laue condition and reciprocal space, Ewald sphere, lattice vibration, the Debye–Waller factor, Lorenz factor, application of kinematical diffraction, structure factor and basics of structure solving, phase problem in crystallography, anomalous diffraction and some examples, introduction to Rietveld refinement method.
- **Diffraction by Perfect Crystals:**
  Kinematical reflection from few layers, basics of dynamical theory, Darwin's theory of extinction depth, integrated intensity, standing waves, higher order reflection, effect of absorption, asymmetric Bragg geometry, DuMond diagrams, applications in synchrotron X-ray monochromators, X-ray topography.
- **X-ray Absorption:**
  X-ray absorption from isolated atoms, extended X-ray absorption fine structure (EXAFS), near edge X-ray absorption (XANES), EXAFS equation, basics of EXAFS data acquisition and sample preparation, transmission versus fluorescence modes of EXAFS.
- **X-ray Fluorescence:**
  Theoretical details and data analysis, details of the experimental technique, sample preparation, trace element quantification and related issues.
- **Photo Emission Spectroscopy and X-ray Magnetic Circular Dichroism:**
  Basics of photoemission and inverse photoemission, experimental setup, photoelectron and Auger electrons, core level binding energies, chemical shifts, line shapes and background, valence band structure determination, resonant photoemission, angle resolved photoemission and band structure determination, spin polarized photoemission, basics of XMCD.

Course Outcomes:

- Students will be able to understand the generation and interaction of X-rays with matter, and apply X-ray diffraction, absorption, fluorescence, and photoemission techniques for material characterization, structural analysis, and element-specific studies.

References:

1. Elements of Modern Optics, *Jens Als-Nielsen & Des McMorrow*
2. Dynamical Theory of X-ray Diffraction, *Andre Authier*
3. Soft X-Rays and Extreme Ultraviolet Radiation, *David Attwood*

03PHYS04-013-C Research Methodology & Research Publication Ethics

(30 Lectures Hrs)

Coordinators: Dr. V. B. Tiwari
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Course Details:

- **Module A: Research design and methods (10 lectures)**

  - **1. Objectives and types of research:**
    Motivation and objectives. Research methods vs Methodology. Types of research – Descriptive vs Analytical; Applied vs Fundamental; Quantitative vs Qualitative; Conceptual vs Empirical.

  - **2. Research Formulation:**
    Defining and formulating the research problem – selecting the problem – necessity of defining the problem – importance of literature review in defining a problem – literature review – primary and secondary sources – reviews, treatise, monographs-patents – web as a source – searching the web – critical literature review – identifying gap areas from literature review – development of working hypothesis.

  - **3. Research design:**
    Basic principles – need of research design – features of good design – important concepts relating to research design – observation and facts, laws and theories, prediction and explanation, induction, deduction, development of models. Developing a research plan – exploration, description, diagnosis. Experimentation: proper approach – importance of recording observation, maintaining the records, sample history, transparency in data recording. Determining experimental and sample designs.

  - **4. Writing thesis and research papers:**
    Structure and components of scientific reports – types of report – technical reports and thesis – significance – different steps in the preparation – layout, structure and language of typical reports – illustrations and tables – bibliography, referencing and footnotes – oral presentation – planning – preparation – practice – making presentation – use of visual aids – importance of effective communication. Manuscript drafting based on 'Experimental data and Literature Survey'. Where to publish?, impact factor of journals, citation databases, metrics.

  - **5. Statistical treatment of data and errors:**
    Value of statistics; errors and statistics – limitation of analytical methods; accuracy; precision; classification of errors; minimisation of errors; significant figures and computations; standard deviation; normal distribution; comparison of results – student's t-test; F-test; Chi-square test; propagation of errors.

- **Module B: Research ethics and Publication ethics (10 lectures)**

  - **1. Research ethics:**
    Philosophy and ethics, Ethics with respect to Science and research, Intellectual honesty and research integrity, Scientific misconducts- fabrication, falsification and plagiarism, redundant publications- duplicate and overlapping publications, selective reporting and misrepresentation of data, Environmental impacts - Ethical issues - ethical committees - Commercialization.

  - **2. Publication ethics:**

Definition, introduction and importance, Best practices, standards setting initiatives and guidelines, Conflict of interest, Publication misconduct, Violation of publication ethics, authorship and contributorship, Identification of publication misconduct, complaints and appeals, predatory journals and publishers, Copyright - Royalty - Intellectual property rights and patent law – Trade Related aspects of Intellectual Property Rights - Reproduction of published material - Plagiarism - Citation and acknowledgement - Reproducibility and accountability.

- **Module C: Computational and experimental methods (10 lectures)**

  This module is CI/OCC specific and the syllabus can be specified by the CI/OCC. Typical topics covered as a part of this module could be:

  - **1. Computational methods:**
    Mathematical modeling, Numerical methods of analysis using Python.

  - **2. Experimental methods:**
    Principles of Instrumentation.

Course Outcomes:

- Students will be able to design and conduct scientific research with rigor, analyze and interpret experimental and computational data using statistical and computational tools, write and present scientific reports and publications effectively, and uphold professional, ethical, and publication standards in research.

Reference:

1. *M. Anthony, A. M. Graziano, and M. L. Raulin,* Research Methods: A Process of Inquiry, Allyn and Bacon (2009).
2. *R. A. Day,* How to Write and Publish a Scientific Paper, Cambridge University Press (1992).
3. Science and methods by Henry Poincare, translated in English by Francis Maitland Source: *www.archive.org/details/sciencemethod00poinuoft (1914).*
4. *B. L. Garg, R. Kardia, F. Agarwal, and U. K. Agarwal*, An Introduction to Research Methodology, RBA Publishers (2002).
5. *C. R. Kothari*, Research Methodology: Methods and Techniques, New Age International (2000).
6. *S. C. Sinha, and A. K. Dhiman*, Research Methodology, Ess Publications (2 volumes) (2002).
7. *R. Paneer Selvam*, Research Methodology, Prentice Hall India Learning Private Limited; Second edition (2013).