Instructor: Dave Stevenson, x6534, djs@caltech.edu

TA: Valeria Kachmar, vkachmar@caltech.edu [154 S Mudd]

Class Meeting Times: MWF 10-11, 162 S Mudd. Class is in person and attendance is expected. We might schedule additional hours as back-up but only if we (unexpectedly) miss a regular lecture time. TA Valeria will separately set up meetings in person (or Zoom if she prefers) to help with problem sets, projects and other questions.

Rationale: The idea is to provide you with an understanding of the basic ideas and techniques in planetary structure and evolution. This includes exoplanets. The course will not give you all the tools to do research in this area; those tools often come from basic science (e.g., material covered in Ph101, Ph 136, Ae/Ge 160, etc.) But you will get bits of these tools, an awareness of why they are useful, and see how the observations tie into the basic science.

What you will need (or need to catch up on):

(a) Thermodynamics, an elementary understanding of the link between thermodynamics and statistical physics, elementary quantum mechanics and specifically its link to statistical mechanics (at least to the extent of knowing what is meant by Fermi and Bose statistics).

(b) Some E&M (~ the level of Ph 106), and the math tools commonly used in physics (i.e., applied math at the level of ACM 95/100).

(c) You will not be assumed to know any fluid dynamics, but you will need to pick up some aspects of this quickly.

Background Material and References: There is no good textbook that covers all aspects of the course, and there are parts of the course for which there is no good textbook at all.
However, there is a "textbook" on our web page, in the form of lecture notes. After years of little change, this is undergoing quite major revision and improvement and is headed towards a published book (Cambridge University Press). Nearly all chapters (in close to final form) will be on the web by first week of class, though the problems at the end of each chapter will be incomplete in some cases or imperfect still. I will be sending this text to them in April but they will do (or improve) the figures. Class lectures will follow this text, more or less, but inevitably there is more emphasis on some parts than others. It helps if you read the notes in advance of the lecture.

The following books are of possible use in the geology library. In some but not all cases you might be able to find electronic versions, sometimes even for free!

Anderson, D. L. *Theory of the Earth* [also available for free on the web]
Canup and Righter (Eds) *Origin of the Earth and Moon*
Hubbard, W. B. *Planetary Interiors*
Jackson, I. (Editor) *The Earth’s Mantle*
Lodders, K. and Fegley, B. *The Planetary Scientist’s Companion*
Merrill, R. T., McElhinney, M. W. and McFadden, P. *Magnetic field of the Earth*
Newsom, H. and Jones, J. (Eds) *Origin of the Earth*
Poirier, J-P. *Introduction to the Physics of the Earth’s Interior*
Ringwood, A. E. *Origin of the Earth and Moon*
Schubert & Turcotte *Geodynamics*
Schubert, Turcotte and Olson *Mantle Convection in the Earth & Planets*
Stacey, F. D. *Physics of the Earth*
Taylor, S. R. *Solar System Evolution*
Zharkov, V. N. and Trubitsyn, V. P. *Physics of Planetary Interiors*

Anderson and Stacey contain some of thermodynamics background that we use. Hubbard is closest to the intent of this course but out of date or sparse in many aspects. Poirier has some of the condensed matter physics. Zharkov and Trubitsyn is occasionally useful. Taylor, Newsom and Jones, and Ringwood, deal mainly with cosmochemical and origins issues (a small part of the course). Schubert & Turcotte books emphasize earth and continuum mechanics (not including low viscosity fluid dynamics). Lodders and Fegley is an all-purpose compilation of lots of neat stuff, especially cosmochemical data. Jackson is Earth-specific.
Although not on reserve, there are several books in the University of Arizona Space Science series (mostly with blue covers, typically 1000 pages, and typically but not always titled with the name of a planet). Examples: *Mercury, Venus, Venus II, Mars, Jupiter, Saturn, Uranus, Neptune, Origin and Evolution of Planetary and Satellite Atmospheres, Protostars and Planets I, II, III, IV, V*, *Origin of the Earth and Moon*; etc. There is a relatively new *Jupiter* (Cambridge University Press, 2006, ed. Fran Bagenal) and an even newer *Saturn* (based on Cassini. There are three conference proceedings for *Origin of the Moon*. Existing books that purport to be on exoplanets are mostly mediocre.

Books that are useful for the background physics include: anything by Landau and Lifshitz (e.g. *Statistical Physics, Fluid Mechanics, Elasticity*) the new book *Modern Classical Physics* by Thorne and Blandford (based on Caltech’s Ph 136; I have a PDF if you ask nicely but probably illegal!), Ashcroft and Mermin’s *Solid State Physics*, Chandrasekhar’s *Stellar Structure*, Parker’s *Cosmic Magnetic fields*, etc.

PDFs exist for free (try Google) of Landau and Lifshitz (out of copyright). Excellent though terse.

There are also some useful review papers (though not as many as you might hope!) Exoplanets evolves so quickly that it is difficult to find good reviews in that area.

**Structure of the Course:**
1. It is a good idea to read the online lecture chapter(s) before class. Typically, I do not go through derivations on the board, except when they are particularly instructive. Concepts are emphasized. Participation will be enforced through questions that you ask or I ask! Class participation counts for 10% of the grade in the course.

2. The chapters approximate lectures but do not, however, necessarily coincide with individual lectures. There are problems at the end of the chapters and about one half are given sketch answers in the text. Usually (but not always) some subset of those problems make up the assigned problem sets, given to you roughly once a week online, at least for about the first two thirds of the quarter. Problem sets count for 40% of the final grade. These should be submitted to Valeria in electronic form (e.g., pdf)
3. The main part of the grade (50%) is a term project that you will need to choose soon; you will give a preliminary oral report (midway through the quarter) to the class to explain the problem. A final oral report and written report will be due at the end of the quarter. They are both important to the grade. The term project is on a research problem (i.e. could in principle turn into publishable research).

**Outline of the Course:** The number of lectures listed is only approximate and based on one-hour lectures (three per week):

1. The basic ideas of planetary structure (1 lecture)
2. Solar system formation and the materials from which planets are formed (*a brief cosmochemical background*). 1 lecture
3. The condensed matter physics of planet-forming materials (*thermodynamics, phase transitions and transport properties*). 5 or 6 lectures
4. “Static” models of planets. (*Generic considerations rather than details of specific planets*). 2-3 lectures
5. The observations that constrain planetary structure and evolution. (*Gravity, rotational and tidal behavior, magnetism, seismology, heat flow, surface structure*). 3 lectures
6. Heat transport and fluid dynamics of planets. (*General principles of planetary differentiation including magma oceans, core formation, crust formation, subsolidus convection, giant planet cooling, origins of oceans and atmospheres, life, etc.*) 5 lectures
7. How planets generate magnetic fields. (*Core convection, introductory dynamo theory*). 2-3 lectures
8. [Maybe] A survey of what we know and don’t know about each planet: includes satellites & exoplanets. Some of this material is sprinkled about in earlier lectures but there will also be an attempt to summarize.
9. Student project reports. ~15/20 minutes presentation per student. Dates not yet determined but regular lectures will end Friday May 31 so the final presentations would likely be Wednesday June 5 or maybe Friday June 7.

The only holiday in the calendar is Memorial Day (May 27) so there will likely be 3 lectures per week for the weeks beginning April 1, 8, 15, 22, 29; May 6, 13, 20 and then 2 lectures the week of May 27 (a total of 26 lectures).