Course: M.Sc (Physics)

Semester	3
Paper Number	13 (MPHC4314)
Paper Title	Elective (For Astroparticle Physics: General Theory of Relativity) and Advanced Lab II
No. of Credits	6
Course description/objective	**Group A:** This is a basic course on the general theory of relativity where the students will be made familiar with the principles of relativity, the concept of curved space-time and its role in the visualization of the effect of gravity, and the formulation of tensor calculus necessary to build up the relevant theory. This will be applied to derive the important formulas like the geodesic equations, equation of geodesic deviation and Einstein field equations. The students will also become familiar about the energy-momentum tensor for different matter distributions, and will learn the linearized field equations and the formulation of gravitational waves, along with the simplifying gauges. They will learn about the solution of Einstein's equations and their corresponding geometry, the classical tests of general relativity and the Raychaudhuri equation of cosmological dynamics. **Group B:** The purpose of including this topic in the syllabus is to make the students familiar with some standard experimental methods or techniques to verify some theories of physics and to study the characteristics of some systems. The objective of this course is to help the students to develop the skills necessary to perform experiments and also to learn how to analyze the experimental data for the following purposes or experimental schemes: to study the temperature dependence of dielectric constant, to find the magnetic susceptibility of a paramagnetic specimen using Guoy's balance, to study the characteristics of a solar cell, to study the characteristics of Hall effect in metal, to study the surface roughness using a surface profilometer, to determine the band gap of a given semiconductor material, to study viscosity using a rotating viscometer, to study thermo-luminescence of alkali halides, to study viscous fingering in Hele-Shaw cell.
Course Outcome	**Group A** CO1: Learn the principles of general relativity and the interpretation of gravity as the manifestation of curvature of space-time. CO2: Extend the knowledge of tensors and use it to express important concepts of relativity like parallel transport, geodesic deviation, and the Bianchi identity. Learn to determine the trajectories of particles for various space-time geometries. CO3: Learn to determine the energy-momentum tensor for simple matter distributions. Learn the Lagrangian formulation of general relativity and the derivation of the Einstein field equations and the geodesic equation from variational principles. CO4: To learn about the gravitational energy-momentum pseudo tensor, and find the linearized field equations. Find the gravitational wave solutions and get acquainted with the simple gauges. Learn to interpret the effect of gravitational waves on the geodesic equation and geodesic deviation. CO5: Learn the simple solutions to the Einstein field equations like the Schwarzschild solution and FRW metric. Learn the importance of the classical tests of general relativity. CO 6: The students will also become aware of cosmologicaldynamics and learn the congruence properties of geodesics. **Group B** The Course Outcome of Advanced Lab-II is given below in the form of a list of experiments that the students will be taught to perform. While performing each of these experiments (listed below), they are expected to learn the experimental techniques as well as the theories required for the analysis of experimental data. Students will learn to

	represent their experimental findings properly. As an obvious outcome of the course, the experimental skill of each student is expected to be sufficiently enhanced. CO1: An experimental studyof the temperature dependence of dielectric constant. CO2: An experimental study of the determination of magnetic susceptibility of a paramagnetic specimen using Guoy's balance. CO3: An experimental studyto characterize a solar cell. CO4: An experimental studyto find the characteristics of Hall effect in metal. CO5: An experimental studyto measure the surface roughness using a surface profilometer. CO6: An experimental study to determine the Band gap of a given semiconductor. CO7: An experimental study of viscosity of a given sample using rotating viscometer. CO8: An experimental study of thermo-luminescence of alkali halides. CO9: An experimental study of viscous fingering in Hele-Shaw cell.
Syllabus	**Group A: (Elective)** **General Theory of Relativity[36 lectures]** Non-inertial frames and non-Euclidean geometry; Concept of curved space-time; Equivalence principle; General coordinate transformations and the general covariance of physical laws. [4 lectures] Recapitulation of tensors: Tangent space and dual space, Contravariant and covariant vectors (Tangent vectors and 1-forms), Metric tensor, Christoffel connection on a Riemannian space and Covariant derivative. Parallel transport and the affine connection; Intrinsic derivative and Equation of geodesics. Gravitation as space-time curvature: Curvature tensor and its properties; Bianchi identities; Equation for geodesic deviation; Relativistic Tidal Forces. [6 lectures] Energy-momentum tensor of dust and perfect fluid; Conservation laws; Hilbert's variational principle and Einstein-Hilbert action; Einstein's equation; Newtonian approximation; geodesic equations from variational principle. Weak field metric and gravitational energy-momentum pseudo tensor; linearized field equations. Gravitational waves: wave equation in linearized theory, gravitational wave solutions, plane waves, transverse traceless gauge, quadrupole formula, effect on test particles. Observation of Gravitational waves with LIGO and discussion of the proposed INDIGO consortium. [17 lectures] Static, spherically symmetric space-time; Schwarzschild's exterior solution and Schwarzschild geodesics; form of metric in the Newtonian limit. Effective potential for particle orbits in Schwarzschild metric, nature of R=2M surface, ISCO; Classical tests of GR: Motion of perihelion of Mercury; Bending of light; Gravitational red shift; Radar echo delay. [6 lectures] Elements of Cosmological dynamics: Weyl's postulate and the cosmological principle, co-moving coordinates; Maximally symmetric spaces and Robertson-Walker metric (no derivation); Expanding universe; anisotropies, vorticity and shear; Raychaudhuri equation

	[3 lectures] **<u>Group B: Advanced lab II</u>** **<u>List of Experiments</u>** 1. To study the temperature dependent Dielectric constant of a given specimen. 2. To find the magnetic susceptibility of a paramagnetic specimen using Guoy's balance or other suitable method. 3. Characterization of a Solar cell. 4. To study the Hall effect in metal. 5. To study surface roughness using a surface profilometer. 6. Determination of Band gap of a given semiconductor material. 7. Rotating viscometer. 8. Study of colour centers and thermoluminescence of alkali halides. 9. Viscous fingering in Hele-Shaw cell.
References	**<u>Group A</u>**: 1. A.K. Raychaudhuri, S. Banerji, and A. Banerjee: General Relativity, Astrophysics and Cosmology 2. J.V. Narlikar: An Introduction to Relativity 3. P.A.M. Dirac: General Theory of Relativity 4. L.D. Landau and E.M. Lifshitz: The Classical Theory of Fields 5. M. P. Hobson, G. P. Efstathiou and A. N. Lasenby: General Relativity - An Introduction for Physicists 6. R.M. Wald: General Relativity 7. S. Weinberg: Gravitation and Cosmology 8. C.W. Misner, K.S. Thorne and J.A. Wheeler: Gravitation 9. W. Rindler: Relativity - Special, General, and Cosmological **<u>Group B:</u>** 1. Physics of Semiconductor Devices by S.M. Sze, Wiley. 2. Solid State Electronic Devices by Streetman, Pearson Education India. 3. Semiconductor Optoelectronic Devices by P. Bhattacharya, Prentice Hall. 4. Semiconductor Devices, Physics & Technology, Sze & Lee, Wiley. 5. The Hall Effect and Its Applications by Chien & Westgate, Springer 6. The Hall Effect in Metals and Alloys, By Colin M. Hurd, Springer. 7. Viscometry for Liquids by S.V. Gupta, Springer
Evaluation	Total: 100 **<u>Group A:</u>** CIA: 10 End Semester Examination: 40 **<u>Group B:</u>** CIA: 30 marks (10 (LNB) + 20 (Lab performance)) End Semester Examination: 20