ATOMIC AND MOLECULAR PROCESSES

This model syllabus defines the core material for Atomic and Molecular Processes. Instructors should use their discretion in deciding the ordering of topics and the depth to which each is covered. It is anticipated that instructors will draw upon a range of examples from astrophysics and planetary science to illustrate the core material.

REVIEW OF QUANTUM MECHANICS

Elementary concepts to be reviewed as necessary

Operators
Schrödinger equation
Angular momentum

HYDROGEN ATOM

Solution for single electron atoms and its relation to the spectroscopy of hydrogen

Solution for hydrogen: energy levels, wavefunctions, spherical harmonics
Hydrogen spectroscopy and its nomenclature
Time-independent perturbation theory
Origin of fine and hyperfine structure, the Zeeman effect

MULTI-ELECTRON ATOMS

An understanding of how, in principle, the structure of multi-electron atoms can be understood, and how this relates to observed spectroscopy and selection rules

Single electron orbitals: order of filling shells
Hamiltonian including perturbation terms
L-S coupling, its nomenclature and spectroscopy
Time-dependent perturbation theory
Selection rules

MICROSCOPIC RADIATIVE PROCESSES

Atomic physics aspects of radiative transfer with application to understanding spectral line profiles. Macroscopic radiative transfer is covered in Radiative and Dynamical Processes.

Blackbody radiation
Einstein A and B coefficients, stimulated emission, maser action
Optical depth
Spectral line profiles (natural, thermal, collisional)

Curve of growth

IONIZATION, EXCITATION, COOLING

Summary of different processes responsible for ionization, excitation, and radiative cooling of atomic gas, along with the regimes in which each is important

Ionization equilibrium in different limits (Saha, coronal, photoionization)
Rate coefficients and the concept of detailed balance
Radiative cooling of a plasma
Spectral diagnostics of density and temperature
Coulomb collisions, non-thermal excitation processes
Charge exchange

MOLECULAR PHYSICS AND SPECTROSCOPY

Quantum mechanics of molecules necessary to understand molecular spectra (electronic, vibrational and rotational transitions)

Molecular orbitals
The rigid rotator, harmonic oscillator, and their applicability to real molecules
Electronic, vibrational and rotational spectra

THERMODYNAMICS AND STATISTICAL MECHANICS

An introduction to thermodynamics / statistical mechanics at the level needed to understand, for example, how simple equations of state (e.g. for degenerate material) are derived

Definition of thermodynamic quantities
Laws of thermodynamics
Partition functions, ensembles, and their relation to thermodynamics
Quantum statistics