Special Relativity and Particle Physics

MIT High School Studies Program
Fall 2008

"What I'm really interested in is whether God could have made the world in a different way; that is, whether the necessity of logical simplicity leaves any freedom at all."
-- Albert Einstein

"Our imagination is stretched to the utmost, not, as in fiction, to imagine things which are not really there, but just to comprehend those things which are *there."*
-- Richard P. Feynman

Welcome to Special Relativity and Particle Physics!

Instructor: Jacob Sanders
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Time and Place: Saturdays, 1:00 PM–3:00 PM
Room 1-277

Course Website: http://www.people.fas.harvard.edu/~sanders/HSSP

Course Description

What does $E = mc^2$ really mean? Why can't anything travel faster than light? Is time travel possible? How are new particles discovered?

Following in the footsteps of Einstein, we'll embark on a careful study of special relativity. We'll cover time dilation, length contraction, Lorentz transformations, velocity addition, energy and momentum, and particle collisions. We'll discover that space and time are really weird, and we'll resolve many cool paradoxes. We'll then consider gravity, leading us briefly into general relativity and black holes. Finally, we'll conclude with particle physics; you'll learn the difference between bosons and fermions, quarks and leptons, and matter and antimatter.

Course Prerequisites

1. High-school algebra and trigonometry
2. A physics course covering basic Newtonian mechanics

Please take these prerequisites seriously in order to get the most out of the course.

Lectures

I want lectures to be as interactive and exciting as possible. I will frequently ask questions and pose paradoxes (relativity is full of intriguing paradoxes). Your active thought and participation will be essential to answering the questions and resolving the paradoxes. You should never be afraid to participate. In addition, I *love* answering questions, so you should always feel free to ask questions at any time—before class, during class, after class, and by e-mail. Really—whenever you are confused or curious, you should ask! In addition, please let me know whenever you think I am going too quickly or too slowly. I am happy to adjust the pace depending on your feedback. In short, this course is for *you*, and I want to do everything in my power to make you *love* it.

Lecture Notes

I will attempt to post lecture notes after each class session on the course website listed above, in order to supplement notes you take in class.

Problem Sets

I will post (approximately) weekly problem sets reviewing the material covered in class. These are completely optional, but you will get much more out of the course if you attempt at least some of the problems. You are also strongly encouraged to try some of the problems with your classmates; you'll make new friends *and* get to learn more physics. Most of the problems are not designed to be particularly difficult, but rather just to give you a chance to practice using the material. And of course they are lots of fun!

Recommended Textbooks

There is *no* required textbook. Instead, the lectures will form the backbone of the course. But just in case you'd like to read more about these fascinating topics (and who wouldn't?), I recommend:

- Edwin F. Taylor and John Archibald Wheeler. *Spacetime Physics: Introduction to Special Relativity*. New York: W. H. Freeman and Company, 1992.

  This book is *loads* of fun to read: concepts are explained well, the examples are really cool, there are many illustrations, and the mathematics is not overwhelming.

- Jearl Walker. *Halliday/Resnick Fundamentals of Physics.* Extended 8th Ed. Hoboken, NJ: John Wiley & Sons, 2008.

  This is a common, well-written AP Physics textbook. Chapters 37 and 44 are relevant to this course, but we will often go into greater depth in lecture.

Grades

There are absolutely no quizzes, no tests, and no grades. Relax, enjoy, and try to learn as much as you can! Think of this course as an intellectual candy store. It should be both hard *and* fun.

Frequently Asked Question

How much mathematics will be used in this course?
I intend to give a full mathematical treatment of special relativity; those of you math-types looking for a rigorous course should not be disappointed. However, the nice thing about special relativity is that the mathematics is extremely accessible to high-school students. We will need only high-school algebra and high-school trigonometry in order to give a complete quantitative description of the theory. If you know algebra and trigonometry, you will have no mathematical trouble with this course. In particular, I will *never* use any calculus in this course. The real challenge of special relativity lies in understanding the *meaning* behind the mathematics, and I sincerely hope you will embark on this thrilling and rewarding challenge with me.

Tentative Schedule

Class 1: September 13, 2008

- Why Physicists Thought They Knew Everything in 1900
- Why Physicists Were Wrong: History of Special Relativity
- Basic Postulates of Special Relativity
- Loss of Simultaneity and the Train Paradox

Class 2: September 20, 2008

- Time Dilation and the Twin Paradox
- Length Contraction and the Ladder-in-a-Barn Paradox
- Lorentz Transformations

Class 3: September 27, 2008

- The Invariant Interval
- Timelike, Lightlike, and Spacelike Events
- Spacetime Diagrams

Class 4: October 4, 2008

- Velocity Addition
- Why Nothing Ever Travels Faster Than Light
- Rapidity

No Class on October 11, 2008

Class 5: October 18, 2008

- Momentum and Energy in Special Relativity
- The *Real* Meaning of $E = mc^2$
- Particle Collisions
- How New Particles Are Discovered

Class 6: October 25, 2008

- Four-vectors
- Review of Special Relativity

Class 7: November 1, 2008

- Introduction to General Relativity
- Gravity and the Curvature of Spacetime
- Black Holes

Class 8: November 8, 2008

- The Zoo of Elementary Particles
- Fermions and Bosons
- Quarks and Leptons
- Matter and Antimatter

Class 9: November 17, 2008

- The Four Forces of Nature
- Grand Unification Theories (GUTs)
- Theories of Everything (TOEs)
- What Should You Learn Next?