ATOMIC AND MOLECULAR PROCESSES: ASTR-5110

This document presents topical guidelines for instructors of one of the five APS core graduate courses. It is provided as a reference to support instructors in their syllabus preparation, and to assist the APS Examinations Committee in their review of those syllabi. Following each set of primary/recommended topics (in black), we list suggested optional topics (in *violet*) and example applications to APS research fields (in green) suitable for student projects, scientific coding, or homework exercises. It is anticipated that instructors focus at least two-thirds of class time on the primary course topics, with the remaining time spent on optional topics or other related topics of the instructor's choosing. Instructors are encouraged to draw upon a range of examples from astrophysics, planetary science, and solar/space physics to illustrate the core material. The current version of these guidelines was adopted by the AY20-21 and AY21-22 Graduate Curriculum and Concerns Committees (GCCC). Future changes/updates will be made regularly; alternately, changes can be proposed to the GCCC.

Basics of Quantum Mechanics

Postulates; operators
The Schrödinger equation (connection to probabilities & observables)
Importance of quantized angular momentum & spin
Application: potential-well penetration for thermal particles undergoing fusion

Atomic Structure

The hydrogen atom: energy levels, wavefunctions & spherical harmonics
Perturbation theory: degeneracy, level splitting, radiation
Level splitting: fine & hyperfine structure; the Zeeman effect
Multi-electron atoms: orbitals & shell-filling
Spin-orbit interactions: L-S coupling, *J-J coupling*
Time-dependent Hamiltonian, including perturbation terms
Application: fitting/simulating Zeeman-split spectral lines formed by magnetized atmospheres

Atomic Spectroscopy

Hydrogen spectroscopy and nomenclature
Selection rules for line transitions; spectroscopic notation
Einstein A & B coefficients (stimulated emission/absorption; spontaneous emission)
Collisional excitation & de-excitation
Source functions and detailed balance
Line formation (emission vs. absorption); optical depth
Line broadening (natural, thermal, collisional); introduction to the curve of growth
Blackbody radiation; partition functions; quantum statistics
Practical spectroscopic data analysis tools; fitting line profiles
Application: properties of the CMB: blackbody radiation & quantum fluctuations
Application: diagnostic potential of equivalent widths & emission measures

Molecular Physics & Spectroscopy

Molecular orbitals; electronic, vibrational, & rotational spectra
Rigid rotator & harmonic oscillator descriptions of observed modes
Molecular spectroscopy selection rules for diatomic molecules
Application: ortho-para H_2 interconversion in Jupiter's atmosphere and/or supernova shocks
Application: deriving column density from rotational emission (e.g., CO isotopologues)

Ionization and Recombination

Rate coefficients
Ionization/recombination equilibrium in the Saha, coronal, and nebular limits
Collision rates and heating
Radiative cooling of a plasma
Charge exchange; nonthermal excitation processes
Molecular formation and dissociation
Application: origin of the stellar spectral sequence (OBAFGKM)
Application: stable phases of the interstellar medium (CNM, WNM/WIM, HIM)
Application: assessing properties of nebulae (temperature, density) from forbidden lines