CONCEPTS IN RELATIVITY AND QUANTUM THEORIES in Fall 2018 (PL3007)

Course Code	PL3007	**Professor(s)**	Claudio Piani
Prerequisites	None	**Office Number**	C202
Class Schedule	W: 09:00-11:55 in SD-6	**Office Hours**	by appointment
Credits	4	**Email**	cpiani@aup.edu
Semester	Fall 2018	**Office Tel. Ext.**	618

Course Description

The nature of reality changed in fundamental ways in the early part of the 20th century. Concepts of duration, length, sequential order, simultaneity, weight, energy, location, mass, substance and void became a matter of perspective or ‘reference frame’. Scientists had been trying to explain apparently ‘absurd’ results, such as Maxwell’s *EM* wave equations or the photovoltaic effect, within the framework of classical physics. Much like what Ptolemy did with Aristotle’s model of the dynamics of the heavens before Copernicus and Kepler got it right, or, at least, not so wrong. In this course, I will present the basic principles, and derive the implications, of the theory of Special Relativity, I will describe the concepts and equivalences underlying the theory of General Relativity and show you why we know them to be correct (or at least not very wrong), I will introduce quantum theory and the quantum model of the atom and explain why it is better than plum pudding (see J. J. Thomson’s 1904 “plum pudding” model for the atom). In this course, you will learn about time travel, $e=mc^2$, black holes and wormholes. Is it true that if you run straight towards a cement wall it is just possible that you will make it through to the other side unharmed? Yes.

Course Learning Outcomes

To understand the historical sequence of scientific discoveries that led to the crisis of classical physics.
To become acquainted with the assumptions and implications of the theory of Special and General Relativity
To become acquainted with the unintuitive implications of quantum mechanics.

General Education

This course can be used to fulfill the “Mapping the World” or “Comparing Worlds Past and Present” (GE115) requirement

Course Outline

PART 1: RELATIVITY

- ? **1) Course presentation**: synopsis, learning goals, grading policy, auxiliary reading material, etc.. Comparing the modern, classic and pre-classic physical universe. Relativity and quantum as the two fundamental concepts of modern physics.
- ? **2) From Aristotle to Galileo.** The pre-classical (Aristotelian) universe. Impulse equals displacement. The heliocentric solar system and perpetual circular orbits. Early empirical incongruities and Ptolemy’s epicycles. Copernicus and the geocentric cosmology. Kepler’s elliptical orbits. Galileo’s experiments on gravitation (the myth of the leaning tower of Pisa) and the concept of inertia.
- ? **3) Newton and the deterministic classical universe**. Law of motion and it’s three formulations (classroom experiments). Law of universal gravitation (the myth of Newton’s apple). Objects ‘falling’ or ‘orbiting’ around Earth are governed by the same law and subject to the same force.
- ? **4) Light, electricity and magnetism**. Pre-classical electricity and magnetism. Electric charge and magnetism as a fundamental property of matter. Early empirical results. Action at a distance and pre-relativistic questions of speed or information. Concept of force field. Equivalence of magnetism and moving electric charge or, the equivalence of electricity and moving magnetic charge. The electromagnetic wave equation and the speed of light.
- ? **5) Implications of Maxwell’s wave equation.** Speed of light is a fundamental constant of the universe. The apparent paradox of Maxwell’s equation. The absolute frame of reference and the 19th century search for aether. Aberration of starlight.
- ? **6) The 1887 Michelson-Morley experiment**. Early attempts to measure the Earths speed through the aether. Setup of the Michelson-Morley experiment, results and implications. Harbingers of Relativity: ‘the Lorentz contraction’.
- ? **7) Einstein and Special relativity**. Brief Biographic notes. Fundamental principal of special relativity. Apparent absurd implications.
- ? **8) Counterintuitive results of Special Relativity.** Events and four dimensional Minkosky space. Relativisticly correct language and relativistic common sense. Light clocks, time dilation. Rotations of reference frames in space-time. EVERYTHING is ALWAYS travelling at the speed of light through 4 dimensional time-space ?!?!
- ? **9) More counterintuitive results of Special Relativity.** Relativistic muon decay experiment. Traveling twins paradox. Limits of special relativity. Real time-travel.
- ? **10) Even more counterintuitive results of Special Relativity.** Simultaneity is relative. Some theoretical examples. The concept of local time. Space contraction.
- ? **11) Just a few more counterintuitive results of Special Relativity.** Consequence on causality. Concepts of past and future and ‘elsewere’. Real examples. Can two

observers travel at the speed of light relative to each other? Can they travel faster? Relativistic combination of velocity. Light can move slower while traveling in substances.

- ? **12) Midterm**
- ? **13) E=MC²**. This was not part of the first 1905 paper in relativity. The equivalence between mass and energy is a consequence of conservation of Relativistic Momentum. (Maybe we can derive the equation in class?). E=MC2 and nuclear weapons. The sun as a nuclear reactor. Other examples of mass to energy conversions. Sub-atomic examples and pair-creation events. Mass increase with speed. Concluding remarks of Special Relativity
- ? **14) General Relativity (a product of cogitation!)**. Limits of Newton's theory of gravity. Action-at-a-distance paradox. Ernst Mach and the precursors of General Relativity. Gravity and acceleration equivalence. Einstein's elevator. Weightlessness in space and other nonsense. Tidal forces and space-time distortion. Geometry on the surface of the Earth. Uniform velocity (constant speed along a straight line) in curved space-time. Gravitational sling shot.
- ? **15) Curved space-time.** Role of matter and energy. Cling-film analogy: a class experiment. Elliptical orbits as straight lines in curved space-time. Recent experimental confirmations of General Relativity: orbital precession, neutron stars and pulsars, gravitational time dilation, gravitational lensing (The Einstein Cross).
- ? **16) Black holes**: What goes up need not come down and the concept of escape speed. Escape speed and compression of matter. Definition of black holes. Event horizon. Falling into a black hole: time freeze, tidal stretching and extreme time travel. Formation of a black hole and supernovas (real examples from the Hubble telescope). Rotating black hole, wormholes and Hollywood nonsense.
- ? **17) Hubble telescope: movie.**

PART 2: QUANTUM

- ? **18) The elementary constituents of matter**: Early 1800s: Dalton's chemistry and identification of elements. Mendeleyev and the periodic table of elements. Late 1800: Becquerel and the Curie family, radio decay and subatomic particles. Thompson and cathode rays. Discovery of the electron and the 'plum pudding' model of the atom. Rutherford and Geiger, the 'gold foil' experiment and the 'solar system' model of the atom. Matter is mostly empty space. Discovery of the nucleus. Failures of the Rutherford model**:** electrons collapse onto the nucleus, spectral lines, ultraviolet catastrophe.
- ? **19) Max Plank and the quantum:** The photoelectric effect. The solution to the ultraviolet catastrophe and the Plank constant (1900). Energy is quantized. Einstein's explanation of the photoelectric effect (1905). Photons are hypothesized. Light has a particle nature. Niels Bohr atomic model (1911). Spectral lines explained. Why we do not notice quantization.
- ? **20) Is Light a wave or a particle?** Light reflects, refracts, has colour. Newton-Huygens debate on the nature of light. Young's proof of the nature of light as a wave (1801, interference experiment).
- ? **21) Quantum uncertainty:** Heisenberg's principle and quantum. Measurement as interaction with the system. Trying to measure both position and momentum of an electron. Einstein never said 'God does not play dice' though he never agreed with the

uncertainty principle.

- ? **22) Does matter have a wave nature?** Yes it does. The DeBroglie wavelength (1923). Why we do not notice the wave nature of matter. Interference pattern experiment with electrons (cathode rays). Statistical interpretation of the matter-wave probability density wave. Schrodinger equation and Bohr atom model revisited. How does the matter-wave allow you to (maybe) walk through walls? We don’t know ‘how’. We know it can happen and does. Uncertainty principle revisited with the matter-wave.
- ? **23) Implications of Quantum dynamics.** Superposition states and the collapse of the wave function. Schrodinger’s Cat. The Copenhagen interpretation. The multiverse theory. Limits of the macroscopic application of quantum dynamics. Spin detection and the EPR (Einstein, Podolsky, Rosen) experiment.
- ? **24) Different kind of particles**. The Standard Model of all existing particles. Quarks, leptons and bosons. The fundamental forces: gravity, electro-weak and strong.
- ? **25) Cosmology**. Red sift and the expanding universe. The age of the universe. Formation of atoms, transparency of the universe and background cosmic radiation. Formation of heavier elements We are born of stardust.
- ? **26) Concluding remarks and wrap-up.** Screening of movie ‘Contact’ with running commentary from students.

Textbooks

This course doesn't have any textbook.

Attendance Policy

COURSE SPECIFIC ATTENDANCE POLICY:

Diligent daily note-taking is essential for the successful completion of this class. Five or more absences (excused or not) is likely to result in an “F”. Missed quizzes cannot in be retaken and are graded as “0”. Students arriving in class 10 min. or more after start time are considered absent. Standard AUP attendance policy is enforced (below).

Students studying at The American University of Paris are expected to attend ALL scheduled classes, and in case of absence, should contact their professors to explain the situation. It is the student’s responsibility to be aware of any specific attendance policy that a faculty member might have set in the course syllabus. The French Department, for example, has its own attendance policy, and students are responsible for compliance. Academic Affairs will excuse an absence for students’ participation in study trips related to their courses.

Attendance at all exams is mandatory.

IN ALL CASES OF MISSED COURSE MEETINGS, THE RESPONSIBILITY FOR COMMUNICATION WITH THE PROFESSOR, AND FOR ARRANGING TO MAKE UP MISSED WORK, RESTS SOLELY WITH THE STUDENT.

Whether an absence is excused or not is ALWAYS up to the discretion of the professor or the department. Unexcused absences can result in a low or failing participation grade. In the case of excessive absences, it is up to the professor or the department to decide if the student will receive an “F” for the course. An instructor may recommend that a student withdraw, if absences have made it impossible to continue in the course at a satisfactory level.

Students must be mindful of this policy when making their travel arrangements, and especially during the Drop/Add and Exam Periods.

Grading Policy

ITEM	Number	Duration	% of Final grade
Weekly quizzes	>10	20 min.	30%
Midterm	1	80 min.	30%
Final	1	4 hours	40%

Other