20'th Century Concepts in Space, Time, and Matter

Phys-UA20, Fall 2019

The 20th century saw revolutionary changes in our understanding of nature of the universe, and the sorts of phenomena possible within it. Space and time were found to follow new principles that stretched the imagination. Small objects were observed to behave as if they can traverse parallel universes. Matter and energy became mathematically equivalent, and the energy that could be unlocked from matter was vast. My intention is to provide you with an in-depth introduction to these new pictures that emerged. The emphasis will be conceptual, and not on the traditional approach of solving lots of mathematically modeled problems. You should, however, be facile with ordinary high school algebra, and prepared to manipulate some simple equations. A few concepts from trigonometry and geometry will come up as well. I will help you along when needed.

Required book: (Available at the bookstore)

- David J. Griffiths, *Revolutions in Twentieth-Century Physics (Cambridge University Press, 2013)*

Lecture Material: Weekly lecture slides and other useful resources are posted on the course Blackboard site under "Course Documents".

The following may be of interest if you would like further reading:

- Albert Einstein and Leopold Infeld: *The Evolution of Physics (Simon and Shuster, NY 1966)*
- Richard Feynman: *The Character of Physical Law (MIT, Cambridge 1965)* movie available at: http://research.microsoft.com/apps/tools/tuva/index.html
- Richard Feynman: *Six Easy Pieces: Essentials of Physics By Its Most Brilliant Teacher (Basic Books, NY 2005)*
- Carlo Rovelli, *The Order of Time (Riverhead Books, 2018)*
- Brian Greene: *The Fabric of the Cosmos: Space, Time, and the Texture of Reality (Alfred A. Knopf, NY 2004)*
- N. David Mermin: *It's About Time: Understanding Einstein's Relativity (Princeton University Press, 2005)*

Homework assignments: will also be posted on the course website and answers will appear after the due date of each assignment.

Your responsibility in this course is as follows:

- **Lectures:** It is important that you attend lectures. This course covers a broad territory, and there will be material presented in lecture that is not found in the assigned reading.
- **Reading:** Also, it is important that you do the assigned reading **before coming to the lectures**. You are encouraged to ask questions about the reading during lecture.

- **Homework Problems:** Assignments will be made each week in lecture. Other than the first homework, your solutions are to be handed in at the beginning of lecture on the date due (or before). Late problems will not be accepted. Solutions to the homework will be posted on the web site. There will also be a required report due in the 2nd half of the class.
- **Exams:** There will be 2 in-class exams during the term and a final exam. Absence from an exam will be excused only with advanced notice (if possible) and proof of **serious** illness.
- **Questions:** Ask questions. If you are completely lost, let me or the Teaching Assistant know **as soon as possible** (either during lecture, at a problem session, or soon afterward). **It is very important not to get lost in this course**, as later lectures depend on the material covered in earlier lectures. I hope that the class atmosphere is informal enough to permit you to ask questions when you don't understand what has been said or if some incomprehensible term was used.

Grades: Course grades will be based on the two in-class exams, the final exam, assigned problems, and a brief research report. The relative weighting is:

First Midterm	20%	(tentatively, Oct. 17)
Second Midterm	20%	(tentatively, Nov. 19)
Homework	20%	
Final Exam	30%	(Dec. 17, 10am-11:50am – regular class location)
Report	10%	

I am available to answer questions about the lectures, homework, any aspect of the course, any aspect of physics, or anything else for that matter. You can reach me as follows:

L. Andrew Wray (lecturer):	
Office:	726 Broadway, Room 1070
Telephone:	212-998-7737
Email:	lawray@nyu.edu
Office Hours:	Fridays from 11:00am – 1:00pm. I'm also available immediately after class, and by appointment.

There is a teaching assistant for this course who is also available to answer questions and help with homework:

Teaching assistant: Austin McDowell	
Email:	atm426@nyu.edu
Office Hours:	Tuesdays at 2pm, or by email appointment.

You are always welcome to send me email if you have any questions or comments.

Lecture Schedule (approximate)

Homework and reading will be assigned separately. Lecture slides will be posted to the course website.

The first half of the course will deal primarily with classical physics, special and (briefly) general relativity and the structure of space-time. The second half is concerned with thermodynamics, the quantum theory and the structure of matter.

1. Overview and some history. Mathematical review (Sept. 3)
2. *Background*: position, velocity, acceleration, vectors. And: a sneak peek into special relativity – the light clock and time dilation. (Sept. 5)
3. *Background*: Newton's Laws, forces. (Sept. 10)
4. *Background*: coordinates, frames, relative motion, Galilean transformations. (Sept. 12)
5. Special relativity spacetime diagrams. The invariant interval. (Sept. 17)
6. Two observer spacetime diagrams. The Lorentz transformation. (Sept. 19)
7. Relative velocity, paradoxes, causality. (Sept. 24)
8. *Background*: potential and kinetic energy, momentum and their conservation. (Sept. 26)
9. Relativistic momentum and $E = mc^2$. (Oct. 1)
10. *Background*: Newtonian gravity, local g. (Oct. 3)
11. A taste of general relativity: equivalence principle, time dilation, gravity as geometry, and black holes. (Oct. 8)
12. Structure of the universe. Friedmann equation. Hubble's law. (Oct. 10)
13. No class - Monday schedule (Oct. 15)
14. **Midterm I: Forces, Motion, and Relativity** (Oct. 17)
15. *Background*: waves and electric and magnetic fields. (Oct. 22)
16. *Background*: wave superposition, interference. (Oct. 24)
17. Photoelectric effect, black body radiation, and the need for a new "quantum" theory. (Oct. 29)
18. Solving problems with quantum mechanics: De Broglie and the Bohr atom. (Oct. 31)
19. Wave-particle duality, the uncertainty principle, and quantum tunneling. (Nov. 5)
20. EPR, entanglement, what is a measurement? (Nov. 7)
21. What is (our) matter? Atoms, electrons, Pauli exclusion, degeneracy pressure. (Nov. 12)
22. The new quantum world. (Nov. 14)
23. **Midterm I**I: Waves and the Quantum World. (Nov. 19)

24. Exotic particles and where to find them (I): Hadrons and Leptons. (Nov. 21)
25. Exotic particles (II): Bosons (Nov. 26)
26. Interaction, scattering, and Feynman diagrams (I). (Dec. 3)
27. Interaction, scattering, and Feynman diagrams (II). (Dec. 5)
28. Quantum + Computing = ? (Dec. 10)
29. Review and special topic/discussion. (Dec. 12)