

Indian Association for the Cultivation of Science

School of Physical Sciences

PHS 5104/PHD 112

INTEGRATED MSC-PHD COURSE

Gravitation and Cosmology

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Note: Due to the current COVID-19 situation the schedule presented here can change.

1 Main points to remember

- **Course Webpage**: I have created a webpage, where all the details regarding this course will be posted. You are encouraged to check the webpage in regular intervals. You can access it by clicking here. Or, copy paste the following url to your browser: *https://sumantachakraborty.weebly.com/general-relativity.html*. You are also encouraged to check the "announcements" section located here.
- Assignments and Evaluation: I will hand over one assignments for every five classes. These you have to submit to me and it will be evaluated for your internal assessment. Further evaluation will be based on a mid-semester exam of twenty five marks and then a final examination with fifty marks. Please contact the academic office for further clarifications regarding the course.
- **Communications**: The main mode of communication outside the class will be through emails. Thus I would request all of you to check emails at least once everyday. The assignments as well as other instructions will be handed over through emails only.

2 Syllabus

- Basics of tensor analysis, Differentiation and Integration, Gravity and its connection with differential geometry, Rindler metric and principle of equivalence.
- Diffeomorphism, Covariant and Contravariant tensors under general coordinate transformations, Parallel transport, Affine connection, Riemann curvature tensor, Einstein's equations, Energy momentum tensor.
- Reissner Nordstrom geometry, Kerr Geometry, Black hole Physics, Kruskal-Szekers coordinate, Penrose diagram, Surface gravity, Hawking temperature, Hawking radiations, Elements of Black hole mechanics.
- Cosmological principle, Friedman-Robertson-Walker metric, equation of state, Hubble constant, Inflationary cosmology, Dark energy.

3 Books and Articles

- Spacetime Physics E. Taylor and J.A. Wheeler W.H. Freeman.
- Gravitation: Foundations and Frontiers T. Padmanabhan Cambridge University Press.
- Mechanics L.D. Landau and E.M. Lifschitz Pergamon Press.
- Classical Theory of Fields L.D. Landau and E.M. Lifschitz Pergamon Press.
- A First Course in General Relativity B. Schutz Cambridge University Press.
- Relativity W. Rindler Oxford University Press.
- Exploring Black Holes: Introduction to General Relativity E. Taylor, J.A. Wheeler Cambridge University Press.
- Gravitation and Spacetime H.C. Ohanion and R. Ruffini Cambridge University Press.
- Introducing Einstein's Relativity Ray D' Inverno Oxford University Press.

4 Time Scale

The course will start from **28th September** and will continue till **7th January**. The mid semester examination will take place within **22nd - 29th November** and the final examination will happen in between **17th - 24th January**. Possibly we will have around **25** classes. Below a tentative course structure has been presented, I will try to stick to this schedule.

- Class-01 Basic Introduction to Gravity; General Remarks; Definition of a tensor and its properties; Tensor Algebra.
- Assignment-01 First assignment will be handed over.
- Class-02 Illustration through examples; Symmetries of a tensor; Notion of a metric tensor; Its properties.
- Class-03 Idea of covariant derivative. Another look into Lorentz transformation.
- Class-04 Lagrangian of a relativistic particle; Implications; Second rank symmetric tensor field to describe gravity.
- Assignment Submission-01 First assignment must be submitted.
- Class-05 Weak Equivalence Principle; Rotating observer, Accelerated observer; Spacetime as seen by accelerated and rotating observer.
- Class-06 Another version of equivalence principle; Idea of Local inertial frame; Motion of a particle in a gravitational field; Gravitational Redshift.
- Assignment-02 Second assignment will be handed over.
- Class-07 Local Inertial frame; Geodesic equation.
- Class-08 Other forms of Geodesic equation; Importance of Christoffel connection. Various identities involving Christoffel symbol.
- Class-09 Parallel Transport; Lie Transport and Killing Vectors; Broad overview of lessons learned.
- Class-10 Notion of spacetime curvature; Commutator of covariant derivative as a measure of curvature.
- Class-11 Properties and identities satisfied by the curvature tensor will be derived and discussed; Field Theory in Curved Spacetime; Modifications to scalar field theory and electrodynamics will be addressed.
- Class-12 Action principle for gravity; How to arrive at the Einstein-Hilbert action? Deriving Einstein's equations in vacuum.
- Assignment Submission-02 Second assignment must be submitted.
- Class-13 Varying the Matter Action and completing the derivation of Einstein's equation with matter. Basic Properties of field equation and weak field limit of gravity.
- Class-14 Gravitational Waves.
- Class-15 How to arrive at a spherically symmetric solution; Writing down Einstein's equations for the same situation. Derivation of Schwarzschild Solution.

- Assignment-03 Third assignment will be handed over.
- Class-16 Trajectory of a Particle; Perihelion precession; Bending of light; Other Tests of General relativity.
- Class-17 Interior Solution; Tolman-Oppenheimer-Volkoff Equation.
- Class-18 Writing down the Schwarzschild solution in various other coordinates and Spacetime diagram for Schwarzschild spacetime.
- Mid-Semester Examination.
- Assignment Submission-03 Third assignment must be submitted.
- Class-19 Notion of Penrose diagram for flat spacetime and for Schwarzschild spacetime.
- Class-20 Derivation of Schwarzschild de-Sitter and Reissner-Nordström solution; Notion of black hole temperature.
- Assignment-04 Fourth assignment will be handed over.
- Class-21 Idea about Kerr solution and black hole thermodynamics.
- Class-22 Introduction to Cosmology and the notion of homogeneity and isotropy; Kinematics in cosmological spacetime; Particle motion; redshift and all that.
- Class-23 Derivation of Friedman equations; Consequences and the matter content of the universe.
- Class-24 Thermal History of the Universe.
- Assignment Submission-04 Fourth assignment must be submitted.
- Assignment-05 Fifth assignment will be handed over.
- Class-25 Accelerated expansion of the universe.
- Class-26 Inflationary cosmology.
- Assignment Submission-05 Fifth assignment must be submitted.
- Final Examination will take place.