Course Description: This course discusses chemical thermodynamics and applies it to the origins and history of primitive planetary materials. The types of planetary materials will be discussed together with an overview of the chemical setting of their origins. We will discuss thermodynamic formalism, the various chemical pathways through which planetary materials are believed to have formed, the characterization and numerical methods we use to quantify such origins, and we will consider several case studies.

Schedule: We will meet Monday and Wednesday from 11:00AM to 12:15PM in room 312 in the Kuiper Space Sciences Building.

Instructors:

(Prof.) Thomas (Tom) Zega, tzega@lpl.arizona.edu, 520-626-1356, Kuiper Space Sciences Building, Room 522. Office Hours: By appointment.

(Prof.) Krishna Muralidharan, krishna@email.arizona.edu, 520-626-8997, Mines Building, Room M125E. Office Hours: By appointment.

Required Textbook: None. We will draw from several textbooks, but lectures are intended to be self-contained. Lecture slides and a list of textbooks will be posted on the class website.

Course Learning Objectives: During this course, (1) students will be provided with an overview of planetary materials including their types and constituent mineralogy; (2) the astrophysical settings and chemical pathways of the origins will be discussed; and (3) students will be exposed to state-of-the-art materials characterization techniques and thermodynamic methods necessary to interpret the microstructural features and chemical composition of these underlying materials. Students will demonstrate an understanding of course material through problem sets and several case studies where they attempt to reverse engineer the thermodynamic conditions under which planetary materials formed in the early solar system.

Course Learning Outcomes: Upon completion of the course, students: (1) should be able to describe the astrophysical context in which a variety of planetary materials formed whether in our solar system or outside of it in the case of presolar and interstellar grains; (2) be able to infer and the chemical pathways through which planetary materials formed based on their microstructure and spatial relationships using example case studies; and (3) be able to perform basic thermodynamic modeling using existing thermodynamic code to infer quantitatively the pressure and temperature conditions under which such materials formed in the early solar protoplanetary disk. In addition, graduate students completing this course will be able to evaluate critically the scientific literature on the chemical pathways and thermodynamic origins of a range of planetary materials. Learning outcomes will be assessed based on class participation, problem sets, a mid-term, and final written exam.

Undergraduate Student Requirements: All undergraduate students are required to complete problem sets and exams.

Graduate Student Requirements: In addition to completing problem sets and exams, graduate students will be expected to present a case study on a planetary-material assemblage of their choosing, either from the literature or from a sample on which they are working. The presentation will be accompanied by a written report to be structured as a scientific paper that includes an abstract, introduction, results, discussion, and conclusion. Evaluation of the case study will be based on the oral presentation and the written report and constitute 15% of the grade (see performance metrics below). Both the oral presentation and the paper will be graded based on description of the motivation and statement of the problem as well as the depth of the results and discussion.

Absence and Class Participation Policies: Absences for any sincerely held religious belief, observance, or practice will be accommodated where reasonable. See http://policy.arizona.edu/human-resources/religious-accommodation-policy. Absences pre-approved by the UA Dean of Students (or dean's designee) will be honored.

Class website: All lectures and problem sets will be posted in PDF form to the class website (URL to be provided). Supplemental material for lectures, e.g., journal articles, figures, will also be posted. We will try to have each lecture uploaded prior to class and will alert you via email when the lecture is online.

Performance Metrics (undergraduate):
Mid-term exam: 30%
Final exam: 30%
Problem sets and laboratory practical work: 30%
Class participation: 10%

Performance Metrics (graduate):
Mid-term exam: 30%
Final exam: 30%
Problem sets and laboratory practical work: 15%
Case study: 15%
Class participation: 10%

Grading Scale (%):

A	≥ 90
B	80 to 89
C	70 to 79
D	60 to 69
E	< 60

Credit is not given for assignments that are turned in late.

- See for http://registrar.arizona.edu/courses/final-examination-regulations-and-information?audience=students&cat1=10&cat2=31 final-exam regulations.
- See http://www.registrar.arizona.edu/students/courses/final-exams for the final exam schedule.
- The final exam for our class is scheduled for…

Classroom Behavior: No mobile phone use during class unless it is somehow involved in the lecture/discussion. Computers are allowed to take notes or otherwise for lecture-relevant content. No Facebook or other social media activities are permitted or anything else that might be construed as behavior that distracts from the lecture.

Threatening Behavior Policy: The UA policy on threatening behavior prohibits threats of physical harm to any member of the University community: policy.arizona.edu/education-and-student-affairs/threatening-behavior-students.

Academic Integrity Policy: The Student Code of Academic Integrity prohibits plagiarism: deanofstudents.arizona.edu/policies-and-codes/code-academic-integrity.

Nondiscrimination and Anti-Harassment Policy: Please see University Policy 200E on prohibited behaviors: http://policy.arizona.edu/human-resources/nondiscrimination-and-anti-harassment-policy

Accommodations for Students with Disabilities: For students with disabilities, reasonable accommodations will be provided by the Disability Resources Center: drc.arizona.edu/instructors/syllabus-statement

Disclaimer: The information contained in this course syllabus, other than the grade and absence policies, may be subject to change with reasonable advance notice, as deemed appropriate by the instructor.

Lecture Topics

Part 1. The astrophysical setting of solar-system formation

- The solar protoplanetary disk and cosmochemical models of solar-system formation
- Planetary material types
- Chemical thermodynamic formalism
    - First three laws of thermodynamics
    - Phase equilibria
- Chemical processes in the solar protoplanetary disk
    - Vapor-solid condensation
    - Melt solidification
    - Aqueous chemistry

Part 2. Characterization of planetary materials

- Tools of the trade – Laboratory Methods
    - Optical microscopy
    - Scanning x-ray microanalysis
    - Secondary Ion Mass Spectrometry
    - Transmission electron microscopy
- Tools of the trade – Numerical Methods
    - Density-functional theory
    - Molecular dynamics
    - Phase-field theory
    - Computational thermodynamics

Part 3. Case Studies in Primitive Planetary Materials

- How do we go from characterization to a thermodynamic model?
    - Presolar grains
    - Calcium-aluminum-rich inclusions

- Chondrules
- Chondrite Matrix Material