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 computational methods we use to quantify such origins, and we will consider several case studies.

Schedule: We will meet Tuesday and Thursday from 2:00 PM to 3:15 PM in room 312 in the Kuiper Space Sciences Building.

Instructors:

(Prof.) Thomas (Tom) Zega, tzega@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.

Course Format and Teaching Methods: Lecture only.

Course 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, exams, and several case studies where they attempt to reverse engineer the thermodynamic conditions under which planetary materials formed in the early solar system.

Expected 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.

Makeup Policy for Students Who Register Late: Students who register after the first lecture may make up missed assignments before the deadline of those assignments.

Course Communications: All lectures and problem sets will be posted in PDF form to the class d2L site. 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. Other notifications will be sent by email via d2L.

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.

Assignments and Examinations: There will be a mid-term on or about October 15, 2024. Our final exam is scheduled for Monday, December 16 from 3:30PM to 5:30pm. Problem sets will be assigned for each lecture topic listed below and you will be given a week to complete them.

- See https://www.registrar.arizona.edu/finals for the final exam regulations and schedule

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

Grading Scale and Policy (graduate):
- Mid-term exam: 30%
- Final exam: 30%
- Problem sets: 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.

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.

Incomplete (I) or Withdrawal (W): Requests for incomplete (I) or withdrawal (W) must be made in accordance with University policies, which are available at http://catalog.arizona.edu/policy/grades-and-grading-system#incomplete and http://catalog.arizona.edu/policy/grades-and-grading-system#Withdrawal respectively.

Dispute of Grade Policy: One week will be given for dispute of grades on problems sets and two weeks for grades on exams.

Lecture Topics and Schedule

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

Classroom Behavior: To foster a positive learning environment, students and instructors have a shared responsibility. We want a safe, welcoming, and inclusive environment where all of us feel comfortable with each other and where we can challenge ourselves to succeed. To that end, our focus is on the tasks at hand and not on extraneous activities (e.g., texting, chatting, reading a newspaper, making phone calls, web surfing, etc.). Students are asked to refrain from disruptive conversations with people sitting around them during lecture. Students observed engaging in disruptive activity will be asked to cease this behavior. Those who continue to disrupt the class will be asked to leave lecture or discussion and may be reported to the Dean of Students.

Some learning styles are best served by using personal electronics, such as laptops and iPads. These devices can be distracting to other learners. Therefore, students who prefer to use electronic devices for note taking during lecture should use one side of the classroom.

Additional Resources for Students

UA Academic policies and procedures are available at https://catalog.arizona.edu/syllabus-policies.

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 instructors.