**Relativity (PHY 408)**

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http://chi.physics.sunysb.edu/lectures/spring-2025/

[Announcements](http://chi.physics.sunysb.edu/lectures/spring-2025/announce.shtml)

[Lecture Notes](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/notes.shtml)

[Mathematica Notebooks](http://chi.physics.sunysb.edu/lectures/spring-2025/notebooks/notebooks.shtml)

This course covers special and general relativity. After a short review of special relativity and relativistic covariance, we cover the basics of geometry and tensor analysis to arrive at the Einstein equations. We will discuss the non-relativistic limit of these equations, the black hole solutions and the gravitational wave solutions. The course is loosely based on the textbook by Sean Carrol, Spacetime and Geometry: An Introduction to General Relativity. Also useful are [lecture notes by Gerard't Hooft](http://chi.physics.sunysb.edu/lectures/spring-2025/thooft.pdf) and the textbook, A first Course In General Relativity, by Bernard Schutz.

A tentative course plan is:

L1 Definitions in Special Relativity

L2 Proper Time, Lorentz Transformations

L3 Addition of Velocities, Four Vectors

L4 Lorentz Group, Infinitesimal Generators

L5 Invariant Tensors, Dual Tensor

L6 Four Velocity, Action, Momentum, Force

L7 Relativistic Lagrangian

L8 Relativistic Dynamics

L9 Four Current, Four Potential, Lagrangian

L10 Energy Momentum Tensor

L11 Equivalence Principle

L12 Gravitational Field in Relativistic Mechanics

L13 Constant Acceleration, Rindler Space

L14 Curvilinear Coordinates

L15 Tensors, Integration Measure

L16 Proper Time and Proper Length

L17 Parallel Displacement, Covariant Derivative, Christoffel Symbols

L18 Transformation of Christoffel Symbols

L19 Contraction of Christoffel Symbols

L20 Motion of a Particle in a Gravitational Field

L21 The Riemann Tensor

L22 Bianchi Identity, Ricci Tensor

L23 Action of a Gravitational Field

L24 Einstein Equations

L25 Weak Gravity Limit

L26 Deflection of Light by a Gravitational Field, Perihelium Shift

L27 Schwartzschild solution and Black Holes

L28 Gravitational Waves

Class attendance is essential, and your feedback is very important. Everyone should be able to follow the lecture at all times. Questions during class on the material and my explanations are strongly encouraged. I may give quizzes to find out if I have been sufficiently clear.

This class meets Mon-Wed 2.00-3.20 in Psychology A146. The first class meeting is Monday January 27.

**Prerequisites**

Tow semesters of a Griffiths level course in electrodynamics is essential as well as a strong background in Mathematics. Basic knowledge of Mathematica is required -- some of the homework problems rely on this framework.

**TextBook and Lecture Notes**

As I said above, the required text book is Sean Carrol, Spacetime and Geometry: An Introduction to General Relativity.

**Grade Calculation**

The course grade will be based on homework, a midterm exam, a final exam and class participation, according to the formula 15 percent homework, 5 percent for class participation (including possible quizzes), 30 percent for the midterm and 50 percent for the final. Students who get less than 25 percent correct of the final can expect an F grade for this course. Note that the weight of the homework is actually much higher because without spending of lot of time on the homework you will not be able to solve the exam problems in a satisfactory way.

**Final Exam:** Friday May 16, 2025, 2.15 - 5.00 pm. Frivolous excuses such as I have booked a flight back home or I have two exams on the same day will not be accepted.

**Class Times and Venue:**Mon-Wed 2.00 -- 3.20, in Psychology A146.

**Office Hours**

Wednesday 12.00 -- 2.00, may change if there are conflicts.

**Homework**

Homework will be assigned weekly, and must be submitted on paper. It will be assigned on Wednesday and is due next Tuesday at the beginning of the class. No extensions of the homework deadline will be given. If the handwriting or scan is not sufficiently clear, it is my prerogative not to grade the homework. Copying homework solutions from the internet is not allowed, but collaboration with fellow students is encouraged. I will check if homework solutions have been copied from the web or other sources. The home work will be graded on effort, but I will supply solutions of all problems.

**Course Website:** [PHY 408 Website](http://chi.physics.sunysb.edu/lectures/fall-2024/index.shtml)

**University Policies**

We will comply with University Policies with regards to religious holidays, accessibility, disabilities, academic integrity, etc.. See, [the Provost Webpage](https://www.stonybrook.edu/commcms/provost/faculty/handbook/academic_policies/policies_and_procedures_for_instructors.shtml) and [University Syllabus statement](https://www.stonybrook.edu/commcms/faculty-pathways/pages/policies_and_procedures_for_instructors.php) for details.

Send corrections and comments about this WEB page to jacobus.verbaarschot@stonybrook.edu. Last updated 01/22/2025.

**Homework Assignments**

[Homework Set # 1, Due Tuesday September 10, 9.30 am, 2024](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/hws24-1.pdf)  
[Solutions](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/sol-hwf24-1.pdf)

[Homework Set # 2, Due Tuesday September 17, 9.30 am, 2024](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/hwf24-2.pdf)  
[Solutions](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/sol-hwf-24-2.pdf)

[Homework Set # 3, Due Tuesday October 1, 9.30 am, 2024](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/hwf24-3.pdf)  
[Solutions](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/sol-hwf24-3.pdf)

[Homework Set # 4, Due Tuesday October 8, 9.30 am, 2024](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/hwf24-4.pdf)  
[Solutions](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/sol-hwf24-4.pdf)

[Homework Set # 5, Due Thursday October 17, 9.30 am, 2024](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/hwf24-5.pdf)  
[Solutions](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/sol-hwf24-5.pdf)

[Homework Set # 6, Due Thursday October 24, 9.30 am, 2024](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/hwf24-6.pdf)  
[Solutions](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/sol-hwf24-6.pdf)

[Homework Set # 7, Due Thursday November 14, 9.30 am, 2024](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/hwf24-7.pdf)  
[Mathematica code for problem 1](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/poincare-disk.nb)  
[Solutions](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/sol-hwf24-7.pdf)

[Homework Set # 8, Due Thursday November 21, 9.30 am, 2024](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/hwf24-8.pdf)  
[Solutions](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/sol)

[Homework Set # 9, Due Thursday December 5, 9.30 am, 2024](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/hwf24-9.pdf)  
[Solutions](http://chi.physics.sunysb.edu/lectures/spring-2025/homework/sol)

**Mathematical Notebooks**

[**Exapansion of potential of charge above conducting plane in speherical harmonics**](http://chi.physics.sunysb.edu/lectures/spring-2025/notebooks/v-image.nb)

**Lecture Notes for Relativity (PHY408)**

[Lecture 1, 1-27-2024](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p1-30)  
Relativity, Invariant Distance, Proper Time (Caroll 1.2)

[Lecture 2, 1-29-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p1-30)  
Lorentz transformations, Rapidity, Lorentz Contraction, Addition of Velocities

(Carroll 1.3, 1.4) [Lecture 3, 2-3-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p1-30)  
4-vectors, Lie algebra of the Lorentz Group, Tensors (Carroll 1.3, 1.6, 1.7)

[Lecture 4, 2-5-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p1-30)  
Invariant Tensors, Large Lorentz Transformations (Carroll 1,9, 1.10)

[Lecture 5, 2-10-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p1-30)  
Action of a Relativistic Particle,Lagrangian, Lagrange Equations of Motion (Carroll 1.10)

[Lecture 6, 2-12-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p1-30)  
Four Current, Four potential (Caroll 1.8)

[Lecture 7, 2-17-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p1-30)  
Lagrangian of EM field, Lorentz Force. Lorentz Transformations of E and B (Carroll 1.8, 1.10) , Energy Momentum Tensor (Carroll 1.9)

[Lecture 8, 2-19-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p1-30)  
Dust, Ideal Fluid, Continuity Equation

[Lecture 9, 2-24-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p37-46.pdf)  
Euler Equation (Carroll 1.9), Manifolds, Tangent Vectors, Forms (Carroll 2.2, 2.3) Metric, Signature, Canonical Form (Carroll 2.5)

[Lecture 10, 2-26-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p37-46.pdf)  
Domain of Dependence, Horizon (Carroll 2.7), Tensor Densities (Carroll (2.9), Derivatives (Carroll 3.2)

[Lecture 11, 3-3-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p49-80.pdf)  
Tensorial Property (Carroll 2,2),

[Lecture 12, 3-5-2024](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p49-80.pdf)  
Covariant derivative of GR (Carroll, 3.3) Parallel Transport

[Lecture 13, 3-10-2024,](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p49-80.pdf)  
Geodesic Equation (Carroll 3.3)

[Lecture 14, 3-12-2024](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p49-80.pdf)  
Examples

[Spring Break, No Lecture, 3-17/19-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p49-80.pdf)

[Lecture 15, 3-24-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p49-80)  
Curvature Tensor, Ricci Tensor (Carroll 3.6) Properties of the Riemann Tensor (Carroll 3.7)

[Lecture 16, 3-26-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p49-80)  
Midterm Exam: p1-48 of notes, and first 5 homework sets

[Lecture 17, 3-31-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p49-80)  
Properties of Riemann Tensor (Carroll 3.7)

[Lecture 18, 4-2-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p49-80)  
Einstein Equation, (Carroll 4.2)

[Lecture 19, 4-7-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p49-80)  
Newtonian Limit (Carroll 4.2, 7.1)

[Lecture 20, 4-9-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p49-80)  
Gravitational Radiation (Carroll 7.4, 7.5)

[Lecture 21, 4-14-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p86-125.pdf)  
The Schwartzschild Solution (Carroll 5.1)

[Lecture 22, 4-16-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p86-125.pdf)  
  
Bending of Light (Carroll 7.3)

[Lecture 23, 4-21-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p86-125.pdf)

[Lecture 24, 4-23-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p86-125.pdf)  
Perihelium Shift (Carroll 7.3)

[Lecture 25, 4-28-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p86-125.pdf)  
Singularities of the Schwartzschild Metric (Carroll 5.6, 5.7)

[Lecture 26, 4-30-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p86-125.pdf)  
Kruskal Coordinates, Penrose Diagram (Carroll 5.6, 5.7)

[Lecture 27, 5-5-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p86-125.pdf)  
Hilbert Einstein Action (Carroll 4.)  
Equivalence Priciple(Carroll 2.1)

[Lecture 28, 5-7-2025](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/p86-125.pdf)  
Rindler Coordinates (Carroll 9.5)  
Thermodynamics of Black Holes and Hawking Radiation (Carroll 9.6)

[Final Exam, Friday. 5-16-2025, 2.15-5.00 pm in regular class room](http://chi.physics.sunysb.edu/lectures/spring-2025/notes/notes.shtml)