Ph.D courses in Physical Sciences

For Ph.D (Sciences) a minimum of 20 Credits through course work have to be completed from the following courses (being offered at particular laboratories), out of which a few are mandatory. The courses have to be selected on the recommendations of the doctoral advisory committee (DAC) of the Ph.D. student.

Mandatory Courses:

Course Code	Course Name	Credits
1. 1-001	Research Methodology	2
2. 4-001	CSIR-800 Societal Programme	4
3. 4-002	Project Proposal writing (I & II)	4

4-001

Six of eight weeks have to be dedicated on a project concerned with societal/rural issues under the CSIR-800 Programs (4 Credits). This course will need to be completed during the residency period after the PhD comprehensive examination and before submission of their PhD thesis

4-002

Two subject proposals to be prepared before comprehensive by selecting topics of high relevance and novelty and will have state-of-the-art review, methodologies, recommendations, etc. (2 Credits each).

Depending on the academic background of the candidate, proposed area of research, category of PhD programme, and recommendation of the doctoral advisory committee, each PhD candidate will need to complete an appropriate mix of 1-xxx (2-4 credits), 2-xxx (6-8 credits), and 3-xxx (2-4 credits) level courses that meet or exceeds the minimum number of credits requirements.

1. CSIR-CEERI (Central Electronics Engineering Research Institute, Pilani)

C. No.	Course Name	L-T-P-C
PHY(CEERI) :1-001	Research Methodology	1-1-0-2
PHY(CEERI) : 1-136	Technical Communication	2-0-0-2
PHY(CEERI) :2-136	Project Management	2-0-0-2
PHY(CEERI) :2-141	Physics of Semiconductor Materials and Devices	4-0-0-4
PHY(CEERI) :2-142	Unit Processes in Semiconductor Technologies	3-0-0-3
PHY(CEERI) :2-143	CMOS Digital VLSI Design	3-0-0-3
PHY(CEERI) :2-144	Characterization Techniques for Semiconductor Materials, Technologies and Devices	3-0-0-3
PHY(CEERI) :2-145	Semiconductor Processing Technologies Laboratory	0-0-4-2
PHY(CEERI) :2-146	CMOS-based Physical Design Laboratory	0-0-4-2
PHY(CEERI) :2-147	Semiconductors Related Characterization and Measurement Techniques Laboratory	0-0-4-2
PHY(CEERI) :2-148	HDL-based Digital Design Laboratory	0-0-4-2
PHY(CEERI) :2-151	Electromagnetic Theory and Transmission Lines	4-0-0-4
PHY(CEERI) :2-152	Microwave Communication	2-0-0-2
PHY(CEERI) :2-153	Numerical Techniques and CAD of Microwave Tubes	4-0-0-4
PHY(CEERI) :2-154	Microwave and Millimeter-wave Tube Technologies	3-0-0-3
PHY(CEERI) :2-155	Microwave Components Characterization and Tube Processing Techniques Laboratory	0-0-6-3
PHY(CEERI) :2-156	Microwave Devices Characterization and Tube Sub-assembly Fabrication Laboratory	0-0-6-3
PHY(CEERI) :3-136	Advanced Self-Study (Special Topic)	0-2-4-4
PHY(CEERI) : 3-141	MEMS Technology, LTCC and Packaging	3-0-0-3
PHY(CEERI) :3-142	Physics and Design of MEMS and Microsensors	3-0-0-3
PHY(CEERI) :3-143	Nanoelectronic Devices and Technologies	3-0-0-3
PHY(CEERI) :3-144	Advanced VLSI Technologies and Devices	3-0-0-3

C. No.	Course Name	L-T-P-C
PHY(CEERI):3-145	CMOS Analog Design	3-0-0-3
PHY(CEERI):3-146	Advanced VLSI System Architectures	3-0-0-3
PHY(CEERI):3-147	Optoelectronic Materials, Devices and Technologies	3-0-0-3
PHY(CEERI):3-148	Photonic Materials, Devices and Technologies	3-0-0-3
PHY(CEERI):3-151	MEMS Technology, LTCC and Packaging Laboratory	0-0-4-2
PHY(CEERI):3-152	Design of MEMS and Microsensors Laboratory	0-0-4-2
PHY(CEERI):3-153	Nanoelectronic Technologies Laboratory	0-0-4-2
PHY(CEERI):3-154	Study and Seminar on Advanced VLSI Technologies	0-0-4-2
PHY(CEERI):3-155	CMOS Analog Design Laboratory	0-0-4-2
PHY(CEERI):3-157	Optoelectronic Devices and Technologies Laboratory	0-0-4-2
PHY(CEERI):3-158	Photonic Devices and Technologies Laboratory	0-0-4-2
PHY(CEERI):3-161	Slow-wave Devices : Principles and Design	4-0-0-4
PHY(CEERI):3-162	Fast-wave Devices : Principles and Design	3-0-0-3
PHY(CEERI):2-163	CAD of Microwave Tubes Laboratory	0-0-4-2
PHY(CEERI):3-164	High Power Microwave Devices, Systems and Applications	3-0-0-3
PHY(CEERI):3-165	Electron Emitters and Surface Characterization	2-0-0-2
PHY(CEERI) : 3-166	Plasma-filled Microwave Sources	2-0-0-2
PHY(CEERI):3-167	Vacuum Microelectronic Devices	2-0-0-2
PHY(CEERI) : 4-001	CSIR-800 Societal Programme	0-0-8-4
PHY(CEERI):4-002	Project Proposal Writing	0-1-6-4

Brief Description of Physical Science Courses at CSIR-CEERI (Course Level-Wise)

PHY(CEERI) : 1-001 : Research Methodology : 1-1-0-2
Course Coordinator : Raj Singh

Introduction, terminology, and scientific methods; Types of research; Research process and steps; Identifying a research problem; Literature survey, appreciation of existing literature, identification of knowledge gaps; Conception of novel approach to solve the problem; Role of theory, modeling, and simulation; Design of experiments, testing and characterization strategies; Quantitative methods and data analysis; Qualitative analysis; Communicating research results; Thesis writing and oral presentation; Ethics in research.

PHY(CEERI) : 1-136 : Technical Communication : 2-0-0-2
Course Coordinator : Raj Singh

Role and importance of technical communication; Effective written and oral communication; Ethical issues; Technical report writing; Technical / R&D proposals; Research paper writing; Letter writing and official correspondence; Emails; Oral communication in meetings and group discussions; Oral presentations; Use of modern aids.

PHY(CEERI) : 2-136 : Project Management : 2-0-0-2
Course Coordinator : Raj Singh

Introduction; Project formulation, evaluation and initiation; Project planning and scheduling; Risk management; Project execution and implementation; Project monitoring and control; Project closure; Project documentation; Leadership and teamwork issues; Complex projects; Advances and trends.

PHY(CEERI) : 2-141 : Physics of Semiconductor Materials and Devices : 4-0-0-4
Course Coordinators : J. Akhtar and S. C. Bose

Semiconductors; Inorganic and organic, single crystalline, polycrystalline, porous, amorphous crystal structures, and material properties; Si, GaAs, GaN, SiC; Energy band diagrams; Dielectric constant, permeability, permittivity, sheet resistance, resistivity, mobility, thermal conductivity and heat dissipation; Piezo-resistive and piezo-electric effects; Defects, dislocations and micro-plasma, phonon dynamics, ion-solid interactions; Electron transport in semiconductors, minority carrier life time, avalanche breakdown phenomena, Hall effect; Theory of p-n junction, Schottky barrier, MOSFETs and MESFETs, IMPATTs and BARRITTs; Hetro-structures, strained semiconductors; Photovoltaics and solar cell; Solid state sensors and transducers; MOS analysis.

PHY(CEERI) : 2-142 : Unit Processes in Semiconductor Technologies : 3-0-0-3
Course Coordinator : G. Eranna

Crystal growth techniques, wafer preparation and shaping, chemical cleaning, thermal oxidation, photo-lithography, chemical etching (wet and dry), chemical vapor deposition techniques, thermal diffusion, ion implantation, metalization, chemical mechanical polishing, rapid thermal processing.

PHY(CEERI) : 2-143 : CMOS Digital VLSI Design : 3-0-0-3
Course Coordinator : A. Karmakar

Introduction to MOSFET from designer's viewpoint; MOS inverter : static and switching characteristics; MOS capacitor; Layers in VLSI design; Design rules and technology interface; Stick diagrams and Layout design; Propagation delay, Fan-out consideration; CMOS Latch-up; Scaling; Combinational MOS logic circuits : pass-transistors/transmission gates, primitive logic gates, complex logic gates; Sequential MOS logic circuits : latches and flip-flops; Dynamic logic circuits; Clocking issues; CMOS subsystem design.

PHY(CEERI) : 2-144 : Characterization Techniques for Semiconductor Materials, Technology and Devices : 3-0-0-3
Course Coordinator : K. J. Rangra and G. Eranna

Resistivity, Contact resistance, barrier height, carrier and doping concentration, mobility and carrier life time measurement techniques; Test structures for technology characterization; Analysis of surfaces, interfaces, thin films and devices; E-beam based techniques, Scanning Electron Microscopy and allied techniques; Material analysis techniques; Scanning probe Techniques; Ion-beam based techniques; Interferometry based techniques for materials and device characterization; Optical characterization.

PHY(CEERI) : 2-145 : Semiconductor Technologies Laboratory : 0-0-4-2
Course Coordinator : G. Eranna

Laboratory practices and safety considerations; Wafer preparation and shaping; Chemical cleaning; Thermal oxidation, photo-lithography; Wet chemical etching; Dry etching; Chemical vapor deposition; Thermal diffusion; Ion implantation; Metalization.

PHY(CEERI) : 2-146 : CMOS-based Physical Design Laboratory : 0-0-4-2
Course Coordinator : A. Karmakar

Laboratory practices and safety considerations; SPICE simulation; Schematic editor, Layout editor, DRC, LVS; Transfer and output characteristics NMOS transistor, parameter variations; CMOS inverter design, inverter threshold, noise margin, propagation delay; Layout of CMOS inverter, n-well design rules, LVS, static and transient characteristics, DRC; 2-input NAND/NOR gate; D latch and flip-flop; Post-extract simulation.

PHY(CEERI) : 2-147 : Semiconductors Related Characterization and Measurement Techniques Laboratory : 0-0-4-2
Course Coordinator : K. J. Rangra and G. Eranna

Laboratory practices and safety considerations; IV and CV Measurements; Resistivity, thickness, thin-film surface and bulk defects; grain size measurement; AFM/STM surface analysis; Stress and deformation measurements; Measurement of sheet resistance, junction depth, carrier mobility, doping profile estimation, minority carrier life-time measurement; Model parameter extraction experiments.

PHY(CEERI) : 2-148 : HDL-based Digital Design Laboratory : 0-0-4-2
Course Coordinator : A. S. Mandal

Laboratory practices and safety considerations; Introduction to HDLs; Simulation of behavioral, Architecture/RTL, data-flow and structural HDL code; Sub-system design using HDL : various adder architectures, BCD arithmetic, various counters, traffic-light controller, *etc.*; Mini-project. *(SystemC, VHDL and/or SystemVerilog will be used as the HDL for the laboratory.)*

PHY(CEERI) : 2-151 : Electromagnetic Theory and Transmission Lines : 4-0-0-4
Course Coordinator : A. K. Sinha

Maxwell's equations; Wave equations and their solutions; Boundary Conditions and their applications; Electromagnetic energy and power flow; Poynting theorem. Transmission lines; Wave-guide and coaxial components. Scattering matrix representation; Propagation of electromagnetic waves through homogeneous, in-homogeneous, and anisotropic media. Surface resistance and RF resistance. Ferrite devices. Waveguides and resonators. Characteristic and interaction impedances. Quality factors (loss and diffractive). Impedance Matching. Measurement of "Q", power, noise figure, S-parameters, dielectric constant and loss tangent, dispersion and impedance characteristics, and loss parameters.

PHY(CEERI) : 2-152 : Microwave Communication : 2-0-0-2
Course Coordinator : V. V. P. Singh

Ground/surface wave, space-wave, and sky-wave modes of communication; Tropo-sphereic Communication; Line of sight communication and system performance; Active and passive repeaters and their design; Analog and digital communication; Mobile communication; Satellite communication system; Earth station design criteria and direct reception system; Satellite transponders and their design criteria; PhPHY(CEERI)-noise, intra-pulse and inter-pulse noises and their significance.

PHY(CEERI) : 2-153 : Numerical Techniques and CAD of Microwave Tubes : 4-0-0-4
Course Coordinator : V. Srivastava

Numerical solution of linear and non-linear differential equations of higher orders; Analytical and numerical techniques to the solution of electromagnetic field problems; Numerical techniques for the electrical, thermal, and structural design of slow-wave and fast-wave microwave tubes; Spent beam analysis for efficiency enhancement; Special focusing techniques for multi-beam electron guns; PIC simulation techniques; Finite difference and finite element techniques; Method of moments applied to microwave devices.

PHY(CEERI): 2-154: Microwave and Millimeter-Wave Tube Technology : 3-0-0-3
Course Coordinator : R. S. Raju

Fundamentals of vacuum technology. Vacuum generation and measurement, and leak detection. Ultra-high vacuum techniques. Surface physics and analysis in relation to electron Emitters. Electron-tube grade materials and their characteristics. Chemical processing. Heat treatment and special techniques: brazing, sintering, sputtering, TIG/electron beam/laser welding, glass-to-metal and ceramic-to-metal sealing, loss coating, and helix fitting. Vacuum processing of integrated devices. Design of tools, jigs, and fixtures. Engineering / mechanical design of components. Special machining techniques.

PHY(CEERI): 2-155: Microwave Components Characterization and Tube Processing Techniques Laboratory: 0-0-6-3
Course Coordinator: O. S. Lamba

Laboratory practices and safety considerations; Scattering parameters; Measurement of impedance and characterization of cavities; Dispersion and impedance characterization of RF structures; RF loss measurements; UHV techniques; Heat treatment in protective atmosphere; Ceramic-to-metal sealing techniques; Chemical processing of components.

PHY(CEERI) : 2-156 : Microwave Devices Characterization and Tube Sub-assembly Fabrication Laboratory : 0-0-6-3
Course Coordinator: L. M. Joshi

Laboratory practices and safety considerations; Device characterization using spectrum analyzer, scalar/vector analyzer; Break-down tests; X-ray radiography; Cathode characterization using Auger and Thermal emission microscope; Hot RF characterization of devices; Metal-to-metal brazing techniques; Leak detection; TIG/laser welding; Vacuum processing of devices; Cathode fabrication.

PHY(CEERI) : 3-136 : Advanced Self-study (Special Topic) : 0-2-4-4
Course Coordinator: Senior Scientists

This will involve readings from published literature or books about new frontiers on a specific topic related to the field of electronics under guidance of senior scientist(s). A report needs to be submitted and a seminar on the special topic needs to be presented.

PHY(CEERI) : 3-141 : MEMS Technology, LTCC and Packaging : 3-0-0-3
Course Coordinator: B. D. Pant and P. K. Khanna

Review of Silicon crystal and unit processes; Processing steps for MEMS device fabrication; photo-lithography and backside mask alignment; Surface and bulk micro-machining techniques; Deep reactive ion etching; LIGA process; Wafer-level bonding and packaging techniques; LTCC technology, materials, LTCC process steps, bonding and packaging; Testing and characterization of technology; Reliability and residual stress issues.

PHY(CEERI) : 3-142 : Physics and Design of MEMS and Microsensors : 3-0-0-3
Course Coordinator : Ram Gopal and K. J. Rangra

Overview of Microsensors; Mechanical properties of materials and essentials of structural mechanics; Electro-mechanical, magneto-mechanical and piezo-based sensing; Structural elements for MEMS and microsensors (Beams, plates, cantilevers, bridges and diaphragms); Electrostatic sensing and actuation (parallel plate and torsional structures, time domain analysis); Micro-fluidics; Scaling laws and miniaturization; Micro-system design principles; MEMS simulation and design Tools; RF MEMS; Reliability issues in microsensors; Examples and applications of MEMS microsensors.

PHY(CEERI) : 3-143 : Nanoelectronic Devices and Technologies : 3-0-0-3
Course Coordinator : Anil Kumar

Low-dimensional structures (Quantum well, quantum wire, quantum dot, quantum confinement); Confinement energy level, band-gap enhancement, absorption-emission spectra, blue shift, luminescence; Nanoelectronic Devices (Single electron box, Coulomb blockade, single electron transistor, pump, turnstile, trap, memory); Simulation, Modeling of single electron devices and applications; Technology for fabrication of nanostructures and nanoelectronic devices; Next generation lithography techniques; Characterization of nanoscale materials and nanodevices.

PHY(CEERI) : 3-144 : Advanced VLSI Technologies and Devices : 3-0-0-3
Course Coordinator : G. Eranna and W. R. Taube

Overview of VLSI technology; Effect of scaling on MOS devices and interconnections; Hot electron degradations and drain engineering structures; Process and material requirements for VLSI devices; Advanced thin-film deposition and VLSI process techniques; High-k dielectric and low-k dielectric materials; Process integration of high-k metal gate for nanoscale CMOS technology; Device characterization, failure diagnosis and reliability measurements; Carrier transport mechanisms, velocity saturation, ballistic transport; Nanoscale MOSFET, FinFET and Multi-gate FET; Emerging materials and future devices.

PHY(CEERI) : 3-145 : CMOS Analog Design : 3-0-0-3
Course Coordinator : S. C. Bose

Basic concepts of transistors and diodes, their modeling, large-signal and small signal analysis, CMOS technology, clock feed-through; Reference sources : bias circuits, band-gap reference circuit, cascode current mirror; Single-stage amplifier, common source amplifier, drain and gate amplifier, differential amplifier; Operational amplifier; Comparators; Switched-capacitor circuits; Introduction to data converters; Issues of analog layout and device noise.

PHY(CEERI) : 3-146 : Advanced VLSI System Architectures : 3-0-0-3
Course Coordinator : A. S. Mandal

Introduction and review of basic computer architectures, CISC and RISC processors; Pipelining, hazards, exception handling, optimization techniques, synchronous and asynchronous pipelining; Memory organization, caches, virtual memory, memory management; Arithmetic circuits, algorithms and architectures for high-radix adders, multipliers, sine-cosine and exponential computation; Instruction-level parallelism, super-scalar, super-pipelined and VLIW architectures, array and vector processors; Multiprocessor architectures and parallel architectures, synchronization, memory consistency; DSP architectures; Performance improvement techniques; ASIP; Low-power architectures; Fault-tolerant architectures; Case-study on Algorithm-to-Architecture; Future trends.

PHY(CEERI) : 3-147: Optoelectronic Materials, Devices and Technologies : 3-0-0-3
Course Coordinator : C. Dhanvantri

Optoelectronic Materials; Growth of Epitaxial materials; Characterization of Epitaxial Materials; Optoelectronic Devices (Light Emitting Diodes, Semiconductor Lasers, UV, Visible and IR Photo-detectors and Receivers, Solar Cells); Compound semiconductors and advanced electronic devices; Compound Semiconductor Technologies; Packaging of compound semiconductor components; Applications and trends.

PHY(CEERI) : 3-148 : Photonic Materials, Devices and Technologies : 3-0-0-3
Course Coordinator : S. Pal

Introduction to Photonics; Basic photonic components and their technologies; Propagation of Electromagnetic waves; Optical waveguides and optical fibers; Principle of optical fiber communications, Transmission capacity, Dispersion and losses in optical fiber; Coupled mode theory in guided wave systems; Materials and fabrication technologies; Types of waveguides; Basic photonics devices and components; Optical sensors and sensing techniques; Optical MEMS; Fiber gratings and waveguide gratings; Photonic crystal based waveguides and devices; Packaging of photonic devices; Applications of photonic devices; Recent trends.

PHY(CEERI) : 3-151 : MEMS Technology, LTCC and Packaging Laboratory : 0-0-4-2
Course Coordinator : B. D. Pant and P. K. Khanna

Laboratory practices and safety considerations;; Wafer cleaning; Lithography : front and backside alignment; Bulk micro-machining; DRIE process; LPCVD; Metalization; Wafer bonding; Surface planarization; Wafer dicing; LTCC process; Packaging.

PHY(CEERI) : 3-152 : Design of MEMS and Microsensors Laboratory : 0-0-4-2
Course Coordinator : Ram Gopal and K. J. Rangra

Laboratory practices and safety considerations; MEMS design tools; Design of pressure sensors of various types; Design of gas sensors of various types; Acoustic, Ultrasonic, micro-resonator, ISFET; RF MEMS design and simulation.

PHY(CEERI) : 3-153 : Nanoelectronic Technologies Laboratory : 0-0-4-2
Course Coordinator : Anil Kumar

Laboratory practices and safety considerations; Fabrication of metal thin films by sputtering/e-beam/resistive-heating and measurement of film thickness by making steps using wet etching; Experiments on growth of Silicon nanoparticles and their optical characterization; Experiments with nanolithography and nanopatterning; Simulation of single electron devices using SIMON; Simulation of inverter circuit using SET in SIMON; Operation of AFM/STM; Analysis of AFM/STM images; Study of annealing effect on roughness/grain size of metal films by AFM/STM imaging and analysis.

PHY(CEERI) : 3-154 : Study and Seminar on Advanced VLSI Technologies : 0-0-4-2
Course Coordinator : G. Eranna and W. R. Taube

This will involve literature search, review and study of current research on materials, process methodologies and simulations, and novel applications related to advanced VLSI technologies and nanoelectronics. Simulation studies and experiments may also be carried out, where possible. A study report is to be submitted and a seminar is to be given.

PHY(CEERI) : 3-155 : CMOS Analog Design Laboratory : 0-0-4-2
Course Coordinator : S. C. Bose

Laboratory practices and safety considerations; I-V characteristics of MOSFET, estimation of early voltage; Clock feed-through and its minimization; Bias generation architecture simulation; Band-gap reference circuit simulation; Design and simulation of various amplifiers; Design and simulation of 2-stage CMOS operational amplifier; Layout of analog circuits.

PHY(CEERI):3-157 : Optoelectronic Devices and Technologies Laboratory : 0-0-4-2
Course Coordinator : C. Dhanvantri

Laboratory practices and safety considerations; Lift-off process for Ohmic Contact on GaAs substrate; TLM measurements for specific contact resistance; RIE process for GaAs etching; LI Characteristics of 980 nm Laser Diode; Transistor characteristics of GaAs Power MESFET; LED Characteristics; Photoluminescence characterization of GaN epitaxial material; Characterization of PIN-FET receiver module.

PHY(CEERI) : 3-158 : Photonic Devices and Technologies Laboratory : 0-0-4-2
Course Coordinator : S. Pal

Laboratory practices and safety considerations; Measurement of refractive index and thickness of planar waveguides; Propagation loss measurement of planar waveguides; Design of 1x2 and 1x4 optical power splitter; Measurement of insertion loss, uniformity and polarization-dependent loss of a packaged 1x8 optical splitter at C+L band region; Design and simulation of Bragg gratings; Waveguide patterning by photo-lithography; Testing of MUX/DEMUX by DWDM test set-up; Chip-level testing: alignment of DUT (in a diced chip) to the source and the detector with x-y-z alignment stages.

PHY(CEERI) : 3-161 : Slow-wave Devices – Principles and Design : 4-0-0-4
Course Coordinator : V. Srivastava and L. M. Joshi

Classification and high frequency limitations of conventional electron tubes. Formation and confinement of an electron beam. Slow-wave structures, couplers and RF windows. Beam-wave interaction mechanism. Spent beam collection. Efficiency enhancement by phase-velocity tapering and multi-stage depressed collection. Different types of devices, their operation, and characteristics, High power and wide bandwidth issues. Future trends.

PHY(CEERI) : 3-162 : Fast-wave Devices – Principles and Design : 3-0-0-3
Course Coordinator : A. K. Sinha

Merits of fast-wave devices over slow-wave devices. Operating principle of a gyrotron and design of its components: magnetron injection gun, beam tunnel, RF interaction cavity, magnetic field, non-linear taper, RF window, mode converter and collector. Beam-wave interaction and mode selection criteria. Other fast-wave devices: gyro-TWT, gyro-klystron, peniotron and FEL. Applications of gyro-devices and future trends. High Power Microwave (HPM) Devices.

PHY(CEERI) : 3-163 : CAD of Microwave Tubes Laboratory : 0-0-4-2
Course Coordinator : R. K. Sharma and S. K. Ghosh

Laboratory practices and safety considerations; Components design : electron guns, slow-wave structures, fast-wave structures, RF cavities, RF windows, collectors; Electron beam and RF wave interaction simulation; Thermal and structural design and simulation; CAD of complete tube; Computer aided engineering drawing.

PHY(CEERI) : 3-164 : High Power Microwave Systems and Applications : 3-0-0-3
Course Coordinator : L. M. Joshi

Special EW (Radar, ECM, ECCM) systems and their requirements in respect of microwave and millimeter wave devices; Types of jamming; Linear accelerators, Microtrons, Synchrotrons, Plasma heating systems, Proton accelerators, and Thermonuclear reactors; Other applications like imaging, spectroscopy, biomedical, industrial heating, electronic power conditioners, and modulators.

PHY(CEERI) : 3-165 : Electron Emitters and Surface Characterization : 2-0-0-2
Course Coordinator : R. S. Raju

Physics of electron emission, emission equation; Temperature limited and space-charge limited emission; Methods of determining work function; Oxide coated cathodes, Dispenser cathodes, Field emitters, Explosive emission cathodes, Secondary emitters; Fabrication and characterization of cathodes; Life testing and surface analysis techniques; Nano-cathodes.

PHY(CEERI) : 3-166 : Plasma-Filled Microwave Sources : 2-0-0-2
Course Coordinator : Ram Prakash and U. N. Pal

Plasma and its physical parameters; Saha equation and its relevance; Motion of charged particles in static and slowly varying electric and magnetic fields; Motion of relativistic charged particles; Types of gaseous discharge; Hollow-cathode discharge and other kinds of low-pressure discharges; General features of electrons emission, control and extraction of electrons and ions from plasma in DC and pulsed mode conditions; Plasma sources for axially symmetric electron beams; Plasma cathode electron gun (PCE-gun); Advantages of plasma filling in high power microwave devices; Operating principles, characteristics, and applications of different types of plasma-filled devices including the pasotron.

PHY(CEERI) : 3-167 : Vacuum Microelectronic Devices : 2-0-0-2
Course Coordinator : R. K. Sharma

Basic semiconductor technologies like reactive ion etching, photo-lithography, oxidation, CVD, sputtering, LIGA; MEMS technologies; Design considerations in vacuum microelectronic devices; Photonic band-gap structures, folded wave guide and ladder structures; Tera Hertz devices including reflex klystrons; Micro-fabricated devices like TWT and klystrino; Combination of vacuum and semiconductor technologies in microwave devices, including microwave power module and their applications.

PHY(CEERI) : 4-001 : CSIR-800 Societal Programme : 0-0-8-4
Course Coordinator : Raj Singh

A project needs to be undertaken in rural area for 6-8 weeks duration aligned to the CSIR-800 programme. The theme of the project may be chosen from the CSIR-800 document or from any other government department related to benefiting and empowering the economically lower 800 million Indians by way of S&T innovations. The aim is to interact with underprivileged people in the villages and propose solutions in the area of health, agriculture, energy, water, food, education, *etc.*

PHY(CEERI) : 4-002 : Project Proposal Writing : 0-1-6-4
Course Coordinator : Raj Singh

Definition of a scientific project proposal; Components of a proposal; Need and purpose of the proposal; Aims and objectives; Background and present status; Proposed methodologies and approaches; Scheduling and mile-stones; Resource allocation; Budgeting; Monitoring and evaluation mechanisms; Referencing and citing; Use of data, graphs, tables, figures; Proposal funding agencies and their formats.

Every student needs to submit two proposals --- one related to PhD research topic and the second in any field of electronics.

2. CSIR-CMMACS (Centre for Mathematical Modelling and Computer Simulation, Bengaluru)

S. No.	Course No.	Course Title	L-T-P-C
1	PHY/MIS(CMMACS) 1-001	Research Methodology	1-1-0-2
2	PHY(CMMACS) 2-241	Statistical and Computational Methods	2-1-0-3
3	PHY(CMMACS) 2-242	Global Navigation Satellite System (GNSS) theory and its applications	2-1-0-3
4	PHY(CMMACS) 2-243	Applied Seismology and Geohazard	2-1-0-3
5	PHY(CMMACS) 2-244	Advanced mathematical methods in weather and climate predictions	1-2-0-3
6	PHY(CMMACS) 2-245	Numerical Analysis and Fortran Programming	3-0-0-3
7	PHY(CMMACS) 2-246	Earthquake and Volcano Deformation	2-1-0-3
8	PHY/MIS(CMMACS)3-247	Advanced Self Study	0-2-4-4
9	PHY/MIS(CMMACS)-4-001	CSIR-800 Societal Programme	0-0-8-4
10	PHY/MIS(CMMACS)-4-002	Project proposal writing	0-1-6-4

Brief Description of Physical Science Courses at CSIR-CMMACS (Course Level-Wise)

PHY/MIS(CMMACS)- 1-001: Research Methodology : 1-1-0-2
Course Coordinator: P Goswami

Introduction, Research terminology and scientific methods, different types and styles of research, role of serendipity, creativity and innovation, Scientific and critical reasoning skills, art of reading and understanding scientific papers, literature survey. Measurements in research - primary and secondary data. Quantitative methods and data analysis, Qualitative analysis, Communicating research results. Designing and implementing a research project. Ethics in research, Plagiarism, Case studies. Laboratory safety issues – lab, workshop, electrical, health & fire safety, safe disposal of hazardous materials.

Role & importance of communication, Effective oral and written communication. Technical report writing, Technical/R&D proposals, Research paper writing, Dissertation/Thesis writing, Letter writing and official correspondence. Oral communication in meetings, seminars, group discussions; Use of modern aids; Making technical presentations.

PHY(CMMACS) : 2-241 : Statistical and Computational Methods: 2-1-0-3
Course Coordinator: N K Indira

Basic Concepts: Discrete and continuous data, Sample and Population, Events and Probability, Frequency, Table and Frequency distribution, Random variable and expectations, Measures of central tendency, dispersion and coefficient of variation, Moments and moment generating functions.
Regression and Correlation: Linear regression analysis, Nonlinear regression analysis, Multiple regression Correlations.
Probability and probability distributions: Discrete probability distributions and Continuous Probability distributions.
Classical Time series analysis: Measurement of trend, Measurement of seasonal fluctuations, Measurement of cyclic fluctuations.
Stochastic time series analysis: System definition, System analysis, Model formulation, Modelling procedure, Estimation and validation.
Correlation systems: Principal component analysis, Factor analysis. Analysis of variance. One way classification and Two way classification. Statistical analysis and hypothesis testing. Sampling and sampling distributions, Parametric estimation, Tests of hypothesis, Nonparametric method.

PHY(CMMACS) :2-242 : Global Navigation Satellite System (GNSS) theory and it applications to Geosciences: 2-1-0-3
Course Coordinator Sridevi Jade

Introduction to GNSS geodesy, GNSS theory, GNSS reference frames, sources of errors and correction, positioning using GNSS observables, GNSS data collection, data processing and analysis, GNSS applications for Geoscience, Modelling of GNSS derived surface deformation.

Introduction to GNSS geodesy covers the state of art on Global Navigation Satellite systems, its components, geodesy, Military and Civil applications. GNSS reference frames: Introduction to celestial and terrestrial reference frames, Earth Centered Earth fixed reference frame and earths pole of rotation. Sources of errors and corrections: Introduction of positioning using GNSS satellites, errors involved covering orbit, clock errors, troposphere and ionosphere errors, miscellaneous errors. Positioning using GNSS observables: To determine the precise position and time, error correction, different types of positioning. GNSS data and processing theory: Models involved in data processing and analysis. GNSS applications to Geoscience: Surveying, continental deformation studies, landslide hazard mapping, Glacier dynamics, Volcano deformation, troposphere and ionosphere modeling, InSAR (Interferometric Synthetic Aperture Radar), GIS (Geographical Information System) etc. Modelling of GNSS deformation: brief introduction of different kind of modeling techniques that are currently being used.

PHY(CMMACS): 2-243: Applied Seismology and Geo Hazard: 2-1-0-3
Course Coordinators: Imtiyaz A Parvez

Basic concept of seismology, seismicity, wave propagation and seismic hazard using ground motion modeling and microtremors.

Overview of Seismology and Seismotectonics: Earth and its Interiors, Plate Tectonics, Causes of Earthquakes, Seismic Waves, Earthquake Magnitudes, Earthquake Intensities, Seismicity patterns and tectonic settings, Overview of seismogenic source zones in India

Basic concepts of Earthquake sources and wave propagation: Introduction to the Fourier Transform and its use in seismology, Double-couple force systems, Omega-square and Haskell source models Directivity, Wave propagation and waveform modeling, Source parameters to determine from teleseismic modeling, Source time function and fault slip, Wave propagation at regional distances, Empirical study of regional wave propagation

Earthquake Recurrence Statistics: Earthquake magnitude and magnitude scales, Seismometry, Gutenberg Richter relation Maximum magnitude, Characteristic earthquake models, Maximum earthquake magnitudes, Relationship of seismological parameters to field geology parameters, Poisson vs. other models of earthquake recurrence

Seismic Hazard Analysis: Concept of Earthquake hazard analysis, Ground motion modelling for hazard analyses Role of Attenuation law, Probabilistic and Deterministic seismic hazard analysis, Uncertainties in hazard evaluation, Role of random scatter, Role of modeling uncertainty Hazard deaggregation, site effects and ground motion modeling.

PHY(CMMACS): 2-244 : Advanced mathematical methods in weather and climate predictions: 1-2-0-3
Course Coordinator : K Rameshan

To introduce advanced mathematical methods used in weather and climate prediction. Introduction to weather and climate predictions, Statistics and Probability, Review Statistical Mechanics, Review Complexity and information theory, Basics. Liouville equation; Fokker-Plank Equation; Singular vectors; Stochastic Optimals. Chaos and deterministic Predictability; Ensemble forecasts; Nonlinear forecasts.

PHY(CMMACS): 2-245: Numerical Analysis and Fortran Programming: 3-0-0-3
Course Coordinator : P S Swathi

This is a programming-intensive course which will make the students write Fortran codes for numerical analysis topics. There is no separate lab component. Programming assignments will be integral to the course and not considered as lab assignments.
The topics covered will include: Basics of computer floating point arithmetic, Fortran programming and debugging, Taylor series, solution of algebraic equation, linear systems – direct and iterative methods, eigen value problems, least squares and singular value decomposition, interpolation and extrapolation, numerical differentiation and integration, numerical solution of ordinary differential equations

PHY(CMMACS): 2-246: Earthquake and Volcano Deformation: 2-1-0-3
Course Coordinator: **Anil Earnest**

Theoretical concepts of earthquake faulting, stress in crust, mechanics of earthquakes, rupture propagation, earthquake clustering and migration, coulomb stress loading, the crustal deformation cycle, models of strain accumulation, earthquake cycle and recurrence times, observational techniques for strain and recurrence quantification, qualitative and quantitative seismo-tectonic analysis, mechanisms of various tectonic regime earthquakes, slow and tsunamigenic earthquakes, aseismic slip, seismic coupling, episodic tremor and slip, induced seismicity, mechanisms, volcanism - basics, structure and evolution of spherical magma chamber.

PHY/MIS(CMMACS)- 3-247: Advanced Self Study:0-2-4-4
Course Coordinator: PhD Guide

Aims to train the student on learning, on one's own, topics that are not formally taught in a course. This would involve primarily three components - collection of relevant literature on a chosen topic, organization of relevant material into a written report based on candidate's own critical understanding and finally presentation of the findings in front of wide audience in the form of a seminar. Thus communication skills are also expected to be honed up (4 credits)

PHY/MIS(CMMACS)-4-001: CSIR-800 Societal Programme: 0-0-8-4
Course Coordinator: Dr P Goswami / Dr Ehrlich Desa

The students have to undertake a project in rural area for 6-8 weeks in line with CSIR-800 programme which is primarily prepared at empowering 800 million Indians by way of S & T inventions. The theme for the project may be chosen from CSIR-800 document and as per expertise available at individual laboratory.

Students will choose the topics in consultation with Doctoral Advisory Committee (DAC).

PHY/MIS(CMMACS)-4-002: Project proposal writing: 0-1-6-4
Course Coordinator: PhD Guide

Two subject proposals to be prepared before comprehensive examination by selecting topics of high relevance and novelty, and will have state-of-the art review, methodologies, recommendations etc. (2 credits each)

3. CSIR-CSIO (Central Scientific Instruments Organization, Chandigarh)

Sr. No.	Course No.	Course Title	L-T-P-C
1	PHY/ENG(CSIO)-1-001	Research Methodology	1-1-0-2
2	PHY/ENG(CSIO)-1-311	Mathematics for Engineers and Scientists	3-1-0-4
3	PHY(CSIO)-2-311	Sensors and Actuators	3-0-2-4
4	PHY(CSIO)-2-312	Optics and Opto-electronics	3-1-0-4
5	PHY(CSIO)-3-311	Advanced Materials and Nano Science	3-0-2-4
6	PHY(CSIO)-3-312	Photonic Devices and Systems	3-0-2-4
7	PHY(CSIO)-3-313	Analytical Instrumentation	3-0-2-4
8	PHY/ENG(CSIO)-3-001	Advanced Self Study	0-2-4-4
9	PHY/ENG(CSIO)-4-001	CSIR-800 Societal Program	0-0-8-4
10	PHY/ENG(CSIO)-4-002	Project proposal writing	0-1-6-4

Brief Description of Physical Science Courses at CSIR-CSIO (Course Level-Wise)

PHY/ENG(CSIO)-1-001: Research Methodology: 1-1-0-2
***Course Coordinator:* Dr HK Sardana**

Introduction to Research: Importance, study of literature, defining research problem, hypothesis formulation, experimental design
Data Collection and Measurement: Methods and techniques, probability and probability distributions, sampling and sampling designs
Data Analysis: Testing of hypothesis, statistical tests and analysis, data interpretation, multivariate analysis, model building, forecasting methods
Report writing and Presentation: Ethics in research, Plagiarism, substance of reports, formats, referencing, oral presentation skills
General practices followed in Research – literature and data management, Safety practices in the laboratory, Intellectual property rights (IPR).

PHY/ENG(CSIO)-1-311: Mathematics for Engineers and Scientists:3-1-0-3
***Course Coordinator:* Dr GS Singh**

Calculus: Differential Calculus, Partial differentiation, Integral Calculus, Multiple integrals, Vector Calculus
Complex Analysis: Complex numbers and functions, Matrices, Calculus of Complex Functions.
Differential Equations: Differential equations of first order, linear differential equations, Differential equations of different type, series solution of differential equations and special functions, partial differential equations.
Series & Transforms: Series, transforms, and complex transforms.

PHY(CSIO)-2-311: Sensors and Actuators:3-0-2-4
***Course Coordinator:* Dr Sunita Mishra**

Sensor Technologies: Physical principles & basic mechanisms in sensor systems, semiconductor processing, processing of ceramic and glasses, thin and thick film technologies, processing of micro-sensors
Sensor Structures: Impedance type, semiconductor based, resonance based, electro-chemical cell, colorimetric and fibre optic sensors.
Sensing Effects and Performance: Dielectric, sorption, conductivity, resistivity, optical behaviour, selective chemical sensing, multi-array sensing, Transduction principles, transducer characteristics, classification of transducers, methods for characterisation of transducers-performance characteristics, static & dynamic characteristics, error analysis.
Actuators: Principles of actuation mechanism, architecture of control electronics, development methodology of motor/actuator control, micro actuators, stepper motors, brushed DC motors, brushless DC motors and hydraulic and pneumatic actuators, Bimorph actuators.
Sensor Applications: Mechanical, acoustic, temperature, IR, humidity, magnetic material, MEMS, ion-selective, medicine and biology.

PHY(CSIO)-2-312: Optics and Opto-electronics:3-1-0-3
***Course Coordinator:* Subhash Jain**

Basic optics: Reflection and refraction of plane waves, polarization, diffraction; two-beam and multiple beam interference, Fabry-Perot interferometer, micro-optic components, laser basics and applications.
Optical fibre properties: Fibre characterisation techniques, directional couplers, connectors, splices, fibre polarization components, wavelength division multiplexing, fibre gratings, optical spectrum analyzer, OTDR.
Light-matter interaction: Interaction of radiation with material, optical sources and detectors, Q-switching and mode locking in lasers, light detection techniques, fibre optic and radiation sensors, photonic crystals, holey fibre, fibre half-block and birefringent fibres, electro-optic effects, acousto-optic effect, nonlinear optics and parametric amplification, fibre amplifiers and laser systems.

PHY(CSIO)-3-311: Advanced Materials and Nano Science:3-0-2-4
***Course Coordinator:* Dr Akash Deep**

Alloys and their properties: Ferrous & non-ferrous alloys, shape memory alloys, chemical composition, mechanical properties, electrical and magnetic properties, heat treatment, metal processing, elastic behaviour, optical materials.
Semiconductor Materials: Semiconductor materials- electronic and optical properties.
Polymers: Chain growth polymers, step growth polymers, photochromic polymers & conducting polymers, optical applications, photochromic lenses, liquid crystal polymers, photo simulated shape changes.
Nano structured materials: Characterization techniques, thin film growth, coating, powders, semiconductor nanostructures, fabrication, quantum dot processing technologies, bio-nano materials and applications.

PHY(CSIO)-3-312: Photonic Devices and Systems:3-0-2-4
***Course Coordinator:* Randhir Bhatnagar**

Photonic Devices: Optical and Photonic band gap materials, Device Structures and Characteristics, Optical Amplifiers, Distributed Feedback Laser, Distributed Bragg Reflector Laser.
Biophotonics: Photobiology, Fluorescence and Evanescent Biosensors, FBG/LPG based sensing, Bioimaging, Principle and Technique of Confocal Microscope, Raman Microscope, Near Field Scanning Optical Microscopy, Bio-Nano-Photonics and its applications.
Photonic Sensors and Systems: Raman, Brillion and Rayleigh scattering based Sensors and Systems, FBG Interrogation Techniques and Systems, Surface Plasmon Resonance Sensors and Systems.

PHY(CSIO)-3-313: Analytical Instrumentation:3-0-2-4
***Course Coordinator:* Dr AK Paul**
Introduction: Basics of analytical instrumentation, use of computers in analytical instrumentation, statistical techniques, atomic emission and absorption spectroscopy (UV-visible, NIR, IR, FTIR, X-ray).

Elemental analysis: Detection of atoms, molecules and aerosols, glow discharge spectroscopy for elemental analysis
Separation techniques: Chromatography (gas, ion and liquid) and headspace analysis.
Electro-Chemical Instrumentation: Introduction and overview of electrode processors, kinetics of electrode reactions, potentials sweep methods, impedance spectroscopy.
Microscopy: Concept of scanning electron microscopy, transmission electron microscopy, tunnelling microscope and atomic force microscope, applications in material characterization.

PHY/ENG(CSIO)-3-001: Advanced Self Study:0-2-4-4
Course Coordinator: PhD Guide

The main focus of this course is to encourage self-learning in the niche areas of the candidate's interest. The candidate is expected to do an extensive literature survey in the chosen research area and submit an written report of the work and present the work to group of experts in the form of a seminar.

PHY/ENG(CSIO)-4-001: CSIR-800 Societal Programme:0-0-8-4
Course Coordinator: **Dr Pawan Kapur**

The students have to undertake a project in rural area for 6-8 weeks in line with CSIR-800 programme which is primarily prepared at empowering 800 million Indians by way of S & T inventions. The theme for the project may be chosen from CSIR-800 document and as per expertise available at individual laboratory. Students will choose the topics in consultation with Doctoral Advisory Committee (DAC).

PHY/ENG(CSIO)-4-002: Project proposal writing:0-1-6-4
Course Coordinator: **Dr Pawan Kapur**

Two subject proposals to be prepared before comprehensive examination by selecting topics of high relevance and novelty, and will have state-of-the art review, methodologies, recommendations etc. (2 credits each)

4. CSIR-IMMT (Institute of Minerals and Materials Technology, Bhubaneswar)

Sr. No.	Course No.	Course Title	L-T-P-C
1	PHY(IMMT)-1-001	Research Methodology	2-0-0-2
2	PHY(IMMT)-2-346	Computational Methods & Numerical Analysis	3-0-2-4
3	PHY(IMMT)-2-347	Technologies for mineral resource utilization	3-0-2-4
4	PHY(IMMT)-2-348	Material characterization techniques	3-0-2-4
5	PHY(IMMT)-2-349	Recycling of Material Resources	3-0-2-4
6	PHY(IMMT)-2-350	Process Instrumentation & Control	3-1-0-4
7	PHY(IMMT)-2-351	Science for engineers	3-0-0-3
8	PHY(IMMT)-2-352	Fundamentals of Engineering Analysis	3-0-0-3
9	PHY(IMMT)-2-353	Process design & simulation	3-0-2-4
10	PHY(IMMT)-2-354	Advanced Extraction Methods	3-0-0-3
11	PHY(IMMT)-2-355	Advanced Topics in Materials Resource Engineering	3-0-2-4
12	PHY(IMMT)-2-356 (3-0-2-4)	Energy & environment	3-0-2-4
13	PHY(IMMT)-2-357	Mineralogy and mineral chemistry	3-0-2-4
14	PHY(IMMT)-3-346	Computational Fluid Dynamics	3-0-2-4
15	PHY(IMMT)-3-347	Advanced Materials: Characterization and Processing	3-1-2-4
16	PHY(IMMT)-4-001	CSIR-800 Societal Programme	0-0-8-4
17	PHY(IMMT)-4-002	Subject Proposal - I	0-1-6-4
18	PHY(IMMT)-4-347*@	Subject Proposal - II	0-1-6-4

Brief Description of Physical Science Courses at CSIR-IMMT (Course Level-Wise)

PHY (IMMT)-1-001: Research Methodology: 2-0-0-2
***Course Coordinators*: Dr. D.B. Ramesh, Dr. D. P. Sandha, Dr. D.P. Das**

1. Research Methodology - Introduction

- Meaning, Concept, Need
- Historical Research
- Survey Research
- Experimental Research
- Fundamental and Applied Research

2. Literature Search & Review of Literature

3. Research Tools

- Measurement of Variables
- Presentation of Data
- Statistical Techniques – All Basic Techniques, Null hypothesis, Error Analysis, Interval estimation, Statistical Significance, *Examples:* Analysis of variance (ANOVA), Chi-squared test, Correlation, Factor analysis, Mann–Whitney U, Mean square weighted deviation (MSWD), Pearson product-moment correlation coefficient, Regression analysis, Spearman's rank correlation coefficient, Student's t-test and z-test, Time series analysis
- Statistical Packages:
    - **MS Excel** - Introduction, Getting Data into Excel, Activating the Data-Analysis Tools, Using Excel to Determine a Confidence Interval, Using Excel for t-Tests of Hypotheses, The t-Test for Independent Samples, The t-Test for Dependent (and Matched-Pair) Samples, Using Excel for ANOVA, Using Excel for Correlation, Using Excel for Linear Regression, Using Excel for Chi-Square Tests, The Chi-Square Goodness-of-Fit Test and the Chi-Square Test of Association
    - **MATLAB** - Introduction and Key Features, Developing Algorithms and Applications, Analyzing and Accessing Data, Visualizing Data, Performing Numeric Computation, Publishing Results and Deploying Applications

4. Research Types and Methods

- Observation Method
- Questionnaire Method
- Interview Method
- Experimental Method

5. Research Process

- Designing a Research: Characteristics, Purpose
- Research Plan
- Analysis and Testing

- Quantitative Methods and Data Analysis
- Qualitative Analysis

6. Communicating Research Results

- Journal paper
- Thesis
- Project proposal
- Report
- Web publishing
- Seminar and Oral presentations

7. Research Ethics and Plagiarism

8. Case Studies

PHY (IMMT)-2-346: Computational Methods & Numerical Analysis: 3-0-2-4
***Course Coordinators*: Dr. D. P. Das, Mr. S. Rath**

Computation & Programming: Notions of syntax and semantics of programming languages, Concept of algorithm, Systematic development of programs, Computer Architecture & Memory management, Object Oriented Programming & Data structure, parameter passing mechanisms, Program design practices.
Numerical Scientific Computing: Numerical differentiation & integration, Solving polynomial equations, Computational matrix, Transforms
Computer Graphics: Input / Output devices, Raster & Vector Graphics, Drawing algorithms; Windowing and 2D/3D clipping. 2D & 3D Geometrical Transformations, Viewing Transformations, Animation Techniques
Statistical Analysis: Statistical Concepts, Conditional Probability and independence, Regression Analysis, Design of Experiments, Support Vector Machine, Statistical Inference, Optimisation.
Practical/ Lab Work: Statistical Analysis using standard statistical package, application modelling using MATLAB, application programming practices with standard graphics libraries like open GL.

PHY (IMMT)-2-347: Technologies for Mineral Resource Utilization: 3-0-2-4
***Course Coordinators*: Mr. P.S.R. Reddy, Prof. D.D. Misra, Prof. B.K. Mishra**

Particulate technology, particle size distribution, sizing methodology, size-reduction and classification processes; Particulates in suspension, stability, Rheology and settling; Solid-liquid separation methods; Physics, chemistry, and engineering design as applied to gravity, magnetic, electrostatic, and froth flotation processes

PHY (IMMT)-2-348: Materials Characterization Technique: 3-0-2-4
***Course Coordinator:* Dr. B. K. Mahapatra**

Size and surface area analysis; Interaction of X-rays with matter, diffraction techniques and applications; Optical principles of microscopy; electron diffraction, imaging (various contrasts), determination of crystal structure, burgers vector, electron beam-specimen interactions and other applications of Transmission Electron Microscopy; Applications of Scanning Electron Microscopy and, Electron Probe Micro-Analyser; Principles of Quantitative Microscopy: Overview of other characterization techniques such as Auger electron spectroscopy, Scanning Tunneling Microscopy, Atomic Force Microscopy.

PHY (IMMT)- 2-349 : Recycling of Material Resources: 3-0-2-4
***Course Coordinator*: Dr. K. Sanjay**

Mining and metallurgical wastes classification, investigation and evaluation of waste deposits, waste and circulatory management during recycling.
Unit operations involving materials recycling processes such as pre-treatment (physical and chemical), roasting, calcination, sintering, leaching, solid-liquid separation; Solution, concentration and purification techniques—precipitation, cementation, solvent-extraction, evaporation, crystallization, electrowinning, electroremediation; Resources and recycling technologies across the major materials sectors, and case studies including wastes in steel and aluminium production; Recycling of E-wastes and secondaries; Economic evaluation and project implementation: Flow-sheet development, mass and energy balance, costing, techno-economic feasibility report (TEFR) preparation, financial investment in waste recycling, project planning and implementation, work safety.

PHY (IMMT)-2-350: Process Instrumentation & Control: 3-1-0-4
***Course Coordinator*: Dr. D. P. Das**

Introduction to instrumentation in process industry, Different types of sensors and actuators, Computerized data acquisition, Monitoring and analysis of data (Time series and spectral analysis), Process control, PID Control, Introduction to PLC, SCADA & DCS, Networking and communication in industry, Artificial neural network & Fuzzy logic based control, Laboratory work.

PHY (IMMT)-2-351: Science for engineers: 3-0-0-3
***Course Coordinator*: Dr. Bikash K. Jena**

Concepts of atomic and molecular energy levels leading to description of plasma state, plasma physics—thermal and non-equilibrium plasma, plasma diagnostics, methods of plasma processing of materials and minerals; Industrial plasmas, new concepts of resource utilization using plasma, Crystal structure and defects, electron and hole in lattices, Band gap module and tailoring : -optical and electrical, variable band gap.

Structure and Bonding; Molecular basis of chemical reactions, reaction kinetics, structural effect on reactivity; Complexation concepts, Spectroscopy, Metals in biological domain, Molecular engineering; Computational approaches for structure-function correlation, Surfaces and interfaces, Chemical theories involved in solution, concentration and purification, Micelles, surfactants and their application for bulk processing of mineral resources.
Cell types structure and function; Bio-molecules: composition and bonding; Overview of amino acids, proteins, carbohydrates, nucleic acids, lipids, enzymes, vitamins and minerals; DNA replication; Membranes, Introduction to bio-mineral processing.

PHY (IMMT)-2-352: Fundamentals of Engineering Analysis: 3-0-0-3
***Course Coordinator*: Dr. Swati Mohanty**

Fundamental concepts of fluid flow, heat and mass transfer; Shell balance approach for molecular and convective transport processes;
Formulation and solution of ordinary and partial differential equations that describe physical systems of importance in engineering; some applications to minerals and materials processing
Numerical methods: finite difference, numerical solution of ordinary and partial differential equations.

PHY (IMMT)-2-353: Process Design & Simulation: 3-0-2-4
***Course Coordinator*: Prof. B. K. Mishra, Dr. C. Eswariah**

Preliminary resource evaluation methods; Identification and development of process flow sheet; Elementary evaluation of plant performance; Spread-sheet development for plant data analysis; Introduction to simulation environment using MODSIM, simulator structure, numerical analysis of simulation, sequential method of simulation, practical application of plant simulation; Materials and energy balance, mass balance smoothing, data reconciliation in terms of grade and recovery, analysis of complex flowsheet for mass balancing, examples of material balance smoothing; Application of modeling and residence time distribution concepts for plant data interpretation; Parameter estimation: linear regression, one, two, and multi-linear regression; models nonlinear in parameters; Case studies of typical process plant design and operation.

PHY (IMMT)-2-354: Advanced Extraction Methods: 3-0-0-3
***Course Coordinator:* Dr. R. K. Paramguru**

Fundamentals of commercially important nonferrous pyrometallurgical extraction processes; Thermodynamics of high-temperature processes and solid-gas reaction kinetics; Heterogeneous kinetics, multi-phase systems, Electrodics, Semiconductor electrochemistry; Application: roasting, sulphide-oxide-sulphate systems, oxide-chloride systems, smelting, kinetic analysis, bath smelting, dynamic contact angle-free energy correlation; Electro-smelting—present practice and future trends; Direct electro winning, possible electrode systems, conduction types, future trends.

PHY (IMMT)-2-355:Advanced Topics in Materials Resource Engineering:3-0-2-4
Course Coordinator: Dr. S.K. Singh

Plasma Processing
Introduction, Basic plasma and gas discharge concepts, Glow discharge plasmas, Thermal plasmas, Plasma torches and sprays, Plasma chemistry, etching and polymerization, Plasma coatings, Diamond and diamond-like films, Diagnostics/Probes, Plasma Spraying, Preparation of nano powders, Plasma smelting, Plasma sintering

Powder Metallurgy
Production of metal and alloy powder, particle size & shape, microstructure, Powder compaction, Sintering (Solid state sintering & Liquid phase sintering), Hot pressing, Sintering furnaces & atmospheres, Applications of powder metallurgy.

Corrosion Science & Engineering
General introduction, Electrochemical reactions, Thermodynamic concepts, Eh-pH diagram, Prevention of corrosion

Rheology
Fundamentals, Types of viscometers and rheometers, Applications

PHY (IMMT)-2-355: Energy & Environment: 3-0-2-4
***Course Coordinator*: Dr. B. C. Acharya**

Important Indian minerals & related environmental issues; Environmental impact due to mining in Orissa; Case study on graphite resources of Orissa and environmental management, Environmental issues related to mining, processing and products – solid wastes**,** Environmental impact analysis and management plan, Case studies related to environmental management of minerals and materials industries; Effluent treatment (nutrients removal) through microbial activity, Vulnerability and adaptation technologies for sustainable development, Pollution generation and management – Effluents, Environmental laws and global issues related to environment, Conservation of energy in different production and processing steps, Energy audit in mineral and material processing industries.
PHY (IMMT)-2-357: Mineralogy and Mineral chemistry: 3-0-2-4)
Course Coordinator:

Process mineralogy, Liberation Studies using QEMSCAN, Mineral chemistry using EPMA, Identification of mineral phases through XRD.

Geochemistry : Chemical composition of the Earth, elementary statistics for geochemistry; major, minor and trace elements including rare earth elements;

element partitioning between minerals and melts; petrogenesis, Geochemical Classification of elements, Geochemical differentiation, Isomorphism, Polymorphism, Atomic substitution and Geochemical cycle.

Analytical Geochemistry: Chemical analysis of rocks and minerals, digestion techniques, preparation of standards, estimation of major oxide percentages using spectrophotometric /flame photometric and titrimetric methods. Preparation of calibration curves. Gravimetric estimation of silica and R2O3. Determination of noble metals. Introduction to Neutron Activation Analysis, principles of ICP, XRF & AAS analysis.

Statistical Methods in Geosciences: Introduction to probability: random experiments, events, sample space, definitions of probability. Conditional probability and independence of events, Bayes theorm. Random variables, discrete and continuous probability distributions, joint probability distributions, conditional probability distributions. Mathematical expectation, moment generating and characteristic functions. Binomial, Poisson, Normal, Gamma, Exponential, Hypergeometric, Multinomial, Chi-square, t, and F distributions. Introduction to statistical inference, sampling distributions, point and interval estimation, hypothesis testing involving one and two univariate populations. Linear models ANOVA. Linear and multiple regression. Introduction to multivariate techniques PCA, factor analysis, linear discriminant analysis, classification

PHY (IMMT)-3-346: Computational Fluid Dynamics: 3-0-2-4
***Course Coordinator*: Dr. Swati Mohanty**

Introduction to Computational fluid dynamics; Conservation equations: momentum, energy and mass balance equations; Discretization methods: Finite difference method, Finite element method, Finite volume method; Structured and unstructured grid; Multiphase flows: fluid-fluid, fluid-solid; Turbulence modeling: Direct Numerical Simulation, Large Eddy Simulation, Reynolds Averaged Navier Stokes model; CFD modelling of some mineral and material processing unit operations; Introduction to CFD software.

PHY (IMMT)-3-347: Advanced Materials: Characterization and Processing: 3-1-2-4
***Course Coordinator:* Dr. B. B. Nayak**

Theory: Fundamentals of crystallography, crystal structure and structure determination by XRD, electron diffraction and neutron diffraction in polycrystalline materials, stereographic projection and pole figures, orientation and texture analysis, structure of metals, alloys, solid solution, concept of amorphous, glassy and nano materials and their characterization, defects in crystals, theory of dislocation, Burger vector, plastic deformation, stress measurement by XRD, strengthening mechanism, cold working and heat treatment of steel, hardness and tensile test of steel, concepts in fracture mechanics and fracture determination methods, S-N curve, low cycle fatigue, fatigue mechanism.

Practical: Study of types of high temperature furnaces including plasma furnace, induction and vacuum induction furnace, study and determination of vacuum in rotary and diffusion pumps, high temperature determination by thermocouple and pyrometer, morphology and microstructure observation by various microscopy methods (SEM, TEM, AFM, optical), XRD, Raman spectroscopy and identification of impurities and precipitates in metals, microhardness and nanoindention measurements, tensile, fracture toughness and fatigue tests of steel.

5. CSIR-NCL (National Chemical Laboratory, Pune)

#	Course Code	Course Title	L-T-P-C
1	PHY(NCL):1-001	Research Methodology	2-0-0-2
2	PHY(NCL):1-416	Analytical Tools and Instrumentation	2-0-0-2
3	PHY(NCL):1-417	Basic mathematics and numerical methods	2-0-0-2
4	PHY(NCL):1-418	Basic Chemistry for Interdisciplinary sciences	1-0-0-1
5	PHY(NCL):1-419	Introduction to Nanoscience and Nanotechnology	1-0-0-1
6	PHY(NCL):2-416	Advanced Quantum Mechanics	3-0-0-3
7	PHY(NCL):2-417	Advanced Materials Science	3-0-0-3
8	PHY(NCL):2-418	Advanced Surface Science	2-0-0-2
9	PHY(NCL):2-419	Advanced Materials Characterization Techniques	3-0-0-3
10	PHY(NCL):2-420	Advances in Nanoscience and Nanotechnology	2-0-0-2
11	PHY(NCL):2-421	Thermodynamics and Statistical Mechanics	2-0-0-2
12	PHY(NCL):2-422	Composite Materials	2-0-0-2
13	PHY(NCL):2-423	Carbon Allotropes	1-0-0-1
14	PHY(NCL):2-424	Surface Characterization Techniques	1-0-0-1
15	PHY(NCL):3-416	Mathematical Methods	2-0-0-2
16	PHY(NCL):3-417	Numerical Methods	2-0-0-2
17	PHY(NCL):3-418	Electronic Structure Theory	2-0-0-2
18	PHY(NCL):3-419	Molecular Modeling and Simulation	2-0-0-2
19	PHY(NCL):3-420	Materials and Devices for Energy Conversion	2-0-0-2
20	PHY(NCL):3-421	Functional Ceramics	1-0-0-1
21	PHY(NCL):3-422	Modern Magnetic Materials	1-0-0-1
22	PHY(NCL):3-423	Porous Structures	2-0-0-2
23	PHY(NCL):3-424	Alternate Energy Materials	2-0-0-2
24	PHY(NCL):3-425	Polymers and Colloidal Solutions	2-0-0-2
25	PHY(NCL):3-426	X-Ray Diffraction and Structure of Solids	2-0-0-2
26	PHY(NCL):3-427	NMR Spectroscopy	2-0-0-2
27	PHY(NCL):3-428	Small Angle Scattering Techniques	2-0-0-2
28	PHY(NCL):4-001	CSIR-800 Programme	0-0-8-4
29	PHY(NCL):4-002	Project Proposal Writing (I & II)	0-0-8-4

Brief Description of Physical Science Courses at CSIR-NCL (Course Level-Wise)

PHY(NCL):1-001: Research Methodology: 2-0-0-2
Course Coordinator:

Good laboratory practices, Safety in the laboratory, First Aid in the laboratory, Maintenance of laboratory records, Scientific literature management, Communication skills (scientific writing and presentation), Intellectual property management & planning, Ethics in Science, Computer applications and tools, Statistical methods & Data analysis

PHY(NCL):1-416: Analytical Tools and Instrumentation : 2-0-0-2
Course Coordinator:

Thermal methods (TG, DTG, DTA, TMA, DSC), X-ray methods (XRD, XRF, SAXS), NMR (^{1}H, ^{13}C) and other Spectroscopic methods (EPR, IR, UV, Fluorescence), Chromatographic methods (TLC, GC, LC), Mass spectroscopy, Electron Microscopy (SEM, TEM), Electron Probe Micro Analysis (EDS, WDS), Quantitative Analysis (AAS, ICP, CHN)

PHY(NCL):1-417: Basic mathematics and numerical methods: 2-0-0-2
Course Coordinator:

Determinants and Matrices, Complex Variables, Vector analysis, Infinite Series, Special Functions, Differential Equations, Interpolation and Approximation, Numerical differentiation and Integration, Basic Linux, Introduction to Algorithms, basic programming, Shell and Shell Scripting, Network Computing and Parallel Computing, Matlab/Scilab/Octave/Gnuplot

PHY(NCL):1-418: Basic Chemistry for Interdisciplinary sciences: 1-0-0-1
Course Coordinator:

Basics of inorganic, organic, physical and biochemistry, Nomenclature (IUPAC), molarity, molality and normality, types of bonding, Ionic, covalent and non-bonding interactions, Acids and bases, Atomic structure, periodic table and periodic properties, stoichiometry, chemical reactions and kinetics, solvent effects, functional groups in organic compounds, general named reactions and reaction mechanisms, carbohydrates, lipids, proteins, nucleotides, enzymes, photosynthesis

PHY(NCL):1-419: Introduction to Nanoscience and Nanotechnology: 1-0-0-1
Course Coordinator:

General considerations, Introduction, definitions, consequences of size reduction,
Properties: structural, thermodynamic, optical, electrical and magnetic properties,
Methods of synthesis, Surface modifications, factors governing the stability and assembly, Characterization of nanomaterials, Applications of Nanomaterials

PHY(NCL):2-416: Advanced Quantum Mechanics: 3-0-0-3
Course Coordinator:

Revision of Hydrogen atom and particle in box (1D and 3D), Approximate methods in quantum mechanics; Non degenerate perturbation ; Perturbation treatment of the Helium atom ground state and first excited state; Variation method for helium atom ground state; Comparison of perturbation and variation method, Structure of many electron wave function, Antisymmetry, Valence bond theory for homo and hetero nuclear diatomic molecules; Molecular orbital theory Comparison of MO and VB theory;

Introduction to density functional theory; Hartree Fock theory, Overview of methods beyond Hartree Fock theory; Configuration Interaction; Many body perturbation; Coupled cluster

PHY(NCL):2-417: Advanced Materials Science: 3-0-0-3
Course Coordinator:

Crystal systems and space groups, Close packing and various simple structure types like AB, AB2, AB3 and complex structural types ABX3, AB2X4, etc. Factors affecting crystal structures, Common preparative methods; X-ray diffraction and Electron microscopy, Defect structures, colour centers, reciprocal lattices, Properties of solids – Band theory, metals, insulators, semiconductors, dielectric and ferroelectric properties, magnetic properties, optical properties, ionic conduction; structure-processing-property correlations.

PHY(NCL):2-418: Advanced Surface Science: 2-0-0-2
Course Coordinator:

Introduction to Surface Science - Surface phenomena - Adsorption, Desorption, Adsorption Models, Special properties of surfaces and interfaces, Electronic structure of surfaces, Surface modification and its applications, Nanoscale catalysis and applications, Surface spectroscopy and microscopy tools for nanocatalysis

PHY(NCL):2-419: Advanced Materials Characterization Techniques: 3-0-0-3
Course Coordinator:

Optical Microscopy, Electron microscopy: TEM, HRTEM, SEM, STEM, EDX, FIB, e-beam lithography, Scanning probe microscopy: AFM, STM, MFM, confocal, etc, Raman spectroscopy/microscopy, Thermal analysis techniques, Magnetic measurements, Electrical measurements, Spectroscopic ellipsometry.

PHY(NCL):2-420: Advances in Nanoscience and Nanotechnology: 2-0-0-2
Course Coordinator:

Low-dimensional structures: Quantum wells, Quantum wires, and Quantum dots, Nano clusters & Nano crystals, fullerenes, carbon nano tubes and graphene, Nano Composites, synthesis and characterization techniques, Properties at Nano Scales and comparison with bulk materials, fabrication techniques, general applications, nanomaterials in biology.

PHY(NCL):2-421: Thermodynamics and Statistical Mechanics: 2-0-0-2
Course Coordinator:

Introduction: Thermodynamics – A Macroscopic Theory of Matter; Laws of Thermodynamics, Ideal Gas Laws, Specific Heat Capacities; Concept of Free Energy, Hamiltonian Mechanics, Equilibrium Distributions and Ergodic Hypothesis,
Ensembles, Thermodynamic Functions and the Distribution Function, g(r),Imperfect Gases, Kinetic Theory of Gases, Time Dependent Processes, Phase Transitions

PHY(NCL):2-422: Composite materials: 2-0-0-2
Course Coordinator:

Concept of Composite materials, Various types of composites, Classification based on Matrix Material: Organic Matrix composites, Polymer matrix composites (PMC), Carbon matrix Composites or Carbon-Carbon Composites, Metal matrix composites (MMC), Ceramic matrix composites (CMC); Classification based on reinforcements: Fiber Reinforced Composites, Fiber Reinforced Polymer (FRP) Composites, Laminar Composites, Particulate

Composites, Reinforcements/Fibers ,Types of fibres, Multiphase fibers, Whiskers and Flakes, Mechanical properties of fibres, Processing of Advanced composites, Metal Matrix Composites: Casting – Solid State diffusion technique, Cladding – Hot isostatic pressing; Ceramic Matrix Composites: Liquid Metal Infiltration – Liquid phase sintering; Carbon – Carbon composites: Knitting, Braiding, Weaving; Polymer matrix composites: Preparation of Moulding compounds and prepregs – hand lay up method – Autoclave method – Filament winding method – Compression moulding – Reaction injection moulding, Processing and characteristics of nanocomposites, hybrid composites, functionally graded composites, smart and functional composites.

PHY(NCL):2-423: Carbon Allotropes: 1-0-0-1
Course Coordinator:

Synthesis, characterization, structure, properties and applications of: Diamond, Graphite, Amorphous carbon, Charcoals, Fullerene and related compounds, Carbon nanotubes, Graphene.

PHY(NCL):2-424: Surface Characterization Techniques: 1-0-0-1
Course Coordinator:

XPS, LEED, XAS, SEM, AFM, TEM, NSOM, SPR, SERS, static and dynamic contact angle measurements, Ellipsometry.

PHY(NCL):3-416: Mathematical Methods: 2-0-0-2
Course Coordinator:

Determinants and Matrices : Orthogonal Matrices, Hermitian Matrices, Unitary Matrices, Dioganalisation of Matrices, Vector analysis : Scalar and Vector product, Triple scalar and vector product, Gradient, Divergence, Curl, Vector Integration, Gauss Theorem, Stokes Theorem. Vector Analysis in Curvilinear coordinates and Tensors, Infinite Series: Fundamental Concepts, Convergence tests, Taylors expansion, Power Series, Special Functions: Gamma Function, The Beta Function, Differential Equations: Series Solution-Frobnius Method, Bessel Functions, Legendre Functions, Hermite Functions, Laguerre Functions, Fourier Series, Applications of Fourier Series, Fourier Transforms

PHY(NCL):3-417: Numerical Methods: 2-0-0-2
Course Coordinator:

Fortran and Linux basics, Solution to the linear algebraic equations, Eigen Values problems, Interpolation and extrapolation, Random number and sorting, Minimization and maximization of functions, Modeling of data

PHY(NCL):3-418: Electronic Structure Theory: 2-0-0-2
Course Coordinator:

Post-Hartree-Fock methods: Moller-Plesset perturbation theory (MP2, MP3, and MP4), Configuration Interaction (CI), Coupled-Cluster single double (triple) (CCSD(T))– performance of various methods for the prediction of van der Waal and hydrogen bonding interactions, spectral properties. Density functional theory based methods: Hybrid and Minnesota functional – Application of DFT methods (excitation energy calculations). Density functional methods with Dispersion correction (Grimme's approaches). Car-Parrinello Molecular Dynamics (CPMD) and Born-Oppenheimer Molecular Dynamics (BOMD).

PHY(NCL):3-419: Molecular Modeling and Simulation: 2-0-0-2

Course Coordinator:

Molecular Mechanics: Features of molecular mechanics - Force Fields: Bonds structure and bending angles, Electrostatic Vander Waals and non-bonded interactions, Hydrogen bonding - Derivatives of molecular mechanics energy function - Calculating thermodynamic properties - Force Field for inorganic systems - Energy minimization, Molecular Dynamics Simulation: Molecular Dynamics using simple models, Molecular Dynamics with continuous potentials, Solvent effects, Conformational changes, Thermostats, Barostas, Lincs and shake algorithms, Monte Carlo simulation Methods, sorption, Applications of Molecular Modeling

PHY(NCL):3-420: Materials and Devices for Energy Conversion: 2-0-0-2
Course Coordinator:

Design of organic and Inorganic semiconductors, Approaches to process organic semiconductors by covalent and non covalent modifications , band edges and band gaps, Modulation of charge transport properties, kinetics of electron transfer, Design of small molecule dyes for DSSC, Electron transfer at interfaces, Transistors and solar cells, Fabrication of Devices, Device characterisation using dark current, IV curves under illumination, IPCE, Calculation of Voc, Jsc, Vpp, Ipp, FF and Pmax. hybrid solar cells

PHY(NCL):3-421: Functional Ceramics: 1-0-0-1
Course Coordinator:

Advanced Electronic Ceramics, high temperature ceramic super conductors, Dielectric ceramics, microwave ceramics, low k materials, SOFC materials, solid-ionic conductors, phosphor materials, Impedance analysis, varistors, sensors, ceramic magnets, thermal shock resistance and super plastic ceramics.

PHY(NCL):3-422: Modern Magnetic Materials: 1-0-0-1
Course Coordinator:

Types of magnetism, molecular field theory, measurement techniques, magnetoresistance (AMR, GMR, CMR, TMR), hard and soft magnets, magnetostriction, New magnetic materials, applications.

PHY(NCL):3-423: Porous Structures: 2-0-0-2
Course Coordinator:

Definitions, Micro-Porous and Mesoporous Solids, Structural Chemistry of Zeolite Framework Types, MOFs, COFs, Synthesis, Structure Determination, Role of the Structure-directing Agents, The Chemistry of Microporous Framework Solids, Adsorption and Diffusion, Catalytic Applications, hydrogen storage, separation, CO_2 sequestration, sensors,

PHY(NCL):3-424: Alternate Energy Materials: 2-0-0-2
Course Coordinator:

Energy scenario, Non-renewable and renewable energy sources; description of renewable sources and their importance. Technologies for biomass energy conversion, Solar energy, Wind Turbines, Geothermal Technologies; Applications; Sustainable sources of hydrogen; Fuel cell technologies; Hydrogen storage and distribution; Applications and feasibility assessment; Science, technology and policy of energy conservation; Strategies for enhancing role of renewable energy.

PHY(NCL):3-425: Polymers and Colloidal Solutions: 2-0-0-2
Course Coordinator:

Intermolecular forces and potentials, Overview of Statistical physics, DLVO theory, charged colloids, Poisson Boltzmann theory, Debye radius, Bjerrum length, electrophoresis, zeta potential, diffusion, Hydrodynamic interactions. Brief overview of Phase transitions in hard sphere colloids, Random walk, self avoiding random walk, flexible polymers, persistence length, Excluded volume interactions, Polymer solutions in the dilute limit/semi-dilute limit, Entropy of mixing, theta temperature, rubber elasticity, Polyelectrolytes, polymer at surfaces: Brushes, polymer dynamics.

PHY(NCL):3-426: X-Ray Diffraction and Structure of Solids: 2-0-0-2
Course Coordinator:

Introduction to X-ray crystallography,Crystal growth, evaluation and mounting, Symmetry and space group determination, Background theory for data collection, Data collection using four-circle diffractometers, Area detectors,Crystal lattices, Structure factors, Crystal symmetry, Structure solutions, Structure refinement, An introduction to maximum entropy, Least squares fitting of parameters, Practical aspects of structure refinement, Crystallographic Database, Structure solution from Powder Diffraction Data

PHY(NCL):3-427: NMR spectroscopy: 2-0-0-2
Course Coordinator:

Quantum Mechanics of NMR, Multinuclear NMR spectroscopy, Periodic table of NMR, Heteronuclear double resonance experiments, Magnetization transfer and signal enhancement, NMR of diamagnetic and paramagnetic compounds, Multidimensional NMR: 2D NMR, 1H-1H correlations, Heteronuclear Correlation Spectroscopy, 2D Exchange (EXSY), 2D NOESY, ROESY, DOSY Structure elucidation of small molecules, NMR of macromolecules, Multidimensional NMR Spectra, NMR Spectroscopy of Solids, 2D experiments in solids, semi rigid systems: HR MAS, Magnetic Resonance Imaging: In Vivo NMR, Imaging, MRI, functional MRI, NMR imaging of materials.

PHY(NCL):3-428: Small Angle Scattering Techniques: 2-0-0-2
Course Coordinator:

SAXS and Fourier Transforms, General Theorems in Small Angle Scattering: Particulate systems: Porod and Guinier regimes, Pair density distribution functions, Single particle form factor for spheres, rods and plates, polydispersity, Structure factors for equilibrium concentrated particulate systems, measured structure factors for systems exhibiting polydispersity, Two phase systems: General Theorems, Detailed analysis of scattering from lamellar systems, relevance to semicrystalline polymers.

PHY(NCL):4-001: CSIR-800 programme: 0-0-8-4
Course Coordinator:

PHY(NCL):4-002: Project proposal writing (I & II): 0-0-8-4
Course Coordinator:

6. CSIR-NEERI (National Environmental Engineering Research Institute, Nagpur)

Ph.D Environmental Science

Sl. No.	Code No.	Course Title				
		Compulsory courses	**L**	**T**	**P**	**C**
1	**PHY(NEERI)-1-001**	Research Methodology, Ethics, Communication skills, lab safety	1	1	0	2
2	**PHY(NEERI)-1-451**	Analytical & Instrumentation Techniques for Environment	2	0	2	3
3	**PHY(NEERI)-3-459**	Advanced Self Study designed by Guide	0	2	4	4
4	**PHY(NEERI)-4-001**	CSIR 800 Societal Programme	0	0	8	4
5	**PHY(NEERI)-4-002**	Project Proposal writing	0	1	6	4
		Optional Courses				
6	**PHY(NEERI)-2-452**	Environmental Chemistry & Toxicology	2	0	2	3
7	**PHY(NEERI)-2-453**	Environmental Biotechnology, Microbiology	2	0	2	3
8	**PHY(NEERI)-2-454**	Ecology	2	0	0	2
9	**PHY(NEERI)-2-455**	Environmental Genomics (+Lab)	2	0	2	3
10	**PHY(NEERI)-2-456**	Air and Noise Quality Control Management	2	0	2	3
11	**PHY(NEERI)-2-457**	Water and Wastewater	2	1	0	3
12	**PHY(NEERI)-2-458**	Solid and Hazardous Waste Management	2	0	2	3
13	**PHY(NEERI)-3-460**	Environmental Economics, Policy and Law (Seminar)	2	0	2	3
14	**PHY(NEERI)-3-461**	Materials and Environmental Applications (+Lab)	2	0	2	3
15	**PHY(NEERI)-3-462**	Bioremediation (+Lab)	2	0	2	3
16	**PHY(NEERI)-3-463**	Advanced Treatment Systems	3	0	0	3
17	**PHY(NEERI)-3-464**	Energy & Environment	3	0	0	3

Brief Description of Courses at CSIR-NEERI (Course Level-Wise)

PHY(NEERI):1- 001:Research Methodology:1-1-0-2
***Course Coordinator:* Mr. P.S. Dutt**

Quantitative methodology
Application of statistical concepts/procedures. Graphs, numerical summaries. Normal distribution, correlation/regression analyses, probability, statistical inferences for one or two samples. Hypothesis tests, Chi-square tests. Conceptual understanding/application of statistics. Application of statistical concepts/procedures. Analysis of variance, covariance, multiple regression. Experimental design: completely randomized, block, split plot/repeated measures.
Advanced theory, derivations of quantitative statistics. Descriptive statistics, probability, normal distribution. One-/two-sample hypothesis tests, confidence intervals. Chi square tests. One-way analysis of variance, follow up tests.
Analysis of variance designs (two-/three-way), repeated measures, correlation, simple/multiple regression methods, non-parametric procedures, multivariate analyses.
Survey methods, Principles of measurement, constructing questions/forms, pilot testing, sampling, data analysis, reporting. Students develop a survey proposal and a draft survey, pilot the survey, and develop sampling/data analysis plans.
Oral and written communication, thesis writing.
Creativity and out of box thinking
Intellectual property fundamentals.
Introduction to writing scientific papers.
Ethics in Science
Lab safety norms and guidelines

PHY(NEERI)-1-451: Analytical & Instrumentation Techniques for Environment: 2-0-2-3
***Course Coordinator:* Dr. G.L.Bodhe**

Preparation of standard solution, ppm, ppb. Normal solutions Standard curves; Concept of accuracy, precision and error, Sample reservations, handling of samples and chemical in lab, Sample handling of Volatile and non-volatile organic compounds, pH metry, Solvent partitioning, Titrimetry, Gravimetry
Instrumentation and analytical methods involved in the following techniques and their applications in environment: Colorimetry, Spectrophotometry, Fluorescence Spectroscopy, Visible, Atomic and Infrared spectrometry, Flame photometry, Atomic Absorption Spectroscopy

Chromatography, Gas Chromatography, HPLC, Electrophoresis, X-ray diffraction, X-ray fluorescence, X-ray Emission, Cytophotometry, Bomb colorimetrry, ICP-MS, Utilization of different techniques for analysis of Polycyclic Aromatic Hydrocarbons (PAHs), Pesticide residues, Polychlorinated Biphenyls in the Environment

Basics of Microbiological analysis, Laminar flow, autoclaving etc, preparations of media for culture growth, Microscopy Handling of radioactive and hazardous samples, Determination of radionuclide in the environmental samples: gamma spectrometry, alpha particle spectrometry, beta particle spectrometry, liquid scintillation measurement Management of chemicals and waste generated in labs, safety measures while handling chemicals and instruments, familiarity about various symbols used on the bottles of chemicals etc.

PHY(NEERI)-4-001: CSIR 800 Societal Programme :0- 0- 8- 4
Course Coordinator:

The students have to undertake a project in rural area for 6-8 weeks in line with CSIR-800 programme which is primarily prepared at empowering 800 million Indians by way of S & T inventions. The theme for the project may be chosen from CSIR-800 document and as per expertise available at NEERI. Students will choose the topics in consultation with Doctoral Advisory Committee (DAC).

PHY(NEERI)-2-452 Environmental Chemistry & Toxicology 2 0 2 3
***Course Coordinator:* Dr. R.J.Krupadam, Dr. K Krishnamurthy**

Stoichiometry – First and Second law of Thermodynamics – Gibb's free energy – Chemical potential – Oxidation and Reduction, Nernt equation pH-pE diagrams, Chemical Equillibria, Acid – Base reactions – Solubility product ,Application in heavy metals removal– Solubility of gases in water –– Chemical kinetics – Colloids and Coagulation, water treatment- Sorption- Radio nuclides and nuclear energy.

Transport and transformation of chemicals – Phase Interactions Degradation of food stuffs(carbohydrates, proteins), Detergents, Pesticides, hydrocarbons(aliphatic and aromatic) – Photolysis – Volatility – Classification of elements –– Complex formation –– Hydrophobic interactions – Chemical speciation.

Photochemical reactions in the atmosphere- Degradation of VOCs– Chemical process for the formation of inorganic and organic particulate matter – Oxygen and Ozone chemistry.-Photochemical smog.

Soil classification– Inorganic and organic components of soil –physical and chemical properties of soil- Acid -base and ion exchange reactions-Leaching-Salt affected soil. Principles of green chemistry – Clean synthesis, – Atom economy – Environmental factor 'E' and Quotient 'Q', Nano materials, CNT, T_iO_2.
Toxicants, Distribution, Metabolism of toxicants, sites of action, classification of toxicity – acute and sub-acute toxicity bioassay, Factors influencing toxicity, Elimination of toxicants, Methods of toxicity testing – Evaluation - statistical assessment, sediment toxicity, Bio- chemical markers/indicators, Toxicokinetics, Bioconcentration, Bio-accumulation and Bio magnification in the environment.

Xenobiotics – Chemical carcinogenesis – Genotoxicity assays – Neurotoxicity, Skin toxicity, Immunotoxicity. Renal toxicity, Endocrine disruptors, hormones, receptors.
Toxicity of monomers, solvents, intermediates, products – toxic substrates – Metals and other inorganic Chemicals, Organic Compounds – Persistent chemicals.
Procedures for assessing the risk – Risk measurement and Mitigation of environmental disorders – Factors in risk assessment.

PHY(NEERI)-2-453 Environmental Biotechnology, Microbiology 2 0 2 3
***Course Coordinator:* Dr. Mrs. A. Kapley**

Biological Treatment of Wastewater – Aerobic System, Biological processes for domestic and industrial waste water treatments; Aerobic systems - activated sludge process, trickling filters, biological filters, rotating biological contractors (RBC), Fluidized bed reactor (FBR), expanded bed reactor, Inverse fluidized bed biofilm reactor (IFBBR) packed bed reactors air- sparged reactors, Biological Treatment of Wastewater – Anaerobic System Anaerobic biological treatment - contact digesters, packed column reactors, UASB.

Introduction, constraints and priorities of Bioremediation, Biostimulation of Naturally occurring microbial activities, Bioaugmentation, in situ, ex situ, intrinsic & engineered bioremediation, Solid phase bioremediation - land farming, prepared beds, soil piles, Phytoremediation. Composting, Bioventing & Biosparging; Liquid phase bioremediation - suspended bioreactors, fixed biofilm reactors. Mining and Metal biotechnology – with special reference to Copper & Iron. Microbial transformation, accumulation and concentration of metals, metal leaching, extraction and future prospects. Microorganisms and energy requirements of mankind; Production of nonconventional fuels - Methane (Biogas), Hydrogen, Alcohols and algal hydrocarbons, Use of microorganisms in augmentation of petroleum recovery. Introduction - Xenobiotic compounds, recalcitrance. hazardous wastes - biodegradation of Xenobiotics . Biological detoxification - market for hazardous biotechnology application to hazardous waste management - examples of biotechnological applications to hazardous waste management – cyanide detoxification - detoxification of oxalate, urea etc. - toxic organics - phenols.

Classification of microorganisms – prokaryotic, eukaryotic, cell structure, characteristics, Preservation of microorganisms, DNA, RNA, replication, Recombinant DNA technology.

Distribution of microorganisms – Distribution / diversity of Microorganisms – fresh and marine, terrestrial – microbes in surface soil, Air – outdoor and Indoor, aerosols, biosafety in Laboratory – Extreme Environment – archaebacteria – Significance in water supplies – problems and control. Concentration and detection of virus, Transmissible diseases.

Nutrition and metabolism in microorganisms, growth phases, carbohydrate, protein, lipid metabolism – respiration, aerobic and anaerobic-fermentation, glycolysis, Kreb’s cycle, hexose monophosphate pathway, electron transport system, oxidative phosphorylation, environmental factors, enzymes, Bioenergetics.

Transmission of pathogens – Bacterial, Viral, Protozoan, Indicator organisms of water – Coliforms - total coliforms, E-coli, Streptococcus, Clostridium, Control of microorganisms; Microbiology of biological treatment processes – aerobic and anaerobic, α -oxidation, β-oxidation, nitrification and denitrification, eutrophication.

Factors influencing toxicity. Effects – acute, chronic, concentration response relationships. Test organisms – toxicity testing, Bioconcentration – Bioaccumulation, biomagnification, bioassay, biomonitoring, bioleaching.

PHY(NEERI)-2-454 Ecology 2 0 0 2
Course Coordinator: **Dr. Mrs. A. Juwarkar**

Objective
To acquaint the students with the concept of ecology so that they get well versed with different ecosystems and try to relate them in their day to day life
A brief history; Concept, and major branches *Concept of Speciation:* Types and process *Extinction:* A brief history and reasons

Community Ecology: Concept, Characteristics and dynamics; Interactions; Developmentof community (Plant Succession); Parasitism; Prey-Predator relationship

Population Ecology: Characteristics of population; Dynamics and Interactions;Regulation; Population genetics

Aquatic Ecosystem: Fresh water and Marine system, their types, characteristics and components; Wetlands, their Significance and conservation, Eutrophication and remedial measures

Terrestrial ecosystems: Major terrestrial biomes - Forest, Desert, and Grassland (a brief account); Relationship between Precipitation and temperature in determining the vegetation; Forest Types of India (a concise account)

Biological Invasion: Concept; Pathways of Invasion; Process of Invasion; Mechanism of Invasions; Impact of Invasive Species - Ecological, Environmental, Economical; Some examples of major invasive plants and animals in India

Sustainable Development: The Concept and strategies of sustainable development
Biodiversity: Definition; levels of diversity; alpha, beta and gamma diversity, and their measurement; '*Biodiversity Hotspots'* – concept and a brief account; Biodiversity hotspots of India: a short account; Concept of endangered and threatened species: IUCN Categories of Extinction; Names of a few endangered and threatened animals and plants (of India); Strategies for biodiversity conservation: Concept of Protected Area Networks -National Parks, Wildlife Sanctuaries, Biosphere Reserves (A brief account)

PHY(NEERI)-2-455 Environmental Genomics 2 0 2 3
Course Coordinator: **Dr. H.J.Purohit**

History of genetic engineering, restriction, modifying and polymerase enzymes used in genetic engineering, vectors used in genetic engineering of microbes, Bacterial hosts used in cloning and expression. MolecularTechniques: Isolation of nucleic acids (DNA, RNA, e-DNA, Metagenome), PCR, optimization of PCR, gene specific and degenerate primer design, automated DNA sequencing, pyrosequencing, Principles and techniques of nucleic acid hybridization and Cot curves; Southern blotting techniques; Polymerase chain reaction; RAPD, Real Time PCR, RT- PCR
Construction of cDNA library, PCR based cDNA library, subtractive cDNA library, normalized cDNA library, genomic DNA library, BAC library, Cloning methods using restriction enzymes, cloning in expression vector, cloning of PCR products.

Phylogenetics, cladistics and ontology; Phylogenetic representations – graphs, trees and cladograms; Steps in phylogenetic analysis; Methods of phylogenetic analysis – similarity and distance tables, distance matrix method; Method of calculation of distance matrix (UPGMA, WPGMA); The Neighbour Joining Method;– maximum parsimony, maximum likelihood; Phylogenetic softwares –PHYLIP
Genome maps and types; current sequencing technologies; partial sequencing; gene identification; gene prediction rules and software's; Genome databases; Annotation of genome. Genome diversity: taxonomy and significance of genomes
Methods of sequence alignment: Sequence similarity searches and alignment tools – dynamic programming algorithms; Needlman-Wunch and Smith Waterman, Optimal global alignment and optimal local alignment; Concept ; Programmes (Dot matrix, Dot plot, Dynamic programming) ;Similarity Searches ; Sequence repeats and inversion; Database searching (BLAST and FASTA.Multiple Sequence alignment (MSA) – significance; softwares (Clustal, , ClustalW, Meme)

PHY(NEERI)-2-456 Air and Noise Quality Control Management 2 0 2 3
***Course Coordinator:* Dr. S.K. Goyal**

Structure and composition of Atmosphere – Definition, Scope and Scales of Air Pollution – Sources and classification of air pollutants and their effect on human health, vegetation, animals, property, aesthetic value and visibility- Ambient Air Quality and Emission standards – Air Pollution Indices – Emission Inventories – Ambient and stack sampling and Analysis of Particulate and Gaseous Pollutants.
Effects of meteorology on Air Pollution - Fundamentals, Atmospheric stability, Inversion, Wind profiles and stack plume patterns- Atmospheric Diffusion Theories – Dispersion models, Software application, Plume rise, Effective stack height .

Factors affecting Selection of Control Equipment – Gas Particle Interaction, – Working principle, Design and performance equations of Gravity Separators (cyclone) , Centrifugal separators Fabric filters, Particulate Scrubbers, Electrostatic Precipitators – Operational Considerations - Process Control and Monitoring – Costing of APC equipment – Case studies for stationary and mobile sources.

Factors affecting Selection of Control Equipment – Working principle, Design and performance equations of absorption, Adsorption, condensation, Incineration, Bio scrubbers, Bio filters – Process control and Monitoring - Operational Considerations - Costing of APC Equipment – Case studies for stationary and mobile sources.

Sources and Effects of Noise Pollution – Measurement – Standards –Control and Preventive measures

PHY(NEERI)-2-457 Water and Wastewater 2 1 0 3
***Course Coordinator:* Dr. N.S.Raman**

Water treatment concepts; pretreatment, primary treatment, secondary treatment, tertiary treatment. Water quality standards; characteristics. Theory and design of physicochemical unit operations; screening, grit, removal equalisation, sedimentation, floatation, caogulation-flocculation, filtration, disinfection, membrane processes, desalination, ion-exchange, aeration/gas transfer, precipitation, adsorption. Hydraulics of treatment plant; flow measurement and hydraulic control points, hydraulic analysis of unit operations, hydraulic profile through the treatment plant.

Wasterwater treatment concepts; pretreatment, primary treatment, secondary treatment, tertiary treatment. Water quality standards; characteristics. Theory and design of physicochemical unit operations; screening, grit, removal equalisation, sedimentation. Theory and design of biological unit operations; aerobic and anaerobic processes; Aerobic unit operations for organic carbon removal such as activated sludge, tricling filter, oxidation ditch, oxidations ponds, aerated lagoons, root zone treatment, vermifilter etc. Anaerobic operations for organic carbon removal such as UASB, filters, fluidised/expanded bed systems etc. Biological unit operations for nitrogen and phosphorus removal. Theory and design of Sludge treatment, sludge thickening, sludge drying, incineration, aerobic and anaerobic digestion of sludges. Theory and design of wastewater disposal and systems;disposal to inland water bodies, sea/ocean disposal; land/underground disposal.

PHY(NEERI)-2-458 Solid and Hazardous Waste Management 2 0 2 3
***Course Coordinator:* Dr. S.Y.Bodhke**

Objective

To impart knowledge on the elements of managing solid wastes from Municipal and industrial sources including the related engineering principles, design criteria, methods and equipments.

Types and Sources of solid and hazardous wastes - Need for solid and hazardous waste management Elements of integrated waste management and roles of stakeholders - Salient features of Indian legislations on management and handling of municipal solid wastes, hazardous wastes, biomedical wastes, lead acid batteries, electronic wastes , plastics and fly ash – Financing waste management.

Waste generation rates and variation - Composition, physical, chemical and biological properties of solid wastes – Hazardous Characteristics – TCLP tests – waste sampling and characterization plan - Source reduction of wastes –Waste exchange - Extended producer responsibility - Recycling and reuse

Handling and segregation of wastes at source – storage and collection of municipal solid wastes – Analysis of Collection systems - Need for transfer and transport – Transfer stations Optimizing waste allocation– compatibility, storage, labeling and handling of hazardous wastes – hazardous waste manifests and transport
Objectives of waste processing – material separation and processing technologies – biological and chemical conversion technologies – methods and controls of Composting - thermal conversion technologies and energy recovery – incineration – solidification and stabilization of hazardous wastes - treatment of biomedical wastes

Waste disposal options – Disposal in landfills - Landfill Classification, types and methods – site selection - design and operation of sanitary landfills, secure landfills and landfill bioreactors – leachate and landfill gas management – landfill closure and environmental monitoring – Rehabilitation of open dumps – landfill remediation

PHY(NEERI)-3-460 Environmental Economics, Policy and Law 2 0 2 3
Course Coordinator: **Mr. P.S.Dutt**

Broad aspects of environmental economics; society and environment, sustainable development, management of environment, regional and global environmental strategies, environmental movements. Environmental legislation; role of U.N. and its associate bodies, role of world bank, administering global environmental funds, environmental programmes and policies in developed and developing countries, environmental programmes and policies of the government of India, structural changes for environmental managements, sectoral policies regarding land, water, forestry, energy, industrial pollution, and human resources development. Environmental impact assessment (EIA); rationale and historical development of EIA, methodologies and socio-economic aspects of EIA, status of EIAs in india, case studies stressing socio-economic aspects of EIA. Planning Levels, physical planning and development Cost-Benefit analysis, methods of economic evaluation of intangible environmental resources; contingent method, travel cost, opportunity cost concept of consumer behaviour, environmental consumerism

PHY(NEERI)-3-461 Materials and Environmental Applications 2 0 2 3
Course Coordinator: **Dr. Mrs. S. Rayalu**

Molecular environmental science ,Re-engineered materials and environmental processes, Surface Science and Catalysis including, biomaterials, biomimetic materials, Catalyst synthesis, Supported Catalysts, Biocatalysis ,Photocatalysis, Biophotocatalysis and Environmental catalysis for solar fuels, GHG Emissions and Control , carbon capture and valorisation, biomass gasification , bioenergy and biochar, Adsorption and Water treatment, Catalysts for Renewable energy;

Surface Science and Catalysis including Heterogeneous Catalysis, Catalyst synthesis, Supported Catalysts, Photocatalysis, Environmental catalysis including air pollution control. Ion-exchange, Adsorption and Water treatment, Catalysts for Renewable energy; GHG Emissions and Control

Zeolites and zeolite-like materials (e.g., crystalline microporous aluminophosphates and their derivatives), mesoporous oxides like silica, silica-alumina etc., metal organic frameworks, pillared clays, porous carbons and related materials, Nanoporous materials their synthesis/preparation and structure, post-synthetic modification, characterization and use in various applications like adsorption/separation, catalysis etc.

PHY(NEERI)-3-462 Bioremediation 2 0 2 3
Course Coordinator: **Dr. Mrs. A. Juwarkar**

Concept and dynamics of ecosystem, biogeochemical cycles; Types of ecosystems, Community structure and organisation; Environmental pollution and importance of microbes, Bioremediation: Microcosms, Mesocosms, Bioaugmentation, Biostimulation

Biodiversity, Climate change research, Microbe-Plant interactions, Eco-restoration and Remediation technologies, Environmental Management, Waste management through Eco-friendly approaches, Constructed wetlands for treatment of Wastewaters, Biomolecules in remediation, Microbial diversity in different Ecosystem, Bioremediation/Phytoremediation, Carbon sequestration and Clean Development Mechanisms, Resource recovery from waste, Bio-energy, Bioproduct, Environmental Biotchnology, Green chemistry.

PHY(NEERI)-3-463 Advanced Treatment Systems 3 0 0 3
Course Coordinator: **Dr. S.Y.Bodhke**

Gas phase transfer: Aeration systems, Design of aeration systems.
Membrane filtration: Introduction , Process classification, Membrane configurations, Membrane operation for micro filtration, Ultra filtration and Reverse osmosis, Design of membrane systems

Microbial growth kinetics, Modelling suspended and attached growth treatment processes. Suspended growth processes for biological nitrification and denitrification, Biological nitrogen and phosphorous removal.

Advanced oxidation processes, aeration/stripping, adsorption, nanoparticles, low pressure membrane processes, and sea water desalination. Principles of mass and momentum transport, aquatic chemistry and chemical reaction engineering are applied to these unit processes

Anaerobic sludge blanket processes, Design considerations for Up flow Anaerobic Sludge Blanket process. Theory and design of Sludge treatment, sludge thickening, sludge drying, incineration, aerobic and anaerobic digestion of sludge.

Wetland and aquatic treatment systems; Types, application, Treatment kinetics and effluent variability in constructed wetlands and aquatic systems, Free water surface and subsurface constructed wetlands, Floating plants (water hyacinths and duckweed), Combination systems, Design procedures for constructed wetlands, Management of constructed wetlands and aquatic systems. Physical separation for hazardous solid wastes , gravity flotation, dissolved air flotation, air stripping. Steam stripping, Solvent extraction. Sorption processes and chemical treatment including hydroxide, sulfide, carbonate precipitation, Solidification and stabilization, Oxidation ad reduction of solid wastes. Thermal treatment and incinerator design. Biological treatment introduction and configuration. Safe disposal methodologies. Quantitative Risk analysis and site remediation.

PHY(NEERI)-3-464 Energy & Environment 3 0 0 3
Course Coordinator: **Dr. N.Labhasetwar**

Energy Crisis: Historical events, energy requirement of society in past and present situation, availability and need of conventional energy resources, major environmental problems related to the conventional energy resources, future possibilities of energy need and availability. Non-conventional energy sources: Hydel power plant, tidal energy, biomass energy, wind energy, Hydrogen as a source of energy, energy conversion technologies, their principles,equipment and suitability in context of India. Environmental impacts of these technologies. Solar Energy option: Sun as source of energy, direct methods of solar energy collection,process of photovoltaic energy conversion, solar energy conversion technologies and devices, their principles, working and application, environmental impacts of solar energy. Biomass option: Concept of biomass energy utilization, types of biomass energy, conversion processes, biogas production, biomass gasification process and technologies, environmental impacts of biomass energy. Energy Storage: Types of energy storage, devices for sensible and latent heat storage,energy storage in dry batteries, nickel-cadmium batteries, secondary heat storage,chemical storage, environmental consequences of energy storage systems. Heat Energy recovery systems: Approaches to waste Energy Utilization, Equipment,Utilization System, objective , principles of heat transfer, Gas to Gas heat transfer, Gas to Liquid heat transfer, Recovery of waste heat in coil coating, Non-conventional liquid fuels, Heat recovery by Cogeneration.

7. CSIR-NGRI (National Geophysical Research Institute, Hyderabad)

Sl No.	Course No	Course Title	L	T	P	C
1	**PHY(NGRI)-1-001**	Research Methodology (Data management, Technical writing, communication skills, Ethical standard, Upholding environmental and human concerns)	1	1	0	2
2	**PHY(NGRI)- 2-486**	Introduction to Geosciences (Geophysics, Geology, Geochemistry, GIS)	4	0	0	4
3	**PHY(NGRI)-2-487**	Geophysical Signal Processing , Inverse theory and Computational Methods	3	1	0	4
4	**PHY(NGRI)-3-488**	Geodynamics	1	1	0	2
5	**PHY(NGRI)-3-489**	Geophysical Continua	1	1	0	2
6	**PHY(NGRI)-3-490**	Geophysical Inverse Theory	1	1	0	2
7	**PHY(NGRI)-3-491**	Advanced Seismic and other geophysical techniques for energy resources	1	1	0	2
8	**PHY(NGRI)-3-492**	Nonlinear dynamics and fractals in earth sciences	1	1	0	2
9	**PHY(NGRI)- 3-493**	Electrical and Electromagnetic methods	1	1	0	2
10	**PHY (NGRI)-3-494**	Advanced Geochemistry and Geochronology (+Isotope Geology)	2	1	2	4
11	**PHY (NGRI)-3-495**	Groundwater Exploration, Modeling and Water quality assessment	2	1	0	2
12	**PHY (NGRI)-3-496**	Space Geodesy (GPS, Space Geodesy, Space EM)	2	1	0	2
13	**PHY (NGRI)-3-497**	Advanced Seismology	1	1	0	2
14	**PHY (NGRI)-3-498**	Geomagnetism, Paleomagnetism, Archaeomagnetism	1	1	0	2

15	**PHY (NGRI)-3-499**	Potential Field theory, Gravity and Magnetics	1	1	0	2
16	**PHY (NGRI)-3-500**	Geohazards and geological Risk analyses	1	1	0	2
17	**PHY(NGRI)-3-501**	Planetary Geology	2	1	0	2
18	**PHY(NGRI)-3-502**	Geothermics, Applications to Geodynamics	0	4	0	4
19	**PHY(NGRI)-3-503**	Advanced self study as special topics in Geophysics	0	4	0	4
20	**PHY (NGRI)-4-001**	CSIR-800 Societal Programme	0	0	8	4
21	**PHY (NGRI)-4-002**	Project Proposal Writing (I & II) (Geophysics) / Project Proposal Writing (I & II) (Geology)	0	1	6	4

Brief Description of Physical Science Courses at CSIR-NGRI (Course Level-Wise)

PHY(NGRI):1-001: Research Methodology: 1-1-0-2
(Data management, Technical writing, Communication skills, Ethical standard, Upholding environmental and human concerns)
Course Coordinator: **Prof. M.K.Sen and Senior Scientists**

The course is mainly intended to provide **motivation** and foundation for students that are working to promote responsible conduct of **research for scientific excellence**. The topics will include: general practices followed in **research, orientation**, **literature and data management, Technical writing, communication skills,** Technical writing and presentation, **safety practices** in lab, IPR and Ethical aspects in science, **Ethical standard** required of individual researchers, supervisors, reviewers, editors and science managers, **upholding environmental and human concerns** in conducting experiments and geophysical exploration.

PHY(NGRI)-2-486: Introduction to Geosciences): 4-0-0-4
(Geophysics, Geology, Geochemistry, GIS)
Course Coordinators: **Group of scientists from - geology, Geophysics and Geochemistry**

1. **The solar system:** Origin of the solar system, Earth and other planets
2. **Fundamentals of geochemistry,** origin of elements, geochemical classification of elements, ion substitutions and geochemical distribution and dispersal of chemical elements.

3. **Fundamentals of crystallography**: definitions of crystalline and amorphous states, Morphology of crystals, Symmetry elements, Miller indices and Classification of crystals into 7 systems. Basic mineralogy: definitions, physical and optical properties of minerals and descriptive mineralogy of olivine, pyroxene, garnet, amphibole, micas, quartz, feldspars and feldspathoides and oxides.

4. **Fundamentals of petrology:** Definition of rocks, classification, basics of petrography, descriptive petrology of: (a) Igneous rocks–granite, granodiorite, syenite, porphritic granite, pegmatite gabbro, dunite, dolerite, rhyolite, basalt; (b) Sedimentary rocks- mode of formation source, transportation and deposition, classification of sedimentary rocks; brief description of conglomerate, breccia, sandstone, shale, limestone,

5. Dolomite, shelly limestone; (c) Metamorphic Rock: Definition, Types and agents of metamorphism, grades and zones of metamorphism. Description of Quartzite, marble, slate, phyllite, schist, gneiss, charnockite, and khondalite.

6. **The dynamic Earth**: Surface processes, Concepts of Plate Tectonics, Plate boundaries, Subduction Zones, Hot Spots and mantle plumes, Flood basalt provinces, Triple junctions, mid-oceanic ridges, transform faults, island arcs, foreland basins, back arc basins, sea mounts, bathymetry, Continental Drift, Sea Floor Spreading, making and breaking of continents (Pangaea, Rodinia, Gondwanaland).

7. **Concept of stratigraphy**, standard geological time scale, principles of correlation; introduction to ore minerals, gangue, ore and ore deposits; brief account of mineral resources of India

8. **Gravity and Figure of the Earth: (**a) Size and shape of the Earth, Gravitation, Figure of the Earth, Geoid; (b) Density distribution in the Earth, Gravity anomalies; (c) Concepts of Isostasy Seismology and Internal Structure of the Earth: (a) Elastic waves and their propagation, physical properties of rocks, P waves, S waves, Surface waves including Rayleigh and Love waves, identification of phases in seismograms. (b) Structure of the earth, crust, mantle, core, lithosphere and asthenosphere. (c) Types of seismographs, Earthquake magnitude and intensity, Location of earthquakes, types of earthquake faulting, focal mechanism; (d) Great earthquakes, Seismic hazard

9. **The Earth's Heat: (**a) Heat Flow, sources of heat inside the Earth, Heat transport in the Earth, Thermal storage and transport properties of rocks, rock radioactivity; (b) Distribution of heat flow in continents and oceans, equation of heat conduction, continental and oceanic geotherm.

10. **Geomagnetism and palaeomagnetism**: (a) Magnetic elements and description of the Earth's magnetic field; (b) Origin of Earth's magnetic field, magnetic reversals; (c) Palaeomagnetism, Continental Drift and Polar Wander

11. **Methods in exploration geophysics**: Fundamentals of (a) controlled source seismic studies, seismic refraction and reflection methods, (b) Gravity and magnetic methods, (c) electrical and electromagnetic methods, (d) radioactive methods and (e) well logging; applications in geosciences.

12. **Geographical Information System (GIS),** software, techniques and applications in geosciences.

PHY(NGRI)-2-487: Geophysical Signal Processing, Inverse Theory and Computational Methods: 3-1-0-4

NGRI 2-487A: Geophysical Signal Processing
Course Coordinators: **Dr.S.K.Ghosh and Dr.R.K.Tiwari**

Even and odd functions, Fourier transform and its properties, Discrete Fourier transform, Fast Fourier Transform **(FFT)** algorithm, Z-transform and its relation with Fourier transform, Hilbert transform analytic signal, instantaneous phase and frequency, Definition of Radon transform. **Time and frequency sampling Theorem,** Nyquist frequency, aliasing, Comb function, stationary time series, Wold decomposition theorem, ergodicity, continuous and discrete data, concepts of signal and noise, cross-and auto-correlations in deterministic and statistical senses, spectrum in terms of correlation functions, computation of spectrum for discrete data, **concept of maximum entropy,** concepts of windows and criterion for optimum window, different kinds of windows. **Principles of digital** filtering in time and frequency domains, amplitude and phase characteristics of digital filters, low pass, high pass and band pass filters, Wiener filter, deconvolution , predictive deconvolution, **Beam-steering** with an array of N detectors, velocity filtering, effects of sampling on gravity and magnetic interpretation, FFT in two or more dimensions, vertical derivatives and their interpretation as filters, U**pward and downward continuation** as a filtering process.

NGRI 2-487 B : Inverse Theory
Course Coordinators : **Dr Ravi Srivastav, Dr Abhay Ram Bansal**

Introduction- Forward and Inverse problem, what is an inverse problem? An untold inverse: Deconvolution Interpretation of inaccurate, insufficient and inconsistent data Examples Geophysics, Reservoir Engineering, Medicine etc.
Linear Algebra- Review Vectors and Matrices simple operations, Vector spaces, projections and null space, Matrix and Vector norms, Matrix factorization, Inversion, Ill-posed matrices, Eigen values and eigenvectors physical meaning, condition numbers
Classical Inverse Theory- Existence, stability, uniqueness, Under-determined, Over determined and mixed determined problems, Least squares and maximum likelihood, Data and Model Norm, Lagrange multipliers, Statistical description, Likelihood, Prior and posterior.

NGRI 2-487 C: Preliminary Statistics and Computational Methods
Course Coordinators : **Dr BPK Patro, Dr D.V. Ramanna**

Introduction to Statistical Methods – Mean values and standard deviations, probability, conditional and joint probability, **Baye's theorem**, Binomial, Normal and Poisson Distributions, Gaussian limit of the binomial distribution, Distribution of several random variables, Continuous distributions, Testing of Hypothesis. - Sampling and Large Sample Test-Chi-square test, Theory of Estimation, **Optimization techniques and Time Series**

Analysis. Random variables, Random numbers, Probability, Probability distribution, distribution function and density functions, **Examples of distribution and density functions,** Joint an marginal probability distributions, Mathematical expectation, moments, variances, and covariances, **Conditional probability, Monte Carlo integration,** Importance sampling, Stochastic processes, **Markov chain,** homogeneous inhomogeneous, irreducible and aperiodic processes, The limiting probability.

Numerical computation of derivatives: interpolation, extrapolation of functions, Newton-Raphson Method for finding roots, Numerical solutions of differential equations, Introduction to finite difference and finite element methods for solving partial differential equations, First-order differential equations, Higher order differential equations, Separation of variables, series solutions-Frobenius Method, Greens function, Heat flow or Diffusion Partial Differential Equations,

PHY(NGRI)-3-488: Geodynamics: 1-1-0-2
Course Coordinators : **Dr. R. N. Singh, Dr. V.K. Ghalaut**

GEODYNAMICS: **Plate tectonics,** convergent, divergent and transform plate boundaries, **Global seismicity** in the concept of plate tectonics, seismic zones associated with rift systems, transform boundaries, subduction zones and collisional tectonics. **Orogeny,** epeirogeny and isostasy. **Concept and classification of tectonic associations**. Tectonic classification of India. **Palaeomagnetism and past plate motions**, with special reference to the Indian plate. Heat flow, heat sources, heat transfer and geothermics. **Heat flow,** geothermal gradient and diffusion. Calculation of equilibrium and evolving geotherms. Plate cooling models. **Thermal structure of the oceanic lithosphere.** Bending or flexure of thin elastic plate. **Driving forces for plate motions**. The oceanic lithosphere - ridges, transform faults, trenches and oceanic islands. The continental lithosphere, cratons, sedimentary basins, continental margins and rift zones. **Mantle petrology** and chemical composition. **Silicate phase transitions** and correlation with mantle discontinuities. **The upper mantle transition zone**. Structure of the lower mantle and core. **Models of mantle convection**, evidence for single and double-layered convection.

PHY(NGRI)-3-489: Geophysical Continua: 1-1-0-2
Course Coordinators : **, Dr. A. Manglik, Dr. R. N. Singh**

Fundamentals of Tensors: Vector and matrix algebra, the tensor concept and its advantages, zeroth–order tensors, First-order tensors, second order tensors, examples.

CONTINUUM HYPOTHESIS: Introduction, Notion of a Continuum, Configuration of a Continuum, Mass and density, Description of motion, Material and spatial coordinates. **FUNDAMENTAL LAWS OF CONTINUUM MECHANICS AND RHEOLOGY**: Introduction, Conservation of mass, Balance of linear momentum, General solutions of the equation of equilibrium, Balance energy, Entropy, constitutive relationships, rheological properties of minerals and rocks, rheological models used in geodynamics. Exercises. **STRESS**: Introduction, Body forces and surface forces, Stress component, Stress tensor, Normal and shear stresses, Principal stresses, Stress-deviator, Boundary condition for the stress tensor, Piola-Kirchhoff stress tensors, Exercises, Mohr representation. **DEFORMATION:** Introduction, Deformation gradient tensor, Stretch and Rotation, Strain tensors, Strain-displacement relations, Infinitesimal strain tensor, Infinitesimal strain tensor, Infinitesimal stretch and rotation, Compatibility condition, Principal strains. **ELASTIC EQUATIONS**: Introduction, Generalized Hooke's law. Displacement formulation, Stress formulation, Beltrami Michell equation, some static problems, Elastic waves, Exercises. Theory of faulting, Focal mechanisms, Stress modelling, geophysical applications. **HEAT**
CONDUCTION: Thermal structure of lithosphere, Generalized heat conduction equation, Sources of thermal perturbation (external perturbations vs. internal heat sources), Solution of heat conduction eq (steady state and transient) for given boundary conditions an internal heat sources, application to continental and oceanic lithosphere, methods to determine heat flow and measure radiogenic heat sources, heat flow- heat generation relationship, moving boundary problems**. EQUATIONS OF FLUID MECHANICS:** Fluid as a continuum, stress, strain rate, viscosity, viscous and inviscid fluids; Conservation laws and constitutive relationship; Euler and Bernoulli equations, channel and pipe flow, viscous heating; Stokes flow; Navier-Stokes equation; Boundary layer concept, boundary layer instability analysis; Thermal convection; Viscosity structure of the Earth's interior; exercises

PHY(NGRI)-3-490: Geophysical Inverse Theory: 1-1-0-2
***Course Coordinators : Dr* R.P. Srivastava , Professor M. K. Sen**

Direct inversion methods: Model based inversion methods, linear inverse methods and solution of linear inverse problems, Stability and uniqueness-singular value decomposition analysis, Methods of constraining the solution, Uncertainty estimates, Iterative linear methods for quasi-linear problems, Bayesian formulation, Solution using probabilistic formulation, Linear case, case of weak non-linearity, quasi-linear case. **Monte Carlo Methods:** Enumerative or grid search techniques, Monte Carlo inversion, Hybrid Monte-Carlo-linear inversion, Direct Monte Carlo methods. **Simulated Annealing Methods:** Metropolis algorithm, Mathematical model and asymptotic convergence , Heat bath algorithm, Mathematical model and asymptotic convergence, Simulated annealing without rejected moves, Fast simulated annealing, Very fast simulated reannealing, **Mean** , Neurons, Hopfield neural networks, Avoiding local minimum, Mean field theory, Using SA in geophysical inversion, Bayesian formulation. **Genetic Algorithms :** A classified GA, Coding, selection, crossover , mutation, Schemata and the fundamental theorem of genetic algorithm, problems, Combining elements of SA into a new GA, A mathematical model of a GA , Multimodal fitness functions, genetic drift, Uncertainty estimates, evolutionary programming. **Geophysical Applications of SA and GA: 1**-d Seismic waveform inversion, Application of heat bath SA, Application of GA, Real data examples, Hybrid GA/LI, Pre-stack migration velocity estimation, I-D earth structure, 2-D earth structure, Inversion of resistivity sounding data for I-D earth models, Exact parameterization, Over parameterization with smoothing, Inversion of resistivity profiling data for 2-D earth models, Inversion of synthetic data , Inversion of field data, Inversion of magneto telluric sounding data for I-D earth models , Stochastic reservoir modeling, Seismic de-convolution by mean field annealing and Hopfield network. **Uncertainty Estimation:** Methods of Numerical Integration, Grid search or enumeration, Monte Carlo integration, Importance sampling, Multiple MAP estimation, simulated annealing: The Gibbs' sampler, Numerical examples, Inversion of noisy synthetic vertical electric sounding data.

PHY(NGRI)-3-491: Advanced seismic methods and other geophysical techniques for Energy Resources: 1-1-0-2
***Course Coordinators :* K. Sain and Dr. B Singh, Prof M.K. Sen**

Hydrocarbons: Fundamentals of Hydrocarbon Exploration with special emphasis of Seismic data acquisition, Modeling/Inversion, Seismic data processing; Basic Geological Concepts about sedimentary basins for hydrocarbon generation, migration and accumulation in different traps, Classification and formation mechanism of different type of traps.

1. Seismic Interpretation of different Geological structures for hydrocarbon exploration
2. Seismic Sequence Stratigraphy
3. Direct Detection of Hydrocarbon using Hydrocarbon Indicators.
4. Modern topics in seismic exploration studies.

5. **Exploration for Gas Hydrates**,Gas-hydrates - Definition; Structure; Morphology; Host

rock; Phase curve; Factors on stability of gas-hydrates; Geological control; Petroleum system; Geological, Geochemical and Micro-biological proxies; Energy potential; Seafloor instability

Seismics - Data Acquisition; Data processing; Pre-stack depth migration; Energy Partitioning; AVO modeling; A-B cross plot; Seismic attributes; Attenuation; Inverse-Q Filter; Traveltime tomography; Full-waveform inversion; Impedance inversion; Modeling of OBS data; Vp/Vs;

Rock physics - Biot-Gasmann theory; Effective medium theory; Logs - Sonic; Resistivity; Density; Chloride anomaly

6. **Geothermal Energy** Basic concepts of heat flow and heat transfer, Geothermal systems and resources Geophysical, Geological and geochemical techniques for exploration, Thermal energy of the oceans and related topics.

7. Reservoir characterization is a process that lies between the discovery phase and the reservoir management phase. Key objectives of reservoir characterization focus on modelling each reservoir unit, predicting well behavior, understanding past reservoir performance, and forecasting future reservoir performance.

Defining the purpose: Clarifying the reservoir characterization process and deliverables, Overview of reservoir, Rock and fluid properties, Basics of reservoir rock physics, An overview of seismic inversion, Introduction to Hampson Russell software, Hands on experience on HRS, Geo-statistical simulation of reservoir properties and. Case Studies

PHY(NGRI)-3-492: Nonlinear dynamics and fractal in earth sciences: 1-1-0-2
Course Coordinators : **Dr. Nimisha Vedanti, Dr. R. K. Tiwari**

CONCEPT OF NON-LINEAR DYNAMICS, Basics of fractal, various definitions of fractal, Random fractal, Brownian Motion, Definition of Chaos, Deterministic Chaos, Logistic Map, Different Routes to Chaos, Taken's theory of embedding dimension, Phase Space, Various methods for estimation of Dimension, Concept of Entropy, Determination of Entropy and Liyapunove exponent, Non-linear Forecasting Approaches, Critical **Catastrophe Theory** and application to Critical Phenomenon. Principal Component Analysis

Fractal theory and its applications :Mathematical background, Transformations: rotation, translation, scaling, Basic set theory, Measures and mass distribution, Basic probability theory, Fractal Geometry, Analysis of geometrical objects for fractal behavior, Self similar and self affine, Definition and computation of fractal dimension, Statistical fractal Power law, Testing a time series for fractal behavior, Hurst coefficient, Variogram, Co-variance ,Multi-fractal, Few applications of fractal theory in Earth sciences, Scaling power spectrum, b-value computation, Fractal dimension and its relation with some of the physical phenomenon, viz. occurrence of earthquakes, flow in porous media etc.
Artificial Neural Networks (ANN), The Brain as a Dynamical System., Neural Dynamics Activations and Signals; Activation Models: Neural Dynamical Systems, Additive Neuronal Dynamics, Additive Neuronal Feedback, Additive Activation

Models, General Neural Activations: Cohen-Grossberg and Multiplicative Models. Back propagation algorithm (BPA) ANN. Concept of Bayesian statistics and various aspects of ANN modeling and prediction

PHY (NGRI)-3-493: Electrical and Electromagnetic methods: 1-1-0-2
Course Coordinators : **, Dr B.P.K.Patro, Dr S.K. Verma**

Static fields in free space: Electric charges, coulomb's law, Newton's law, Field intensity, lines of force, charge density, Potential, Conservative fields, equipotent surface, Potential gradient, Poisson's and Laplace Equations, Field and potential of charged sphere, line charge, electric dipole, arbitrary distribution of charges, double layer.

Dialectics and Conductors: nature of dielectrics and conductors, Polar and non polar dielectrics, Polarization and displacement, Electrostatic equation for dielectrics, boundary conditions between two dielectrics, conducting body in electrostatic field, boundary conditions between a dielectric and conductor, tensor of polarizability, capacitance

Harmonic Functions: Orthogonal curvilinear coordinates, spherical and cylindrical coordinates, uniqueness theorem of harmonic functions, method of images, mean value of potential, Green's theorem, Green's function, solution of Laplace equation in unbounded region, Green's equivalent stratum, Dirichlet and Nueman problems, Solution of Laplace equation by separation of variables

Electric Fields in Conductors: Current & current density, Ohm's law in differential & integral form; equation of continuity, Lap lace's equation and boundary conditions; point

electrode near the boundary of two conducting media; dissipation of energy in current flow; relation between resistance and capacitance

Magnetic fields: concept, magnetic field of current, magnetic field of a circular loop & solenoidal current, Integral and differential forms of Ampere's law, magnetic flux, Magnetic vector potential, magnetic dipole, magnetic media magnetization vector, H-field, magnetic susceptibility and permeability, boundary conditions, Ferromagnetism, magnetic poles, magnetic scalar potential, magnetic circuit, relation between gravity and magnetic potentials.

Law of electromagnetic induction, self & mutual inductance, electric & magnetic energy densities, discharge of a capacitor through inductance and resistance, displacement currents, electromagnetic energy and Poynting's theorem,
Maxwell's equations and in complex notation, Wave equation, waves in conducting media, vector and scalar potentials of an electromagnetic field, electromagnetic radiation from an oscillating dipole.

Brief concepts of Electrical methods – data acquisition and processing of data. Concept of apparent resistivity. Homogeneous anisotropic earth potential. Description of geoelectric section. Interpretation of resistivity sounding for horizontal boundaries. Resistivity profiling, apparent resistivity about structures of geometrical shape and arbitrary shape. Basic concepts of IP, time and frequency domains, theoretical and model work

The Electromagnetic theory of induction. Brief concepts of electromagnetic depth soundings. Computation of response for loop and dipole sources for two and three layer earth models. Interpretation of EM sounding Curves. Forward problem – graphical and scale modeling. Inverse problem. Brief concepts of transient sounding – data acquisition and processing. Interpretation of transient EM Soundings. Induced polarization soundings – Parameters involved in measurement, time and frequency domain methods. Brief introduction of MT soundings, data analysis, electromagnetic induction, plane, spherical, non-uniform conductors and model experiments – numerical methods. Data analysis of MT method – Fourier spectra and spectral analysis of various components.

Principles of other EM methods – AFMAG, VLF and Radiowave mapping methods. Brief description of finite element modeling used for VLF method. Interpretation of AFMAG and Radiowave mapping methods.

PHY (NGRI)-3-494: Advanced Geochemistry and Geochronology (+Isotope Geology): 2-1-2-4
Course Coordinators : Dr. Anil Kumar , Dr. YJ. Bhas Dr. Anil Kumar kar Rao, Dr. EVSSK. Babu, Dr. C. Manikyamba

Petrology:
- of isotopic dating
- Definitions
- Basics of Petrography
- Classification of rocks into Igneous, sedimentary and Metamorphic rocks.

Igneous Petrology:

- Magma and magma genesis, Partial melting and Magmatic differentiation, Contamination and Mixing of magmas, Role of Volatile components, Binary and Ternary systems
- Textures and structures of Igneous rocks
- Classification of Igneous rocks - historic perspective and the IUAG systematic
- Petrogenetic Provinces: Continental areas , Layered gabbroic instrusions , Plutonic, Oceanic areas and Oceanic Rift valleys
- Descriptive petrology: Volcanic and Plutonic Igneous rocks
- Continental and oceanic mantle lithosphere
- Magmatism and Plate tectonics
- Mid-Oceanic-Ridge-Basalt (MORB)
- Island arc basalts
- Case histories with Indian examples

Metamorphic Petrology

- Concepts of metamorphism, metamorphic agents and their controlling factors
- Grades of Metamorphism
- Common minerals of metamorphic rocks, textures and structures

- Metamorphic facies concept
- Metramorphism types & products
- Phase diagrams and graphic representation of mineral assemblages
- Prograde and retrograde metamorphism, Metasomatism
- Metamorphic reactions, Elemental exchange–exchange and net-transfer reactions
- Equilibrium thermodynamics and Geothermobarometry
- Barrovian zones and P-T conditions of isograds
- Plate tectonics and metamorphic processes, paired metamorphic belts
- Pressure-temperature time paths in regional metamorphic rocks, Polymetamorphism
- Archaean, Proterozoic terrains-greenstone-amphibolite-granulite terrains of India

Sedimentary Petrology

- Geologic cycle
- Definitions and fundamental concepts in Sedimentary Petrology
- Sedimentary textures (Granulometric analysis, shape and roundness studies, surface textures)
- Petrography of rocks of clastic, chemical and biochemical origin (Conglomerates, Sandstone, Mudstone,Limestone & Dolomite)
- Evaporite, Phosphorite, Chert, Iron and Manganese rich sediments
- Sedimentary structures (Physical structures, Biogenic sedimentary structures, Diagenetic structures)
- Concept of Sedimentary facies association models (Marine, Nonmarine, and Mixed Depositional Environment)
- Sedimentation and Tectonics
- Paleocurrents & Basin Analysis
- Specific Case histories on the sedimentary basins of India

Geochemsitry & Isotope Geochemistry

- Introduction to Geochemistry – its scope,
- Origin of elements
- Geochemical Classification of the elements
- Mobility of chemical elements in geological environment
- Fundamentals of Thermodynamics
- Reversible and irreversible reactions
- Geochemical Cycle
- Geochemical data interpretation in Igneous, sedimentary and metamorphic petrology
- Law of Radioactivity
- Principles Decay schemes and Derivation of equation of age
- Introduction to isotope geochemistry
- Principles of Mass Spectrometry
- Instrumentation for Mass Spectrometry
- K-Ar, Ar-Ar, Rb-Sr, Sm-Nd, Re-Os, Lu-Hf, U-Th-Pb methods of dating the rocks
- Specific case histories

PHY (NGRI)-3-495: Groundwater exploration, Modeling and water quality assessment: 2-1-0-2

Water and Environmental Geosciences

Course Coordinators : **R. Rangrajan, Drs.Shakeel Ahmed, D.V. Reddy, K. Ram Mohan**

Introduction: Hydrological cycle, Components of hydrological cycle (Precipitation, Evaporation, Transpiration, Evapotransipiration, Runoff, Infiltration, and groundwater recharge), Characterization of aquifers, Groundwater flow in saturated/unsaturated porous media.

Groundwater exploration – Basic principles of geophysical methods, i.e. Geo-electrical, Gravity, Seismic, Magnetic and Electromagnetic methods, Ground Penetration Radar, Geochemical methods, Remote sensing and Geographic Information Systems, Soil Gas Radon Emanometry; procedures of data processing and interpretations.

Aquifer Parameters Identification: Recharge evaluation using isotopes and tracers techniques, Lithologically constrained rainfall (LCR) method and Entropy based method; Pumping test analysis, Inverse methods, Electrical resisitivity and Multivariate Geostatistical methods for estimation of Hydraulic conductivity, Transmissivity and storativity.

Groundwater flow modelling: Basic principles and formulation of groundwater flow equations in saturated media, Methods of solutions: Analytical Methods and Numerical Methods (Finite Difference/ Finite Element), Analysis of Hydrogeologic Data for Flow and Mass transport Modeling.

Environmental Geosciences:

Properties of Potential contaminants and related environment and health hazard: (1) Inorganic and organometallic (Nitrogen, Phosphorous, Salts, Radionuclides, Arsenic, Cadmium, Lead, Nickel); Organic (Pesticides, Clorinated Hydrocarbons, Pharmaceutical and Personal care products), water sampling, analysis, units in water quality determination, surface water quality processes, groundwater quality processes, Modes of Contaminants transport-Advection, Dispersion and Molecular diffusion, Formulation and methods of solution of non-reactive contaminants transport equation, Dynamics of freshwater-saltwater interface in coastal region. Remedial methods for removal of soil/water contaminants

Advanced: Introduction to softwares MODFLOW for simulation of ground water flow; MT3D for simulation of contaminants transport, SEWAT for simulation of density dependent transport for Seawater Intrusion, GRACE (Gravity Recovery and Climate Experiment) for estimation of Land water storage variation over land, Decision Support Tools (DST-GW) for estimation of water balance.

PHY (NGRI)-3-496: Space Geodesy (GPS, Space Geodesy, Space EM): 2-1-0-2

Course Coordinators : **Dr. V.M. Tiwari, Dr. V.K. Gahalaut,**

Definition and scope of Geodesy, Earth, Geoid. Ellipsoid of rotation.

Kepler's laws: the celestial sphere, fundamentals of 3-D reference system, spherical trigonometry, geodetic reference systems, principles of space and satellite geodesy, Solar and stellar determinations of astronomic azimuth, astronomic positioning using stars.

Potential theory, spherical harmonics, shape of the earth, rotation and orbit of the earth, satellite orbits; measuring gravity, gravity anomalies, gravimetric geoid; satellite altimetry, use of satellites in determining the earth's gravity field, Basic principles of satellite based gravity observations.

Global Navigation Satellite System (GNSS), Basic principles of GNSS operations, ranging from space, GNSS constellation, its evolution and present state. Description of various satellite systems: GPS, GLONASS, Galileo, WAAS, GAGAN, IRNSS, DORIS, COMPASS etc. Datum and reference frames, Sources of errors in navigation and ranging and their avoidance. Mathematical models for absolute and relative static positioning. Characteristics of GNSS instrumentation and data processing software. Theoretical and practical aspects of planning, execution and data analysis for kinematic and static GNSS surveys.

Basic principles of Synthetic Aperture Radar (SAR)

Use of space geodetic techniques for creation and maintenance of co-ordinate reference frames, control surveying, tectonic geodesy and applications of new generation gravity satellites (GRACE and GOCE) data.

PHY(NGRI)-3-497: Advanced seismology: 1-1-0-2
Course Coordinators : **Dr. N. P. Rao, Dr. P. Mandal, Dr. S. S. Rai, ,**

Basics of seismology including earthquakes, faults, seismic waves, hypocentral parameters, intensity, different magnitudes, and source parameters. Characterization of seismic sources and their radiation characteristics including focal mechanisms and moment tensor inversion.

Continuum mechanics of linear elastic media, including stress, strain and traction. Derivation of linear elastic waves and their characteristics from the equation of motion. Ray tracing in layered and spherically symmetric media including Snell’s law, Huygen’s principle, Fermat’s principle, ray parameter, slowness, Eikonal equation, kinematic ray theory and concept of dynamic ray theory.

Theory of Love and Rayleigh surface waves. Use of surface wave dispersion in deciphering earth’s structure.

Geopysical Tomography- Essentials of synthetic seismograms, anisotropy and teleseismic receiver functions. Theory of one- and three- dimensional velocity inversion and other advance techniques and analyses

PHY(NGRI)-3-498: Geomagnetism, Paleomagnetism, Archaeomagnetism: 1-1-0-2
Course Coordinators : **Dr. Ajay Manglik Dr. Kusmita Arora, Dr. Anil Kumar**

Elements of geomagnetic field, global pattern, time variations, measurement techniques, spherical harmonic analysis, geomagnetic maps, IGRF, origin, crustal and core fields, secular variations

Magnetic properties of minerals and rocks, magnetic remanence, magnetic chronology, excursions and reversals, polar wander

Navier-Stokes equation, boundary layer concept, boundary layer instability analysis, Rayleigh –Taylor instability, convection at large Rayleigh number
Dynamo theory, magneto-hydrodynamic equations, energy budget of the core, convection in rotating spherical shell, driving forces, toroidal and poloidal decomposition, tangent cylinder, numerical simulations, control parameters, scaling laws, influence of mantle dynamics

The Geomagnetic Environment: basic characteristics, field parameters, units of measure, Components of Geomagnetic field and time scales, Observations from surface and satellites, Geomagnetic Indices, Geomagnetic Storms and Disturbances: magnetospheric and ionospheric effects, Geomagnetic reversals: link to paleomagnetism and archeomagnetism, Geomagnetic Theories, geodynamo, Magnetic Maps for the Earth's Surface, geomagnetic anomalies Geomagnetic Coastal Effects: continent-ocean transition, Induction effect of geomagnetic variations for study of conductivity structure

PHY (NGRI)-3-499: Potential Field theory, Gravity and Magnetics: 1-1-0-2
(Potential Field Methods in Applied Geophysics)
Course Coordinators : **Dr.V.M.Tiwari, A.P.Singh**

This course will examine the theory and practice of potential field methods in geophysics. Potential field methods include gravity and magnetic surveys; these methods rely on gravitational and magnetic fields and are used to image the subsurface. The focus of this class will be the forward and inverse modeling of potential field data in resource exploration and geodynamics.
Elements of Potential field:
Mathematical and Physical Fields: Continuity, Examples of scalar and vector fields in Physics, Gravity & Magnetic fields due to bodies of standard shapes and Problems related to potential field theory between gravity and magnetic potentials.

Gravitational and magnetic potentials, equipotential surfaces, forces of attraction - gravity and magnetic, Gauss's (divergence) theorem, Laplace's equation, Poisson's equation, Gauss's integral formula,

Gravity method: Reductions of gravity observations, gravity anomalies (Free-air, Bouguer), fractal analysis, Isostatic models, lithospheric flexure, Interpretation of gravity anomalies {(regional/residual separation, forward (anomalies due to regular and arbitrary 2D and 3D geometrical source, solid angle and line integral approach) and inverse (linear
and nonlinear) modelling methods)}, computation of excess mass, gravity gradient tensor, Integrated modelling of gravity and geoid.

Gravity anomalies over important tectonic domains (rift basins, mountain chains, continental and ocean margins, oceanic ridge, subduction zones), applications to geodynamics.

Magnetic method*:* Reduction of magnetic anomalies. Interpretation of magnetic anomalies forward (magnetic anomalies of 2D and 3D regular and arbitrary shaped bodies) and inverse modeling) , Joint inverse modeling of gravity and magnetic anomalies
Transformations of potential fields (frequency filtering, equivalent stratum, analytic signal, Poisson's relation), ambiguity in interpretation.

PHY(NGRI)-3-500: Geohazards and Geological Risk analyses: 1-1-0-2
Course Coordinators : **Dr.Kirti Srivastava, Dr.R.K.Chadha**
Structural Geology:

Concept of stress and strain, Stress-strain relationships of elastic, plastic and viscous materials, measurement of strain in deformed rocks, behaviour of minerals and rocks under deformation conditions. Folds, their classification and causes, diapirs and salt domes. Shear zones, recognition of shear zones and faults in the field, mechanics of shearing and faulting, Geometry of thrust sheets, Block faulted and rifted regions. Wrench faults and associated structures. Tectonic mélanges, Dome and basin structures, Structural behaviour of igneous rocks, Foliations and Lineations, their classification, origin and significance, Petrofabric analysis (microfabrics), data collection, plotting, symmetry and interpretation, concept of symmetry of fabric of tectonites.

Geotectonics:

Tectonic framework of earth’s crust, interior of earth, Isostasy, convection currents, Wilson Cycle, Continental Drift: Computer fitting, geological and palaeontological evidences in support of continental drift and insitu theories. Sea-floor spreading: Hess’s concept and evidences of sea-floor spreading. Vine-mathew’s magnetic tape recorder. Plate tectonics: Concept of plate and plate movements, plate model of Morgan, nature of convergent, divergent and conservative plate margins, transpression and transtension. Plate tectonics in relation to igneous, sedimentary and metamorphic processes and mineralization. Triple junctions, aulocogens, plume theory, island arcs. Nature and origin of earth’s magnetic field.

Earthquake hazard: Great earthquakes and damages, Paleoseismology, Seismic source and dynamic rupture modeling, Seismic hazard assessment, Strong ground motion prediction through probabilistic and deterministic analysis, simulation of synthetic accelerograms, Seismic hazard maps, Seismic Microzonation, Vulnerability analysis, Seismic risk, Geotechnical analysis, Structural geology, Site amplification effects, Liquefaction potential, Earthquake effects on structures, Earthquake resistant design, Landslides, Tsunamigenic earthquakes.

Tsunami hazard: Causes of tsunami, tsunamigenic zones in the world, tsunami wave Propagation, Shallow water equations, Okada's solution, classical Boussinesq equations, earthquake source parameters as inputs, effects of bathymetry, factors responsible for generation of tsunami, tsunami shoaling and run-up heights, coastal geomorphology, tsunami inundation, tsunami modeling, Bottom Pressure tsunami sensors, tsunami warning system, tsunami forecast.

Avalanches and Volcanic Hazards:

Volcanoes: Etymology, Plate tectonics and hotspots, Divergent plate boundaries, Convergent plate boundaries, Hotspots,Volcanic features, Erupted material:Lava composition,Lava texture. Classification of volcanoes, Notable volcanoes, Effects of volcanoes,Volcanoes on other planetary bodies, Traditional beliefs about volcanoes,Panoramas.Types of Volcanic Eruptions:Volcanic Earthquakes, Directed Blast, Tephra, Volcanic Gases, Lava Flows, Debris Avalanches, Pyroclastic Surge, Pyroclastic Flows, Volcanism and Plate tectonics, Magma, Rheology, Magmatic Gases and Triggering of Eruptions, Volcanic Edifices and Deposits, Eruption types, Pyroclastic flows, Magma/water interactions, Subduction Zones, Mid-ocean ridges, Seamounts and volcanic islands, Continental intraplate volcanism, Hazards and disaster mitigation,Volcanoes and climate.

Geotechnical Engineering

Introduction: Geologic Engineering, Soil Mechanics, Geotechnical Engineering, Historical Development of Geotechnical Engineering, Engineering Geology and Groundwater, Physical Properties of Earth, Earth, Rock and Soil, Rock Groups and Weathering, Soil Formations, Transport, & Deposition of Various Types of Soil Deposits, Soil Physical Characteristics, Clay Formation, Soil Particle Size and Shape and Clay Plasticity, Weight-Volume Relationships, Relative Density, Soil Classification, Water in Soils, Static Water and Its Effects, Static Pressure, Capillary Force, Dynamic Water and Its Effects, Dynamics of fluid flow, Darcy's Law for Flow through Porous Media, Soil Permeability and One-dimensional Flow, Total Stress, Effective Stress, Seepage, Capillary Rise, Quick Condition, 2-D Flow and Flow Net Construction, Soil Stresses, Stresses due to Surface Loads, Stress Distribution, Approximate Solution, Elastic Solution, Influence Charts, Compressibility, Consolidation, and Settlement, Compressibility of Cohesiveless Soil, Consolidation of Cohesive Soil, Time-dependent Settlement and Spring Analogy, The Odometer and Consolidation Testing, Determination of Preconsolidation Pressure, Casagrande Construction Method, Settlement Computations, Time Rate of Consolidation, Terzaghi's One-dimensional Consolidation Theory, Evaluation of Cv (Coefficient of Consolidation), Computation of Rate of Settlement, Soil Strength, Stresses at a Point (Mohr Circle Pole method), Stress-Strain Relationships and Mohr-Coulomb Failure Criteria, Tests for Determining the Shear Strength of Soils, p-q Diagram and Stress Paths.

PHY(NGRI)-3-501: Planetary Geology: 2-1-0-2
***Course Coordinator:* Dr. P. Senthil Kumar**

- Historical development of planetary exploration. Approaches to planetary geological research and methodologies. Application of remote sensing and rover based studies and astronautics in space exploration.
- Fundamentals of astronomy and astrophysics with reference to the Solar System. Galaxies and stars – modes of occurrence and formation theories. Introduction to physics and chemistry of the Solar System. Various models of origin of the Solar System.

- Planetary geological mapping and analysis – mapping of material and structural units – digital tools of geological mapping – stratigraphic relationships and elucidation of geologic history.
- Tools of geophysics to understand the planetary interior and geodynamics of various planetary bodies.
- Exterior geologic processes – the role of atmosphere and surface interaction. Physical and chemical properties of planetary atmospheres – Atmospheric circulation models – causes and consequences of climate change – atmospheric agents of planetary surface modification and space weathering.
- Impact cratering – various approaches to study the impact structures – mechanisms of impact cratering, vaporization, melting, shock metamorphism, fracturing and fragmentation. Stages of impact crater growth during contact, compression and modification stages. Morphology of impact craters, complex craters and multi-ring basins – role of atmosphere on projectile history and ejecta evolution – projectile sources and pathways. Impact crater records of Mercury, Venus, Earth, Moon and Mars. Representation of impact crater density data and age determination for various planetary surfaces. Field geological studies at Lonar crater to identify impact crater parts, materials and field relationships.
- Volcanism in the inner Solar System. Effusive and explosive volcanism in Mercury, Venus, Earth, Moon and Mars. Volcanoes, morphologic types, modes of formation and conditions. Magmas and lavas and their physical and chemical evolution. Thermal evolution of planetary lithosphere and volcanic history of planets. Field visit to Deccan Traps to understand the basics of physical volcanology.
- Tectonic processes in the inner Solar System. Brittle and ductile deformation. Folds, fractures and faults in the planetary surface. Geometry, kinematics and dynamics of tectonic structures. Basics of structural geologic mapping through field studies in the Dharwar craton and southern granulite terrain.
- Mineralogy of planetary surface. Remote sensing and laboratory based studies of reflectance spectroscopy for identification of minerals and rocks on Mars and Moon.
- Asteroids, comets and meteorites: modes of occurrence, morphology, composition, and formation histories.
- Monthly seminars on latest research results from planetary sciences, review of selected science topics, including invited lectures by globally renowned scientists.

PHY(NGRI)-3-502: Geothermics, Applications to Geodynamics: 0-4-0-4
***Course Coordinator:* Dr.Sukanta Roy**

1. Concepts in Geothermics

   (i) Fundamentals of Heat flow
   (ii) Heat transfer inside the Earth
   (iii) Sources of heat
   (iv) Thermal storage and transport properties of rocks
   (v) Heat from radioactivity; relation to heat flow
   (vi) Heat loss from continents and oceans, Energy budget of the Earth

2. Continental Heat Flow

    (i) Determination of virgin rock temperatures, geothermal gradient, heat flow, corrections
    (ii) Measurements of thermal conductivity, diffusivity
    (iii) Analysis of rocks for U, Th and K abundances, radiogenic heat production
    (iv) Anisotropy, temperature and pressure dependence in thermal properties
    (v) Thermal Structure of Continental Lithosphere

3. Oceanic Heat Flow

    (i) Oceanic heat flow
    (ii) Measurement techniques
    (iii) Age dependence of heat flow, bathymetry and lithospheric thickness
    (iv) Ocean Cooling Models; Hydrothermal Circulation
    (v) Thermal Structure of Oceanic Lithosphere (including subduction zones)

4. Applications of Geothermics

    (i) Heat flow and geodynamics
    (ii) Geothermal record of climate change, integration with other proxy indicators of climate change
    (iii) Exploration for geothermal energy resources
    (iv) Geothermics and hydrology

PHY (NGRI)-4-002: Project Proposal Writing (I &II) (Geology) / Project Proposal Writing (I &II) (Geophysics): 0-1-6-4
Course Coordinators: **Prof. M.K.SEN, Anil Kumar, Dr. R.K. TIWARI, Shakeel Ahamad and S..K. Ghosh**

The main aim of this course is to provide the opportunities for students to gain insights and experience in writing project proposals. The topic will cover: Title of Major Program, Category, Title of the Proposed Project, Definition of the research problem, Duration of the project,, Project Investigator (PI), Co-Project Investigator(Co-PI), (Necessary if the PI is retiring within the duration of the project), PROJECT SUMMARY,: PROJECT DESCRIPTON: Motivation, Significance of the Project, State of knowledge, Project organization, Methodology: Work elements, Deliverables, Referencing and citing the published work and acknowledgements:, Project team :existing and required:, Budget estimates (Detailed justification for above requirements) Existing equipment and other resources Equipment and other resources requirement as projected in Budget Estimate, Human Resources Development, Collaborations: National, International etc.

In addition to this course will also provide the opportunities to learn to find research problem and writing a substantial research papers in the style typical of peer reviewed journals such as Earth and Planetary Science, Journal Geophysical Research, Geophysical Research Letters, Nature and Science etc.

Every student needs to submit two proposals in which one proposal should focus on Ph.D research topic and another proposal should deal with any other general interest subject.

21. PHY: (NGRI)-4-001: CSIR-800 Societal Programme: 0-0-8-4
Course Coordinators: **Dr.M.J.Nandan, Dr. Srinagesh, Dr. Devendar**

The theme of the project is to infuse power of scientific and technological awareness and temper to unprivileged rural and poor people, how earth sciences can solve some of their problems related to hazardous and natural calamities like earthquakes and landslides extreme climate changes, use of geophysical methods for finding drinking water, hazards of fluoride in drinking water, conservation of water, energy and the environment, spreading awareness about earthquakes, building relatively safe structures, different earthquake zones in the country. Hazards of radiations and safe mining of atomic minerals.

8. CSIR-NIO (National Institute of Oceanography, Goa)

Course No	**Title of the course**	**L-T-P-C**
	Compulsory courses	
PHY(NIO)-1-001	Research Methodology (August Semester)	1-1-0-2
PHY(NIO)-2-556	Introduction to oceanography (August Semester)	4-0-4-6
PHY(NIO)-2-557*	Junior Level Mathematics (August Semester)	2-0-2-3
PHY(NIO)-2-558	Oceanographic observations (January Semester) (conducted for both August & January batches together)	1-0-4-3
PHY(NIO)-3-559*	Senior Level Mathematics (August Semester)	2-0-2-3
PHY(NIO)-4-001	CSIR-800 Societal Program (Second Year)	0-0-8-4
PHY(NIO)-4-002	Project proposal writing (Second Year)	0-1-6-4
	Optional courses	
PHY(NIO)-3-560	Advanced Self Study	0-2-4-3
PHY(NIO)-3-561	Marine mineral deposits	2-0-2-3
PHY(NIO)-3-562	Quaternary climatology	2-1-0-3
PHY(NIO)-3-563	Micropaleontology	2-0-2-3
PHY(NIO)-3-564	Continental margins and ocean basins	2-1-0-3
PHY(NIO)-3-565	Marine sedimentary processes	2-0-2-3
PHY(NIO)-3-566	Geophysical fluid dynamics	2-0-2-3
PHY(NIO)-3-567	Waves and Tides	2-1-0-3
PHY(NIO)-3-568	Dynamics of the North Indian Ocean *(This course is not offered for 2012-13 Academic Year)*	2-0-2-3
PHY(NIO)-3-569	Marine trophic dynamics & ecosystem functioning	2-0-2-3
PHY(NIO)-3-570	Marine microbiology	2-0-2-3
PHY(NIO)-3-571	Experimental marine biology & ecology	2-0-2-3
PHY(NIO)-3-572	Marine biotechnology	2-0-2-3
PHY(NIO)-3-573	Marine chemical cycling	1-1-2-3
PHY(NIO)-3-574	Marine pollution	2-0-2-3

PHY(NIO)-3-575	Coastal Engineering	2-1-0-3

PHY(NIO)-1-001; PHY(NIO)-4-001 and -002 are AcSIR compulsory common courses.

PHY(NIO)-2-557: For students who have not studied mathematics at HSS Level; PHY(NIO)-3-559: For students who have studied mathematics at HSS Level; Students with Masters in Mathematics need not opt for any of these two, instead they should take one additional elective in level 3 series. * - any one course to be opted.

PHY(NIO)-2-558 involves total 56 hours of work on board research ship and fieldwork equivalent to 2 practical credits. This course will be conducted any time during January-February.

Credits to be acquired from compulsory courses = 22

Credits to be acquired from August Semester = 11

The electives are offered only during the January Semester for those who have already acquired compulsory course credits of preceding year August-Semester.
PHY(NIO)-3-560 can be opted for any of the two semesters.
Only two electives to be opted. Those do not opt for PHY(NIO)-2-557 or PHY(NIO)-3-559 should opt for three electives.
Credits to be acquired from January Semester = 9
Credits for classroom work = 17
Credits for project based and field work = 11

Brief Description of Physical Science Courses at NIO, Goa
(Course level wise)

PHY(NIO)-1-001: Research Methodology: 1-1-0-2
Course Coordinator: S. R. Shetye

The course covers General practices in research (literature and data management); communication skills (writing and presentation); scientific ethics; laboratory safety practices; intellectual property rights (IPR) etc.

PHY(NIO)-2-556: Introduction to oceanography: 4-0-4-6
Course Coordinators: B. Nagender Nath, A. K. Chaubey, S. Prasanna Kumar, M. Ramesh Kumar, D. Desai, M. Gauns, M. Dileep Kumar, V.V.S.S. Sarma

The course deals with various disciplines of oceanographic science. Basics of ocean floor morphology, plate tectonics, geodesy, backarc basins, sedimentary processes, marine mineral deposits, paleoclimatology, coupled ocean-atmosphere system, physical aspects of atmosphere, wind-forced and thermohaline circulations, water masses, air-sea interaction, coastal and estuarine physical processes, seawater composition, salt-balance, marine biogeochemical cycles, biogenic gases and climate, global climate change and ecosystem, exchange of material across marine interfaces, plankton biomass, carbon cycle-biological pump, microbial diversity, energy transformation by living marine organisms, pelagic communities, ecologically sensitive marine habitats, biofouling etc will be covered in this course.

PHY(NIO)-2-557: Junior level Mathematics: 2-0-2-3
Course Coordinators: D. Shankar and S. G. Aparna

This course is designed for those who have not studied maths after tenth standard. The course will start with basic calculus and lead on to differential equations.

PHY(NIO)-2-558:Oceanographic observations and sampling: 1-0-4-3
Course Coordinator: V. Fernando

In this course the students will participate in an oceanographic cruise/field work of four to six days to acquaint with various sampling operations, field equipment and techniques useful to all branches of Oceanography. Few essential lectures /tutorials related to the course will be conducted.

PHY(NIO)-3-559: Senior level mathematics: 2-0-2-3
Course coordinators: P. Dewangan and S. G. Aparna

This course is for those who have studied maths in their undergraduate level. The course is comprised of review of basic calculus and programming, ordinary differential equations, partial differential equations, and numerical analysis. In solving ordinary and partial differential equations, both analytical and numerical methods will be used.

PHY(NIO)-3-560: Advanced self study: 0-2-4-4
Course Coordinator: Ph.D. Guide

This course is designed to prepare the students for research in their field of interest. The student shall choose a subject closely related to the research problem and develop few feasible concepts or hypothesis to be tested through the doctoral program. The PhD guide of the student or a mentor shall conduct this course.

PHY(NIO)-3-561: Marine Mineral Deposits: 2-0-2-3
Course Coordinators: A. Mazumdar and B. Nagender Nath

The course deals with genesis of various marine mineral deposits; exploration and mining aspects of those deposits.

PHY(NIO)-3-562: Quaternary climatology: 2-1-0-3
Course Coordinators: R. Saraswat and V. K. Banakar

The course contains detailed aspects of Quaternary climate change- Ice Age; Fundamental forces driving Quaternary climate variability; Various proxies sensitive to climate change; Extraction of climate information from marine proxies. Fundamentals of dating techniques.

PHY(NIO)-3-563: Micropaleontology: 2-0-2-3
Course Coordinators: R. Nigam and R. Saraswat

The course contains description of various types of marine microfossils (calcareous, siliceous, organic walled); Sample processing for microfossil study; Properties of microfossils used as techniques in paleoclimatology; Marine microfossils and past sea level changes and monsoon variability; Role of marine microfossils in pollution monitoring and petroleum exploration; Laboratory culturing of foraminifera.

PHY(NIO)-3-564: Continental margins and ocean basins: 2-1-0-3
Course Coordinators: K. S. Krishna and P. Dewangan

The course covers Earth’s Interior: Seismology, Seismic reflection and refraction, Potential fields (gravity and magnetics), seismic and magnetic stratigraphy, geomagnetic field and magnetic stratigraphy, formation of continental margin and development of adjacent ocean basin, geological features of the continental margin and associated geophysical signatures, continent-ocean boundary/transition, sedimentary basins of continental margins and hydrocarbon resources, continental drift, seafloor spreading and Plate tectonics, paleo-geographic reconstruction, mid-oceanic ridges and deep ocean and back arc basins

PHY(NIO)-3-565: Marine sedimentary processes: 2-0-2-3
Course Coordinators: V. Ramaswami and B. Nagender Nath

The course contains details of variety of mechanism (physical, chemical, and biological) through which sediment is produced and redistributed from its source regions to ultimate sink in the oceans; various sedimentary processes and their variation through time; sedimentary environments; role of sedimentation processes in global biogeochemical cycles; post depositional changes and application of trace element geochemistry and isotope techniques to important problems in sedimentary processes.

PHY(NIO)-3-566: Geophysical fluid dynamics: 2-0-2-3
Course Coordinator: D. Shankar

This course aims to introduce the students to the fundamentals of Geophysical Fluid Dynamics, with the emphasis being on the large-scale, wind-forced circulation of the North Indian Ocean. In order to present a unified view of the dynamics, whether mid-latitude off-equatorial) or equatorial or coastal, the course will use the linear, continuously stratified (LCS) model as the primary mathematical tool.

PHY(NIO)-3-567: Waves and tides: 2-1-0-3
Course Coordinators: P. Vethamony and A.S.Unnikrishnan

The course deals with classification of surface waves based on wave period and depth of propagation; waves in shallow waters; wave modelling; waves during extreme events; sea-swell interaction in the coastal region; tracing of swells generated in the Atlantic and South Indian Oceans in the AS and BoB; generation of tides in the open ocean; description of various tidal constituents; tidal propagation on the continental shelves; tide-related physical processes on the shelves; characteristics of tidal propagation in estuaries; 1-D and 2-D models of tidal propagation in estuaries; analysis of observed tide gauge data and prediction of tides.

PHY(NIO)-3-568: Dynamics of the North Indian Ocean: 2-0-2-3
Course Coordinator: D. Shankar

This course builds on the GFD course [PHY(NIO)-308] and will show how the processes act in concert to produce the observed circulation. The observational part will go beyond the seasonal cycle and introduce the student to the variability at intra-seasonal and inter-annual time scales. As with the GFD course, in order to present a unified view of the dynamics, this course will use the linear, continuously stratified (LCS) model as the primary mathematical tool. *(This course is not offered for 2012-13 Academic Year)*

PHY(NIO)-3-569: Marine trophic dynamics and ecosystem functioning: 2-0-2-3
Course Coordinators: S.G.P.Matondkar and S. Mitbavkar
The course deals with trophic levels and dynamics; food web dynamics in different ecosystems; population connectivity in marine systems and biogeography; microbes as mineralisers and producers.

PHY(NIO)-3-570: Marine microbiology: 2-0-2-3
Course Coordinators: C. Mohandass and P. A. Loka Bharati

Introduction to marine microbial life and microbial ecology; isolation and identification of marine microbes; bacterial and archaeal fine structure and physiology; microbial nutritional diversity; extremophiles; factors governing microbial biomass build up, physiology and ecological interactions; microbial loop and its biogeochemical significance; environmental controls regulating microbial population structure and size; phylogenetics of marine microbes; physiological profiling of microbial communities; Molecular techniques for microbial community analysis; Ecology of culturable marine microbes; genomics and proteomics; fundamentals of microbial non-culturability; marine viruses; molecular techniques for profiling genetic and functional viral diversity. Coastal pollution. Microbe mineral interaction.

PHY(NIO)-3-571: Experimental marine biology and ecology: 2-0-2-3
Course Coordinators: L. Khandeparker and J. S. Patil

The course contains an overview of experimental marine biology and ecology and deals in detail about culture techniques and quantification of phytoplankton, zooplankton and marine invertebrate larvae; influence of climate change on structure and functioning of ecosystems; microbe-metazoa interactions and biosignalling; life in marine sediments; marine bioinvasion; biofilms/biofouling; chemical ecology

PHY(NIO)-3-572: Marine biotechnology: 2-0-2-3
Course Coordinators: N. Ramaiah and N. Thakur

The course introduces marine biotechnology is an interdisciplinary field that draws from marine biology, chemistry, genomics, bioinformatics and technology. Topics covered in this course are, exploration and strategies for detection, isolation, cultivation of marine microflora, marine pharmaceuticals: discovery and development, enzymes from marine microbes: sources, characterization and applications, marine biodeterioration and bioremediation, marine aquaculture, biomaterials from marine organisms and their characterization, molecular taxonomy and phylogenetics, genomics and proteomics of unique marine microbes and large-scale production of marine microorganisms.

PHY(NIO)-3-573: Marine chemical cycling: 1-1-2-3
Course Coordinators: M. Dileep Kumar and V.V.S.S.Sarma

The course emphasizes on how physical, chemical, biological and geological processes control the abundances of substances in seawater and their cycles in the oceans. The course also covers the regulating processes and mechanisms with respect to marine pollution and changing climate.

PHY(NIO)-3-574: Marine pollution: 2-0-2-3
Course Coordinators: S. S. Sawant and P. Chakraborty

The course contains various aspects of marine chemical and biological pollution; environmental implications of pollution; pollution evaluation and monitoring; pollution management; environmental regulations.

PHY(NIO)-3-575: Coastal engineering: 2-1-0-3
Course Coordinators: S. Sanil Kumar and Jaya Kumar

The course describes various aspects of coastal processes such as wave breaking, near-shore currents, beach and shoreline dynamics, sediment transport, and coastal protection measures.

PHY(NIO)-4-001: CSIR-800 Societal program: 0-0-8-4
Course Coordinators: V. K. Banakar and K. Sreekrishna

The students have to undertake a project in rural area for 6-8 weeks in line with CSIR-800 Program. The CSIR-800 program is primarily prepared at empowering 800 million Indians by way of S & T inventions. The theme for the project may be chosen from the CSIR-800 document and Science Plan for coastal hazard preparedness prepared by NIO. The project should aim to interact with people who are underprivileged and have fewer opportunities to lead better life in the villages and bring out solutions in the area of health, agriculture, hazard preparedness, energy etc. The student will choose the topic in consultation with Doctoral Advisory Committee (DAC).

PHY(NIO)-4-002: Project proposal writing: 0-1-6-4
Course Coordinator: Ph.D. Guide

This course is aimed to prepare the students for effective technical report writing and involves, definition and elements of a scientific proposal, statement of scientific problem, purpose and identifying the sponsors, importance of background information and present status, goals and objectives, experimental and instrumental strategies, field/ laboratory work and data acquisition, data processing strategies, time schedule, budget preparation, monitoring and evaluation, effective communication and language usage, merits of good scientific proposal & demerits of weak proposal, art of referencing and bibliography, illustrations & annexures.

9. CSIR-NPL (National Physical Laboratory, New Delhi)

Sr. No.	Course No.	Title	L	T	P	C
1	**PHY(NPL)-1-001**	**Research Methodology, Technical Writing & Communication Skills**	**1**	**1**	**0**	**2**
2	**PHY(NPL)-2-626**	**Fundamentals of Electronic Materials & Semiconductor Devices**	**2**	**1**	**0**	**3**
3	**PHY(NPL)-2-627**	**Physics & Technology of Thin Films**	**2**	**1**	**0**	**3**
4	**PHY(NPL)-2-628**	**Advanced Materials Characterization Techniques**	**2**	**1**	**0**	**3**
5	**PHY(NPL)-2-629**	**Nanostructured materials**	**2**	**1**	**0**	**3**
6	**PHY(NPL)-2-630**	**Engineering Materials**	**2**	**1**	**0**	**3**
7	**PHY(NPL)-3-626**	**Superconducting & Magnetic Materials**	**2**	**1**	**0**	**3**
8	**PHY(NPL)-3-627**	**Advanced Measurement Techniques & Metrology**	**2**	**1**	**0**	**3**
9	**PHY(NPL)-3-628**	**Advanced Computational Physics**	**2**	**2**	**0**	**4**
10	**PHY(NPL)-3-629**	**Quantum Optics & Advanced Solid State Optical Devices**	**2**	**1**	**0**	**3**
11	**PHY(NPL)-3-630**	**Atmospheric Physics & Environmental Chemistry**	**2**	**1**	**0**	**3**
12	**PHY(NPL)-3-631**	**Advanced Self Study on Special topic**	**0**	**0**	**0**	**4**
13	**PHY(NPL)-4-001**	**CSIR-800 Societal Program**	**0**	**0**	**0**	**4**
14	**PHY(NPL)-4-002**	**Subject Proposal (I & II)**	**0**	**0**	**0**	**4**

Brief Description of Physical Science Courses at CSIR-NPL (Course Level-Wise)

PHY(NPL)-1-001: Research Methodology, Technical Writing & Communication Skills: 1-1-0-2
***Course Coordinator*: A.M. Biradar, Dr. Rina Sharma, Dr. Ranjana Mehrotra & Dr. S.K.Dhawan**

Introduction, Research terminology and scientific methods, different types and styles of research, role of serendipity, creativity and innovation, Scientific and critical reasoning skills, art of reading and understanding scientific papers, literature survey. Measurements in research - primary and secondary data. Quantitative methods and data analysis, Qualitative analysis, communicating research results. Designing and implementing a research project. Ethics in research, Plagiarism, Case studies. Laboratory safety issues – lab, workshop, electrical, health & fire safety, safe disposal of hazardous materials.
Role and importance of communication, Effective oral and written communication. Technical report writing, Technical/R&D proposals, Research paper writing, Dissertation/Thesis writing, Letter writing and official correspondence. Oral communication in meetings, seminars, group discussions; Use of modern aids; Making technical presentations.

PHY(NPL)-2-626: Fundamentals of Electronic Materials & Semiconductor Devices: 2-1-0-3
***Course Coordinator*: Dr. Shailesh Sharma, Dr. J. Pulikkotil & Dr.Pankaj Kumar**

Crystal structure and reciprocal lattice, crystal binding, phonons & thermal conductivity, free electron Fermi gas, energy band diagrams and Fermi surfaces, semiconductor crystals, plasmons-polaritons-polarons, optical properties and excitons, nanocrystalline solids, phase change materials, ferroelectrics and dielectrics, basic equations of semiconductor device operation, p-n junction diode, metal-semiconductor contacts, MOSFETS, LEDs and semiconductor laser, solar cell.

PHY(NPL)-2-627: Physics & Technology of Thin Films: 2-1-0-3
***Course Coordinator*: Dr. K.M.K. Srivatsa, Dr. Sushil Kumar & Dr. Govind**

Vacuum science & technology for thin film processing; thin films growth mechanisms, kinetic models of nucleation; thin film deposition techniques: physical vapor deposition (PVD): evaporation (resistive heating, flash, electron beam, ion beam and pulsed laser), sputtering (mechanisms and yield, dc and rf sputtering, bias sputtering, magnetron sputtering), hybrid and modified PVD, ion plating, ion beam assisted deposition, and vacuum arc deposition; chemical vapor deposition (CVD): reaction chemistry and thermodynamics of CVD, thermal CVD, atmospheric and low pressure CVD, plasma enhanced CVD (PECVD), MOCVD etc.; Chemical techniques: spray pyrolysis, electro deposition, sol-gel and Langmuir Blodgett techniques; types of thin films: metallic, dielectric & semiconducting; optical coating, thin film measurement & characterization, thickness measurements: Fizeau fringes, stylus measurement, ellipsometer etc.; ultra-high vacuum techniques and processes; electron-based techniques for examining surface and thin film processes. Surface processes in adsorption, surface processes in epitaxial growth, electronic structure and emission processes at metallic surfaces; semiconductor surfaces and interfaces; surface processes in thin film devices; in-situ characterization of epitaxial films. Defects in epitaxial films, epitaxial growth of nanostructures on silicon surfaces, graphene, III-V nitride quantum well structures for LED & Solar cells applications.

PHY(NPL)-2-628 : Advanced Materials Characterization Techniques: 2-1-0-3
***Course Coordinator*: Dr. G.Bhagavannarayana, Dr. Sukhbir Singh & Dr.Renu Pasricha**

Fundamentals of X-rays - Bremsstrahlung and characteristic X-rays, Moseley's law, X-ray production (conventional X-ray tubes and synchrotron), X-ray absorption/K-absorption edge/filters ; X-ray crystallography, crystal systems and their corresponding Bravais lattices, space groups, reciprocal lattice, lattice planes and Miller indices, relation between lattice spacing and lattice constants, Bragg's Law, scattering of X-rays by an electron and an isolated atom and atomic structure factor, structure factor for unit cell, calculation of structure factor, X-ray scattering and systematic absences in a few crystal systems ; X-ray analysis for composition and trace elements or impurities - X-ray florescence spectroscopy, energy dispersive spectroscopy, X-ray photoelectron spectroscopy, Auger electron spectroscopy, CHN analyzer ; determination of crystal structures - X-ray Laue, single crystal X-ray and powder X-ray methods.
Characterization of crystalline perfection of single crystals & epitaxial films - crystal defects and lattice mismatch, theoretical aspects of X-ray diffraction, reflection and scattering, high resolution X-ray Diffraction for Bragg and Laue cases, semi-kinematical theory for epitaxial layers for determination of thickness and composition, X-ray reflectometry for determination of density, thickness and interfacial roughness ; experimental aspects - monochromators, point and line focus configurations of X-ray beam, parabolic graded multilayer mirror, flow proportional and scintillation detectors, solid-state pixel detector ; high-resolution X-ray diffractometers - high-resolution X-ray diffraction curves, X-ray topography, X-ray reflectometry, grazing incidence X-ray diffractometry for in-plane diffraction, reciprocal space mapping.
Microscopy Techniques - basics of electron microscopy, electron scattering, electron atom interaction, electron emissions sources, vacuum conditions, scanning electron microscopy, different imaging modes, conventional transmission electron microscopy, high resolution transmission electron microscopy, reciprocal space, selected area electron diffraction, convergent beam electron diffraction, bright field and dark field imaging, scanning transmission electron microscopy, lattice scale imaging, interpretation of high resolution images, scanning tunneling microscopy, atomic force microscopy.
Spectroscopy techniques - Fourier transform infrared spectroscopy, Raman spectroscopy, secondary ion mass spectroscopy, electron paramagnetic resonance

spectroscopy, cathodoluminescence, photoluminescence, defect structure analysis using microscopy and spectroscopy results; particle size analyzer.

PHY(NPL)-2-629: Nanostructured Materials: 2-1-0-3
***Course Coordinator*: Dr. A.K.Srivastava, Dr.H.K.Singh, Dr. D. Haranath**

Introduction to nanomaterials, nanoparticles employing ball milling, gas condensation, laser ablation, thermal and ultrasonic decomposition, reduction methods, self-assemby, low-temperature plasma, thermal high-speed spray, sol gels, precipitation of quantum dots and other procedures; nanolayers by physical vapor deposition methods, PLD, sputtering, e-beam evaporation, MBE; Chemical Vapor Deposition (CVD); nanostructuring by nanopolishing, etching of nanostructures, lithography procedures like optical lithography, electron beam lithography, ion beam lithography, X-ray and synchrotron lithography, focused ion beams, nanoimprinting, atomic force, near-field optics. Characterization of nanomaterials for the structure, composition, defects, interfaces, grain boundaries. Generation, interpretation & application of nano-scaled defects. Physics at low dimensions, heterostructures, band engineering, quantum wires, quantum dots, effective mass approximation, quantum wells in heterostructures, square well of finite and infinite width, triangular and parabolic quantum wells, tunneling transport, potential step, T-matrices, current and conductance, resonant tunneling, tunneling in heterostructures, effects of electric and magnetic fields, density of states, conductivity and resistivity tensors, uniform magnetic field, Landau levels, S-D effect, quantum hall effect, Aharanov-Bohm effect, nanomagnetism, surface/interface magnetism, nanophotonics. Electronic devices based on nanostructures, high electron mobility transistors, resonant tunneling diode, quantum cascade laser, single electron transistor, carbon nanotube and graphene devices and spintronic devices.

PHY(NPL)-2-630: Engineering Materials: 2-1-0-3
***Course Coordinator*: Dr. Ajay Dhar, Dr. T.D. Senguttuvan, Dr. D.K. Misra, Dr. B.P.Singh, Mr. B. Sivaiah**

Classification of engineering materials, material properties, selection of material, advanced and futuristic materials, smart materials, nanomaterials; phase diagram, equilibrium & kinetics, stable & metastable phases, nucleation and growth, metals, alloys and solid-solutions; ceramics, polymers, composites; crystal imperfections, defects, dislocations; elastic and plastic deformation, stress-strain curves, work hardening & dynamic recovery, strengthening mechanisms; solidification and crystallization, recovery, recrystallization and grain growth; creep, fatigue, fracture, oxidation and corrosion; materials processing techniques : liquid metallurgy, powder metallurgy, spray forming; secondary processing techniques : extrusion, forging, rolling; mechanical and metallurgical characterization, structure-property correlations; light weight materials, metal matrix composites, polymer matrix composites, ceramic matrix composites, carbon-based composites, nanocomposites, super-hard materials, dielectric, ferroelectric and piezoelectric materials, magnetic materials

PHY(NPL)-3-626: Superconductivity and Magnetic Materials: 2-1-0-3
***Course Coordinator*: Dr. Pushpa L. Upadhyay, Dr. Anurag Gupta & Dr. V.P.S. Awana**

Introduction to superconductivity; thermodynamics of superconducting transition, two-fluid model London theory, flux-quantization, superconducting tunneling phenomena and energy gap, introduction to microscopic theory (Bardeen-Cooper-Schrieffer) of superconductivity. Type II superconductivity, mixed state and Ginzburg-Landau theory, critical currents, flux-pinning and flux-flow. Magneto-thermal instabilities in type II superconductors. Applications of Superconductivity : materials requirement for superconducting devices, low current devices and superconducting electronics, superconducting thin films, SQUIDs and Josephson junction based devices, detectors and bolometers. High current applications, synthesis methods for wires and tape-conductors, superconducting magnets, energy storage, motors and generators. High Temperature superconductors : introduction & their unusual fundamental properties, electronic and power applications of high-temperature superconductors. Physical Properties of materials at low temperatures (specific heat, thermal conductivity, thermal expansion, electrical conductivity, magnetic and mechanical properties). Production of low temperatures, cryogenic fluids: their properties and storage, transfer devices, temperature control & measurement, production of very low temperatures, vacuum systems as applied to cryogenics.
Magnetic moments of a body, alignment of atomic magnetic moments in a solid, Ferromagnetism, Curie Point and the Exchange Integral, Magnetisation and magnetic domains, Temperature dependence of magnetization, Coercive force and hysteresis,coercivity in fine particles. Ferrimagnetism and Antiferromagnetic order, Neutron magnetic scattering Magnetism of transition metals (elements, alloys and compounds), Rare-earths and Special Oxides (Spinels, Garnets and Perovskites). Magneto-resistance, tunnel magnetoresistance, Spintronics.

PHY(NPL)-3-627: Advanced Measurement Techniques & Metrology: 3-1-0-4
***Course Coordinator*: Dr. A.K. Bandopadhyay, Dr. K.P.Chaudhary, Dr. Ashish Agrawal, S.K.Jaiswal & Dr. Parag Sharma**

Introduction of the measurement science, measurement terminology and vocabulary, basics of uncertainty in measurements, brief advance uncertainty analysis including uncorrelated and correlated measurand, accurate measurement techniques in basic and derived SI units like mass, temperature, length & dimension, pressure & vacuum, force, DC (voltage, resistance & current), AC (high voltage & current, power & energy), LF voltage & current, introduction to quantum SI, quantum definition of mass, e-mass by superconducting magnetic levitation, watt balance, I_2 stabilized He-Ne Laser, Michelson interferometer – principle theory and application, different kinds of interferometer and applications, primary laser and its importance in metrology as a standard, basics of radiometry, radiometric quantities, radiant quantities, realization of radiometry to SI, calibration for spectral irradiance responsivity, high temperature by radiation pyrometry, measurement of Boltzmann constant ‘k’, Josephson voltage standard, quantum hall effect, time and frequency standards, laser cooled cesium fountain, metrology instruments - standards and artifacts for key comparison, introduction to the international organizations BIPM, RMO (APMP, SIM, EORAMET etc.), OIML, ILAC, international data base – key comparison data base (KCDB), calibration measurement capabilities (CMCs), ISO/IEC 17025: 2005 quality system and conformity assessment and their use in support of technical regulations.

PHY(NPL)-3-628: Advanced Computational Physics: 3-0-2-4
***Course Coordinator*: Dr. Ravi Mehrotra, Mr. Ashish Ranjan, Dr. Sumit K. Mishra & Dr. J.Pulikkotil**

Introduction to computer problem solving techniques, design and anatomy of a computer program, programming in C.
Modeling of Data : least square methods, finite difference methods, numerical differentiation and integration, interpolation and extrapolation, statistical analysis
Numerical Methods : root finding, eigen systems, FFT, ordinary differential equations and boundary value problems, Runge-Kutta and predictor corrector methods, partial differential equations
Simulations : molecular dynamics and Monte Carlo methods.

PHY(NPL)-3-629: Quantum Optics & Advanced Solid State Optical Devices: 2-1-0-3
***Course Coordinator*: Dr. A. Sengupta, Dr. H.C. Kandpal, Dr. V.K. Jaiswal, Dr. Poonam Arora & Dr. Parag Sharma**

Introduction to quantum mechanics - quantum theory and wave nature of matter, complementarity, wave function and its interpretation, wave packets and free particle motion, principle of superposition, wave packets and uncertainty relation, spreading of wavepackets ; wave equations and solutions - linear harmonic oscillator, eigen value and eigen functions, motion of wave packets, double oscillator ; different types of potentials - normalization of free particle wave function, potential steps, rectangular potential barrier, periodic potential, potential square well ; coherence theory - classical coherence, quantum coherence ; semiconductor photon sources and detectors - light emitting diodes, laser amplifiers and injection lasers, photodetectors, photoconductors, photodiodes and avalanche photodiodes, single photon detectors ; theory of photoelectric detection of light - differential photodetection probability, joint probability of multiple photodetection, integral detection probabilities, photoelectric detection in a fluctuating field – photoelectric bunching, photoelectric counting statistics of a fluctuating field, photoelectric current fluctuations, Hanburry Brown – Twiss effect – photon antibunching.
Introduction to time and frequency standards including historical perspectives. Basic concepts of frequency standards, macroscopic frequency sources. Basics of laser frequency standards. Characterization of noise processes – amplitude and phase noise. Statistical characterization of the noise processes. Measurement techniques of phase and frequency noise. Introduction to atomic frequency standards, primary and secondary frequency standards. Microwave atomic frequency standards such as

H-maser, Rb cell standards, cesium beam standards. Sources of frequency biases and their evaluation. Physics of cold atoms – laser cooling and trapping. Optical Molasses and magneto optic traps. Polarization gradient cooling. Bose Einstein condensation. Atomic Fountain frequency standards based on cold atoms. Cesium fountain frequency standard. Evaluation of sources of frequency biases. Ion trap frequency standards. Realization of different types of traps. Microwave and optical frequency standards based on trapped ions. Synthesis and translation of optical frequencies including femto-second comb, applications of precision frequency standards.

PHY(NPL)-3-630: Atmospheric Physics & Environmental Chemistry: 2-1-0-3
***Course Coordinator*: Dr. C.Sharma, Dr. M.V.S.N. Prasad, Dr.Shankar Aggarawal, Dr. Sachchidanand Singh & Dr. A.K. Updhayaya**

Structure & composition of earth's lower and middle atmosphere, Photochemistry, Spectroscopy & measurement techniques, Aerosols: concentrations & size distribution, sources, sinks and transport, Atmospheric Radiation Budget, Sources, sink and transport. Atmospheric models, Atmospheric pollution and control strategies, Climate Change- causes, evidence and response, Elementary chemical kinetics, Quality system and traceability issues in atmospheric measurement, Role of International Telecommunication Union (ITU) in frequency allocation, Frequency bands, Mobile radio frequencies, Radio links, Modes of Propagation, Fundamentals of VHF and UHF propagation, Propagation in free space, Effects of Troposphere, Atmospheric ducting and non-standard refraction, Atmospheric attenuation, Communication systems and link budget, Path loss, Noise, Link Margin, Near earth propagation models, Atmospheric effects on satellite communication. Elements of cellular communication systems, Differences between fixed and mobile communication systems, GSM and CDMA concepts, Planning cellular networks, Radio coverage, planning tools, Mobile communication experiments done in various regions of India, Experiments carried out in moving trains, tunnels. Signal variability in urban, suburban and rural regions. Operational agencies working in the above areas, Basics of Ionosphere, Importance of Ionosphere with reference to low latitudes. Effect of ionosphere on VLF, MF and HF communication systems. Sporadic E and Spread F. Various techniques to probe Ionsophere. TEC and Delay and their effect on communication systems. Space weather events. Study of ionospheric precursors of Earthquakes. Empirical modeling of low latitude ionosphere.

PHY(NPL)-3-631 : Advanced Self Study on Special topic: 2-2-0-4
***Course Coordinator*: Senior Scientists, Doctoral Advisory Committee**

This will involve reading from published research literature or books about new frontiers on a specific scientific topic related to the field of research. A report needs to be submitted and a seminar on the special topic needs to be presented.

PHY(NPL)-4-001 CSIR-800 Societal program : 0-0-0-8
***Course Coordinator*: Concerned Supervisor & Dr. Ajay Dhar**

The students have to undertake a 6-8 weeks project concerned with societal/rural issues in line with CSIR-800 Program. The CSIR-800 program is primarily prepared at empowering 800 million Indians by way of S & T inventions. The theme for the project may be chosen from the CSIR-800 document and Science Plan for Physical, Chemical and engineering based projects. The project should aim towards the underprivileged, who have fewer opportunities to lead better life in the villages, and bring out solutions in the area of health, agriculture, environment, energy etc. The student will choose the topic in consultation with his Doctoral Advisory Committee (DAC). This course will need to be completed before the submission of the PhD thesis.

PHY(NPL)-4-002 : Project Proposal Writing – I : 0-0-4-2
& Project Proposal Writing - II : 0-0-4-2
***Course Coordinator*: Concerned Supervisor & Dr. Ajay Dhar**

This course is aimed to prepare the students for effective project proposal writing and involves, definition and elements of a scientific proposal, statement of scientific problem, purpose and identifying the sponsors, background information and present status, state-of-the-art review, novelty, goals and objectives, deliverables, methodologies & detailed work plan, time schedule, budget, monitoring & evaluation and references. The project proposal should be concise, highlighting all the above mentioned points under separate headings. The topics of the project proposal should have high relevance and novelty. This course is to be completed during the residency period before the comprehensive.

National Institute for Interdisciplinary Science and Technology CSIR, Trivandrum
AcSIR Ph.D. Course Work

Physical Science

Course Code	Course Title	L-T-P-C
PHY(NIIST)-1-001	*Research Methodology*	1-0-0-2
PHY(NIIST)-2-521	*Materials Science and Engineering*	2-0-0-2
PHY(NIIST)-2-522	*Advanced Materials Characterisation*	2-0-0-2
PHY(NIIST)-2-523	*Materials Processing Techniques*	2-0-0-2
PHY(NIIST)-2-524	*Electroceramics*	2-0-0-2
PHY(NIIST)-2-525	*Physics of Thin Films*	2-0-0-2
PHY(NIIST)-2-526	*Materials Chemistry*	2-0-0-2
PHY(NIIST)-3-530	*Nano science and Nanotechnology*	3-0-0-3
PHY(NIIST)-3-531	*Dielectric Physics*	3-0-0-3
PHY(NIIST)-3-532	*World of Composite Materials*	3-0-0-3
PHY(NIIST)-3-533	*Advanced Ceramic Processing*	3-0-0-3
PHY(NIIST)-3-534	*Inorganic Phosphors for White LEDs*	3-0-0-3
PHY(NIIST)-3-535	*Solid State Ionics and Fuel Cells*	3-0-0-3
PHY(NIIST)-3-536	*Smart Materials*	3-0-0-3
PHY(NIIST)-3-537	*Superconductivity*	3-0-0-3
PHY(NIIST)-3-538	*Ceramic Microsystems and LTCC*	3-0-0-3
PHY(NIIST)-3-539	*MEMS and EMI Shielding Materials*	3-0-0-3
PHY(NIIST)-3-540	*Materials for Printed Electronics*	3-0-0-3
PHY(NIIST)-3-541	*Semiconducting Oxides for Photocatalysis*	3-0-0-3
PHY(NIIST)-3-542	*Semiconducting Oxides for Thermistors*	3-0-0-3
PHY(NIIST)-3-543	*Inorganic Pigments for Surface Coating*	3-0-0-3
PHY(NIIST)-3-544	*Cryogenics and Vacuum Techniques*	3-0-0-3
PHY(NIIST)-3-545	*Magnetism and Magnetic Materials*	3-0-0-3

SYLLABUS

PHY(NIIST)-1-001: Research Methodology 1-0-0-2

Course Coordinator : C.S. Bhatt
Total Hours: 28 Hrs.

Good laboratory practices, Safety in the laboratory, First Aid in the laboratory, Maintenance of laboratory records, Scientific literature management, Intellectual property management & planning, Ethics in Science, Computer applications and tools, Measurements in research - primary and secondary data Statistical methods & Data analysis

Role and importance of communication, Effective oral and written communication. Technical report writing, Technical/R&D proposals, Research paper writing, Dissertation/Thesis writing, Letter writing and official correspondence. Oral communication in meetings, seminars, group discussions; Use of modern aids; Making technical presentations.

Reference Books:

1. C.R. Kothari, "Research Methodology-Methods and Techniques, New Age Publications (2009).
2. Margaret C. Cahoon, "Research Methodology", Churchill Livingstone, (1987).
3. R. Cauvery, U. K. Sudhanayak, R. Meenakshi, "Research Methodology", S. Chand and Co., (2010).
4. Manoj Sharma, "Research Methodology", Anmol Publishers, (2004).

PHY(NIIST)-2-521: Introduction to Materials Science and Engineering 2-0-0-2

Course Coordinator : T.P.D Rajan, U.S. Hareesh, S. Ananthakumar, K.P. Surendran, M. R. Varma
Total Hours: 28 Hrs.

Introduction to Materials World
Introduction and importance of Materials Science and historic perspective. Basic definitions and classification of materials systems according to Bonding-Pauling and Philips theories.

Atomic Structure and Bonding
Atomic structure and bonding in materials. Crystal structure of materials, Crystal systems, Unit cells and space lattices, Determination of structures of simple crystals by x-ray diffraction, Miller indices of planes and directions, Packing geometry in metallic, ionic and covalent solids. Concept of amorphous, single crystalline and polycrystalline structures, Imperfections in crystalline solids and their role in influencing various properties.

Phase Diagrams
Equilibrium phase diagrams, Solid solutions, Solubility limit, Phase rule, Binary phase diagrams, Eutectic, Peritectic, Eutectoid and Peritectoid reactions, Iron-carbon phase diagram

Properties of Materials
Thermal: Specific heat capacity, thermal conductivity and thermal expansion of materials,
Electrical: Conductors, Superconductors, Semiconductors and Insulators

Magnetic: Magnetism in metallic and ceramic materials, Paramagnetism, Diamagnetism, ferromagnetism, Magnetic hysteresis.
Mechanical: Stress-strain diagram, Modulus of elasticity, Yield strength, Tensile strength, Toughness.

Exotic Materials
Introduction to Smart and Intelligent materials, Nanomaterials - Historical perspective of nanoparticle - Classification of nanomaterials, Nanorods and nanotubes, Synthesis of nanomaterial, Functionally Graded Materials, Quantum Dots

Reference Books:

1. V. Raghavan, "Materials Science and Engineering – First Course", Prentice-Hall of India, (1999).
2. William D. Callister, "Materials Science and Engineering: An Introduction", John Wiley & Sons (2002).
3. D. Hull and D. J. Bacon, "Introduction to Dislocations", 3rd Edition, Pergamon Press, (1984).
4. P. Shewmon, "Diffusion in Solids", A Publication of the Minerals, Metals & Materials Society, (1989).
5. Sidney H. Avner, "Introduction to Physical Metallurgy", Tata McGraw Hill Publihsers, (1997).
6. O.P. Khanna, "A Text Book of Materials Science & Metallurgy", Dhanpat Rai and Sons, New Delhi (2000).
7. Paul Gordon**, "**Principles of Phase Diagrams in Materials Systems", McGraw Hill Inc. (1968)
8. Zhong-lin Wang, Z.C. Kang, "Functional and Smart Materials: Structural Evolution and Structure Analysis", Springer (1998).

PHY(NIIST)-2-522: Advanced Materials Characterisation 2-0-1-2

Corse Coordinators :TPD Rajan, Bhoje Gowd, Majoj R. Varma, K.P. Surendran, M. Vasundhara and Saju Pillai
Total Hours: 28 Hrs.

Microscopy
Optical microscopy (Bright field, Dark field, Phase contrast, differential interference contrast, polarized light, fluorescence and confocal imaging), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Scanning Tunneling Microscopy (STM), Atomic Force microscope (AFM), Energy Dispersive Spectrometry (EDS), Auger Electron Spectroscopy

X-Ray techniques
X-Ray Powder Diffraction (XRD), Single-Crystal X-Ray Structure Determination, X-Ray Fluorescence(XRF), and X-Ray Photoelectron Spectroscopy (XPS)

Thermal Techniques
Introduction, Thermogravimetric Analysis (TG), Differential Thermal Analysis (DTA) and Differential Scanning Calorimetry (DSC)

Spectroscopy
Basic principles, Ultraviolet and Visible Absorption Spectroscopy (UV-Vis), Fourier Transform Infrared Spectroscopy (FT-IR) and Raman Spectroscopy

Electrical and Magnetic Characterization Techniques

Hall Measurement, I-V Analysis, Capacitance Measurements, Magnetometry, SQUID and VSM, Microwave Measurements, Impedance Spectroscopy and Ferroelectric Measurements

Physical Testing

Particle size analysis, BET analysis, Porosimetry, Pyconometry, Density measurements; Tension, Compression, Hardness, Impact toughness, Fracture toughness

Reference Books:

1. D. A. Skoog and J. J Leary, "Principles of Instrumental Analysis", 4th ed., Orlando: Saunders College Publishing, (1992).
2. H. H. Willard, L. L. Merritt Jr., J. A. Dean and F. A. Settle, Jr., "Instrumental Methods of Analysis", 7th ed., CBS Publishers and Distributors, New Delhi, (1986).
3. W.W. Wendlandt, "Thermal Methods of Analysis", John Wiley, New York, (1974).
4. E. N. Kaufmann (ed.) "Characterization of Materials, Vol. 1 & 2", John Wiley & Sons, Inc., New Jersey, (2003).
5. J. M. Walls and R. Smith (ed.), "Surface Science Techniques", Pergamon, Leicestershire, (1994).
6. G. W. Ewing, "Instrumental Methods of Chemical Analysis", 5th ed., McGraw Hill Book Co., Singapore, (1985).
7. B. Raj, T. Jayakumar and M. Thavasimuthu, "Practical Non-Destructive Testing", 2nd ed., Narosa Publishing House, (2002).
8. Evgenij Barsoukov, J. Ross Macdonald "Impedance Spectroscopy: Theory, Experiment, and Applications" Wiley InterScience (2005).
9. B.D. Cullity and C.D. Graham "Introduction to Magnetic Materials" Wiley IEEE Press (2008).

PHY(NIIST)-2-523: Materials Processing Techniques 2-0-0-2

Corse Coordinator: T.P.D. Rajan, K.P. Surendran, M.R. Varma,
Total Hours: 28 Hrs.

Phase Transformation in Materials

Introduction to thermodynamics and kinetics, Basic crystallography, Phase equilibria, Phase diagrams, Thermodynamics of transformations, Free- energy Vs composition curves in relation to phase diagrams, Theory of nucleation and growth kinetics, Diffusion in metals and materials, Phase transformations in thin films, ceramics and glasses, Shape memory effect, Stress induced phase transformations.

Ceramic Processing

Concept of mono-dispersed submicron ceramic powder, Solid state reaction, Kinetic and Thermodynamic considerations, Powders from chemical solutions, Co-precipitation, Hydrothermal and Solvothermal synthesis, Sol-gel techniques, Advanced Forming Processes, Hot pressing, Isostatic pressing, Tape casting, Gel casting, Chemical vapour deposition, Coating processing, Plasma processing and plasma synthesis, Sintering, Driving force of sintering, Vitreous Sintering, Mass transport mechanism during sintering, Sintering models, Homogeneous and heterogeneous nucleation and crystal growth

Metal Processing and Surface Engineering

Materials and processes, Macro, micro and nanostructures, Microstructural evolution, Solidification, Nucleation and growth kinetics, Induction melting, Zone refining, Czechrolski method, Solidification of metals and alloys, Gating and risering of castings, Metal filtration, Special casting techniques, Fettling and heat-treatment of castings, Casting defects, Joining methods, Development of functional and functionally gradient materials, Cellular structures,Metallic foams, Thin films and coatings.

Synthesis of Glasses, Polymers and Composites

Glass: Definition non-crystalline solids & glasses, Glass formation from solid, liquid and gaseous phases, Effects of different oxides on glass properties, Quenching synthesis, Refining of glass, Annealing, Thermal treatment, Chemical treatment, Optical fibre glass production & processes. Glass ceramics- fabrication, advantages of glass ceramic formation, properties and applications

Polymers: Processing of Thermoplastic Polymers, Processing of Thermoset Polymers, Injection Moulding, Compression Moulding, Transfer Moulding, Casting

Composites: Introduction to Fiber-Reinforced Polymers, Molding, Autoclave Molding, Bag Moulding, Resin Transfer Moulding, Compression Moulding, Casting, Pultrusion, Filament Winding

Advanced Materials Synthesis

Solid freeform fabrication, Thick films and thin films, Screen printing, Inkjet printing, Sputter coating DC and RF Sputtering, Chemical vapour deposition of ceramics, Electro vapour deposition, Ceramic membrane processing, Templated synthesis of nanostructures, Nanofabrication, Lithography, Pattern transfer, Layer-by-layer Self-Assembly, Nano contact printing and writing.

Reference Books:

1. A. K. Jena and M. C. Chaturvedi, "Phase Transformations in Materials", Prentice Hall, (1992).
2. D. A. Porter and K. E. Easterling, "Phase Transformations in Metals and Alloys", Van Nostrand Reinhold International, (1989).
3. V. Raghavan "Materials Science and Engineering", PHI, New Delhi, (2004).
4. A. Upadhyaya, G. S. Upadhyaya, "Materials Science and Engineering", Viva Books Pvt. Ltd., New Delhi, (2010).
5. Larry L. Hench, George Y. Onoda "Ceramic Processing Before Firing", Wiley-Interscience; 1st Edn (1978)
6. James S. Reed "Principles of Ceramic Processing" Wiley-Interscience; 2nd Edn (1995).
7. C. Barry Carter and M. Grant Norton "Ceramic Materials: Science and Engineering" Springer, (2007).
8. A.K. Chakrabarti, "Casting Technology and Cast Alloys", PHI Learning Pvt. Ltd., New Delhi (2009).
9. P.L. Jain, "Principles of Foundry Technology", Tata McGraw Hill, (1983).
10. F. V. Tooley, "Hand Book of Glass Manufacture – Vol. I & II," Ogden Publishing Co., NY, (1960).
11. J. E. Shelby, "Introduction to Glass Science and Technology", The Royal Society of Chemistry, (2005).
12. B. Raymond, Seymour and Charles E. Carraher Jr: "Polymer Chemistry - An Introduction", 2nd Edition, Marcel Dekkar, Inc. New York, (1987).

13. A.B. Strong, "Fundamentals of Composites Manufacturing- Materials, Methods and Applications", SME (1989).
14. G. Cao, "Nanostructures and Nanomaterials: Synthesis, Properties and Applications", Imperial College Press, 2004.
15. M. Winterer, "Nano-crystalline Ceramics: Synthesis and Structure", Springer, 2002

PHY(NIIST)-2-524: Electroceramics 2-0-0-2

Corse Coordinator: K. P. Surendran, Manoj Raama Varma
Total Hours: 28 Hrs.

Dielectric Phenomena
Dielectric constant and loss, polarization dielectrics, dielectric strength, ceramic dielectric materials, ceramic insulators such as glasses and porcelain, Linear dielectrics and non linear dielectrics.

Ferroic Materials
Study of piezoelectric / ferroelectric ceramic materials i.e. structure and electrical behavior of barium titanate, FE RAM, Importance of PZT, Morphotropic Phase boundary of PZT, Applications of Piezoelectric Ceramics, Actuators, Piezo Paints, Energy Harvesting. Basic concepts of electroptic phenomena, PLZT and applications

Capacitors
Concepts and examples of titanates, alumina, steatites, mica. Classification of capacitors – class-I and class-II capacitors, Varieties of ceramic capacitors, Preparation methods of MLC capacitors, DRAM basic concepts, Supercapacitors.

Ferrite Ceramics
Origin of magnetism in solids, Classification of magnetic materials, Soft ferrite, Hard ferrite, Spinel ferrite, Hexagonal ferrite, Garnet ferrite, Applications of Ferrite: Permanent Magnet devices, Inductor and Transformer for Low and High Power applications, Ferrite for EMI Suppression, Ferrite for Entertainment Applications

Ceramic Sensors
Classification, Materials systems, Processing and applications. Positive temperature coefficient and negative temperature coefficient ceramics, thermistor, gas sensor, humidity sensor, pressure sensors, ZnO-varistors technology, Varistors, principles, and equivalent circuit, Varistor application.

Microelectronics
Ceramic thick film technology- materials and processing, Thin and thick films in microelectronics and micro systems, Hybrid IC's, Multilayer ceramic technology, Processing of multilayer ceramics, , Low temperature co-fired glass ceramics. Recent advances in microelectronics

Reference Books
1. R.C. Buchanan, "Ceramic Materials for Electronics" , Marcel Dekkar, (1996)
2. D.W. Richerson, "Modern Ceramic Engineering", Marcel Dekkar, (1992).
3. W.D. Kingery, "Introduction to Ceramics", 2nd Ed John Wiley, (1975).

4. R. C. Buchanan (Edt.), "Ceramic Materials for Electronics", 3rd Edition, Marcel Dekker, (2004).
5. L. M. Levinson, "Electronic Ceramics", Marcel Dekker, NY, (1988).
6. N. Setter, "Electro-ceramic-based MEMS: Fabrication Technology and Applications", Springer, 2005.
7. J. Millman, "Microelectronics", McGraw-Hill (2002).
8. A. J. Moulson and J. M. Herbert, "Electroceramics: Materials, Properties and Applications", Wiley; 2nd Edition, (2003).
9. B. Jaffe, W. R. Cook, H. Jaffe and H. L. C. Jaffe, "Piezoelectric Ceramics", R.A.N Publishers, (1990).
10. L. L. Hench and J. K. West, "Principles of Electronic Ceramics", John Wiley and Sons, New York, (1990).

PHY(NIIST)-2-525: Physics of Thin Films 2-0-0-2

Course Coordinator: K. P. Surendran, M. Vasundhara, R.P. Aloysius and Biswapriya Deb
Total Hours: 28 Hrs.

Thin Films-Introduction
Thin films and their importance, Sputter coating, DC and RF sputtering, Magnetron Sputtering, Physical and Chemical Vapour deposition, Electro vapour deposition, Ion Beam Sputtering, Pulsed laser ablation, and Chemical vapour deposition (CVD); Relationships between deposition parameters and film properties, Applications of thin films

Physics of Thin Films
Steps in thin film growth process- sticking coefficients, surface bombardment rate; Thin film growth models- adsorption, thermal accommodation, Van der Waals forces, lifetime of adsorbed species, surface diffusion, chemisorption; Film growth modes- capillary theory of nucleation and growth, coalescence processes;

Epitaxy
Epitaxy-Introduction, Environment for Film Growth- Real surfaces, Surface passivation, Vacuum requirements for film growth, Techniques to grow thin films at atomic scale and to fabricate multilayers/superlattices at nanoscale. Evaporating alloys and compounds, Molecular beam epitaxy (MBE), RHEED, Atomic Layer Deposition

Defects in Thin Films
Different types of crystal growth in epitaxial films, Defects formation in thin films, Effect of Stress, Applications and emerging technologies

Reference Books
1. King-Ning Tu, James W. Mayer, and Leonard C. Feldman "Electronic Thin Film Science for Electrical Engineers and Materials Scientists", Macmillan Publishing Co. (1992).
2. K.L. Chopra, "Thin Film Phenomena", McGraw-Hill, (1969).
3. D. L. Smith, "Thin-Film Deposition, Principles and Practice", McGraw-Hill, (1995).
4. L. B. Freund and S. Suresh, "Thin Film Materials: Stress, Defect Formation and Surface Evolution", Cambridge University Press, (2004).
5. Milton Ohring, "Materials Science of Thin Films", Academic Press (2002).

6. Alfred Wagendristel and Yuming Wang "An Introduction To Physics And Technology Of Thin Films"World Scientific Inc. (1994).
7. Vitaly Shchukin, Nikolai N. Ledentsov and Dieter Bimberg "Epitaxy of Nanostructures - NanoScience and Technology", Springer (2004).
8. Marian A. Herman, W. Richter and Helmut Sitter "Epitaxy: Physical Foundation and Technical Implementation" Springer (2004).

PHY(NIIST)-2-526: Materials Chemistry 2-0-0-2

Course Coordinator : T.P.D. Rajan, Saju Pillai, Bhoje Gowd, S. Ananthakumar and U.S. Hareesh
Total Hours: 28 Hrs.

Materials Systems
Introduction to Ceramics, Polymers, Metals and Alloys and Composites

Defects and Non-stoichiometry
Intrinsic and extrinsic defects - point, line and plane defects; Vacancies, Schottky defects, Frenker defects - Charge compensation in defective solids - non-stoichiometry, Thermodynamic aspects and structural aspects

Diffusion
Fundamentals, defects and defect chemistry, intrinsic, extrinsic defects, defect reactions, diffusion and defects, mechanisms of diffusion, types of diffusion co-efficients, chemical potentials of different systems, Diffusional flux equation, ambipolar diffusion

Composites-Introduction
Definition and classification, Matrix (polymer, metal and ceramics), Thermoset and thermoplastic polymer matrix composites, Reinforcement (glass, aramid and carbon fibres), Functionally graded nanocomposites

Processing of Polymer Composites
Processing of thermoset matrix composite- Hand lay-Up and Spray techniques, Filament winding, Pultrusion, Resin transfer molding, Thermoplastic matrix composite- Film stacking, diaphragm forming, Thermoplastic tape laying, Injection Molding, Sheet molding compounds.

Advanced Materials
Introduction to Functional and Smart materials, High Tc superconductors, Collossal Magnetoresistance Materials, Microwave Dielectrics, Spintronics

Reference Books

1. Bradley D. Fahlman "Materials Chemistry", Springer, 2nd Edition, (2011).
2. Relva C. Buchanan, "Materials Crystal Chemistry" Taylor & Francis, (1997).
3. William D. Callister, "Materials Science and Engineering: An Introduction", John Wiley & Sons (2010).
4. A.R. West,. "Solid State Chemistry and Its Applications" John Wiley and Sons (1984).
5. James F. Shackelford, "Introduction to Materials Science for Engineers", 5th Ed., Prentice Hall, (2000).
6. William F. Smith, "Foundations of Materials Science and Engineering", 3rd Ed., McGraw-Hill, (2004).

7. Larry D. Horath, "Fundamentals of Material Science", 3rd Ed., Prentice Hall, (2006).
8. J. Reed, "*Introduction to the Principles of Ceramic Processing*", 2nd Ed., John Wiley & Sons. (1995).

PHY(NIIST)-3-530: Nano Science & Nanotechnology 3-0-0-3

Corse Coordinator: K. P. Surendran, M. Vasundhara, Biswa Priya Deb, T.P.D. Rajan
Total Hours: 42 Hrs.

Introduction
Introduction and importance of materials at Nano Size, Properties at Nano Scales, Advantages & Disadvantages, Application in comparison with bulk materials, Bottom up and top down approaches, Quantum wire, Quantum well, Quantum dot, Nano clusters & Nano crystals.

Processing of Nanomaterials
Basic fabrication techniques, Top down vs. bottom up techniques, nucleation theory, surface energy, and stabilization; Chemical Processing Methods, Physical processing methods (lithography, thin film deposition and doping) MEMS fabrication techniques-Nano fabrication techniques (E-Beam nano-imprint fabrication, Epitaxy and strain engineering, Scanned probe techniques), Lithography

Nanoparticles
Introduction – Synthetic Methods– wet chemical approach & physical vapour synthesis approach etc – size effect & shape change and their properties – examples of systems involved – characterization techniques – properties & their applications

Nanotubes/Nanowires
Introduction – Different systems involved in nano tubes – single walled, multi-walled tubes. Synthesis procedures (Solid & gaseous carbon source based production techniques etc.) Growth mechanism of carbon nano tubes – properties of carbon nano tubes – characterization – applications

Applications of Nanomaterials
Catalysis, Electronic, Aerospace, Automotive, Surface coatings, Magnetic, Optical, Medicine etc.

Reference Books

1. A.S. Edelstein, R C. Cammarata, "Nanomaterials: Synthesis, Properties and Applications" Edited by IOP Publication (2001).
2. John H Davies, "Physics of Low Dimensional Semiconductors", Cambridge University Press, (1998).
3. Uwe Kreibig and Michael Vollmer "Optical properties of Metal Clusters" Springer, (2002).
4. Carl C. Koch "Nanostructured Materials: Processing Properties and Applications" Noyes Publications, (2009).
5. S.K. Kulkarni, "Nanotechnology: Principles & practices" Capital Publ. Co., New Delhi (2007).
6. C.N.R.Rao, P. John Thomas & G.U. Kulkarni, "Nanocrystals: Synthesis, Properties & Applications", Springer series in Material science 95, Springer -Verlag, (2007).

7. Michael Rieth "Nano Engineering in Science & Technology : An introduction to the world of Nano Design", World Scientific Publishing Co., Inc (2003).
8. Frank J. Owens, and Charles P. Poole Jr "The Physics and Chemistry of Nanosolids"., Wiley Interscience, (2008).

PHY(NIIST)-3-531: Dielectric Physics 3-0-0-3

Course Coordinator: K. P. Surendran, Manoj R. Varma
Total Hours: 42 Hrs.

Electromagnetic Waves
Maxwell's equations, Boundary conditions, EM wave propagation in good dielectrics, Guided waves – Waves between parallel planes, TE, TM and TEM Modes, Velocities of propagation, Wave Guides, Rectangular wave guide

Physics of Dielectrics
Theory of Dielectrics, Dielectrics in an Electric Field, Dielectric Permittivity ε_r, Claussius Mossotti Relation, Polarization mechanisms – Interfacial, Ionic, dipolar and electronic polarizations, Loss factor, Resonance, Theory of Resonance, Absorption and Relaxation, Linear and Nonlinear Dielectrics, Frequency and Temperature dependence of the dielectric permittivity, Evaluation of dielectric properties by parallel plate capacitor method, Applications of dielectrics: dielectric resonator, Substrate, Capacitor, Embedded capacitor, DR filter, DR oscillator and DR antenna.

Characterization of Dielectrics
RE Characterization of Dielectrics using Capacitor Method, Quality Factor of a Resonator, Dielectric Resonators (DR), Characterization of a DR at Microwave frequencies, Dielectric measurements - Network Analyzer, Coupling of Microwaves into a DR, Measurement of ε_r, Q and Temperature Coefficient of Resonant Frequency (τ_f). Hakki and Coleman Method, Cavity method, Cavity Perturbation Technique, Split post dielectric resonator (SPDR), Estimation of dielectric loss by spectroscopic methods.

Metamaterials
Introduction, Theory and Electrodynamics of Metamaterials, Negative Refraction, Fermats Principle, Waves through Left Handed Slab, Electromagnetic Bandgap Metamaterials, Superprism Effects, Bulk and 2D Metamaterials, Low Loss Metamaterials for Microwave and RF Applications

Emerging Dielectrics
Monolithic Microwave Integrated-Circuit Growth, MMIC Fabrication Techniques, Substrate Materials, Conductor Materials, Resistive Materials, Low κ Dielectrics, Polymer-ceramic and Ceramic-glass Composites, High κ Gate Dielectrics, Super capacitors

Reference Books

1. Edward. C. Jordan and Keith. G. Balmain Electromagnetic Waves and Radiating Systems" Prentice Hall India Pvt. Ltd (1996).
2. W. D. Kingery, H. K. Bowen and D. R. Uhlmann "Introduction to Ceramics", Second edition-John Wiley and Sons (1976).

3. L.F. Chen, C.K. Ong, C.P. Neo, V.V. Varadhan, V.K.Varadhan “Microwave Electronics: Measurement and Materials Characterization”, Wiley, (2004)
4. S. O. Pillai “Introduction to Solid State Physics”, New Age Science, (2010)
5. M T Sebastian “Dielectric Materials for Wireless Communication”Elsevier (2008) .
6. Darko Kajfez and Pierre Guillon “Dielectric Resonators”, Artech House Inc. (1986).
7. Fred D. Barlows, Aicha Elshabini (Editor) “Ceramic Interconnect Technology Handbook”, CRC Press (2007).
8. Ricardo Marqués, Ferran Martín, Mario Sorolla “Metamaterials with Negative Parameters: Theory, Design and Microwave” John Wiley & Sons, Hoboken USA, (2006)
9. Nader Engheta, Richard W Ziolkowski (Eds) “Metamaterials: Physics and Engineering Explorations”, Wiley Interscience Hoboken USA, (2006)
10. Tie Jun Cui, David Smith, Ruopeng Liu (Eds) “Metamaterials: Theory, Design, and Applications” Springer, New York (2010)
11. Ken Kuang, Franklin Kim and Sean S. Cahill “RF and Microwave Microelectronics Packaging”, Springer (2009).

PHY(NIIST)-3-532: World of Composite Materials 3-0-0-3

Course Coordinator: T.P.D. Rajan, Saju Pillai, E. Bhoje Gowd
Total Hours: 42 Hrs.

Introduction
General Introduction and Concept, Historical development, Concept of Composite materials, Material properties that can be improved by forming a composite material& its engineering potential

Classification of Composites
Basic definitions, Various types of composites, Classification based on Matrix Material: Organic Matrix composites Polymer matrix composites (PMC), Carbon matrix Composites or Carbon-Carbon Composites, Metal matrix composites (MMC), Ceramic matrix composites (CMC); Classification based on reinforcements: Fiber Reinforced Composites, Fiber Reinforced Polymer (FRP) Composites, Laminar Composites, Particulate Composites

Basic Constituent Materials in Composites
Types of Reinforcements/Fibers: Role and Selection or reinforcement materials, Types of fibres, Glass fibers, Carbon fibers, Aramid fibers, Metal fibers, Alumina fibers, Boron Fibers, Silicon carbide fibers, Quartz and Silica fibers, Multiphase fibers, Whiskers, Flakes etc., Mechanical properties of fibres.
Matrix Materials: Functions of a Matrix, Desired Properties of a Matrix, Polymer Matrix (Thermosets and Thermoplastics), Metal matrix, Ceramic matrix, Carbon Matrix, Glass Matrix etc

Processing of Advanced Composites
Metal Matrix Composites: Casting – Solid State diffusion technique, Cladding – Hot isostatic pressing.
Ceramic Matrix Composites: Liquid Metal Infiltration – Liquid phase sintering
Carbon – Carbon composites: Knitting, Braiding, Weaving

Polymer matrix composites: Preparation of Moulding compounds and prepregs – hand lay up method – Autoclave method – Filament winding method – Compression moulding – Reaction injection moulding.

Special Systems

Introduction to Processing and characteristics of nanocomposites, hybrid composites, functionally graded composites, smart and functional composites

Reference Books

1. Krishan Kumar Chawla "Composite Materials: Science and Engineering" Springer (1998).
2. Deborah D. L. Chung "Composite Materials" Springer, (2003).
3. Derek Hull, T. W. Clyne "An introduction to Composite Materials" Cambridge University Press (2002).
4. T. W. Clyne, P. J. Withers "An Introduction to Metal Matrix Composites" Cambridge University Press. (2003).
5. Klaus Friedrich, Stoyko Fakirov and Zhong Zhang, "Polymer Composites: From Nano-to Macro-Scale" Springer (2010)
6. David A. Colling and Thomas Vasilos "Industrial Materials: Volume 2, Polymers, Ceramics and Composites" Prentice Hall (1995).

PHY(NIIST)-3-533: Advanced Ceramic Processing 3-0-0-3

Course Coordinator: S. Ananthakumar, U. Hareesh and K.P. Surendran
Total Hours: 42 Hrs.

Ceramic Processes before Firing

Introduction to ceramic processing methods, Comminution process, Mechanical effects in comminution, Dry milling, Wet milling, Tumbling milling, Planetary ball milling, Vibratory ball milling, Particle size characterization, BET analysis, pyconometry, Agglomeration of fine particles, Sintering-aids and dopants, Surfactants, Wetting agents , Dispersants, Binders and plasticizers, Viscosity, Green body forming

Fundamentals of Ceramic Forming

Consolidation of ceramic powders, Mechanical compaction, Powder packing, Uniaxial pressing, Isostatic pressing, Hot pressing, Hot isostatic pressing, Slip casting, Tape casting, Plastic forming, Extrusion, Injection moulding, Rapid prototyping, Green machining

Sintering of Ceramics

Dilatometry, sintering curve, kinetics of sintering, solid state sintering, liquid phase sintering, reaction sintering, microwave sintering, spark plasma sintering, laser sintering, rate controlled sintering, density analysis, grain size and microstructure analysis techniques

Advanced Functional Ceramic Coatings

Co-precipitation, Solgel processing, Coating techniques, Rheology of coating precursors, Functional coatings, Wetting and non wetting surfaces, Coating characterizations, Multilayered coatings, Nanocomposites, Porous ceramics ceramic membranes, Organic-inorganic nano hybrids

Advanced Electronic Ceramics and Applied Superconductors

Dielectric ceramics, Microwave ceramics, Lowκ materials, SOFC materials, Solid-ionic conductors, Phosphor materials, Impedance analysis, Varistors, Sensors, Superconductivity and high temperature ceramic super conductors, Ceramic Inks

Advanced High Temperature Ceramics

Engineering Ceramics – Properties and applications of Al_2O_3, SiC, Si_3N_4, Zirconia, Mullite, Al_2TiO_5, Rare earth phosphates, B_4C, Cubic Born nitride, Thermal shock resistance and super plastic ceramics

Reference Books

1. Raghavan V, "Materials Science and Engineering – First Course" , Prentice-Hall of India, 1999.
2. William D. Callister, "Materials Science and Engineering: An Introduction", John Wiley & Sons (2001).
3. W. David Kingery, H. K. Bowen, Donald R. Uhlmann "Introduction to Ceramics", [2nd Edition], Wiley & sons (2002).
4. C. Barry Carter and M. Grant Norton "Ceramic Materials: Science and Engineering", Springer
5. F.H Norton "Elements of Ceramics", Addison Wesley (1974).
6. Fritz Aldinger, Volker A. Weberruss, "Advanced Ceramics and Future Materials: An Introduction to Structures, Pro[perties Technologies and Methods" Wiley VCH GmbH (2010).
7. M.W Barsoum, Fundamentals of Ceramics - Series in Material Science and Engineering. by, Taylor and Francis (2002).
8. M. N. Rahaman, "Ceramic Processing" CRC Press (2006)
9. M. N. Rahaman, "Sintering of Ceramic" CRC Press (2007)
10. Relva C. Buchanan, "Ceramic Materials for Electronics", Taylor & Francis, (2004).

PHY(NIIST)-3-534: Inorganic Phosphors for White Light Emitting Diodes **3-0-0-3**

Course Coordinator: P. Prabhakar Rao
Total Hours: 42 Hrs.

Solid State Chemistry

Classification of solids – Unit cell – Bravais lattice – Symmetry elements – Symmetry operations, Molecular point groups – Point group notations –Classification of space groups Miller indices of a crystal plane – Experimental method of X-Ray Diffraction – Reciprocal lattice – Crystal structure – lattice energy of ionic crystals – Factors affecting crystal structure – Defects in solids, Point defects, Line defects, Vacancies, Distortions.

Fundamentals of Phosphors

Fundamentals of Luminescence -Fluorescence and Phosphorescence - Electronic transition in an atom - Radiative and nonradiative transitions - Configurational coordinate model -Selection rules - Einstein coefficients - Design of phosphors - Electronic processes leading to luminescence - Energy transfer between identical/unlike centers - Energy migration and concentration quenching - Crystal field splitting - Rare earths and their spectral properties - Dieke diagram - Spectral intensities of f-f transitions: Judd-Ofelt theory – Long afterglow phosphors - Phosphor Quantum dots - Applications of phosphors

Phosphor Converted WLEDs

Lighting Quality: CIE Chromaticity diagram, Color temperature, Color Rendering Index, Lighting efficiency and efficacy - Solid-state lighting – LED - Mechanism behind photon emission in LEDs - Current Technology - Current Uses - Inorganic light emitting diodes - Phosphor converted White light emitting diodes – Approaches: Phosphor Down Conversion, Color Mixing - Conventional Approach for Improving CRI - Direct-White Phosphor

Reference Books

1. H. V. Keer "Principles of Solid State", New Age International, (1993)
2. Anthony R. West "Solid State Chemistry and its Applications", Wiley India P Ltd (2007)
3. G. Blasse, B. C. Grabmaier "Luminescent Materials", Springer-Verlag, (1994).
4. Adrian Kitai "Luminescent Materials and Applications", John Wiley & Sons Ltd (2008).
5. C. Ronda "Luminescence, From Theory to Applications", Wiley VCH Verlag GmbH (2008).
6. R. C. Ropp "Luminescence and the Solid State", Elsevier (2004).
7. S. Shionoya, W. M. Yen, H. Yamamoto (Editors) "Phosphor Handbook "(2nd Edition), CRC Press (2006)

PHY(NIIST)-3-535: Solid State Ionics and Fuel Cells 3-0-0-3

Course Coordinator: P. Prabhakar Rao
Total Hours: 42 Hrs.

Solid State Ionics

Bonding and structure: Classification of solids-Unit cell-Bravais lattice-Miller indices of a crystal plane-Experimental method of X-ray Diffraction-Reciprocal lattice-Crystal structure-Lattice energy of ionic crystals-Factors affecting crystal structure-Defects in solids-Point defects, line defects-Vacancies-Distortions

Electrical conductivity: Electrical conductivity of metals and covalent solids-Origin of band gap-FD statistics and Fermi energy-Density of states-Thermal conductivity of metals-Factors affecting electrical conductivity-Direct and indirect semiconductors-The 'Hole' concept-Temperature dependence of mobility-Temperature variation of charge carrier densities-Extrinsic semiconductivity-Superconductivity-Hopping conduction-Ionic conductivity-Superionic conductivity-Structure, defects and conductivity

Electrochemical Impedance Spectroscopy

Ionic conductivity measurements-Basic impedance spectroscopy measurement-Response to a small signal stimulus in the frequency domain-Impedance related functions: Admittance, Modulus function, Dielectric permittivity-Advantages and limitations of Impedance Spectroscopy

Fuel Cell Technology

Introduction-Basic structure-Critical functions of cell components-Fuel cell types: Polymer Electrolyte Fuel Cell (PEFC), Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), Solid Oxide Fuel Cell (SOFC)-Characteristics of fuel cells-Advantages and disadvantages-Fuel Cell Performance-Role of Gibbs free energy and Nernst potential-Ideal performance-Cell energy balance-Cell efficiency-Effect of temperature and pressure on fuel cell performance-SOFC: Electrolyte materials

Reference Books

1. Principles of Solid State – H. V. Keer, New Age International, (1993)
2. Solid State Physics: Structure And Properties of Materials, M. A. Wahab, Narosa Publishing House, (1999).
3. Impedance Spectroscopy: Theory, Experiment and Applications- J. Ross Macdonald, Wiley Interscience (2005).
4. Fuel Cell Handbook (Seventh Edition) - EG & G Technical Services, Inc. (2004).
5. High Temperature Solid Oxide Fuel Cells: Fundamentals, Design and Applications- Subhash C. Singhal and Kevin Kendall, Elsevier (2003).

PHY(NIIST)-3-536: Smart Materials 3-0-0-3

Course Coordinator: K. P. Surendran, M. Vasundhara
Total Hours: 42 Hrs.

Charge Transport

Dielectric devices, Electrets, Material types and properties of Electrets, Space charge electrets, Charge distribution, Depolarization, Thermally Stimulated Depolarization currents.

Piezoelectric Sensors

Piezoelectricity, Phase transition, Piezoelectric and Pyroelectric coefficients, Hysteresis loop; structure-property relationship, Relaxor ferroelectrics, An introduction to sensors and transducers, Piezo-resistive sensors, Resistive strain gages, Piezoelectric sensors, Capacitive, Inductive and optical methods, Tactile sensors, Touch screens, Fingerprint sensors, Piezo-electric based inkjet print-head.

Ferroelectric Devices

Linear and non-linear dielectric, piezo-, pyro- and ferroelectric crystals; Structural Phase Transition, Dipole and thermodynamical theory of order-disorder and displacive type of phase transition, Structural, Dielectric, Electrical, Spectroscopic and optical properties of ferroelectrics; Ferroelectric devices; Electro-optic modulator, Light valves, Pyroelectric detectors, Micromachined Transducers, Computer memory and display devices, Non-volatile devices.

Smart Materials

Overview of Smart Materials and Microsystems, Feynman's vision, Electrostrictive materials, Magnetostrictive and Magnetoelectric materials, Shape Memory Alloys, MEMS, Topological Insulators, Electrorheological and Magnetorheological Fluids, Energy Harvesting Materials and Applications, Applications of Engineering Smart Structures and Products

Emerging Memory Technologies

Random access memories (RAM): classification and operation, SRAMs, DRAMs: history and challenges.Phase Change Memory (PCM); Magnetoresistive Random Access Memory (MRAM); Ferroelectric Random Access Memory (FeRAM), Comparison and future directions

Reference Books

1. Ahmad Safari, E. Koray Akdogan, "Piezoelectric and Acoustic Materials for Transducer Applications", Springer (2008).

2. C. Z. Rosen, B.V. Hiremath and R. Newnham (Editors) "Piezoelectricity, Key papers in Physics" American Institute of Physics (2004).
3. Jasprit Singh, "Smart Electronic Materials: Fundamentals and Applications", Cambridge University Press, (2005).
4. Michelle Addington and Daniel L. Schodek, "Smart Materials and Technologies", Elsevier (2005).
5. A.J. Moulson and J.M. Herbert, "Electroceramics: Materials, Properties, Applications", 2nd Ed., John Wiley & Sons, (2003).
6. G. Gautschi, "Piezoelectric Sensorics: Force, Strain, Pressure, Acceleration and Acoustic Emission Sensors, Materials and Amplifiers", Springer, (2002).
7. D.J. Leo, "Engineering Analysis of Smart Material Systems", Wiley (2007).

PHY(NIIST)-3-537: Superconductivity 3-0-0-3

Course Coordinator: R.P. Aloysius, M.R. Varma, M. Vasundhara
Total Hours: 42 Hrs.

Basics of Superconductivity

Introduction to superconductivity; Thermodynamics of superconducting transition, Two-fluid model London theory, Flux-quantization, Superconducting tunneling phenomena and energy gap, introduction to microscopic theory (Bardeen-Cooper-Schrieffer) of superconductivity. Type II superconductivity, mixed state and Ginzburg-Landau theory, critical currents, flux-pinning and flux-flow.

Applications of Superconductivity

(i) High power applications: Superconducting cables, transformers and magnets, superconducting fault current limiters, superconducting current leads, superconducting motors, magnetic levitation, superconducting energy storage systems, NMR and MRI applications.

(ii) Electronic applications: Superconducting filters, SQUIDs and Josephson junction based devices, detectors and bolometers. Rapid Single Flux Quantum (RSFQ) Superconductor Electronics

High-Tc Superconductors

High-Tc superconductor types and classes, Properties of high-Tc superconductors, weak links and critical current density, flux pinning and critical current density. Preparation and processing of high-Tc superconductors, general applications of high-Tc superconductors

Reference Books

1. D.R. Tilley, & J. Tilley, "Superfluidity and Superconductivity", Bristol: Hilger (1990).
2. J.F. Annett, "*Superconductivity, Superfluids and Condensates"* Oxford (2004).
3. M. Tinkham, "*Introduction to Superconductivity"* McGraw Hill, Singapore (1996)
4. P.G. de Gennes, "*Superconductivity of Metals and Alloys"* Addison-Wesley (1999)
5. Schmidt, V.V. "*The Physics of Superconductors: Introduction to Fundamentals and Applications*" , Springer (1997).
6. Brehm, J.J. & Mullin, W.J. "*Introduction to the Structure of Matter*", Wiley(2000).

PHY(NIIST)-3-538: Ceramic Microsystems and LTCC 3-0-0-3

Corse Coordinator: K. P. Surendran
Total Hours: 42 Hrs.

Introduction
Package function and hierarchy, Evolution of Packages, PWB, SMT and Hybrid Circuits, Technology drivers, Single chip packages, Multichip Modules Introduction to Packaging Technologies, Silicon Efficiency and other packaging parameters, Low loss transmission systems, Package reliability, Environmental effects, Thermal mismatch and fatigue, Types of thermal failures, Other assorted failure processes, Packaging Processes: Process description, Sealing

Integrated Technology
Clean room concept, Growth of single crystal Si, Cleaning and etching, Physical Vapour Deposition, Chemical Vapour Deposition; Epitaxial growth Oxidation, Diffusion, Ion implantation, Lithography, Plasma deposition and etching, Metallization, VLSI Process Integration, Packaging Summary and Future trends in microelectronics

Ceramic Packages
Materials and fabrication processes for Alumina ceramic packages and Low Temperature Ceramic packages, Thick film paste technology, Post fire processes, Brazing, CBGA, Concepts of integrated ceramic packaging, Plastic Packages, Types of plastic packages, Comparison with ceramic packages, Moulding compounds and lead frames, Moulding Processes, Applications and future trends

Low Temperature Cofired Ceramic Technology
Introduction, Glass additives, Thick Film and Cofiring metallization methods, Resistors and High K Materials, Processing of LTCC – Powder preparation, Mixing, Casting Green Tapes, Via Punching, Printing and Lamination, Cofiring, Reliability, Piezoelectric LTCC, MEMS in LTCC, Future of LTCC

Reference Books

1. Rao R. Tummala, Eugene J. Rymaszewski and Alan G. Klopfenstein “Microelectronics Packaging Handbook, Parts I, II, III” Chapman & Hall, (1997)
2. Merrill L. Minges “Electronic materials Handbook, Volume 1: Packaging” ASM International, (1989).
3. Charles A. Harper “Electronic Materials and Processes Handbook”McGraw-Hill Prof Med/Tech, (2003).
4. Yoshihiko Imanaka, “Multilayered Low Temperature Cofired Ceramics (LTCC) Technology”, Springer (2005).
5. Glenn R. Blackwell “The Electronic Packaging Handbook”, Taylor & Francis, (1999).
6. V. Varadan, K.J. Vinoy, S. Gopalakrishnan “Design and Development Methodologies, Smart Material Systems and MEMS”, Wiley (2008).
7. Deborah Chung “Materials for Electronic Packaging” Butterworth-Heinemann, (1995).
8. Fred D. Barlow, III, Aicha Elshabini “Ceramic Interconnect Technology Handbook” Taylor & Francis, (2007).
9. Tai-Ran Hsu “MEMS & Microsystems: Design and Manufacture”, TMH, 1st Edition (2007).
10. “A.K.Aatre, Ananth Suresh, K.J.Vinoy, S. Gopalakrishna,, K.N.Bhat.,Micro and Smart Systems” by John Wiley Publications (2002).

PHY(NIIST)-3-539: MEMS and EMI Shielding Materials 3-0-0-3

Course Coordinator: K. P. Surendran
Total Hours: 42 Hrs.

Electromagnetic Interference
Retarded Potentials and concepts of radiation, Radiation from a small current element, Introduction to Electromagnetic Interference and Electromagnetic compatibility, Sources of EMI – Intersystems and Intrasystem, EMI predictions and Modelling, Cross talk, EMI coupling modes, Methods of eliminating interference, Shielding, Grounding, EMI testing: Emission testing, Susceptibility testing

Microwave Propagation in Ferrites
Microwave Ferrites, Permeability Tensor, Wave Propagation in Ferrite Medium, Faraday Rotation, Birefringence, Ferrite Loaded Waveguides, Ferrite Circulators, Isolators and Phase Shifters, Basic Parameters for Ferrite Devices

Conducting Polymers and EMI Shielding
Characteristics of Conducting Polymers, Electrochemistry of electronically conducting polymers-source of electronic conduction in polymers – Solitons, Polarons and Bipolarons, Semiconductors and conducting polymers

Composites in Microelectronics
Fabrication of Microelectronic devices: Crystal growth and wafer preparation, Film Deposition oxidation, Lithography, bonding and packaging, Reliability and yield, Printed Circuit boards, Computer aided design in Micro electronics, Surface mount technology, Integrated circuit economics

MEMS
Introduction, Materials for MEMS manufacturing, MEMS basic Processes - Deposition process-Physical and Chemical Vapour Deposition, Patterning-Lithography-Photolithography, Electron beam Lithography, Ion Beam lithography ray Lithography, Diamond Patterning - Etching Processes: Wet etching-Isotropic etching, Anisotropic etching-HF etching-Electrochemical etching, Dry etching-Vapor etching-Xenon difluoride etching-Plasma etching-Sputtering, Reactive ion etching(RIE), Die preparation - MEMS manufacturing Technologies Applications of MEMS

Reference Books

1. William Duff G., & Donald White R. J, "*Series on Electromagnetic Interference and Compatibility*", Vol.5, EMI Prediction and Analysis Technique – (1972).
2. Weston David A., "*Electromagnetic Compatibility, Principles and Applications",* (1991).
3. Kaiser B. E., "*Principles of Electromagnetic Compatibility",* Artech House, (1987).
4. Bemhard Keiser, "Principles of Electromagnetic Compatibility", 3rd Ed, Artech house, Norwood, 1986.
5. Rao R. Tummala, Eugene J. Rymaszewski and Alan G. Klopfenstein "Microelectronics Packaging Handbook, Parts I, II, III" Chapman & Hall, (1997)
6. Tai - Run Hsu, MEMS & Micro Systems Design and manufacture, McGraw-Hill, (2002).
7. Robert E. Collin, "Foundations for Microwave Engineering", 2nd Ed., McGraw Hill, (1992).

8. D.S.Soane and Z. Martynenko (Eds.), "Polymers in Microelectronics", Elsevier,Amsterdam, (1989).
9. B. Wessling, "Electronic Properties of Conjugated Polymers", Vol.3, Springer, Berlin, (1989).
10. Manas chanda and Salil K Roy "Plastics Technology Handbook", (4th edition), CRC press, New York (2000).

PHY(NIIST)-3-540: Materials for Printed Electronics 3-0-0-3

Course Coordinator: K. P. Surendran
Total Hours: 42 Hrs.

Silicon Technology
Development of Microelectronics, Nanostructure region, Complexity problem, Challenges in Nanoelctronics, Semiconductor as based materials, Band diagram of semiconductor, Inhomogeneous semiconductor band diagram, Different types of transistor integration, Microminiaturization Process - methods and limits, Scaling, Milestone of silicon technology, Limits, Integrated optoelectronics.

Uncertainty of Nanodevices
Limits of Integrated Electronics, Survey of Limits, Replacement of Technologies, Energy Supply and Heat Dissipation, Parameter Spread as Limiting Effect, Limits due to Thermal Particle motion, Debye Length, Thermal Noise, Reliability of as Limiting Factor, Physical limits, Thermodynamic Limits, Relativistic Limits, Final Objectives of Integrated Electronic Systems, Removal of uncertainty by Nanomachines, Uncertainties in Nanosystems

Molecular Electronics
Single molecule electronic devices, Transport in molecular structures, Molecular interconnects polymer surfaces and interfaces preparation, Metamaterials, Photonic band gap systems, Application and devices.

Printing Technologies
Ingredients of printing ink pigments, Vehicles and additives, Manufacturing of printing ink, general formulation of printing ink, Inkjet printing- Gravure printing and Flexographic printing-Flex graphic printing, Gravure printing- Roll-to-Roll techniques. Screen printing: History, Stencils, Screening materials. Screens– multifilament, mono filaments, Selecting mesh material, Screen Preparation, Image transfer, Squeegee, Variety of blade shape and application, On-contact printing, Off-contact printing. Screen ink uniqueness

Printing with Functional Fluids
Inks and Functional Fluids, Solvent-, Oil-, Water-based, UV-curing fluids, Phase-change fluids, Dispersions and suspensions, Nano-particle and CNT-fluids, Rheology and measurement technologies, Formulations of functional fluids for inkjet printing (nano-particles and nano-tube suspensions, polymer solutions, ceramic fluids, bio-fluids etc) Applications in electronics, displays, data storage, optical, biological, medical applications etc.

Reference Books
1. K. Goser, P. Glosekotter and J. Diens tuhl, "Nanoelectronics and Nanosystems -From Transistors to Molecular Quantum Devices" , Springer, (2004).

2. Herve Rigneault, Jean-Michel Lourtioz, Claude Delalande, Ariel Levenson, “Nanophotonics”, Wiley ISTE (2006).
3. W.R.Fahrner, “Nanotechnology and Nanoelectronics – Materials, Devices and Measurement Techniques” Springer, 2006.
4. William A. Goddard, III, Donald W. Brenner, Sergey E. Lyshevski “Handbook of Nanoscience, Engineering and Technology”, Kluwer publishers, (2012).
5. W.R.Fahrner, “Nanotechnology and Nanoelectronics – Materials, Devices and Measurement Techniques” Springer, 2006.
6. NIIR Board “Hand Book on Printing Technology (Offset, Gravure, Flexo, Screen)” Asia Pacific Business Press (2003).
7. Andy MacDougall, “Screen Printing Today: The Basics”, St Media Group International Inc., (2008).
8. John Stephens “Screen Printing” Blueprint, (1987).
9. NIIR Board “The Complete Technology Book on Printing Inks” Asia Pacific Business Press (2000).
10. E. A. Apps ”Printing Ink Technology” L. Hill, (1958).
11. Norman Underwood “The Chemistry and Technology of Printing Inks” D. van Nostrand Company, (2008).

PHY(NIIST)-3-541: Semiconducting Oxides for Photocatalysis of Water 3-0-0-3

Course Coordinator: P. Prabhakar Rao
Total Hours: 42 Hrs.

Semiconductors

Bloch theorem, energy bands, Kronig-Penny model, motion of electrons in one dimension, concept of effective mass and holes, distinction between metals, insulators and Semiconductors, Band theory of semiconductors, Intrinsic semiconductors: electrons and holes, Intrinsic carrier densities, General properties of extrinsic semiconductors: n-type and p-type semiconductors, Energy level diagrams, Fermi level, Mobile charge carriers in semiconductors, drift, conductivity and mobility ,The mass-action law, Direct band gap materials, Band gap tailoring, Indirect band gap materials, Effective mass, Population of donor and acceptor levels in thermal equilibrium, Extrinsic carrier densities, Temperature dependence of electrical conductivity

Semiconducting materials and light

Interaction of light with semiconductors, Optical absorption: Direct and indirect-Optical Constants, Generation and recombination of excess carriers: Direct recombination ,Indirect recombination, Photoconductivity-Steady and transient, Effects of traps, Recombination through traps, Recombination at surfaces, Minority carrier generation and recombination, Contact problems, Metal semiconductor contacts, Schottky barrier

Photocatalytic Water Splitting for Energy production

Semiconductor electrodes for solar energy conversion, Reduction of CO_2 at illuminated semiconductor electrodes, Photocatalysis: mechanistic studies, applications, Photocatalytic activity, Effect of surface area on photocatalytic activity, Effect of electron-hole recombination on photocatalytic activity

Band bending at Semiconductor/liquid interface, Barrier height and flat band potential, Photoelectrochemical reactions at Semiconductor microparticles: energy structure, Kinetics at semiconductor microparticles, Effect of size

Reference Books

1. J.P. Srivastava “Elements of Solid State Physics”, Prentice Hall of India
2. Masao Kaneko and Ichiro Okura “Photocatalysis: Science and Technology”, Kodansha and Springer Publications
3. Jenny Nelson “Physics of Solar Cells”, Imperial College Press
4. S. M. Sze “Physics of Semiconductor Devices”, John wiley & Sons
5. John Sydney Blakemore “Solid state physics”, Cambridge University Press
6. A. J. Dekker “Solid State Physics”, Springer

PHY(NIIST)-3-542: Semiconducting Oxides for Thermistor Applications **3-0-0-3**

Course Coordinator: P. Prabhakar Rao
Total Hours: 42 Hrs.

Semiconductors

Bloch theorem, energy bands, Kronig-Penny model, motion of electrons in one dimension, concept of effective mass and holes, distinction between metals, insulators and Semiconductors, Band theory of semiconductors, Intrinsic semiconductors: electrons and holes, Intrinsic carrier densities, General properties of extrinsic semiconductors: n-type and p-type semiconductors, Energy level diagrams, Fermi level, Mobile charge carriers in semiconductors, drift, conductivity and mobility ,The mass-action law, Direct band gap materials, Band gap tailoring, Indirect band gap materials, Effective mass, Population of donor and acceptor levels in thermal equilibrium, Extrinsic carrier densities, Temperature dependence of electrical conductivity

Electrical transport in semiconducting oxides

Electric charge carriers and their motion under electric field, Electrical transport: Band Conduction, Defect-Controlled Conduction, Electrical Transport by Tunneling Process Electrical Transport by Hopping Process, Polaron Conduction, Conductivity relaxation in semiconducting oxides, Dependence of electrical conductivity on temperature and frequency, Jonscher’s universal power law, Jump relaxation model.

Semiconducting oxides for NTC Thermistor applications

Sensors, Thermistors, Thermistor parameters, Challenges for making high temperature NTC thermistors, Factors affecting the thermistor parameters: structure, microstructure, doping of impurities, Temperature dependence of electrical conductivity, Arrhenius equation for conductivity, Calculation of activation energy

Reference Books

1. A. J. Dekker *“Solid State Physics”*, Springer.
2. J.P. Srivastava *“Elements of Solid State Physics*”, Prentice Hall of India.
3. S. M. Sze *“Physics of Semiconductor Devices*”, John Wiley & Sons.
4. John Sydney Blakemore *“Solid state physics*”, Cambridge University Press.
5. Kwan Chi Kao *“Dielectric Phenomena in Solids*”, Elsevier Academic Press.
6. Gorur G. Raju *“Dielectrics in Electric Fields*”, Marcel Dekker, New York.
7. By N. F. Mott and E. A. Davis *“Electronic Processes in Non-Crystalline Materials*”, Clarendon Press, Oxford.

PHY(NIIST)-3-543: Inorganic Pigments for Surface Coating Applications 3-0-0-3

Course Coordinator: P. Prabhakar Rao
Total Hours: 42 Hrs.

Chemistry of Transition metals and Rare Earths
General characteristic properties of transition elements – Co-ordination chemistry of transition metal ions – Ligand field theory – Splitting of d orbitals in low symmetry environments – Jahn-Teller effect – Interpretation of electronic spectra including charge transfer spectra – Spectrochemical series – Nephelauxetic series

Molecular Structure and Bonding
Bonding theories – Valence Bond Theory – Crystal field theory – Molecular orbital approach – Structure and bond Properties – Spectral properties – Color of transition metals – d-d transitions – Metal to ligand and ligand to metal charge transfer transitions – Color of rare earth elements

Theory of Color
Interaction of light with matter – Reflection – Absorption – Transmission – Band theory of semiconductors – Band gap – Causes of color – Color from ligand field effects – Color from molecular orbitals – Color from charge transfer – Color in semiconductors – Color from impurities in semiconductors – Color from color centers.

Inorganic Pigments
General information and economic importance – Classification of pigments– General chemical and physical properties – White pigments –Colored pigments – mixed-metal oxide pigments and ceramic colorants – Corrosion protection pigments, luster pigments – Luminescent pigments – Magnetic pigments – Color properties – Colorimetry – Kubelka–Munk Theory – Multiple Scattering – Mie's Theory –Applications of pigments in coating industry

Reference Books

1. J. D. Lee, Concise Inorganic Chemistry; 4th Edn, Chapman and Hall, London, (1992).
2. Shriver Atkins, Inorganic chemistry 5th Edn, Oxford University Press, (2009).
3. Solid State Chemistry, R.C.Ropp , Elsevier.
4. J. E. Huheey, E. A. Keiter and R. L. Keiter, Physical Chemistry: Principles of Structure and Reactivity, 4th Edn.; Addison-Wesley Publishing Co., New York, (1993).
5. G. Buxbaum and G. Pfaff, Industrial Inorganic Pigments, 3rd Edn.,Wiley VCH, 2005.
6. Steven K. Shevell, the Science of Color, 2nd Edn, Elsevier, 2003.

PHY(NIIST)-3-544: Cryogenics and Vacuum Techniques 3-0-0-3

Course Coordinator : M. Vasundhara, Biswapriya Deb, K.P. Surendran
Total Hours: 42 Hrs.

Production and measurement of low temperature
The range of low temperature; Importance of vacuum; Different pumps to produce vacuum of required order (Rotary pump, Diffusion pump, Turbo-molecular and Cryo-pumps), Different Guages to measure the Vaccum; Properties of liquid oxygen, liquid nitrogen and liquid helium;

Construction of Thermostat and Cryostat. Measurement of low temperature using different techniques.

Physical properties of solid at low temperature:

a) Transport properties:
Dielectric constant and its measurement; Electrical properties of solid; Low temperature specific heat of solid, Electric Thermo Power, Thermal Conductivity.

b) Magnetic Properties:
Low temperature Magnetic susceptibilities; Electron paramagnetic resonance, Nuclear magnetic resonance etc.
d*) Hyperfine properties:*
Nuclear magnetic properties; Electric quadrupolar effect at nuclear site; Mossbauer effect and other hyperfine properties of the solids.

e) Spectroscopic properties:
Infra red and visible spectra, Zeeman spectra; Formation of laser and its principles; Use of laser in Spectroscopy; Laser cooling.

Reference Books

1. Guy K. White "Experimental Techniques in Low Temperature Physics",3rd Edition, Clarendon Press, Oxford, (1979).
2. A. Roth "Vacuum Technology", North Holland, Amsterdam, (1982).
3. Guglielmo Ventura and Lara Risegari "The Art of Cryogenics: Low-Temperature Experimental Techniques", 1st edition, Elsevier, (2008).
4. Christian Enss and Siegfried Hunklinger "Low-Temperature Physics", Springer, (2005).
5. Jack W.Ekin, Experimental Techniques: Low Temperature Measurements, , OUP Oxford, (2006).

PHY(NIIST)-3-545: Magnetism and Magnetic Materials for Technological Applications **3-0-0-3**

Course Coordinator: M. Vasundhara, Manoj R. Varma and R.P. Aloysius
Total Hours: 42 Hrs.

Magnetism
Fundamentals of magnetism and magnetic properties of materials , Magnetic moments of electrons, theory of electron magnetism,Classical versus quantum mechanical pictures, diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism, crystal field environments, dipolar and exchange interactions, magnetic domains, magnetic anisotropy and magnetostriction.

Magnetic Materials
Transition metals, their alloys and oxides, rare earths and their oxides, organic and molecular magnets, Spintronics, magneto resistive materials, Gaint magneto resistance, magneto-optical

materials, Biomagnetism and spin glasses. Experimental techniques in magnetic characterization, Magnetic measurements of properties for materials evaluation.

Technological Applications

Soft magnetic materials for electromagnets, Hard magnets, Permanent magnets, Magnetic refrigeration, Magnetic recording technology, Magnetoelectric materials and devices, Magneto-optical devices.

Reference Books

1. B.D. Cullity and C.D. Graham “Introduction to Magnetic Materials”, 2nd edition, IEEE Press, (2009).
2. Magnetism in Condensed Matter, Stephen Blundell, Oxford University Press, (2001).
3. Nicola A. Spaldin “Magnetic Materials”, Cambridge Univesity Press (2003).
4. Robert C. O'Handley, Modern Magnetic Materials, John Wiley & Sons, (1999).
5. Sōshin Chikazumi, Stanley H. Charap “Physics of Magnetism”, R. E. Krieger Pub. Co., 1978
6. A.V.Narlikar “Frontiers in Magnetic Materials”, Springer (2000),
7. K.J.H. Bushcow and F.R.De Boer “Physics of Magnetism and Magnetic materials”, Kluwer Academic Publisher, (2004).
8. Leszek Malkinski “Advanced Magnetic Materials”, (2012).