Welcome to 8.033!

Credit: Image painted by Harm Kamerlingh Onnes. Source: Wikimedia Commons.

Relation to other courses

8.20 covers 60% of material - either stay in 8.033 and coast through initially or take 8.224 ("Exploring Black Holes"). Taking *both* 8.20 and 8.224 waives the 8.033 requirement.

Surgeon General's Warning

- **False sense of security:** Many of you will may think you know it all from books, other courses, *etc.*Don't get lulled into false sense of security!
- **Unusual style:** Not everything is proven from the beginning (cf. 8.01 & 8.02). For SR, we'll derive everything from Einstein's 2 postulates, but for cosmo and GR we jump right into the middle and work out cool consequences from equations you'll need to take at faith
- **Non-intuitive:** This may be your first real departure from intuitive physics.
- **Collaboration:** OK to collaborate on problem sets, but you *must* hand in your own work. Copying ==> trouble.
- **Night owls:** Like to stay up all night? View Friday as part of the weekend? Consider grad school & postdoc! No credit for late problem sets. Attendance crucial: saves you time, and beyond books, there'll be $\sim$ 30% value-added that you're responsible for on exams. If you miss a lecture, see friend or TA.
- **Unfamiliar math:** Calculus of variations
- **Lots of PowerPoint:** Keep me from going to fast and erasing too soon

How to do well in the course:

- Come to class
- Use study guide
- Do all psets
- Study with someone else
- Don’t waste time on pset all-nighters with no help

I’ve never failed a student who really tried hard.

YOUR GRADE:
20% weekly problem sets
20% Quiz 1 (1 hour)
20% Quiz 2 (1 hour)
40% Final exam (3 hours)

Lecture plan:

- L1-5: Background
- L6-13: Special relativistic kinematics
- L14-23: Special relativistic dynamics
- L24-25: Relativity of E&M
- L26-29: Cosmology
- L30-39: Curved spacetime & black holes

See the detailed syllabus for a lecture-by-lecture list of topics. The GR part will be limited; we'll mostly work out consequences of FRW and Schwarzschild metrics, and perhaps whet your appetite for a full GR course.

Reading:

1. We'll start with Resnick (the whole book). On the side, browse French and (highly recommended!) Einstein. N.B. BOOK LATE!
2. For dynamics and E&M, we do French (5-8).
3. For cosmology, there will be handouts.
4. For black holes, we'll do Taylor & Wheeler.

Consider printing the lecture notes beforehand and writing notes on the during class.

The History of Physics in 10 minutes

1. Ancient civilizations (what limited them?)
2. Newtonian Mechanics (1600's) (8.01, 8.06)
3. Electromagnetism (1800-1875) (8.02, 8.03, 8.07)
4. Stat Mech & Thermo (1850-1900)
5. Relativity (Einstein 1905, 1916) (8.033, 8.20, 8.224)
6. Quantum Mechanics (1900-1926)
7. 1900's breakthroughs
8. What's left for you to do?

Newtonian Mechanics (1600's)

Tycho Brahe	1546-1601	Danish
Johannes Kepler	1571-1630	German
Sir Isaac Newton	1642-1727	English

Principia published 1678

Era of gravitational astronomy (1700's)

Leonhard Euler	1707-1783	Swiss
Alexis Clairaut	1713-1765	French
J. D'Alembert	1717-1783	French
Joseph Lagrange	1736-1813	French
Pierre Laplace	1749-1827	French

Era of electricity & magnetism (1800-1875)

Carl F. Gauss	1777-1855	German
André Ampere	1775-1836	French
Michael Faraday	1791-1867	English
Georg Ohm	1787-1854	German
James C. Maxwell	1831-1879	Scottish

Statistical Mechanics & Thermodynamics (1850-1900)

Clausius	1822-1888
Joule	1818-1889
Kelvin	1824-1907
Helmholtz	1821-1871
Maxwell	1831-1879
Boltzmann	1844-1906
Planck	1858-1947

Relativity

Albert Einstein	1899-1955

(Lorentz, Riemann, Schwarzschild, Kerr, FRWL, Wheeler, Kruskal, Hawking, ...)

Quantum Mechanics

Max Planck	1858-1947
Niels Bohr	1885-1962
Louie de Broiglie Max Born	1882-1970
Werner Heisenberg	1901-1976
Erwin Schödinger	1887-1961
Wolfgang Pauli	1900-1958
John von Neumann	
Paul Dirac	
Hugh Everett, III	1930-1982
Hans-Dieter Zeh	

Einstein

In 1905, at age 26, while working in a patent office with almost no contact to academia, he wrote three monumental papers:

- Photoelectric effect
- Brownian Motion
- Special theory of relativity

Completed general relativity in 1916. Learn from his approach!

Hints of relativity in the physics you already know

Special relativity

Maxwell's equations in vacuum imply

$$\nabla^2 \mathbf{E} - \frac{1}{c^2}\ddot{\mathbf{E}} = 0.$$

- This implies (as you learned in 8.02) waves traveling at speed c at *any* frequency (big shock then — now observed over range $10^3 - 10^{27}$ Hz).
- But speed c relative to what? No reference to any particular frame.
- Consider flashlight on train. Either the equation is lacking something or something else is wrong. We'll explore what the big deal is.

General relativity

(Please slow me down!)

Combining

$$F = ma$$

with

$$F = \frac{GmM}{r^2}$$

shows that the gravitational acceleration

$$a = \frac{GM}{r^2}$$

is mass-independent as long as

"inertial mass" = "gravitational mass".

Is it?

- Galileo's Pisa experiment showed it with low precision.
- Eötvös (1890) and later others showed with high precision that a independent of both mass and composition (density, atomic element, matter/antimatter, etc). Coincidence?
- In GR, Einstein explained it as gravity being a purely geometric effect. Follows from his equivalence principle.

Key lessons of the course

Special relativity

- Space and time are inextricably merged as 4D spacetime.
- Fast moving clocks appear slower, shorter and heavier.
- $E = mc^2$

General relativity

- Spacetime is not static but dynamic, globally expanding and locally curving and contracting to form black holes *etc.*
- Matter curves spacetime
- Things moving straight through curved spacetime appear deflected (gravity)

______________________ $\leftarrow$ (your theory here)

- Think for yourself.
- Question authority.
- Don't dismiss ideas just because they sound weird.

Expect physics to feel weird!

- Relativistic driving movie
- Black hole movie

Next time:

symmetry
in physics