Physics 470: Relativity, Spacetime & Gravity *Spring 2024*

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	Room	Time
Lecture	Gulick 223	9:40-10:40 MWF

Texts

- James Hartle, *Gravity: An Introduction to Einstein's General Relativity* (Addison Wesley)
- T. M. Helliwell, *Special Relativity* (University Science Books)

Recommended Text

- Edwin Taylor and John Wheeler, *Spacetime Physics* (Freeman)

More advanced reading

- Charles Misner, Kip Thorne, and John Wheeler, *Gravitation* (Freeman)

Course Objectives

This course is an introduction to Albert Einstein's special and general theories of relativity. After completion of the course, students will be able to solve straightforward problems in relativity.

About Physics 470

PHYS 470 is a physics capstone course. It has been almost a hundred and twenty years since Einstein published his paper *"On the Electrodynamics of Moving Bodies."* In this paper Einstein reconciled Maxwell's theory of electrodynamics with the Galilean relativity principle of Newtonian mechanics by replacing Newton's universal time and absolute space with a space and time that depend on an observer's state of motion and replacing the Galilean relativity transformations with the Lorentz transformations. Ten years later, Einstein published his General Theory of Relativity, which reconciled Newton's theory of Universal Gravitation with the special relativity principle, placing a capstone on classical physics. We will understand how Einstein came to his conclusions, how space and time are unified into spacetime, and some of the consequences of special relativity. We will also understand why it is necessary to replace Newton's theory of Universal Gravitation by the theory of General Relativity. We will explore the physics of a few of the exact solutions of General Relativity, including the gravitional field of a massive object, black holes, general relativistic effects in the solar system, and cosmology. If time permits, we will examine the field equations of General Relativity, which describe how matter curves spacetime much as Maxwell's equations describe how electric charges create the electromagnetic field.

Course Requirements

Regular Homework Problems
2 Exams
Final Exam

Office Hours

Initially office hours will be Tuesday at 11:00 am, Friday at 2:00 pm, and by appointment. If these hours are inconvenient for you, please let me know and I'll try to find some more convenient times.

Grading
Grades in this class will be based on the following elements.

- **Participation** I expect each student to do the assigned readings and problems and to bring questions and comments to class and to participate in class discussions. Implicit in this is the expectation that all students will attend all classes. The grade for participation will be assigned at my discretion at the end of the semester.

- **Homework** Homework will be assigned on a regular basis and collected. I reserve the right not to give credit for late homework assignments, based on the belief that keeping up is an essential ingredient for success in the course. You may work together on the homework. Indeed, I encourage you to work together to understand the problems. However, you must each separately write up solutions in your own words (and equations) and may not turn in something you do not understand. (That is, you may not simply paraphrase someone else's solution as your own.) Paraphrasing without understanding, or outright copying, are plagiarism, a form of academic dishonesty.

- **Exams** There will be two mid-term exams and a final exam. The final exam will be comprehensive. Dates for the mid-term exams will be announced in lecture. The mid-term and final exams are likely to be take-home exams. The final exam will be in the period set by the Registrar, which should be Tuesday, May 7, 2024 at 1:30PM.

- **Quizzes** There may be quizzes in class, mostly for your own diagnostic use. Any quizzes will be announced in advance and will count towards your participation grade.

The relative weights of each element of the grade for the course is as follows.

Element	Weight
participation	10%
homework	30%
mid-term exams	30%
final exam	30%

Disability Accommodations
Students with a documented disability for which they may need accommodations that they have not yet obtained should self-identify by logging into the Accommodate Portal and complete the Accommodation Request Intake Form. Accommodations and services will only be provided once the registration and documentation process is complete. See the guidelines for documenting disabilities. Returning students may log in to the Accommodate Portal and request semester accommodation letters. Students who need to meet to add or discuss accommodations should schedule an appointment in the Accommodate Portal.

Direct questions about this process or Disability Services at HWS to Shanelle France or Thom Mascia (x3351), in Disability Services at CTL. Should you need to meet to add or discuss accommodations, please schedule an appointment in the Accommodate Portal.

Academic Integrity
Students should familiarize themselves with the principles of academic integrity in the handbook of community standards. Work on an exam that is clearly not one's own will receive zero credit.

All future recommendation letters will mention any relevant academic dishonesty. Deceit in the form of academic dishonesty is indicative of untrustworthiness and low moral character in general and therefore ought to disqualify a student from any future position of responsibility. It is generally obvious in physics that there has been information transfer between students as there are very few correct ways of solving a problem, and many many possible errors one can make, even if the approach is correct. It is very unlikely that two students will take the exact same wrong approach to a problem or make exactly the same errors.

Outline of the Course

This syllabus is ambitious. I suspect that we will probably get through much of this material, though perhaps not at the depth covered by some of the text.

Newtonian Physics and Galilean Invariance
Inertial Frames. Universal time & absolute space. Galilean transformations. Invariance of Newton's second law.

Maxwell's Equations break Galilean Invariance
Transformations of fields. Wave equation is not Galilean invariant. Maxwell & Newton only consistent in a universal rest frame.

Einstein fixes the discrepancy without an Æther
Postulates of special relativity. Time dilation. Lorentz contraction. Lorentz transformations. Simultaneity is relative. Seeming paradoxes. Minkowski geometry & spacetime diagrams. Special relativistic mechanics.

Gravity & Geometry
Problems with Newtonian gravity. Can SR incorporate gravity? Gravitational & inertial mass. The Equivalence Principle: gravity as a fictitious force. Newtonian gravity in spacetime terms.

Describing curved spacetime
Coordinates. Metric tensor. Geometric quantities for diagonal metrics. Vectors in curved spacetime.

Geodesics
Variational principle. Geodesic equation.

Geometry outside a spherical star
Schwarzschild metric. Gravitational redshift. Precession of perihelion. Deflection of light. Solar system tests. Parametrized Post-Newtonian Parameters.

Miscellaneous Issues
Gravitational lensing. Accretion disks. Binary pulsars.

Black holes
Collapse to a black hole. Kruskal-Szekeres coordinates. Astrophysical black holes. Hawking radiation.

Rotating solutions
Frame dragging. Geodetic precession. Kerr geometry. Horizon of a rotating black hole. The Ergosphere.

Gravitational waves
Linearized gravitational wave. Detecting gravitational waves. Polarization. Gravitational wave interferometers.

Cosmology

Homogeneous, isotropic spacetimes. Cosmological redshift. Friedman-Robertson-Walker models.

Einstein field equations

Covariant derivatives. Tidal gravitational forces. Geodesic deviation. Riemann curvature. Einstein equation in vacuum. Stress-energy tensor.