Ge/Ch 128 - Cosmochemistry (3-0-6)

Instructor: Geoff Blake, 165 S. Mudd, x6296, gab@gps.caltech.edu
Office Hours: M, T, 11 a.m.-noon, W, Th 1-2 p.m. (e-mail or drop by anytime!)

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Office Hours: 1-4 p.m. Wed.

Class Time: M 3-4, p.m., T/Th 9:30 - 10:30 a.m.; 162 S. Mudd.

Description:
This course will examine the chemistry of the interstellar medium, of protostellar nebulae, and of primitive solar system objects with a view towards establishing the chemical evolution of atoms in the interstellar radiation field to complex molecules and aggregates in the early solar system. Emphasis will be placed on identifying the physical conditions in various objects, time scales for physical and chemical change, chemical processes leading to change, observational constraints, and various models which attempt to describe the chemical state and history of cosmological objects in general and the early solar system in particular.

Prerequisite: Instructor’s permission. 3 lecture hours/week + bi-weekly problem sets. Midterm + final. No text required. Final will consist of a short oral presentation and written report.

Courses of related interest:

Ay126. Interstellar Medium. Second term.
Ch120. The Nature of the Chemical Bond. First, second, third terms.
Ch135. Chemical Dynamics. Third, second terms.
Ge140. Introduction to Isotope Geochemistry. Second term.
Course Lecture Outline (Topics, not Lecture numbers)

I. Introduction to the cosmic environment
   The four phases of the interstellar medium (ISM). Types of interstellar clouds with examples of physical conditions and time scales. Cloud structure and distance scales. Star formation, YSOs, and protostellar disks.

II. Introduction to interstellar molecules and dust
   Galactic ecology, exchange of gas and dust between stars and the interstellar medium. Molecular survey: abundances by cloud type, observational techniques and examples, distributions and correlations. Interstellar grains and mantles: opacity laws, composition from UV, visible, IR spectroscopy, mantle formation and desorption, lifecycles of grains.

III. Molecule formation mechanisms
   In situ synthesis required, so derive required formation rates in gas phase and on surfaces. Examine collision rates in ISM, show many processes too slow.

IV. Physics of chemical reactions
   Derive ion-molecule reaction rate theory, compare with neutral/neutral chemistry and e⁻/ion recombination. Energetics of reactions: potential energy surfaces, barriers, temperature dependence.

V. Types of chemical reactions
   Positive ion reactions (radiative association, ion-molecule, condensation, charge transfer, etc.), negative ion reactions, neutral/neutral reactions (bimolecular, surface, atom-radical, etc.).

VI. The first gas-phase bond: H₂

VII. Observational properties of diffuse clouds
   Restatement of molecules present and physical conditions. Atomic abundances and ionization potentials, the Lyman limit. Photoionization rates, ionization equilibrium, and initial atom/ion abundances. Photodissociation with typical cross sections, example rates, types.

VIII. Bond formation and chemistry of key species in diffuse clouds

IX. Observational properties of dense clouds
   Physical conditions and molecular abundances with example spectra, lifetimes, and correlations. The radiation field: ionization equilibrium, local UV, X-ray sources. Special cases: shocks, circumstellar shells, T-Tauri phases.

X. Chemical processes and timescales in dense clouds
   Cosmic ray ionization, ion loss processes: reactions with H₂, with O, and with other neutrals, recombination with e⁻. Ionization equilibrium: H₃⁺ to H/CO⁺ conversion, metals, depletion, effects of grains.
XI. Major chemical cycles in dense clouds
  C⁺-C-CO conversion sequence (observational and theoretical), review of C⁺ cycle, the C cycle. The CO chemical cycle: dependence on H₂O/OH, branching into hydrocarbon/organics channel. Organic pathways, reactions of CH₃⁺. The H₂O cycle and conflict with observations.

XII. Formation of complex molecules and chemistry of minor elements in dense clouds
  Radiative association reactions (especially with CH₃⁺), formation of aldehydes, formates, etc. Carbon chains and rings. Other chains: Cₙ-CN, Cₙ-O, Cₙ-S, etc. Chemistry of Cl, S, Si, P.

XIII. Isotopes and isomers in the interstellar medium
  Chemical fractionation: D, ¹³C, ¹⁵N, and ¹⁸O chemical fractionation reactions and temperature dependence. Photochemical fractionation: D/H fractionation of hydrocarbon clusters, D/H fractionation of small hydrides (water, methane) and temperature dependence. Isomer specific molecule formation in the ISM.

XIV. Interstellar dust

XV. Icy grains and Grain Mantles

XVI. Chemical models of the interstellar medium
  Various types of chemical models (static, time dependent, dynamical, gas phase vs. surface, etc.) with successes and failures of each with comparison to observations. Diffuse cloud → dense cloud, dense cloud → protosolar nebula boundary conditions.

XVII. Physics of the solar nebula hypothesis #1

XVIII. Physics of the solar nebula hypothesis #2
  Planetesimal formation, accretion, timing and effects of stellar winds. Timescales for stellar and planetary formation. Observational constraints.

XIX. Introduction to solar nebula chemistry
  Chemistry through the accretion shock, density increase. Compare/contrast kinetic timescales, thermodynamics. The equilibrium/condensation model, nebular thermochemistry.

XX. Detailed Equilibrium-Condensation Models and Thermochemistry
  The equilibrium condensation sequence of various elements and minerals. Condensation products vs. oxygen/hydrogen fugacity. Volatile content of bodies with distance in pre-solar nebula.

XXI. Introduction to meteorites and interstellar dust particles
  Classification of meteorite types, bulk abundances in meteorites and IDPs. Isotope ratios in and chemical properties of the major elements (H,C,N,O,Si,...) in meteorite classes. Residues
from meteoritical samples, concentrating on those with possible interstellar origins. Collection and analysis of interplanetary dust and its possible relation to the ISM.

XXII. Meteorites #2
Trace elements in meteorites, inclusions and isotope effects in small samples. Extinct radionuclides, fractionation problems, inclusions and the equilibrium/condensation model. Deduction of solar system formation time scales from isotope measurements.

XXIII. Origins of comets
The Oort cloud. Formation of cometary nuclei and creation of short vs. long period orbits. Non-orbital comets.

XXIV. Chemistry of comets
Cometary composition as a function of formation location. Chemistry in cometary comae and tails. The Giotto results from Comet Halley. Are comets “interstellar” or “nebular”?

XXV. Jovian planets and satellites

XXVI. Formation of the terrestrial planets
Composition of the inner terrestrial planets and their relationship to meteoritical (chondritic) composition. Comparisons with equilibrium-condensation models. Safranov scenarios and the possible role of giant impacts in volatile partitioning.

XXVII. The early Earth
Accretion history of the Earth, impacts. Evolution of the volatile budget of the Earth, possible magma ocean. Buffering by magma of primitive atmosphere. Relation of very early Earth to present day abundances. Pre-biotic chemical evolution.

XXVIII. The Grand Picture
Overview of current best estimates of the connections between the interstellar medium and our solar system. Analysis of how much the previous chemical history of the galaxy determined the evolution of solar system bodies. Future directions of laboratory, observational and theoretical research.
Some Useful Reference Books for Ge/Ch 128: Cosmochemistry

Text Material in “Cosmochemistry” (most in Robinson Astrophysics Library):


Useful Physics and Chemistry Texts:


Older reviews and tutorials of “historical” interest:


