241/PHY/CC401

COURSE ID: 241/PHY/CC401

ATOMIC AND MOLECULAR PHYSICS

Marks (Theory): 70 **Credits: 4**

Marks (Internal Assessment): 30 **Time: 3 Hours**

Note: The examiner will set 9 ques ons, asking two ques ons from each unit and one compulsory ques on by taking course learning outcomes (CLOs) into considera on. The compulsory ques on (Ques on No. 1) will consist of at least 4 parts covering the en re syllabus. The ques on paper is expected to contain problems to the extent of 20% of the total marks. The examinee will be required to a empt 5 ques ons, selec ng one ques on from each unit and the compulsory.

Course Outcomes:

After successful completion of the course on Atomic and Molecular Physics, a student will be able to:

- *Understand the quantum mechanical structure of atoms, including fine, hyperfine, and Zeeman effects.*
- *Study the principles and applications of molecular spectroscopy, including rotational, vibrational, Raman, and electronic spectra.*
- *Explore the fundamental concepts and mechanisms of laser physics, NMR, and ESR spectroscopy.*
- *Analyze energy levels, selection rules, and coupling schemes in one- and many-electron atoms.*
- *Apply spectroscopic methods to interpret atomic and molecular transitions, including line broadening and dissociation phenomena.*

Unit I

Atomic Structure and Spectra: Review of one-electron and two-electron atoms: Derivation of quantum numbers and their physical interpretation, Spectra of hydrogen and helium atoms, Electric dipole selection rules, Fine structure of spectral line: relativistic correction, spin orbit interaction, Lamb shift, Hyperfine structure and isotope shifts, Many-electron atoms: LS-coupling, jj-coupling, Lande interval rule, Spectra of alkalis, Characteristic X-rays spectra, Moseley's law and Auger transitions. Normal and anomalous Zeeman effect, Paschen-Back effect, First and second order Stark effect.

Unit II

Magnetic Resonance and Laser Principles: Nuclear magnetic resonance (NMR): Basic principles, Bloch equations, Spin-spin and spin-lattice relaxation, Chemical shift and coupling constant; Electron spin resonance (ESR), Laser: Absorption, spontaneous and stimulated emission. Einstein coefficients, Population inversion, Optical resonator, Gain coefficient, Laser rate equation of three level systems, Ruby laser, He-Ne Laser, Semiconductor laser, Line broadening mechanism: natural, Doppler, and collision broadening.

Unit III

Molecular Rotational and Vibrational Spectroscopy: Rotational spectra of rigid diatomic molecules, Isotope effect in rotational spectra, Intensity of rotational lines, Non rigid rotator, Infrared spectroscopy: Vibrational Energy of diatomic molecule, Infrared selection rule, Molecule as anharmonic oscillator, Spectra of the vibrating diatomic molecule, Vibrational-rotational spectra of diatomic molecules, Raman Spectroscopy: Raman effect, Pure rotational Raman spectra, Vibrational Raman Spectra, Nuclear Spin and intensity alternation in Raman spectra.

Unit IV

Electronic Spectroscopy: Born Oppenheimer approximation, Basics of Vibrational coarse structure of electronic levels, Deslanders table, Progression and sequences, Intensity of electronic levels: Frank Condon Principle, Rotational fine structure of electronic bands, The Fortrat parabole, Dissociation and pre-dissociation of molecules, Fluorescence spectroscopy: Fluorescence and Phosphorescence, Jablonski Diagram.

References/Books:

1. Bransden, B.H., & Joachain, C.J. (2003). Atomic, Molecular and Optical Physics. Pearson Education.
2. Kumar, R. (2013). Atomic and Molecular Physics. Campus Books International.
3. Aruldhas, G. (2007). Molecular Structure and Spectroscopy (2nd ed.). Prentice-Hall of India.
4. Banwell, C.N., & McCash, E.M. (1994). Fundamentals of Molecular Spectroscopy (4th ed.). McGraw-Hill.
5. Haken, H., & Wolf, H.C. (2005). The Physics of Atoms and Quanta: Introduction to Experiments and Theory (7th ed.). Springer.
6. Chang, R. (2005). Principles of Molecular Spectroscopy. McGraw-Hill Education.

COURSE ID: 241/PHY/CC402

STATISTICAL MECHANICS

Marks (Theory): 70 **Credits: 4**

Marks (Internal Assessment): 30 **Time: 3 Hours**

Note: The examiner will set 9 ques ons, asking two ques ons from each unit and one compulsory ques on by taking course learning outcomes (CLOs) into considera on. The compulsory ques on (Ques on No. 1) will consist of at least 4 parts covering the en re syllabus. The ques on paper is expected to contain problems to the extent of 20% of the total marks. The examinee will be required to a empt 5 ques ons, selec ng one ques on from each unit and the compulsory.

Course Outcomes:

After successful completion of the course on Classical Mechanics, a student will be able to:

- *Understand postulates of classical and quantum statistical mechanics*
- *Learn the ensemble formulation of statistical mechanics, and its application for the calculation of thermo-dynamical quantities for simple systems.*
- *Formulate the quantum mechanical ensemble theory and its usefulness for the derivation of laws of quantum statistics such as Fermi-Dirac (FD) and Bose-Einstein (BE) statistics.*
- *Able to apply the ideas of phase-transitions of first and second order, ferromagnetism using Ising models.*
- *Able to differentiate between Bosonic and Fermionic systems and understand phenomenon such as black-body radiation, Bose-Einstein condensations*

Unit I

Review of thermodynamics: Extensive and intensive Thermodynamic Variables, Quasistatic and non- quasistatic processes, laws of thermodynamics, Concept of Entropy, Second Law of Thermodynamics in terms of Entropy, entropy of a probability distribution, Thermodynamic Potentials: Internal Energy, Enthalpy, Helmholtz Free Energy, Gibb's Free Energy. Maxwell's thermodynamic Relations and their applications, Random Walk.

Unit II

Classical ensemble theory: Phase space, Microstates and Macrostates, Postulate of equal a priori probability, Concept of Statistical Ensembles, Ensembles average, Liouville's theorem, The microcanonical ensemble, Boltzmann relation for entropy, Sackur-Tetrode equation, Canonical ensemble; partition function; Helmholtz free energy, Grand-canonical ensemble, Equivalence of the various ensembles. Classical Ideal gas and Harmonic Oscillator using canonical and grand-canonical ensamble.

Unit III

Quantum Statistics: The density matrix, Equation of motion for density matrix, Indistinguishable particles in quantum mechanics. Bosons and Fermions. Bose-Einstein statistics, Ideal Bose gas, photons, Bose-Einstein condensation. Fermi-Dirac statistics, Fermi energy, Ideal Fermi gas, Black Body Radiation.

Unit IV

Interacting systems and Phase transitions: Thermodynamic description of phase transitions, phase transition of first and second order, Interacting spin systems. The Ising model. Exact solution of Ising model in one-dimension (1D), Mean-Field solution in Higher Dimensions. Paramagnetic and Ferromagnetic Phases. Critical exponents, Landau theory of Phase transition.

References/Books:

1. Statistical Physics of Particles, Mehran Kardar (Cambridge University Press, 2007).
2. Statistical Mechanics, Kerson Huang (2^{nd} Edition, Wiley-India, 2008).
3. Statistical Mechanics, R.K. Pathria (Butterworth-Heinemann, 1996).
4. Statistical Mechanics: An Advanced course with problems and solutions, Ryogo Kubo (North- Holland, 1965).
5. Fundamentals of Statistical & Thermal Physics, F. Reif.

241/PHY/SM402

PHYSICS LAB

(For 4^{th} semester)

Marks (Internal): 50 **Credits: 6**

Marks (End Semester exam): 100 **Time: 3 Hours**

Course Outcomes:

After successful completion of the course on Physics lab, a student will be able to:

- *Understand the principles and working of radiation detectors and spectrometers.*
- *Perform measurements and analyze interaction of radiation with matter.*
- *Develop skills in materials characterization techniques.*
- *Analyze and interpret physical phenomena related to magnetic, thermal, and superconducting properties.*
- *Acquire competence in modern experimental techniques for advanced materials research.*

Students assigned the electronic laboratory work will perform at least 10 experiments (Note: List of experiments may vary)

List of experiments

1. To study the gamma spectra of NaI(Tl) scintillator for 137Cs source
2. To study the alpha spectrum from natural sources, Th and U.
3. To determine the gamma-ray absorption coefficient for different elements.
4. To study the absorption of beta rays in Al and deduce end-point energy of a beta emitter.
5. To calibrate the given gamma-ray spectrometer and determine its energy resolution.
6. Magnetic susceptibility of hydrated copper sulfate.
7. Determine the crystallite size of nanomaterial using Debye Scherer method.
8. Transition temperature of a ferroelectric material.
9. Determination of band gap energy of metal-oxide nanoparticles using UV Spectrophotometer.
10. Study of surface morphology of a material by scanning electron microscopy (SEM)
11. High temperature superconductivity experiment.
12. Study of infrared spectroscopy of a material by FTIR
13. Electron paramagnetic resonance experiment.
14. Thermo-luminescence studies.

diffraction in optical imaging, resolving power of telescope in diffraction grating, its use as a spectroscopic element and its resolving power, Resolving power of microscope.

Unit-III

Polarization: Plane Polarized light, elliptically polarized light, wire grid polarizer, Sheet polarizer, Mauls' Law, Brewester Law, Polarization by reflection, Scattering, Double reflection, Nicol prism, Retardation plates, Production Analysis of polarized light, Quarter and half wave plates.

Unit-IV

Optical Fiber communication: Introduction, Historical development, general system, advantages, disadvantages, and applications of optical fiber communication, optical fiber waveguides, Ray theory, cylindrical fiber, single mode fiber, cutoff wave length. Optical Fibers: fiber materials, photonic crystal, fiber optics cables, speciality fibers.

References/Books:

1. Fundamentals of Optics: F.A. Jenkins and Harvey E White, (Megraw Hill) 4th Edition, 2001.

2. Optics: Ajoy Ghatak, (McMillan India) 2nd Edition, 7th Reprint, 1997

3. Optics: Born and Wolf, (Pergamon Press) 3rd Edition, 1965.

4. Laser Fundamentals: W.T. Silfvast (Foundation Books), New Delhi, 1996.

5. Laser and Non-Liner Optics: B.B. Laud (New Age Pub.) 2002 6. Laser: Svelto, Plenum Press) 3rd Edition, New York

6. Fiber optic communication – Joseph C Palais: 4th Edition, Pearson Education

241/PHY/DS401

Discipline-Specific Course(s)

(Choose one out of 241/PHY/DS401& 241/PHY/DS402 Options)

COURSE ID: 241/PHY/DS401

CONDENSED MATTER PHYSICS-II

Marks (Theory): 50 **Credits: 3**

Marks (Internal Assessment): 25 **Time: 2 Hours**

Note: The examiner will set 9 questions asking two questions from each unit and one compulsory question by taking course learning outcomes (CLOs) into consideration. The compulsory question (Question No. 1) will consist of at least 4 parts covering entire syllabus. The question paper is expected *to contain problems to the extent of 20% of total marks. The examinee will be required to attempt 5 questions; selecting one question from each unit and the compulsory.*

Course Outcomes:

After successful completion of the course on Condensed Matter Physics-II, a student will be able to:

- *Explicate response of band electrons to an external electric field and their scattering, and calculate currents in bands.*
- *Develop a semi-classical description of electrical transport in metals using the Boltzmann approach, and explain different thermoelectric effects.*
- *Calculate the electronic structure of nano-scale 1D, 0D solids in effective mass approximation, and use it to explain the electrical transport in these solids.*
- *Treat the electron-electron interactions in Hartree and Hartree-Fock approximations using the variational principle and apply these to calculate electronic properties of simple metals.*
- *Learn the concept of screening and calculate the screened potential using the Thomas-Fermi.*
- *Learn the method of density functional theory and concept of exchange and correlation within the independent-electron approach.*

Unit – I

Electron transport phenomenon: Motion of electrons in bands and the effective mass tensor (semi-classical treatment); Currents in bands and holes; Scattering of electrons in bands (elastic, inelastic and electron-electron scatterings); The Boltzmann equation, Relaxation time *ansatz* and linearized Boltzmann equation; Electrical conductivity of metals, Temperature dependence of resistivity and Matthiesen's rule; energy and thermal current densities in linear response (excluding derivations), Thermoelectric effects, Thermopower, Seebeck effect, Peltier effect, The Wiedemann-Franz law.

Unit – II

Nanostructures and Electron Transport: Nanostructures; Electronic structure of 1D systems: 1D sub-bands, Van Hove singularities; 1D metals- Coulomb interactions and lattice couplings; Electrical transport in 1D: Conductance quantization and the Landauer formula, Two barriers in series- Resonant tunneling, Incoherent addition and Ohm's law, Coherence-Localization; Electronic structure of 0D systems (Quantum dots): Quantized energy levels, Semiconductor and metallic dots, Optical spectra, Discrete charge states and charging energy; Electrical transport in 0D- Coulomb blockade phenomenon.

Unit – III

Beyond independent electron approximation-I: The basic Hamiltonian in a solid: Electronic and ionic parts, The Born-Oppenheimer Approximation; The Hartree method using with variational principle; Exchange: The Hartree-Fock approximation, Hartree-Fock equation (without derivation), Koopmans' theorem; Application of Hartree and Hartree-Fock methods to homogeneous electron gas- One-electron energy, Band width, DOS, Effective mass, Ground-state energy, Exchange energy; Concept of correlation energy.

Unit – IV

Beyond independent electron approximation-II: Screening in an electron gas: Thomas-Fermi theory, Density functional theory: Hohenberg-Kohn theorems, derivation of Kohn-Sham equations, solution of self-consistent Kohn-Sham equations, Exchange-correlation functionals, Local density approximation (LDA), Generalized gradient approximation (GGA).

References/Books:

1. Introduction to Solid State Physics (7th edition) by Charles Kittel.
2. Solid State Physics by Neil W. Ashcroft and N. David Mermin.
3. Solid State Physics: An Introduction to Theory and Experiment by H. Ibach and H. Luth.
4. Electronic structure basic theory and practical methods by Richard M. martin.
5. Principles of the Theory of Solids (2nd edition) by J. M. Ziman.
6. Applied Solid State Physics by Rajnikant.

241/PHY/DS402

COURSE ID: 241/PHY/DS402

MATERIAL SCIENCE-II

Marks (Theory): 50 **Credits: 3**

Marks (Internal Assessment): 25 **Time: 2 Hours**

Note: The examiner will set 9 questions asking two questions from each unit and one compulsory question by taking course learning outcomes (CLOs) into consideration. The compulsory question (Question No. 1) will consist of at least 4 parts covering entire syllabus. The question paper is expected to contain problems to the extent of 20% of total marks. The examinee will be required to attempt 5 questions; selecting one question from each unit and the compulsory.

Course Outcomes:

After successful completion of the course on Material Science-II, a student will be able to:

- *Understand the fundamental aspects of crystal structure and phase formations.*
- *Understand the fundamental aspects of electron microscopic techniques and apply for real life problems.*

Ranjit

- *Understand the basics, working principles and working of spectroscopic techniques.*
- *Understand the basics, working principles and working of Optical and Thermal Characterization Techniques.*

Unit – I

Structural Characterization Techniques: X-rays generation; crystal lattice, diffraction-Brags equation; X-ray diffractometer instrumentation; Small and Wide-angle X-ray diffraction. Applications of Powder X-Ray Diffraction (PXRD)-identification of phases, crystallite size determination, intercalation in compounds; Quantitative X-ray diffraction.(W H Analysis,)

Unit – II

Probing/microscopy techniques: Interaction of electrons with solids, Optical microscopes vs electron microscopes, Scanning electron microscopy (SEM), Transmission electron microscopy (TEM), High resolution Transmission electron microscopy (HRTEM), Scanning Probe Microscope (SPM): Atomic force microscopy (AFM), scanning tunneling microscopy (STM).

Unit – III

Spectroscopy techniques: Electron Spin Resonance (ESR) spectroscopy, , UV-Vis Spectroscopy, Secondary Ion Mass Spectroscopy (SIMS): basic principle, working, yield of secondary ions and applications, X-ray absorption spectroscopy (XAS), X-ray photoelectron spectroscopy (XPS), Photoluminiscence Spectroscopy.

Unit – IV

Optical and Thermal Characterization Techniques: UV-Visible spectroscopy, Fourier transform Infrared spectroscopy, Raman spectroscopy and its applications, Thermogravimetric analysis (TGA), Differential thermal analysis (DTA), Differential Scanning Calorimetry (DSC).

References/Books:

- Advanced Techniques for Materials Characterization, Materials Science Foundations (monograph series) A. K. Tyagi, Mainak Roy, S. K. Kulshreshtha and S. Banerjee, Volumes 49 – 51 (2009).
- Fundamentals of Surface and Thin Film Analysis, L.C. Feldman and J. W. Mayer
- Surface Analysis Methods in Material Science, D. J. O'Connor, B. A. Sexton and R. St. C Smart (Eds), Springer Series.