Astronomy 601 - Fall 2005
"Radiative Processes"

Instructor

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Schedule

Lectures on Tuesday and Thursday from 2:00pm to 3:15pm
Room CSS 0201

Course Description

The emission, absorption and scattering of radiation by matter with astrophysical applications. Emphasis on basic theory and problem-solving. (i) *Radiative transfer:* specific intensity, transfer equation, opacity, diffusion, scattering. (ii) *Statistical mechanics of matter and radiation:* LTE, level populations, rate equations. (iii) *Electrodynamics:* Maxwell equations, spectra of radiation, polarization, dipole and multipole radiation, Thompson scattering. (iv) *Plasma radiation:* bremsstrahlung and synchrotron emission, Compton scattering, EM wave propagation in plasmas. (v) *Atomic and molecular radiation:* energy levels, Einstein coefficients, oscillator strengths, line broadening.

Textbooks

Required: *The Physics of Astrophysics Volume I: Radiation* by F.H. Shu
Recommended: *Radiative Processes in Astrophysics* by G. Rybicki and A. Lightman

Course Grading

Homeworks	50%
Midterm Exam	20%
Final Exam	30%

There will be one in-class Midterm exam and an in-class Final (the dates of the exams are shown below in the "Tentative course outline" section). Class participation is strongly encouraged. Class attendance is instead required. Homework will be assigned every week or every other week. Their due dates will be announced at the time they are assigned. On the due date the students will be expected to turn in their homework in class. The homework turned in will be graded and returned to the students. I will provide solutions and discuss them in class.

Letter Grades

85%-100%	A
70%-85%	B
55%-70%	C
40%-55%	D

I may rescale the grades depending on the average class performance. Of course the rescaling can only increase your final grade.

Tentative Course Outline - *28 lectures & 2 exams*

A. Radiative transfer - *6 lectures*

1. **Th Sept. 1**: Radiation definitions; specific intensity, photon distribution function, occupation number, energy density, flux, momentum flux, radiation pressure (Shu Ch. 1; R-L § 1.1-1.3)
2. **Tu Sept. 6**: Equation of radiative transfer; emissivity and opacity, blackbody radiation, radiation thermodynamics, Stefan-Boltzmann law (Shu Ch. 1; R-L § 1.4-1.5)
3. **Th Sept. 8**: Bose Einstein statistics; Planck spectrum; Rayleight-Jeans and Wien limits, radiation constant, effective temperature, color temperature and brightness temperature (Shu Ch. 1,2; R-L § 1.5)
4. **Tu Sept. 13**: Moment equations; radiative diffusion approximation, Rosseland mean opacity, scattering and random walks (Shu Ch. 2; R-L § 1.7-1.8)
5. **Th Sept. 15** : General solution of radiative transfer equation, source function, optically-thick and -thin limits, LTE, line formation, absorption and emission spectra, limb darkening (Shu Ch. 3; R-L § 1.4)
6. **Tu Sept. 20**: Plane-parallel atmospheres: radiative equilibrium, grey opacity, Eddington approximation (Shu Ch. 4; R-L § 1.8)

B. Statistical Mechanics of matter and radiation - *5 lectures*

1. **Th Sept. 22**: Statistical mechanics, definitions of entropy, temperature, chemical potential, pressure, grand canonical partition function (Gibbs sum), Thermodynamics: thermodynamic identity, grand potential, entropy (Shu Ch. 6; R-L § 1.5)
2. **Tu Sept. 27**: Quantum statistical mechanics: Fermion and Boson partition functions, grand potentials, occupation numbers (Shu Ch. 6; R-L § 1.5)
3. **Th Sept. 29**: Statistical equilibria: reaction equilibrium, Boltzmann law for internal level populations, Saha equation for ionization state populations, free particle partition functions, application to partial ionization and absorption line strengths (Shu Ch. 7; R-L § 9.5)
4. **Tu Oct. 4**: Rate equations and detailed balance, Einstein A and B coefficients, relations to emissivity, absorption opacity, cross-section, oscillator strength (Shu Ch. 8; R-L § 1.6)

5. **Th Oct. 6**: Collisional processes: rate coefficients, Einstein relations, radiation transfer in moving media, Sobolev (LVG) approximation, thick and thin limits, photon trapping and escape probability (Shu Ch. 9)

C. Classical Electrodynamics - *7 lectures*

1. **Tu Oct. 11**: Maxwell equations, vacuum electromagnetic wave equations, plane parallel waves, EM energy and momentum flux [Poynting vector and Maxwell stress tensor] (Shu Ch. 11; R-L § 2.1-2.2)
2. **Th Oct. 13**: Fourier spectra of radiation, elliptically polarized waves (Shu Ch. 12; R-L § 2.3-2.4)
3. **Tu Oct. 18**: *Midterm exam*
4. **Th Oct. 20**: Stokes parameters and polarization, application to dust polarization (Shu Ch. 12; R-L § 2.4)
5. **Tu Oct. 25**: EM wave equation with sources, scalar and vector potentials, gauge transformations, retarded potentials (Shu Ch. 13; R-L § 2.5)
6. **Th Oct. 27**: Green's function solutions for inhomogeneous wave equations, single particle (Lienard-Wiechert) retarded potential (Shu Ch. 13; R-L § 3.1-3.2)
7. **Tu Nov. 1**: Wave zone, electric dipole radiation, radiation reaction, Thomson scattering Rayleigh scattering (Shu Ch. 14; R-L § 3.3-3.6)
8. **Th Nov. 3**: Multipole radiation: magnetic dipole, electric quadrupole, permitted and forbidden transitions (Shu Ch. 15; R-L Ch. 5)

D. Plasma radiation and transfer - *5 lectures*

1. **Tu Nov. 8**: Thermal Bremsstrahlung (Shu Ch. 15; R-L Ch. 5)
2. **Th Nov. 10**: Compton scattering (R-L Ch. 7)
3. **Tu Nov. 15**: Radiation from relativistic charges (Shu Ch. 16, 17; R-L Ch. 4)
4. **Th Nov. 17**: Synchrotron radiation (Shu Ch. 18, 19; R-L Ch. 6)
5. **Tu Nov. 22**: EM waves in plasmas, dispersion, Faraday rotation (Shu Ch. 20; R-L Ch. 8)
6. **Th Nov. 24**: *Thanksgiving holiday*

E. Atomic and molecular structure and radiation (QED) - 5 lectures

1. **Tu Nov. 29**: Electromagnetic Hamiltonian (Shu Ch. 21; R-L § 10.1)
2. **Th Dec. 1**: Semiclassical theory of radiative transitions: quantum matter/radiation interaction Hamiltonian, theory vector potential, **E** and **B** fields, semiclassical radiation energy density, absorption and emission Hamiltonians (Shu Ch. 22; R-L § 10.1)
3. **Tu Dec. 6**: Time dependent perturbation theory, propagator, one and two photons transitions, transition probabilities and rates for absorption/emission [Fermi's golden rule] (Shu Ch. 22; R-L § 10.1)

4. **Th Dec. 8**: Dipole approximation, bound-bound transition rates and cross-sections, oscillator strengths, matrix elements, Einstein A and B coefficients for bound-bound transitions (Shu Ch. 23; R-L § 10.2, 10.3, 10.5)
5. **Tu Dec. 13**: Bound-free transitions in the Born approximation, photoionization and recombination rates and cross-sections, Einstein-Milne relations, line width and natural broadening (Shu Ch. 23; R-L § 10.5, 10.6)
6. **Monday Dec. 19**: *Final exam*