<table>
<tr><td colspan="2">QUANTUM PHYSICS AND APPLICATIONS</td><td>Semester</td><td>I/II</td></tr>
<tr><td>Course Code</td><td>1BPHYS102/202</td><td>CIE Marks</td><td>50</td></tr>
<tr><td>Teaching Hours/Week (L:T:P: S)</td><td>3:0:2:0</td><td>SEE Marks</td><td>50</td></tr>
<tr><td>Total Hours of Pedagogy
(Theory and Lab hours)</td><td>64</td><td>Total Marks</td><td>100</td></tr>
<tr><td>Credits</td><td>04</td><td>Exam Hours</td><td>03</td></tr>
<tr><td>Examination type (SEE)</td><td colspan="3">Descriptive</td></tr>
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Course outcome (Course Skill Set)

At the end of the course, the student will be able to:

1. Explain core quantum concepts and their computational relevance.
2. Analyze electronic behavior in metals and semiconductors for key material properties.
3. Discuss superconductivity phenomena and their role in quantum systems.
4. Describe radiation–matter interaction and photonic device operation.
5. Summarize fundamentals of quantum computing and predict simple circuit outcomes.

Module-1

Quantum Mechanics:

de Broglie Hypothesis, Heisenberg's Uncertainty Principle and its application (Broadneing of Spectral Lines), Principle of Complementarity, Wave Function, Time independent Schrödinger wave equation (Derivation), Physical significance of a wave function and Born Interpretation, Expectation value and its physical significance, Eigen functions and Eigen values, Particle inside one dimensional infinite potential well, Role of higher dimensions (Qualitative), Waveforms and Probabilities, Particle inside a finite potential well and quantum tunneling, Numerical Problems.

Text Book : 1, 2 Reference Books : 1, 2 Number of Hours: 8

Module-2

Electrical Properties of Metals and Semiconductors:

Failures of classical free electron theory, Mechanisms of electron scattering in solids, Matheissen's rule, Assumptions of Quantum Free Electron Theory, Density of States, Fermi Dirac statistics, Fermi Energy, Variation of Fermi Factor With Temperature and Energy, Expression for carrier concentration in a conductor, Mention of expression for electrical conductivity, Success of quantum free electron theory of metals, Derivation of electron concentration in an intrinsic semiconductor, Expression for electron and hole concentration in extrinsic semiconductor (Qualitative), Fermi level for intrinsic(with derivation) and extrinsic semiconductor (no derivation), Hall effect, Numerical Problems.

Text Book : 1 , 3 Reference Book : 1, 9 Number of

Module-3

Superconductivity:

Zero resistance state, Persistent current, Meissner effect, Critical temperature, Critical current (Silsbee Effect) – Derivation of expression of critical current for a cylindrical wire using ampere's law, Critical field, Formation of Cooper pairs - Mediation of phonons, Two-fluid model, BCS Theory - Phase coherent state, Limitations of BCS theory, examples of systems with low and high electron-phonon coupling, Type-I and Type-II superconductors, Formation of Vortices, Explanation for upper critical field, Cooper pair tunneling (Andreev reflection), Josephson junction, Flux quantization, DC and AC SQUID (Qualitative), Numerical Problems.

Text Books : 1, 3 , Reference Book: 3 , 4 Number of Hours: 8

Module-4

Photonics :

Interaction of radiation with matter – Einstein's A and B coefficients and derivation of expression for energy density, Prerequisites for lasing actions, Types of LASER, Semiconductor diode LASER, Use of attenuators for single photon sources, Optical modulators – Pockel's effect, Kerr effect, Photodetectors – Single Photon Avalanche Diode, Superconducting Nanowire Single Photon Detector, Optical fiber, Derivation of Numerical aperture, V-number, Number of modes, losses in optical fiber, Mach-Zehnder interferometer, Numerical problems.

Text Books: 1, 2, Reference Book: 5, 6 Number of Hours:8

Module-5

Quantum Computing:

Moore's law - limitation of VLSI, Classical vs Quantum Computation, bit, Qubit and its properties, Bloch Sphere, Dirac notation, Brief discussion on types of qubit, Superconducting qubits, Harmonic oscillator (qualitative) – Need for anharmonicity, Charge qubit, Operators and Operations (matrix form), Quantum Gates – Pauli Gates, Phase gate (S, T), Hadamard Gate, Two qubit gates – CNOT gate, Entanglement, Bell States, Predicting the outputs of various combinations of single and two-qubit gates, Numerical Problems.

Text Book: 4 , Reference Book :7, 8 Number of Hours:8

PRACTICAL COMPONENTS OF IPCC

PART – A: FIXED SET OF EXPERIMENTS

1. Determination of wavelength of LASER using Diffraction Grating.
2. Determination of acceptance angle and numerical aperture of the given Optical Fiber.
3. Study the Characteristics of a Photo-Diode and to determine the power responsivity / Verification of Inverse Square Law of Light
4. Determination of Planck's Constant using LEDs / Black-Body.
5. Determination of Fermi Energy of Copper.
6. Determination of Energy gap of the given Semiconductor.
7. Black-Box Experiment (Identification of basic Electronic Components)
8. Resonance in LCR circuit and determination of coefficient of self induction.
9. Study the I-V Characteristics of a Bipolar Junction Transistor and hence determine α and β.
10. Determination of resistivity of a semiconductor by Four Probe Method.
11. Predicting the outputs of various combinations of single and two-qubit gates using QUIRK Quantum Simulator. a) https://www.quirk-e.dev/ b) https://algassert.com/quirk
12. Predicting the outputs of various combinations of single and two-qubit gates using QISKIT.
13. Air-wedge / Newtons to study the interference by the division of amplitude.
14. Experimental Data Analysis using Spread Sheet.

Note :

1. At least ten laboratory experiments must be conducted.
2. Minimum one quantum simulation experiment is mandatory and should be conducted either in the computer lab for the entire batch or on dedicated systems in the physics lab.

Suggested Learning Resources: (Text Book/ Reference Book/ Manuals):

Text books:

1. Engineering Physics, Satyendra Sharma and Jyotsna Sharma, Pearson, 2018.
2. Engineering Physics, S L Kakani, Shubra Kakani, 3rd Edition, 2020, CBS Publishers and Distributers Pvt. Ltd., 2018
3. Solid State Physics, S. O. Pillai, New Age International
4. Quantum Computing, Parag K Lala, McGraw Hill, 2020.

Reference books / Manuals:

1. Beiser, A. (2002). Concepts of Modern Physics (6th ed.). McGraw-Hill Education..
2. Griffiths, D. J. (2018). Introduction to Quantum Mechanics (2nd or 3rd ed.). Pearson.
3. Tinkham, M. (2004). Introduction to Superconductivity (2nd ed.). Dover Publications.
4. Mishra, P. K. (2009). Superconductivity – Basics and Applications. Ane Books.

5. LASERS and Non-Linear Optics, B B Loud, New Age International,
6. Saleh, B. E. A., & Teich, M. C. (2019). Fundamentals of Photonics (3rd ed.). Wiley
7. Nielsen, M. A., & Chuang, I. L. (2010). Quantum Computation and Quantum Information (10th Anniversary ed.). Cambridge University Press.
8. Vishal Sahani, Quantum Computing, McGraw Hill Education, 2007 Edition.
9. Solid State Physics, A J Dekker (2000), Indian Ed., Macmillan Publishers India, New Delhi.

Web links and Video Lectures (e-Resources):

1. NPTEL – Quantum Mechanics I (IIT Madras): https://nptel.ac.in/courses/115106066
2. NPTEL – Physics: Introductory Quantum Mechanics (NOC): https://archive.nptel.ac.in/courses/115/104/115104096
3. Solid State Physics – NPTEL (IIT Madras) https://nptel.ac.in/courses/115106127
4. A Brief Course on Superconductivity – NPTEL IIT Guwahati (Prof. Saurabh Basu)
5. Playlist Introduction Video: https://www.youtube.com/watch?v=SHoGV-sezNI
6. Full playlist available via the YouTube channel description or archive link.
7. Concepts in Magnetism and Superconductivity – NOC (IIT Kharagpur)Series start (Lecture 1): https://digimat.in/nptel/courses/video/115105131/L01.html
8. Introduction to Photonics – NPTEL (IIT Madras, Prof. Balaji Srinivasan) Lecture 03 to Lecture 12 cover: Direct video link (start Lecture 03): https://nptel.ac.in/courses/108106135/03
9. Semiconductor Optoelectronics – NPTEL (IIT Delhi, Prof. M. R. Shenoy)Direct video link (start relevant lecture): https://nptel.ac.in/courses/108108174/05
10. Lecture 04 – Quantum Computing Basics: https://www.youtube.com/watch?v=-fttE1SzpD8
11. Lecture 08 – Quantum Gates and Circuits Part 1: https://www.youtube.com/watch?v=nGPr1QM_XrY

Teaching-Learning Process (Innovative Delivery Methods):

The following are sample strategies that educators may adopt to enhance the effectiveness of the teaching-learning process and facilitate the achievement of course outcomes.

1. Self-Learning using AI Tools
2. Activity Based Learning
3. Gamification of Activities
4. Short Animations and Videos
5. Models and Working Models
6. Simulations and Interactive Simulations
7. Experiential Learning
8. Flipped Class Learning
9. Hybrid Learning
10. ICT Based Learning

Assessment Structure (IPCC): (Circular-Ref.: VTU/BGM/IPCC 2025/3748, DATED: 24TH Oct 2025)

The assessment for each course is equally divided between Continuous Internal Evaluation (CIE) and the Semester End Examination (SEE), with each component carrying **50% weightage** (i.e., 50 marks each).

The CIE Theory component will be **25 marks** and CIE Practical component will be **25 marks**.

The CIE Theory component consists of IA tests for **25 marks**. The CIE Practical component for continuous assessments will be for **15 marks** through rubrics and for lab Internal Assessment will be conducted for **10 marks** through rubrics.

- To qualify and become eligible to appear for SEE, in the **CIE theory component**, a student must score at least **40% of 25 marks**, i.e., **10 marks**.
- To qualify and become eligible to appear for SEE, in the **CIE Practical component**, a student must secure **a minimum of 40% of 25marks**, i.e., **10marks**.
- To pass the **SEE**, a student must secure **a minimum of 35% of 50 marks**, i.e., **18 marks**.

A student is deemed to have **completed the course** if the **combined total of CIE and SEE is at least 40 out of 100 marks**.

Rubrics for Learning Activity (Based on the nature of learning activity, design the rubrics for each activity):

	Superior	Good	Fair	Needs Improvement	Unacceptable
Performance Indicator 1 (CO1 - PO1, PO2, PO5, PO11)	Clearly explains quantum principles (e.g., uncertainty, wave function) with computational relevance	Explains core principles accurately with minor conceptual gaps	Basic understanding with limited linkage to applications	Fragmented explanation with weak application context	Fails to explain quantum concepts or relevance to computation
Performance Indicator 2 (CO2 - PO1, PO2, PO3, PO5, PO11)	Accurately analyzes electron behavior using classical and quantum models for conductivity	Reasonable analysis with some misinterpretation of models	Basic recognition of conduction principles with weak analysis	Limited understanding and incorrect application of models	No meaningful analysis of conduction mechanisms
Performance Indicator 3 (CO3 - PO1, PO2, PO4, PO5, PO11)	Effectively evaluates superconducting principles and applies them in quantum contexts	Good understanding of concepts but lacks depth in application	Identifies phenomena but struggles with significance or relevance	Limited and inaccurate explanation of superconductivity	Fails to explain or apply superconductivity principles
Performance Indicator 4 (CO4 - PO1, PO2, PO4, PO5, PO11)	Demonstrates clear understanding of radiation-matter interaction and device principles	Explains device operations with minor misconceptions	Recognizes device function but lacks technical depth	Inadequate understanding of photonic principles	Unable to interpret or explain device behavior
Performance Indicator 5 (CO5 - PO1, PO2, PO3, PO5, PO11)	Accurately summarizes quantum computing concepts and predicts circuit behavior	Good explanation of quantum gates with some errors in logic application	Basic description of qubits and circuits without predictive insight	Inconsistent understanding of quantum computing logic	Fails to explain or apply quantum computing principles

Rubrics for CIE – Continuous assessment:

	Superior	Good	Fair	Needs Improvement	Unacceptable
Performance Indicator 1 (CO1 - PO1, PO2,	Clearly explains quantum principles (e.g., uncertainty,	Explains core principles accurately with	Basic understanding with limited linkage	Fragmented explanation with weak application	Fails to explain quantum concepts or relevance to compu-

PO5, PO11)	wave function) with computational relevance	minor conceptual gaps	to applications	context	tation
Performance Indicator 2 (CO2 - PO1, PO2, PO3, PO5, PO11)	Accurately analyzes electron behavior using classical and quantum models for conductivity	Reasonable analysis with some misinterpretation of models	Basic recognition of conduction principles with weak analysis	Limited understanding and incorrect application of models	No meaningful analysis of conduction mechanisms
Performance Indicator 3 (CO3 - PO1, PO2, PO4, PO5, PO11)	Effectively evaluates superconducting principles and applies them in quantum contexts	Good understanding of concepts but lacks depth in application	Identifies phenomena but struggles with significance or relevance	Limited and inaccurate explanation of superconductivity	Fails to explain or apply superconductivity principles
Performance Indicator 4 (CO4 - PO1, PO2, PO4, PO5, PO11)	Demonstrates clear understanding of radiation-matter interaction and device principles	Explains device operations with minor misconceptions	Recognizes device function but lacks technical depth	Inadequate understanding of photonic principles	Unable to interpret or explain device behavior
Performance Indicator 5 (CO5 - PO1, PO2, PO3, PO5, PO11)	Accurately summarizes quantum computing concepts and predicts circuit behavior	Good explanation of quantum gates with some errors in logic application	Basic description of qubits and circuits without predictive insight	Inconsistent understanding of quantum computing logic	Fails to explain or apply quantum computing principles

Rubrics for SEE / CIE Test:

	Superior	Good	Fair	Needs Improvement	Unacceptable
Performance Indicator 1 (CO1 - PO1, PO2, PO5, PO11)	Clearly explains quantum principles (e.g., uncertainty, wave function) with computational relevance	Explains core principles accurately with minor conceptual gaps	Basic understanding with limited linkage to applications	Fragmented explanation with weak application context	Fails to explain quantum concepts or relevance to computation
Performance Indicator 2 (CO2 - PO1, PO2, PO3, PO5, PO11)	Accurately analyzes electron behavior using classical and quantum models for conductivity	Reasonable analysis with some misinterpretation of models	Basic recognition of conduction principles with weak analysis	Limited understanding and incorrect application of models	No meaningful analysis of conduction mechanisms
Performance Indicator 3 (CO3 - PO1, PO2, PO4, PO5, PO11)	Effectively evaluates superconducting principles and applies them in quantum contexts	Good understanding of concepts but lacks depth in application	Identifies phenomena but struggles with significance or relevance	Limited and inaccurate explanation of superconductivity	Fails to explain or apply superconductivity principles
Performance Indicator 4 (CO4 - PO1, PO2, PO4, PO5, PO11)	Demonstrates clear understanding of radiation-matter interaction and device principles	Explains device operations with minor misconceptions	Recognizes device function but lacks technical depth	Inadequate understanding of photonic principles	Unable to interpret or explain device behavior

Performance Indicator 5 (CO5 - PO1, PO2, PO3, PO5, PO11)	Accurately summarizes quantum computing concepts and predicts circuit behavior	Good explanation of quantum gates with some errors in logic application	Basic description of qubits and circuits without predictive insight	Inconsistent understanding of quantum computing logic	Fails to explain or apply quantum computing principles

Suggested rubrics for Practical continuous assessment:

Performance Indicators	Excellent	Very Good	Good	Satisfactory
Fundamental Knowledge (4) (PO1)	The student has well depth knowledge of the topics related to the course (4)	Student has good knowledge of some of the topics related to course (3)	Student is capable of narrating the answer but not capable to show in depth knowledge (2)	Student has not understood the concepts clearly (1)
Design Of Experiment (5) (PO2 & PO3)	Student is capable of discussing more than one design for his/her problem statement and capable of proving the best suitable design with proper reason (5)	Student is capable of discussing few designs for his/her problem statement but not capable of selecting best (4)	Student is capable of discussing single design with its merits and de-merits (3)	Student is capable of explaining the design (1-2)
Implementation (8) (PO3 & PO7)	Student is capable of implementing the design with best suitable algorithm considering optimal solution. (7-8)	Student is capable of implementing the design with best suitable algorithm and should be capable of explaining it (5-6)	Student is capable of implementing the design with proper explanation. (3-4)	Student is capable of implementing the design. (1-2)
Result &Analysis (5) (PO4)	Student is able to run the program on various cases and compare the result with proper analysis. (5)	Student will be able to run the program for all the cases. (4)	Student will be able to run the code for few cases and analyze the output (3)	Student will be able to run the program but not able to analyze the output (1-2)
Demonstration (8) (PO8)	The lab record is well-organized, with clear sections (e.g., Introduction, Method, Results, Conclusion). Transitions between sections are smooth. (7-8)	The lab record is organized, with clear sections, but some sections are not well-defined. (5-6)	The lab record lacks clear organization or structure. Some sections are unclear or incomplete. (3-4)	The lab record is poorly organized, with missing or unclear sections. (1-2)

Note: Can add Engineering & IT tool usage based on the nature of the course

Suggested Learning Activities may include (but are not limited to):

- Course Project
- Case Study Presentation
- Programming Assignment
- Tool/Software Exploration
- Literature Review
- Open Book Test (preferably at RBL4 and RBL5 levels)

- GATE-based Aptitude Test
- Assignment (at RBL3, RBL4, or RBL5 levels)
- Any other relevant and innovative academic activity
- Use of MOOCs and Online Platforms