PROGRAMME AND COURSE STRUCTURE WITH CREDIT DISTRIBUTION

FOR

UG Degree Programmes with Single Major

IN

PHYSICS

(*w.e.f. 2023-2024*)

BANKURA UNIVERSITY
BANKURA
WEST BENGAL
PIN 722155

STRUCTURE IN PHYSICS
(UG Degree Programmes with Single Major)

SEMESTER –VII

Category of Course				Marks			Teaching hours/Week		
	Course code	Course Title	Credit	I.A.	ESE	Total	Lec	Tu	Lab
1. Major (MJ) ::DSC	S/PHS/701/MJC-17	**Advanced Quantum Mechanics**	**3 (Th)+ 1(Lab)=4**	**10**	**25 (Th) + 15 (Lab)**	**50**			
2. Major (MJ) ::DSC	S/PHS/702/MJC-18	**Molecular Spectroscopy**	**3 (Th)+ 1(Lab)=4**	**10**	**25 (Th) + 15 (Lab)**	**50**			
3. Major (MJ) ::DSC	S/PHS/703/MJC-19	**Advanced Classical Electrodynamics**	**3 (Th)+ 1(Lab)=4**	**10**	**25 (Th) + 15 (Lab)**	**50**			
4. Major (MJ) ::DSC	S/PHS/704/MJC-20	**Advanced Classical Mechanics**	**3 (Th)+ 1(Lab)=4**	**10**	**25 (Th) + 15 (Lab)**	**50**			
5. Minor Stream	S/PHS/705/MN-7	**Atomic and Molecular Spectroscopy**	**3 (Th)+ 1(Lab)=3**	**10**	**25 (Th) + 15 (Lab)**	**50**			
Total Credit= 4+4+4+4+4=20				**Total number of courses= 5**					

PROGRAMME OUTCOME

The Undergraduate (UG) programme of Physics is composed of major, minor and interdisciplinary subjects. The syllabus is based on the National education policy which covers almost all the fields of Physics. The students will be enriched with plenty of knowledge after the completion of the course. The complete syllabus is compatible with the competitive examination for higher studies and research. In this programme there are various multidisciplinary courses. The students will acquire multidisciplinary skills which will be of tremendous value to them.

Semester-VII
(Major)
Credit= 3+1=4

MJC-17: Advanced Quantum Mechanics (Theory) (Credit-3)

1. Approximation methods:
Time independent perturbation theory for non-degenerate and degenerate states (derivation of first order corrections of energy eigenvalues and wave functions and derivation of Second order correction of energy eigenvalues), Application of time independent perturbation theory - Anharmonic oscillator, Zero point energy of one-dimensional harmonic oscillator, Ground state of Hydrogen atom, Ground state energy of Helium atom, Stark effect in hydrogen atom. Variational method: Concept of method of variation and its application for finding the ground state of Helium atom, Deuteron problem, WKB method: Connection formulae, Application.

Time-dependent perturbation theory: Schrodinger, Heisenberg, Interaction picture, Transition probability, Constant and Harmonic perturbation, Fermi's golden rule, adiabatic and Sudden approximation. **Relativistic Quantum Mechanics** The Klein-Gordon equation for a free particle, the Dirac equation, Probability and current densities, Free particle solution, and negative energy states.

2. Generalized angular momentum:
Infinitesimal rotation, Generator of rotation, Commutationrules, Matrix representation of angular momentum operators, Spin, Pauli spin matrices, Rotation of spin states, Coupling of two angular momentum operators, Clebsch Gordon co-efficient, applications.

3. Symmetries:
Symmetries, Invariance principle and Conservation laws, Space translation, Time translation, Space rotation, Irreducible spherical tensor operators, Wigner-Eckert theorem and itsapplications, Space inversion, Time reversal.

4. Scattering theory:

Scattering of a particle by a fixed Centre of force, scattering amplitude, differential and total cross sections. Method of partial waves, phase shifts, optical theorem. Scattering by a hard sphere and potential well. Integral equation for potential scattering. Green's function. Born approximation. Yukawa and Coulomb potential.

Books Recommended:

1. Introduction to Quantum Mechanics, 3rd Edition, Cambridge University Press, 2018.
2. Quantum Mechanics: Concepts and Applications, 2nd Edition, Wiley, 2009.
3. Computational Physics, 2nd Edition, Pearson, 2006.
4. An Introduction to Computational Physics, 2nd Edition, Cambridge University Press, 2006.
5. Numerical Recipes: The Art of Scientific Computing, 3rd Edition, Cambridge University Press, 2007.
6. Scilab Official Documentation and Scilab Official Website
7. Scilab by Example, Create Space Independent Publishing Platform, 2012.

MJC-17: Advanced Quantum Mechanics (Lab) (Credit-1)

List of Practical's (to be done in Sci-Lab)

1. To solve the one-dimensional time-independent Schrödinger equation numerically using the finite difference method, determine the energy eigen values and normalized eigen functions for infinite and finite potential wells, and compare the numerical results with analytical solutions.
2. To calculate the first-order energy corrections of a quantum anharmonic oscillator using time-independent perturbation theory and compare the perturbative results with numerical solutions.
3. To estimate the ground-state energy of the helium atom using the variational method with an appropriate trial wave function and optimize the variational parameter to obtain the best approximation.
4. To compute the transmission probability of a particle through a potential barrier using the WKB approximation and compare the results with exact numerical calculations.

5. To simulate the dynamics of a two-level quantum system under harmonic perturbation, determine the transition probability between quantum states, and study Rabi oscillations under resonant and non-resonant conditions.
6. To construct and manipulate spin-½ quantum states using Pauli spin matrices, simulate spin rotations under arbitrary rotation operators, and visualize the evolution of quantum states on the Bloch sphere.
7. To compute Clebsch–Gordan coefficients for coupled angular momentum systems, construct coupled basis states, and study the addition of two quantum angular momenta.
8. To implement the fundamental symmetry operators of quantum mechanics, investigate their action on quantum states, and verify the associated conservation laws through numerical simulations.
9. To calculate scattering phase shifts, differential and total scattering cross-sections using the partial-wave method, and verify the optical theorem for hard-sphere scattering.
10. To determine the scattering amplitude and differential scattering cross-section for Yukawa and Coulomb potentials using the first-Born approximation and compare the characteristics of short-range and long-range interactions.

Course Outcomes:

Upon successful completion of this course, students will be able to:

1: Master Approximation Techniques

Apply time-independent perturbation theory, the Variational method, and the WKB approximation to calculate energy eigenvalues and wavefunctions for complex systems, such as the Stark effect in hydrogen and the ground state of Helium.

2: Analyze Time-Dependent Phenomena

Formulate and solve problems involving time-dependent perturbations, transition probabilities, and Fermi's Golden Rule, while distinguishing between the Schrödinger, Heisenberg, and Interaction pictures of quantum dynamics.

3: Execute Angular Momentum Algebra

Evaluate generalized angular momentum operators, construct matrix representations, and implement the coupling of angular momenta using Clebsch-Gordan coefficients for multi-particle systems.

4: Synthesize Symmetries and Conservation Laws

Relate physical symmetries (space/time translation, rotation, and inversion) to fundamental conservation laws and utilize the Wigner-Eckert theorem to simplify the calculation of matrix elements for spherical tensor operators.

5: Formulate Scattering Solutions

Develop mathematical models for particle scattering using partial wave analysis and the Born approximation to determine differential and total cross-sections for various potential fields, including Yukawa and Coulomb potentials.

MJC-18: Molecular Spectroscopy (Theory) (Credit-3)

Introduction: Types and origin of molecular spectra, characterises, modes of molecular excitation, line width of spectra, intensity of spectral lines.
Born-Oppenheimer approximation and separation of electronic and nuclear motions in molecules. Band structures of molecular spectra. Breakdown of the Born-Oppenheimer approximation. [4 Lectures]

Microwave and far infrared spectroscopy: Rotational spectra of diatomic molecules under rigid rotator and non-rigid rotator models. Selection rules. Spectral structure. Stark effect in molecular rotational spectra (no derivation necessary). [8 lectures]

Infrared spectra: Vibrational spectra of diatomic molecules as a harmonic oscillator and anharmonic (no derivation necessary for this one) oscillator models. Symmetry properties of molecular wave functions. Draw backs of linear harmonic oscillator model. Selection rules and spectral structure. Absence of Spectral Lines in Infrared Spectra. Morse potential, Dissociation energy, isotope effect. Rotational-vibrational spectra of diatomic molecules; P- and R-branches. [12]

Raman spectroscopy: Raman Effect. Classical treatment, Stokes and anti-stokes lines. Polarizability ellipsoid and intensity of Raman bands, Drawbacks of the classical explanation, Quantum theoretical explanation. Selection rules for both rotational and vibrational Raman spectra of diatomic molecule and their spectral features, Rotational-vibrational Raman spectra and O- and S-branches, Resonance Raman Spectroscopy, Elementary idea of Surface Enhanced Raman spectroscopy and Non-linear Raman effect. [12 Lectures]

Electronic spectra of diatomic molecules: (a) Vibrational structure of electronic spectra, Progression and sequence, Emission and absorption spectra, Idea of zero-zero band, Isotope shifts, Molecular constants in ground and excited electronic states, Molecular bonding – elementary idea, (b) Rotational structure of electronic spectra, P-, Q- and R-branches, Formation of band heads and shading of bands, (c) Intensity distribution in the vibrational structure of electronic spectra (both absorption and emission) of diatomic molecule, Frank-Condon Principle, Fortrat parabolae, (d) Hund's coupling cases. [9 Lectures]

Reference Books:

1. G. Herzberg. 'Molecular Spectroscopy (Diatomic Molecules)' Van-Nostrand.
2. G. M. Barrow. 'Molecular Spectroscopy'. McGraw-Hill.
3. J. Michael Hollas. 'Modern spectroscopy'. John-Wiley & sons.
4. C. L. Banwell and E. M. McCash. 'Fundamentals of Molecular Spectroscopy' Tata-McGraw-Hill.
5. G.Aruldhas, 'Molecular Spectroscopy'.
6. Bransden and Joachin. 'Atoms and Molecules'
7. M. Hammermesh, 'Group Theory'. Addison-Wesley
8. A. W. Joshi. 'Group Theory'. Wiley Eastern Ltd.

MJC-18: Molecular Spectroscopy (Lab) (Credit-1)

1. To determine the different wavelengths of Helium spectrum.
2. Analysis of the Mercury Spectrum: Identify the prominent lines (Yellow doublet, Green, Blue-violet).
3. Determination of the separation between D_1 and D_2 lines of Sodium Spectrum.
4. Franck–Hertz Experiment to Demonstrate Quantization of Atomic Energy Levels.
5. Analysis of rotation-vibration spectrum of diatomic molecule (HBr or nay relevant molecule).
6. Analysis of rotational Raman Spectra of N_2 molecule.
7. To determine the Bohr magneton value by Zeeman Effect set up.

Reference Books

1. Molecular Spectroscopy—Experiment and Theory: From Molecules to Functional Materials: 26 (Challenges and Advances in Computational Chemistry and Physics) by Andrzej Koleżyński (Editor), Magdalena Król (Editor), Springer
2. Spectroscopy Principles and Instrumentation by Mark F. Vitha, Wiley
3. Introduction to Experimental Infrared Spectroscopy: Fundamentals and Practical Methods, Wiley

Course Outcomes:

Upon successful completion of this course, students will be able to:

1: Appraise Molecular Approximations

Explain the physical significance and limitations of the **Born-Oppenheimer approximation** and describe how the separation of electronic, vibrational, and rotational motions leads to the observed band structures in molecular spectra.

2: Analyze Rotational Dynamics

Determine molecular parameters (such as bond lengths and moments of inertia) by analyzing **Microwave spectra** using both rigid and non-rigid rotator models and applying appropriate selection rules.

3: Evaluate Vibrational Transitions Model molecular vibrations using harmonic and anharmonic (Morse potential) oscillators to interpret **Infrared (IR) spectra**, calculate dissociation energies, and explain the impact of isotope substitution on vibrational frequencies.

4: Interpret Raman Scattering Apply the principles of **Raman spectroscopy** to identify rotational and vibrational modes, distinguish between Stokes and anti-Stokes lines, and evaluate the effect of nuclear spin on spectral intensities.

5: Characterize Polyatomic and Electronic States

Differentiate between IR and Raman activity using the **principle of complementarity**, identify normal modes of vibration in polyatomic molecules, and interpret electronic transitions including vibrational progressions and sequences.

6: Demonstrate Experimental Proficiency Acquire hands-on skills in calibrating spectrometers, analyzing complex rotation-vibration data (e.g., for **HBr** or $\mathbf{N_2}$), and verifying fundamental quantum phenomena like the **Zeeman Effect** and **Raman scattering**.

MJC-19: Advanced Classical Electrodynamics (Theory) (Credit-3)

Interaction of Electromagnetic (EM) wave with matter: Absorption of EM wave in a medium, Beer-Lambert law and attenuation, Classical theory of dispersion: normal and anomalous dispersions, complex refractive index, Kramers-Kronig relations, Classical theory of scattering: Rayleigh scattering, Mie scattering **[8 Lectures]**

Electromagnetic (EM) Wave Propagation: Plane wave propagation in general directions. EM wave propagation through dilute plasma. Plasma frequency. Orbit theory of drift motions in a plasma. Pinch effect. Instability in pinched plasma column. Plasma oscillations, short wavelength of plasma oscillation and Debye screening length, Effect of external magnetic field on wave propagations, Reflection of uniform plane waves at normal incidence.

[12 Lectures]

Electromagnetic (EM) Radiation: Concept of retarded potentials, Solution of inhomogeneous wave equations. Liénard–Wiechert potential, Fields of a uniformly moving charge, Fields of an accelerated charge: Fields, radiation (power) and angular distribution from a charge at low velocity (non-relativistic), radiation (power) from a charge at linear motion and circular motion or orbit, angular distribution of power for linearly accelerated charges, relativistic correction, Bremsstrahlung and Cerenkov radiation, Basic radiation principles and the Hertzian dipole, Antenna specifications, Different types of antenna, Electric dipole radiation, Magnetic dipole radiation, Power radiated by a point charge. [15 Lectures]

Transmission Lines: Transmission lines and wave propagation. Transmission line equation. Lossless propagation. Condition for Distortion less Transmission and Minimum Attenuation, Transmission lines of finite length.

[5 Lectures]

Wave guides and resonant cavities: Basic concept of wave guides, TE & TM modes, Rectangular waveguide, circular waveguide, resonant cavities, rectangular cavity resonator-TE, TM modes. Power loss in a cavity-Q of a cavity.

[5 Lectures]

Reference Books:

1. Classical Electrodynamics- J. D. Jackson.
2. Classical Electromagnetic Radiation- J. Marion
3. Introduction to Electrodynamics- D. J. Griffiths.
4. Classical Electricity and Magnetism- W. K. H. Panofsky and M. Phillips.
5. Electricity and Magnetism- E. M. Purcell and D. J. Morin
6. Introduction to Plasma Physics and Controlled Fusion- Francis F. Chen
7. Introduction to Special Relativity- R. Resnick.

Couse Outcome:

On completion of this course, students will be able to

(i) Know the various types of interactions of EM wave with matter viz. absorption, scattering and dispersion

(ii) Understand basics of Maxwell's equations in different forms, acquire knowledge regarding propagation of EM wave through dilute plasma

(iii) Comprehend the concept of retarded potentials and the origin of radiation as well as the theory of antenna.

(iv) Grow the concept of the physics of transmission lines, wave guides and resonant cavities

(v) Comprehend the concept of retarded potentials and the origin of radiation as well as the theory of antenna.

MJC-19: Advanced Classical Electrodynamics (Lab) (Credit-1)

1. Verification of the Cauchy's Dispersion Formula: Measure the refractive index for different colors and fit them to $n=A+B/\lambda^2$.
2. To study the dispersion of EM waves in a dispersive medium and determine the phase and group velocities for different frequencies.
3. Determination of the Absorption Spectrum of Iodine Vapor: Gently heat the tube and observe the absorption bands in the visible region.
4. Verification of the voltage and current distribution along a transmission line and study the formation of standing waves under different load conditions.
5. To study the frequency response of a transmission line by measuring the attenuation and phase shift of signals over a range of frequencies.
6. To determine the characteristic impedance (Z_0) of a transmission line.
7. To determine the guide wavelength (λ_g) operating and cutoff frequencies of a rectangular wave-guide.

Couse Outcome:

On completion of this course, students will be able to gather hand on knowledge of some of the topics that are taught in the theory of this course.

MJC-19: Advanced Classical Mechanics (Theory) (Credit-3)

1. Variational calculus in Physics

Basic ideas of functionals; Variational principle and Lagrangian Formulation; Euler's equations of motion for simple systems: harmonics oscillators, simple pendulum, spherical pendulum, coupled oscillators; Cyclic coordinates: Symmetries and conservation laws; Legendre transformations and the Hamiltonian formulation of mechanics; Hamilton's canonical equations and their applications; Lagrangian and Hamiltonian for relativistic particles; Principle of least action.

2. Canonical Transformation

Equations of point; generating functions and examples; Lagrange and Poisson brackets and their applications; Invariance of Poisson bracket under canonical transformation; Equations of motion in Poisson Bracket; infinitesimal canonical transformation; constants of motion and symmetry principles; generators of infinitesimal symmetry transformation; Noether's theorem; integral invariant of Poincare; Conservation theorems and angular momentum relation in Poisson brackets; Liouville's theorem.

3. Hamilton-Jacobi equation

Hamilton-Jacobi equation for Hamilton's principle and characteristics functions; Physical significance of these functions; Application of Hamilton-Jacobi equation in linear harmonic oscillator, particle falling under gravity etc.; Action angle variables & applications; Path from classical to quantum mechanics.

4. Rigid body dynamics:

Lagrange's equations of motion for a rigid body; Euler's theorem on the motion of a rigid body; infinitesimal rotations. Euler's equations of motion. Force free motion of a rigid body; heavy symmetrical top with one point fixed; precession and nutation; Larmor precession; gyroscope and asymmetrical top, condition for Fast and sleeping top.

Reference Books

1. Goldstein, Poole and Safko: Classical Mechanics – Addison Wesley / Narosa.
2. Landau and Lifshitz: Mechanics – Pergamon.
3. Rana and Joag: Classical Mechanics – Tata-McGraw Hill.
4. Whittaker: Analytical Dynamics of Particles and Rigid Bodies – Cambridge.

5. Fetter and Walecka: Theoretical Mechanics of Particles and Continua – McGraw Hill.
6. Raychaudhuri A. K: Classical Mechanics – Oxford.
7. Bhatia: Classical Mechanics – Narosa.
8. K.C. Gupta: Classical mechanics of particles and rigid bodies-New Age International.

MJC-19: Advanced Classical Mechanics (Lab)(Credit-1)

1. To determine the angular momentum of a rotating flywheel by measuring its rate of gyroscopic precession.
2. To verify the principle of conservation of angular momentum using a spinning gyroscope.
3. To verify the Newton's second law of motion using Atwood's machine.
4. To determine the acceleration due to gravity (g) using Atwood's machine.
5. To study the dependence of acceleration on (i) total mass and (ii) mass difference using Atwood's machine.

Course Outcomes:

Upon successful completion of this course, students will be able to:

1: Master Variational Formalisms Apply variational calculus and the Principle of Least Action to derive Euler-Lagrange equations for diverse physical systems, including relativistic particles and coupled oscillators.

2: Execute Hamiltonian Dynamics Perform Legendre transformations to transition between Lagrangian and Hamiltonian formalisms and solve Hamilton's canonical equations for complex mechanical systems.

3: Analyze Canonical Transformations Evaluate the invariance of Poisson brackets under canonical transformations and utilize generating functions to simplify the equations of motion in phase space.

4: Synthesize Symmetries and Conservation Laws Relate physical symmetries to fundamental conservation laws through **Noether's Theorem** and apply Liouville's Theorem to understand the evolution of phase-space density.

5: Solve Hamilton-Jacobi Problems Implement the Hamilton-Jacobi equation and action-angle variables to solve periodic systems, facilitating the conceptual transition from classical trajectories to quantum mechanical states.

6: Model Rigid Body Motion Formulate and solve Euler's equations for rigid body dynamics, specifically analyzing the stability and motion of asymmetrical and symmetrical tops, including precession and nutation.

7: On completion of this course, students will be able to gather hand on knowledge of some of the topics (e.g. absorption, dispersion, transmission line, waveguide) that are taught in the theory art of this course.

MN-7: Atomic and Molecular spectroscopy (Theory) (Credit-3)

1. Atomic spectroscopy

The spectra of hydrogen atom, orbital magnetic moment of an atom, Larmor precession (statement), limitation of old quantum theory, vector atom model, Electron spin, magnetic moment due to electron spin, space quantization, geomagnetic ratio, spin orbit interaction, Land g-factor, Stern-Gerlach's experiment, Zeeman effect: Normal Zeeman effect and Anomalous Zeeman effect, Sodium D-Line Splitting , Paschen-Back effect, stark effect.

Pauli's exclusion principle, Coupling Scheme: L-S and j-j coupling, electronic configuration, distribution of electron in a sub-shell and shells, non-equivalent and equivalent electrons, Hund's rules.

2. Molecular spectroscopy

Category of molecular spectra, Origin of molecular spectra, Energy levels of diatomic molecules under rigid rotator, Selection rules, Spectral structure, Structure determination, Isotope effect, Rotational spectra of polyatomic molecules.

Energy levels of diatomic molecules under simple harmonic (no deduction necessary for this one) models, Selection rules and spectral structures.

Luminescence: Fluorescence and Phosphorescence, Raman Effect: Characteristics of Raman lines, quantum theory of Raman Effect, Stokes and anti stokes Raman lines. Raman Effect with laser source, application, NMR and ESR.

Books Recommended:

1. Quantum Mechanics, Robert Eisberg and Robert Resnick, 2nd Edn., 2002, Wiley.
2. Quantum Mechanics, Leonard I. Schiff, 3rd Edn. 2010, Tata McGraw Hill.
3. Quantum Mechanics, G. Aruldhas, 2nd Edn. 2002, PHI Learning of India.
4. G. Herzberg. 'Molecular Spectroscopy (Diatomic Molecules)' Van-Nostrand.
5. G. M. Barrow. 'Molecular Spectroscopy'. McGraw-Hill.
6. J.Michael Hollas. ' Modern spectroscopy'. John-Wiley & sons.
7. C. L. Banwell and E. M. McCash. 'Fundamentals of Molecular Spectroscopy',Tata- McGraw-Hill.
8. G. Herzberg. 'Molecular Spectroscopy (Diatomic Molecules)' Van-Nostrand.

MN-7: Atomic and Molecular spectroscopy (Lab) (Credit-1)

1. **Determination of the Rydberg Constant (R_H):** Measure the wavelengths of the Balmer series (H_α, H_β, H_γ).
2. **Measurement of Sodium D-line Splitting:** Measure the angular separation between D_1 and D_2 lines to calculate the wavelength difference (≈ 6 Å)
3. **Analysis of the Mercury Spectrum:** Identify the prominent lines (Yellow doublet, Green, Blue-violet) and calibrate the spectrometer.
4. **Verification of the Cauchy's Dispersion Formula:** Measure the refractive index for different colors and fit them to $n = A + B/\lambda^2$.
6. **Determination of the Absorption Spectrum of Iodine Vapor:** Gently heat the tube and observe the absorption bands in the visible region.

Course Outcomes:

Upon successful completion of this course, students will be able to:

1: **Appraise the Vector Atom Model** Critically evaluate the transition from old quantum theory to the **Vector Atom Model**, explaining the physical significance of space quantization, electron spin, and the results of the **Stern-Gerlach experiment**.

2: **Analyze Spectral Splitting in External Fields** Quantitatively describe the splitting of spectral lines under the influence of magnetic and electric fields (**Zeeman, Paschen-Back, and Stark effects**) and calculate the **Landé g-factor** for various atomic states.

3: **Apply Coupling Schemes and Hund's Rules** Determine the spectroscopic terms and electronic configurations of multi-electron atoms by applying **L-S and j-j coupling** schemes, **Pauli's Exclusion Principle**, and **Hund's rules**.

4: **Interpret Molecular Rotational and Vibrational Data** Analyze the rotational and vibrational spectra of diatomic molecules to calculate molecular parameters such as bond length and force constants using **rigid rotator** and **harmonic oscillator** models.

5: **Differentiate Scattering and Luminescence Phenomena** Distinguish between the mechanisms of **Fluorescence, Phosphorescence, and the Raman Effect**, utilizing selection rules to predict observable transitions and explaining the impact of laser sources on Raman scattering.

6: Summarize Resonance Spectroscopy Principles Explain the basic principles and applications of **Nuclear Magnetic Resonance (NMR)** and **Electron Spin Resonance (ESR)** in the context of studying atomic and molecular magnetic environments.