Syllabus: APHY/PHY 293 - Einstein and the Birth of Modern Physics
Professor A. Douglas Stone - (office: rm 401, 17 HLH, 432-4279)
Tu/Th, 1:00-2:15 pm

Summary: The first twenty-five years of the 20th century was a turning point in human civilization, as for the first time humankind achieved a systematic and predictive understanding of the fundamental constituents of matter and energy, and the mathematical laws which describe the interaction of these constituents. In addition, the General Theory of Relativity and astrophysical observations opened up for the first time the quantitative study of cosmology, the history of the universe as a whole. Albert Einstein was at the center of these breakthroughs, and also became an iconic figure, the paradigm of scientist genius engaged in research into the fundamental laws of nature. This course will address the nature of the transition to modern physics, based on quantum and relativity theory, through a study of Einstein's science, biography and historical context (as well as that of other scientists of the era). It will also teach or review basic concepts in electromagnetic theory, thermodynamics and statistical mechanics, special theory of relativity, concepts of general relativity, early quantum theory and quantum mechanics. The course will not treat general relativity or the formalism of quantum mechanics in depth due to the advanced nature of the material and also to time constraints. Readings will consist of original scientific papers and secondary biographical and interpretive material, as well as selections from physics text books relevant to the topics covered.

Prerequisites: A full year introductory physics course at Yale (170-171,180-181,201-201,260-261); students with one semester of physics may be admitted to the course with permission of the instructor. Some acquaintance and facility with electromagnetism is very strongly advised.

Assignments: regular short question sheets related to the readings, 3 problem sets with mainly quantitative but also some qualitative/conceptual questions about the meaning of the physics and its historical context. Two exams covering roughly of the first and second half the scientific material, and a final paper treating some aspect of Einstein's science in a historical context. No final exam.

Topic Outline

(Note that this is not a chronological outline of lectures – topics may get treated in a different order)

1. Brief overview of Einstein's life and historical context – why he worked at an historic moment for physical science.

2. Review of the status of physics and chemistry circa 1900:
   a) Development of atomic concepts in physics and chemistry, are atoms "real"
   b) Development of thermodynamics, 1st Law: Heat as energy, role in technology
   c) Thermal radiation
   d) Development of electromagnetic wave theory, interference, Faraday, Maxwell's equations, Hertz, Helmholtz, radio
   e) Measurements of speed of light, puzzle of invariance, concept of ether

2. Statistical mechanics, Kinetic Theory of Gases,
   a) Boltzmann, Maxwell and the ideal gas law, equipartition concept and relation to atomism and Avogadro's number, N_a, gas constant R, Boltzmann's constant k_B
   b) Inferring the properties of atoms from measurements on gases and liquid.
   c) Concept of entropy and 2nd law of thermo, microscopic origin

   d) Controversy about reversibility in time and 2nd law

e) Planck and the search for the law of thermal radiation
f) Wien's Law, Planck's flawed proof and new derivation based on Boltzmann's principle, partial introduction of quantization concepts.
g) Implications of Planck's law, new constants of nature k_B, h, Avogadro's number
h) Einstein's quanta of light; ultraviolet catastrophe, conflict with Maxwellian E&M. Photoelectric effect.
i) Einstein theory of specific heat and the first statement of quantized energy in mechanics
j) Reception of Einstein/Planck concepts
k) Einstein's initial failure with quantum theory of radiation (1908-11)

3. Special Relativity
   a) Motivation: failure to measure "ether", asymmetry in Maxwell Eqs
   b) Lorentz vs Einstein, The Principle of Relativity
   c) Space time events, Lorentz transformations and their interpretation, Lorentz invariance of electromagnetic wave equation
   d) Relativity of time intervals, invariance of causal order, proper time.
   e) $E= mc^2$, Einstein's derivation and its meaning.
   f) Reception of special relativity theory

4. General Relativity
   (a) The principle of Equivalence and its implications
   (b) Effect of gravity on clocks, gravitational redshift, bending of light by mass
   (b) Eclipse expedition and public reception of Einstein and his theories.

5. Quantum Theory
   (a) The Solvay Conference of 1911, and the quantum agenda.
   (b) The Bohr Atom, Bohr-Sommerfeld Quantization, application to harmonic oscillator.
   (c) Einstein Theory of radiation, A,B coefficients, Planck Formula
   (d) Validation of photon concept *(time permitting)*
   (e) Bose statistics and Bose condensation *(time permitting)*

6. Quantum Mechanics (*Not treated in lecture - Possible paper topics*)
   (a) Einstein, De Broglie and Schrodinger, the wave equation for electrons.
   (b) Interpretation of the wavefunction, Born and Einstein.
   (c) Entanglement and EPR, modern implications.

7. Einstein's Impact on physics and beyond (*interspersed with other topics*, *as much as time permits*).

Readings

Stone, A. Douglas. *Einstein and the Quantum*: The Quest of the Valiant Swabian. Princeton: Princeton University Press, 2013. **Required**

Folsing, Albrecht. *Albert Einstein: A Biography*. Translated and abridged by Ewald Osers. New York: Penguin Press, 1998. (selected Chapters).

Einstein, Albert. "*Autobiographical Notes."* In Albert Einstein: Philosopher-Scientist, pp. 1–94. Edited by P. A. Schilpp. La Salle: Open Court, 1970. (excerpts)

Lindley, David, Boltzmann's Atom, New York: The Free Press, 2001 (selected chapters)

Schroeder, Daniel, *Thermal Physics*, Addison Wesley, 2000 (selected chapters)

Shankar, R., *Fundamentals of Physics, Mechanics, Relativity and Thermodynamics,* New Haven, Yale University Press, 2014 (selected chapters).

Original Scientific Papers:

1. James Clerk Maxwell. *"Molecules."* Nature, September 1873, pp. 437–441, Victorian Web, hZp://www.victorianweb.org/science/maxwell/molecules.html, accessed July 20, 2008.

2, Max Planck, "On an Improvement of Wien's Equation for the Spectrum", Proceedings of the German Physical Society, vol. 2, p. 202 (1900); reprinted in translation in Ter Haar, The Old Quantum Theory, 79–80.

3. Max Planck, "On the Theory of the Energy Distribution Law of the Normal Spectrum," Proceedings of the German Physical Society, vol. 2, p. 237 (1900); reprinted in translation in Ter Haar, The Old Quantum Theory, 82–90.

4. Albert Einstein, "A New Determination of Molecular Dimensions", PhD Thesis, reprinted in the Collected Papers of Albert Einstein, vol. 2, doc. 15, pp. 104–122 (1905) - excerpt

5. Albert Einstein, "On the Movement of Small Particles Suspended in Stationary Liquids Required by the Molecular-Kinetic Theory of Heat", Annalen der Physik, vol. 17, pp. 549-560 (1905); reprinted in The Collected Papers of Albert Einstein (CPAE), vol. 2, doc. 16, pp. 549–560.

6. Albert Einstein, "On a Heuristic Point of View concerning the Production and Transformation of Light," Annalen der Physik, vol. 17, pp. 132–148 (1905); reprinted in CPAE, vol. 2, doc. 14, pp. 86–103.

7. Albert Einstein, "On the Theory of Light Production and Light Absorption," Annalen der Physik, vol. 20, p. 199 (1906); reprinted in CPAE, vol. 2, doc. 34, pp. 192–199.

8. Albert Einstein, "Planck's Theory of Radiation and the Theory of Specific Heat," Annalen der Physik, vol. 22, pp. 180–190 (1907); reprinted in CPAE, vol. 2, doc. 38, pp. 214–224.

9. Albert Einstein, "On the Development of our Views on the Nature and Constitution of Radiation", Physikalische Zeitschrift 10 (1909): 817-826; reprinted in CPAE, vol. 2, doc. 60, pp. 379–394.

10. Albert Einstein, "On the Electrodynamics of Moving Bodies," Annalen der Physik, vol. 17, pp. 891–921 (1905); reprinted in CPAE, vol. 2, doc. 23, pp. 140–171.

11. Albert Einstein, "Does the inertia of a body depend upon its energy content?", Annalen der Physik 18 (1905): 639-641, CPAE vol. 2, Doc 24 (1905).

12. Albert Einstein, "On the Relativity Principle and the Conclusions Drawn from it," Jahrbuch der Radioactivitat und Electronik, (1907), reprinted in CPAE, vol. 2, doc. 47, pp. 252–311.

13. Niels Bohr, "On the Constitution of Atoms and Molecules," Philosophical Magazine, vol. 26, p. 1 (1913); reprinted in The Old Quantum Theory, by D. Ter Haar, pp. 132–159.

14. Albert Einstein, “Emission and Absorption of Radiation in Quantum Theory,” Proceedings of the German Physical Society, vol. 18, pp. 318–323 (1916); reprinted in CPAE, vol. 6, doc. 34, pp. 212–216. [time permitting]

15.. Albert Einstein, “On the Quantum Theory of Radiation,” Physikalische Gesellschaft Zurich, Mitteilungen, vol. 18 (1916); reprinted in CPAE, vol. 6, doc. 38, pp. 220–233. [time permitting]

16. Albert Einstein, “Quantum Theory of the Monatomic Ideal Gas, Part Two,” Proceedings of the Prussian Academy of Sciences, vol. 1, p. 3 (1925); reprinted in translation in I. Duck and E.C.G. Sudarshan, eds., Pauli and the Spin-Statistics *(optional reading – paper topic)*