INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Physics

1. **Subject Code:** PHN-640 **Course Title:** Quantum computing for many-body systems
2. **Contact Hours:** **L:** 2 **T:** 1 **P:** 2
3. **Examination Duration (Hrs.):** **Theory:** 2 **Practical:** 2
4. **Relative Weightage:** **CWS:** 10-25 **PRS:** 25 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Both **7. Subject Area:** PEC
8. **Pre-requisite:** Knowledge of basic Quantum Mechanics and Programming
9. **Objective:** The course is designed to provide the basic knowledge of the currently evolving field of quantum computing for many body systems and its applications to solve the problems of Physics.
10. **Details of the Course:**

S.No.	Contents	Contact Hours
1.	**Introduction to Quantum Computation:** Representing Qubit States, Single Qubit Gates, Multiple Qubits and Entangled States, More Circuit Identities, Design of Quantum Circuits, Measurements in Bases other than Computational Basis.	8
2.	**Quantum Algorithms:** Shor's Algorithm, Bernstein-Vazirani Algorithm, Quantum Fourier Transform, Quantum Phase Estimation, Variational Quantum Eigensolver (VQE), SWAP Test, Linear Combination of Unitaries (LCU).	10
3.	**Quantum simulation of many-body Hamiltonian:** Encodings and Transformations (Jordan-Wigner transformation, Gray code encoding), Many-body Hamiltonian, VQE and suitable Ansatz, Simulations results in the presence of hardware noise.	10
	Total	**28**

Laboratory Work:

Lab 1. Quantum Circuits
Lab 2. Quantum Measurement
Lab 3. Shor’s Algorithm
Lab 4. Variational Quantum Eigensolver (VQE)
Lab 5. Quantum Phase Estimation
Lab 6. Iterative Quantum Phase Estimation
Lab 7. Preparation of Excited State and SWAP test
Lab 8. Linear Combination of Unitaries (LCU)
Lab 9. Measurement error mitigation

11. Suggested Books:

S.No.	Name of Authors/Books/ Publisher	Year of Publication/Reprint
1.	M.A. Nielsen and I.L. Chuang, "Quantum Computation and Quantum Information Cambridge", Cambridge University Press.	2010
2.	D.J. Griffiths, "Introduction to Quantum Mechanics", Prentice Hall, Inc.	2016
3.	N.D. Mermin, "Quantum Computer Science: An Introduction", Cambridge University Press.	2007
4.	"Learn Quantum Computation Using Qiskit" https://qiskit.org/learn/	2023
5.	R.M. Roth, "Introduction to Coding Theory", Cambridge University Press.	2006
6.	S.M. Blinder and J.E. House, "Mathematical Physics in Theoretical Chemistry", Elsevier, Amsterdam, Netherlands.	2019

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE /SCHOOL: Department of Physics

1. **Subject Code:** PHC-101 **Course Title:** Computer Programming

2. **Contact Hours:** **L: 3** **T: 0** **P: 2**

3. **Examination Duration (Hrs.):** **Theory:** 3 **Practical:** 0

4. **Relative Weightage:** **CWS:** 10-25 **PRS:** 25 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0

5. **Credits:** 4 6. **Semester:** Autumn 7. **Subject Area:** PCC

8. **Pre-requisite:** Nil

9. **Objective:** To introduce the fundamentals of programming for scientific and engineering applications.

10. **Details of the Course:**

S. No.	Contents	Contact Hours
1.	Introduction to computer hardware and software, Memory, Storage media, Operating system, Top programming languages, Compilers, Interpreters, Installing the required software, Client-server architecture, Remote login, Popular IDEs	4
2.	Data types, variables and assignment, Operators and their precedence, Type conversion, Input and output, Formatted output, Arrays and pointers or tuples and lists.	4
3.	Subprograms or functions, Return values, Optional and keyword parameters, Inline function, Scope of variables among various program blocks, File i/o, Plotting graphs.	6
4.	Decision structures and Boolean logic, Repetition structures, Nested structures, Break/exit, and continue/cycle. Avoiding infinite loops. Vectorization highlighting time complexity and optimization.	6
5.	Numerical Integration: Riemann sum, Trapezoidal and Simpsons rules and their composite forms, Gauss quadrature, Higher dimensional integrals, Monte-Carlo techniques.	6
6.	Interpolation: Linear, Lagrange interpolating polynomial, Piece-wise interpolation, Numerical derivatives using difference formulae and interpolated values.	4

7.	Solving transcendental equations: Root bracketing, Bisection method, Newton's method, Secant method.	4
8.	Solving ordinary differential equations: Euler method, Runge-Kutta methods, higher-order ODEs in vectorized form.	8
	TOTAL	**42**

11. Suggested Books:

S.No.	Name of Authors / Books / Publisher	Year of Publication/Reprint
1.	**"Python Crash Course, 3e, A Hands-On, Projects-Based Introduction to Programming":** Eric Matthes, No Starch Press.	2023
2.	**"Learning Python, 5e":** Mark Lutz, O'Reilly Media, Inc.	2013
3.	**"Object Oriented Programming with C++, 5e":** E. Balaguruswamy, Tata McGraw Hill Education.	2011
4.	**"Computer Programming In Fortran 90 and 95":** V. Rajaraman, Prentice Hall of India.	2006
5.	**"Introductory Methods of Numerical Analysis, 5e":** S.S. Sastry, Prentice Hall of India.	2012
6.	"Introduction to Coding Theory": R.M. Roth, Cambridge University Press.	2006
7.	**"Numerical Recipes: The Art of Scientific Computing , 3e":** W.H. Press, **S.A.** Teukolsky, W.T. vetterling and B.P. Flannery, Cambridge University Press.	2007

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **DEPARTMENT OF PHYSICS**

1. Subject Code: PHC-112 Course Title: **Atomic and Nuclear Physics**

2. Contact Hours: **L: 3** **T: 0** **P: 0**

3. Examination Duration (Hrs.): **Theory 3** **Practical 0**

4. Relative Weightage: **CWS 20-35** **PRS 0** **MTE 20-30** **ETE 40-50** **PRE 0**

5. Credits: **3** 6. Semester: **Spring** 7. Subject Area: **PCC**

8. Pre-requisite: **NIL**

9. Objective of Course: To introduce the concepts in atomic and nuclear physics

10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Atomic Spectroscopy-I:** Bohr's model of H atom, Sommerfeld' extension of the Bohr's model, Qualitative results of the solution of Schrödinger equation of H-atom, fine structure splitting: spin-orbit interaction and relativistic corrections; Lamb shift, hyperfine structure and isotope shifts	08
2.	**Atomic Spectroscopy-II:** Many-electron atoms, Pauli exclusion principle, angular momentum coupling schemes, equivalent and non-equivalent electrons, Hund's rules, ground state configurations of elements in periodic table; atoms in magnetic fields, X-ray spectra	08
3.	Basic ideas of laser and its properties, Maxwell-Boltzmann distribution, Einstein's A and B coefficients, Ruby Laser and He-Ne laser	05
4.	Nuclear shape, size, radii; Basic properties of nuclear force; Mass defect and binding energy; Liquid drop model; Semi empirical mass formula; Evidence of shell structure and magic numbers.	08
5.	Radioactivity and its applications; Basics of α, β and γ decays; Nuclear reactions; Kinematics; nuclear fission and fusion.	09
6.	Basics of detectors and accelerators; Industrial, analytical and medicinal applications.	04
	Total	**42**

11. Suggested Books:

S. No.	Name of Authors/Books/Publishers	Year of Publication/Reprint
1.	Bransden B H and Joachian C J, "Physics of Atoms and Molecules", 2nd Ed. Prentice Hall	2012
2.	Haken H and Wolf H C, "The Physics of Atoms and Quanta", 6th Ed. Springer	2007
3.	Herzberg G, "Molecular Spectra and Molecular Structure: Spectra of Diatomic Molecules", Dover Books on Physics	2010
4.	Lilley J S, "Nuclear Physics", John Wiley and Sons	2001
5.	Ghoshal S N, "Nuclear Physics", S Chand and Company Ltd.	2000
6.	Povh B, Rith K, Scholz C and Zetsch F, "Particles and Nuclei", 2nd Ed. Springer	1999
7.	Heyde K, "From Nucleons to the Atomic Nucleus", Springer	1998
8.	Krane K S, "Introductory Nuclear Physics", Wiley India	2008

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/ CENTRE/SCHOOL: Department of Physics

Subject Code: PHC 114 **Course Title:** Physics Lab-I

L-T-P: 0-0-4 **Credits:** 2 **Subject Area:** PCC

Course Outlines:

List of Experiments

1. Verification of Stefan's law of radiation using a bulb (electrical method).
2. To study the performance of a Torque Transducer.
3. Verification of Faraday and Lenz's law of induction by measuring the induced voltage as a function of time.
4. To study the variation of the magnetic field with the position of paired coils in Helmholtz arrangement along the axis of the coils carrying current.
5. To determine e/m (specific charge) for an electron by magnetron method.
6. To determine Stefan's constant using vacuum tube Diode EZ-81.
7. To study the characteristics of a Linear Variable Differential Transformer (LVDT).
8. Surface tension
9. To verify Stoke's Law
10. Pressure Measurement using strain Gauge Transducer
11. LDR Characteristics.
12. Thermal Expansion.
13. To Determine Plank's Constant by measuring radiation.
14. To study the normal modes and resonance of a coupled pendulum.
15. To determine the spring constant of the coupling spring in a coupled pendulum.
16. To calculate the time period of a coupled pendulum (T_0, T_1, T_B and ν_B, degree of coupling)
17. To determine the mass susceptibility of a para-magnetic material by Quincke's method
18. To determine the value of Planck's constant by measuring radiation in a fixed spectral range.
19. To determine the wavelength of sodium light by Newton's ring.
20. To determine the electronic charge by Millikan's oil drop experiment.
21. To study the V-I Characteristics of LDR, LED, Solar cell, photo transistor.
22. Quarter wave plate.
23. Malus law.
24. Brewster's angle.
25. Single slit diffraction.
26. Double slit diffraction.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Physics

Subject Code: PHO-102 **Course Title:** Space Exploration

L-T-P: 3-0-0 **Credits:** 3 **Subject Area:** OEC

Course Outlines: History of Space Explorations by different Nations, need for Space-based Technology, Need for Knowledge of Space Sciences, Plasma in Near-Earth Space, Waves in the Atmosphere, Atmosphere/Ionosphere of other Planets, Measurement in Space: Active and Passive Remote Sensing and In-situ Measurements, Orbits: Kepler's Law of Planetary Motion, Types of Orbits, Hohmann Transfer Orbit, Satellite Communication and Navigations, Applications of Space Technology.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Physics

Subject Code: PHO-103 **Course Title:** Physics of Quantum Materials

L-T-P: 3-0-0 **Credits:** 3 **Subject Area:** OEC

Course Outlines: Quantum mechanical formulation of Bloch functions in periodic crystals. Classification of materials based on electronic structure. Berry phase in electronic solids. Quantum Hall effect. Topology of graphene. Topological insulators. Topological classification of matter. Topological superconductivity. Applications of quantum materials.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Physics

Subject Code: PHO-104 **Course Title:** Topological Phases of Matter

L-T-P: 3-0-0 **Credits:** 3 **Subject Area:** OEC

Course Outlines: Integer quantum Hall effect. Symmetry protected topological phases. Classification of non-interacting fermionic topological phases. Topological band structures, Berry phases and Chern numbers. Graphene and Topological Insulators. Haldane model. Kane-Mele model. Su–Schrieffer–Heeger model. Topological Superconductors. Topological quantum computing.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Physics

Subject Code: PHO-105 **Course Title:** Introductory Quantum Information Theory

L-T-P: 3-0-0 **Credits:** 3 **Subject Area:** OEC

Course Outlines: Basics of quantum information pertaining to its measures and entanglement quantifiers. With a review of relevant quantum and statistical mechanics, the calculation of Shannon entropy, von Neumann Entropy, Quantum Relative Entropy and Renyi Entropy will be covered. Additional topics: Bipartite Systems, Dense Coding and Teleportation, Entanglement Measures, Shannon's Mutual Information, Markov Chains, Entropy of Partied Systems, Strong Subadditivity, Holevo Quantity, Entropy Exchange.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Physics

Subject Code: PHO-101 **Course Title:** Introduction to Spintronics Technology

L-T-P: 3-0-0 **Credits:** 3 **Subject Area:** OEC

Course Outlines: Fundamentals of magnetism, Spin-orbit interaction, Dipolar interaction, Exchange interaction, Magnetic anisotropy, Spin-dependent transport: Anomalous Hall effect, Anisotropic magnetoresistance (AMR), Giant magnetoresistance (GMR), Tunnelling magnetoresistance (TMR), Spin-valves (SVs), Magnetic tunnel junctions (MTJs), Spin-transfer torque (STT), Spin Hall effect (SHE), Spin currents, Spin-orbit torque (SOT), Orbital Hall effect (OHE), Magnetization switching, Magnetic skyrmions, Magneto resistive random-access memory (MRAM) technology–STT-MRAM, SOT-MRAM, Spin-torque and spin Hall nano-oscillators (STNOs and SHNOs), Spin caloritronic devices, Racetrack memory, Spin-based quantum computing: Spin-logic, Oscillator-based neuromorphic computing, Spin-wave computing.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Physics

Subject Code: PHB-103 **Course Title:** Modern Physics

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** BSC

Course Outlines: Atomic Structure, Solution of Schrodinger equation of Hatom, Maxwell-Boltzmann, Bose Einstein and Fermi Dirac distributions, Laser Physics, Einstein's A and B coefficients, Cubic Crystal structure, Free electron theory of metals, Band theory of solids, classification of solids into metals, Semiconductors and insulators, Magnetic properties of solids, Essential properties of superconductors, Binding energy and stability of nuclei, Liquid drop model, Special Theory of Relativity, Qualitative description of Michelson Morley experiment, Postulates of special relativity, Lorentz transformation, Relativistic momentum, mass and energy.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Physics

Subject Code: PHC-203 **Course Title:** Thermal and Statistical Physics

L-T-P: 3-0-0 **Credits:** 3 **Subject Area:** PCC

Course Outline: Condition of equilibrium and constraints, pressure, temperature, chemical potential, internal energy, heat and entropy, laws of thermodynamics, PV, PT, TS diagram, Enthalpy, Helmholtz & Gibb's functions, Maxwell's thermodynamic relations, phase transitions, inversion curve, Liquefaction of gases, Microstates, phase space, Liouville's theorem, equal a priori probability, Connection between statistics and thermodynamics, Microcanonical and Canonical ensemble, Gibbs paradox, M-B, B-E and F-D statistics, Blackbody radiation.

.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Physics

Subject Code: PHC-207 **Course Title:** Physics Lab – II

L-T-P: 0-0-4 **Credits**: 2 **Subject Area**: PCC

Course outlines: The experiments include: Callendar and Barne's method, Four Probe Method, Maxwellian velocity distribution, Searl's Experiment, Specific Heat Measurement, P-V Isotherms of Ethane gas, Stefan Boltzmann Law, Planck's constant 'h' by photo voltaic cell, Solar Cells Characterization, Thermal Measurements of Metals. Logic gates with TTL ICs, De- Morgan's Law, Flip-flop, interfacing 7-segment display using IC 7447, multiplexer and de- multiplexer, half and full subtractor, half and full adder.

Appendix-A

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Physics

Subject Code: PHC-205 **Course Title:** Digital Electronics

L-T-P: 3-0-0 **Credits:** 3 **Subject Area:** PCC

Course Outlines: Basic logic gates and circuits, Boolean laws, Karnaugh map representation, Multiplexers, Demultiplexers, Encoders, Decoders, Parity generators, Digital ICs, TTL and CMOS logics, Binary, Octal and Hexadecimal systems, Addition and subtraction in different systems, J-K, R-S, T, D, J-K Master-Slave flip-flops, Registers, Counters, D/A and A/D conversions, Schmitt trigger ICs, 555timer.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Physics

Subject Code: PHC-202 **Course Title:** Mathematical Physics

L-T-P: 3-0-0 **Credits:** 3 **Subject Area:** PCC

Course Outlines: Complex analysis: Complex variables, analytic functions and singularities, Cauchy Reimann conditions and harmonic functions, complex integration and associated theorems, calculus of residues. Laplace and Fourier transforms. Beta, Gamma functions. Series solution of ODE and special functions: power series and Frobenius series method, special functions: Legendre, Hermite polynomials, Bessel’s functions, generating functions.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Physics

Subject Code: PHC-204 **Course Title:** Quantum Mechanics-I

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Schrodinger equation, expectation value, observables and operators, commutation relations, Dirac notation; Schrodinger, Heisenberg and Dirac pictures; 1D problems: tunnelling through multiple barriers: resonant tunnelling, simple harmonic oscillator, raising and lowering operators, 2D Problems: electron gas in a magnetic field, Landau levels, 3D problems: symmetry and conservation laws in quantum mechanics, central potential, hydrogen atom, angular momentum and spherical harmonics, time independent non-degenerate perturbation theory.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Physics

Subject Code: PHC-206 **Course Title:** Applied Optics

L-T-P: 3-0-2 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Fermat's Principle, ray equation, matrix method in paraxial optics, unit planes, nodal planes, Huygen's principle, interference by division of wavefront and amplitude, Fraunhofer diffraction, single, double and multiple slit diffraction, Fresnel diffraction, zone plate, Polarization and double refraction, analysis of polarized light, Brewster's law, Malus's law, quarter and half wave plates, optical activity, holography, salient features of optical fiber.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Physics

Subject Code: PHC-212 **Course Title:** Physics Lab-III

L-T-P: 0-0-4 **Credits:** 2 **Subject Area:** PCC

Course Outlines: Cornu's method, Nodal slide, diffraction grating, Newton's Rings, Polarimeter, Hydrogen Spectra, the Lande g factor, Brewster's Angle, Fresnel bi-prism, Double slit diffraction, dispersive power of prism, e/m by Thomson Method, e/m by Magnetron method, Millikan's Oil Drop Experiment.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Physics

Subject Code: PHC-214 **Course Title:** Optics

L-T-P: 3-0-0 **Credits:** 3 **Subject Area:** PCC

Course Outlines: Fermat's Principle, ray equation, matrix method in paraxial optics, unit planes, nodal planes, Huygen's principle, interference by division of wavefront and amplitude, Fraunhofer diffraction, single, double and multiple slit diffraction, Fresnel diffraction, zone plate, Polarization and double refraction, analysis of polarized light, Brewster's law, Malus's law, quarter and half wave plates, optical activity, holography, salient features of optical fiber.