Einstein's Universe

NYU CORE-UA 0204 #nyueinstein
This syllabus is for the 2021 Fall semester.

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Albert Einstein was involved in four important breakthroughs in physics. Two of these are special relativity and general relativity, which changed how we think about space, time, and matter. They brought a new understanding of the equivalence of matter and energy. The other two breakthroughs are the photoelectric effect and brownian motion, which helped to establish that both matter and energy are quantized, not continuous. Einstein's contributions were truly theoretical, in that his work unified or explained phenomena that were well established by the experimental physicists of the time, but which were very hard to understand in the common-sense physical picture that prevailed. Einstein did not participate much in the tremendous scientific revolutions that followed from his work, but we will learn about them in this class: We will learn about how time and space are different for different observers, and how they are affected by gravity. We will learn about how we know that the world is made up of atoms, and how matter and energy are quantized and obey the strange rules of quantum mechanics. We will learn about how the theory of gravity directly predicts both the existence of black holes and the expansion of the Universe, and how both of these things are now extremely well established.

Aims

This course is intended to:

- introduce you to interesting and important concepts in contemporary physics, and
- provide you with some quantitative reasoning and conceptual reasoning skills that can be useful in many contexts, and
- teach you a little bit about the history of science, and the development of physical ideas.

Reading, Lectures, and Problems

There are two Lectures every week, and there will be assigned readings every week. The readings will come from the book *Einstein* by Isaacson, the book *Relativity Demystified* by Wolfson, and various articles on Wikipedia. Read these carefully, but also critically. You will be expected (on the Exams) to be familiar with the content of the readings and the Lectures.

In addition, there will be problem sets, which you are expected to do. These problem sets will not be handed in, nor will they be graded. But some

of the problems, or parts of the problems, will appear (nearly verbatim) on the Exams. Since the Exams will be open notes, it behooves you not just to do these problems, but to bring your solutions with you on Exam days.

You are encouraged to work together with your fellow students on the reading and on the problem sets. You will do better in the class (and have more fun) if you work in a team. But since you will be examined individually, make sure you personally understand the material, even if you work it out in a group.

At no point will we give out solutions to the problems. **Why no solutions?** There is research that shows that students learn more if they do not have a reference solution to a problem they are facing. This has various consequences. One is that if you are doing problems with friends, and one has a solution, do not rely on this solution as a reference solution. For one, it might be wrong. And for two, if you treat it as correct, you won't learn as much. Another consequence is that if you don't understand how to do a problem, or if you are not sure of your solution, you should bring it to your Lab Instructor or Prof Hogg for discussion.

Labs

There is an experimental Lab session each week. These are a required part of the course and make up a significant part of your total grade. In addition, material from the Labs will appear on the Term Exams. Your Lab Instructor is a physicist and teacher, who can help you.

Each Lab Instructor will hold a weekly office hour where you can discuss readings, Lectures, problem sets, and Labs. Office locations and office hour time and day will be announced by your Lab Instructor during the first Lab session.

You must be registered for one Lab section. You will have to submit a Lab Report for each experiment performed. The Lab Report has to include answers to all questions and any data you may have collected. The Lab Report will be due in Lab one week after the experiment has been performed.

Your Lab grade will be based on the Lab experiment and Report for each of the sessions. At the end of the semester, your lowest Lab grade will be dropped. This can be applied to an unexcused absence.

A missed Lab will be graded zero unless it is the result of a health condition or a religious observation. You must notify your Lab instructor in advance in writing if you will miss a Lab for religious reasons. All other absences will be considered unexcused and will result in a Lab grade of zero. **You cannot make up a Lab by attending a Lab session for which you are not registered.**

If you arrive 10 minutes late (or later) for the Lab session you will lose the participation credit for that Lab session.

Late Lab Reports will be penalized five points for each day late (excluding weekend days). If you wish to submit a late Lab Report you must do so by making an arrangement with your Lab Instructor.

Exams

There will be 6 small, low-stakes Term Examinations during the term and one Final Exam. The Exams happen in the last 30 minutes of class time, on dates given in the schedule below. The Exams will take place in the Lecture room. The scope of each Exam will be made clear in Lecture, but in brief, the Term Exams will concentrate on the material in the previous few weeks.

Why so many Exams? Research shows that students learn a full semester of material better when they are presented with frequent, low-stakes tests. The Exams are low-stakes in that each is only worth a small fraction of your final grade, and when they are combined for grading, we will drop the lowest two scores among them. Each Exam gives you an opportunity to recall the material of the course, and also learn where you need to do more work.

The Exams will be open notes. Any written or printed documents are permitted in the Exam room. On the other hand, all electronic devices are forbidden. You will not need a calculator.

Any missed Exam will be graded zero except where forced by a health condition or a religious observation. If there is a health condition that prevents attendance at a Term Exam, or an announced-in-advance (to Prof Hogg) religious observance, it will be pro-rated out of the total score. **No special arrangements will be made and no excuses will be granted for travel conflicts**, no matter what. If you have a non-medical emergency or non-religious conflict that prevents you from making an Exam, you will have to speak with your advisor or a Dean of the College, who can ask us to make an exception.

If you arrive late for any Exam, you will not be given extra time. If you fail to obey any of the instructions given to you by course staff before, during, or after any Exam, your Exam may be graded zero or you may be subject to academic honesty proceedings.

Grading

Grades will be based on a total score generated with these percentages:

Labs (including participation)	40
best four Term Exams combined	35
Final Exam	25
total	100

Note that the combination of all Term Exams will involve dropping (ignoring) your lowest two Exam scores. Grades will be assigned in one-to-one correspondence with the total score according to the following percentage ranges:

total score greater than:	85	80	74	65	60	55	45	30
final grade at least:	A	A−	B+	B	B−	C+	C	D

Why these absolute grading policies? Relative grading policies (in which, say, x percent of the class gets an A) make the student-student inter-

actions essentially competitive. Prof Hogg wants the students in this course to interact cooperatively, not competitively. If you work with your fellow students, and everyone does better on the Exams, everyone's grades improve.

Help

All of the staff involved in this course have office hours. If you can't make their office hours, you should feel free to contact them about the material of the course by email. You get much more out of office hours or even email contact if you have a specific question ready in advance.

Importantly, your best learning resource is your fellow students. Form a study group and work together on the Lecture material, on relevant reading, and on the Labs. Choose a regular time and meet. Multiple lines of research show that students who make use of peer support learn better and perform better on the Exams. They also have more fun.

Rules and Comments

inclusivity: It is Prof Hogg's intent that students from all backgrounds and perspectives be served well by this course, that students' learning needs be addressed, and that the diversity that students bring to this class be viewed as a resource, strength and benefit. Your suggestions are encouraged and appreciated. Please let Prof Hogg or the other staff of the class know if any issues arise or if you feel that we can improve our approaches, for you personally or for other students or for students from minoritized groups more broadly.

audio recordings: While you are not forbidden from making audio recordings during class, you must not post, publish, or share them with others, not even in small sound bites. This is because the classroom setting is a private setting in which everyone should feel free to speak plainly and without regrets. Failure to obey this rule will be considered an act of academic dishonesty.

disabilities: If you have an arrangement with the Center for Students with Disabilities, you must present the relevant forms to Prof Hogg one week in advance of each of the Exams.

academic honesty: The lightest consequence for academic dishonesty that Prof Hogg considers consistent with University and Departmental policy is a reduced grade (by one full letter) in the course and a recommended disciplinary action by the College. Academic dishonesty includes (in addition to the usual kinds of cheating) misrepresenting matters of material importance to the instructors.

staying current: It is every student's individual responsibility to stay up-to-date with the syllabus and any emails sent by the staff regarding the course. Having a broken email address, having an overfull inbox, or not being registered properly in Albert or NYU Classes will not be accepted as excuses for missing things or not knowing about events or assignments. Related to

that, you must have read and understood the content of this syllabus. If there are things here you don't understand, you must ask Prof Hogg about them.

feedback: Please ask questions during Lectures and Labs. If there is something you don't understand, many other students are having the same trouble, guaranteed. If there is some aspect of the pace, content, or structure of the course you don't like, or any other feedback you would like to give, please let Prof Hogg know as soon as possible. If you wait until course evaluation forms are handed out at the end of the semester, you will have benefited next year's class at the expense of your own!

legalese: We apologize for the legal tone of this section of the syllabus. The subject of physics is great fun; operating a sizeable course can be challenging. All of the staff of this course will do everything we can to make this course interesting and enjoyable for everyone. Physics isn't just fun for Prof Hogg; it is his profession and his calling.

Calendar

week of Aug 30: In Lecture this week we will discuss the role Einstein played in physics, and how it has been distorted over time. We will discuss the sizes of atoms.

There will be no Labs this week. Classes start on Sep 02.

week of Sep 06: Lectures: Physical units and scientific notation. Momentum, energy, force.

There will be no Labs this week.

Your reading assignment is Isaacson, *Einstein*, Ch. 1.
Wikipedia: *Classical mechanics* (but read around the calculus; you don't need to understand the calculus).

week of Sep 13: Lectures: Momentum, force, collisions, Newtonian physics and $F = m\,a$. Collisions, and their importance in physics.

Lab: Math Review

Reading: Isaacson, Chs. 2–3;

week of Sep 20: Lectures: How do you measure the masses of atoms? Brownian motion. The kinetic theory of gases.

Term Exam 1 in Lecture on Tuesday Sep 21.

Lab: Kinematics

Reading: Isaacson, Ch. 4; Wikipedia: *Kinetic theory of gases* (but ignore the parts on transport and viscosity).

week of Sep 27: Lectures: Electromagnetism. How waves work. Sound waves and light waves. Superpositions of waves.

Lab: Newton's Second Law

Reading: Isaacson, Chs. 5–6; Wikipedia: *Wave* (ignore the calculus); Wikipedia: *Diffraction*; Wikipedia: *Wave interference*.

week of Oct 04: Lectures: The photoelectric effect. Atom–photon interactions. Quantum mechanics, entanglement.

Term Exam 2 in Lecture on Tuesday Oct 05.

Lab: Interference and Diffraction of Light.

Reading: Wolfson, *Simply Einstein: Relativity Demystified*, Chs. 1–4; Wikipedia: *Photoelectric Effect*; Wikipedia: *Quantum mechanics* (but ignore all the mathematical parts).

week of Oct 11: Lectures: The principle of relativity. The importance of the speed of light. The (failed) experiments to determine absolute motion. The light-clock.

No Lecture on Oct 12; Monday Labs meet on Tuesday Oct 12.

Lab: Measuring the Speed of Sound.

Reading: Isaacson, Ch. 7–8.; Wolfson, Chs. 5–9.

week of Oct 18: Lectures: Time dilation and length contraction.

Lab: The Photoelectric Effect.

Reading: Isaacson, Chs. 9–10; Wolfson, Chs. 10–11.

week of Oct 25: Lectures: The paradoxes of special relativity.

Term Exam 3 in Lecture on Tuesday Oct 26.

Lab: The Michelson Interferometer.

Reading: Isaacson, Chs. 11–12; Wolfson, Chs. 12–14.

week of Nov 01: Lectures: The equivalence of mass and energy, or $E = m\,c^2$. The equivalence of gravitational mass and gravitational charge.

Lab: Special Relativity.

Reading: Isaacson, Chs. 13–14; Wikipedia: *Mass-energy equivalence*.

week of Nov 08: Lectures: The Doppler Shift, Gravitational redshift.

Term Exam 4 in Lecture on Tuesday Nov 09.

Lab: The Principle of Equivalence.

Reading: Isaacson, Chs. 15–16; Wikipedia: *General Relativity*.

week of Nov 15: Lectures: General relativity. The curvature of spacetime (or the acceleration of space). How do we know that the Universe is expanding?

Lab: Observing Cosmological Redshift.

Reading: Isaacson, Chs. 17–18; Wikipedia: *Expansion of the Universe*.

week of Nov 22: Lectures: How do we measure the expansion of the Universe precisely?

Term Exam 5 in Lecture on Tuesday Nov 23.

No Lecture on Nov 25.

No Labs this week.

Reading: Isaacson, Chs. 19–20; Wolfson, Chs. 15–16.

week of Nov 29: Lectures: Gravitational orbits. The Solar System. Kepler's Laws. Escape velocity. Black holes.

Lab: Hubble's Law and the Expanding Universe.

Reading: Isaacson, Chs. 20–21; Wikipedia: *Black Hole*.

week of Dec 06: Lectures: The black hole at the center of the Milky Way and the black hole at the center of M87.

Term Exam 6 in Lecture on Thursday Dec 09.

Lab: Final-exam review 1

Reading: Isaacson, Chs. 22–23; Wikipedia: *Supermassive black hole*; Wikipedia: *Event Horizon Telescope*.

week of Dec 13: Lectures: Gravitational radiation and its discovery and use for astrophysics and cosmology. LIGO project and discoveries.

No Lecture on Dec 16; Dec 14 is the last day of classes.

Lab: Final-exam review 2

Reading: Isaacson, Chs. 24–25; Wikipedia: *LIGO*.

Final Exam: Thursday Dec 16 14:00–15:50 in the Lecture classroom.