AS GRS 713 – Astronomical Spectroscopy

Prof. Clemens – Fall 2012

Catalog Description:

Spectroscopic processes in astrophysics. Energy levels in atoms and molecules. Atomic and molecular spectral lines. Excitation of atoms and molecules. Transfer of line radiation. Spectroscopic instruments. Derivation of physical parameters from spectroscopic observations.

Meeting Times:

Lecture: Mondays 9:30-11am and Wednesdays 2:00-3:30pm in CAS 502

Office Hours:

Mondays 2-3pm, Tuesdays 11-noon, Wednesdays 11-noon, Fridays 1:00-2:00 in room CAS 417, and by appointment (3-6140; *clemens@bu.edu)*

Synopsis:

This course traces the steps from spectral line formation in atoms and molecules through detection and analysis to reveal physical conditions in astronomical settings. It begins with elementary quantum mechanics, from operators and the Schrödinger equation through harmonic oscillators and the hydrogen atom and including all the manifestations of angular momentum. Our approach borrows much from the approach used to train chemists and somewhat less from that used to train physicists, as the applications of the chemists more closely match those of astrophysics and space physics. The quantum mechanical basis of chemical bonds leads into molecular orbitals, molecular energy levels, and their spectral lines. Examples will be drawn from current astronomical literature, highlighting the importance of atomic, ionic, and molecular spectral line analysis to our current understanding of a wide variety of astronomical phenomena.

Texts:

1. **Required**
   "Introduction to Quantum Mechanics in Chemistry, Materials Science, and Biology," by S.M. Blinder, ISBN 0-12-106051-9 (paperback; ~ $50)

2. **Highly (Highly!) Recommended**
   "Introduction to Quantum Mechanics in Chemistry," by Ratner & Schatz, ISBN 0-13-895491-7 (paperback; ~$50, used)
   "Introduction to Quantum Mechanics," (2nd Edition) by Griffiths, ISBN 0-13-111892-7 (hardcopy) [many, most students likely already have a copy of Griffiths]

3. **Recommended**
   "Molecular Quantum Mechanics," (mine is 3rd Edition, a 4th Edition is available) by Atkins & Friedman, ISBN 0-19-855947 (paperback; ~$50, used)

4. **Background and Lecture Sources**
   "The Physics of Astrophysics, Vol 1. Radiation," by Shu, ISBN 0-935702-64-4 – quantum theory is part 3 of this three part book.

"Radiative Processes in Astrophysics," by Rybicki & Lightman, ISBN 0-471-82759-2 – see the last couple of chapters [most students ought to already have this book]
"Microwave Spectroscopy," by Townes & Schawlow, ISBN 0-486-61798-X – the authorative book on molecular spectroscopy

5. **Lecture Sources leading into Interstellar Medium Studies**
"The Physics and Chemistry of the Interstellar Medium," Tielens, ISBN 0-521-82634-9
"Physics and Chemistry of the Interstellar Medium," Kwok, ISBN 978-1-891389-46-7

Grading:

The course grade will be computed by weighting your performance in the following areas by the percentages listed:

Course Component	Percentage Weight
Homework (10-12 expected)	40%
Midterm Exam	30%
Final Exam	30%

Expectations:

Lecture Attendance **–** I expect each student will attend every lecture for this course. Chronic absences (more than 5 lectures) may result in a failing course grade. I also expect (and encourage!) questions and participation in and out of the classroom.

Homework **–** I expect to issue homework assignments nearly every week. Each homework assignment will be due one week later, usually at the ***beginning*** of Tuesday's lecture. I expect every student will complete every homework assignment. Failure to turn in more than 75% of the homework assignments may result in a failing course grade.

Academic Standards **–** I expect the homework you turn in is your work and not the work of your fellow classmates (see below). In class, we will discuss the distinction between allowable collaboration and violation of academic standards.

Exams:

There will be one 75-minute duration, closed-book, in-class ***Midterm Examination*** on Monday, October 29th. It will cover all material up through the preceding lecture.

There will be a 2-hour duration, closed-book ***Final Examination*** on Monday, December 17th from 3-5pm.

Homework:

Late Policy*:* In the real world, missing deadlines can have dire consequences (e.g., failure of a mission to launch on time). Since we are practicing for the real world and trying to instill the highest work ethic, the late policy for homework this semester is serious:

Failure to turn in a homework assignment –
on the designated date,
by the designated time, and
in the designated format (see below)
will result in a loss of 15% of the total value of the assignment ***for each additional calendar day.***

Homework Format:

Homework must be:

- ☐ written in **INK**,
- ☐ no more than one problem per page (though any one problem may cover multiple pages),
- ☐ written on the front side of each paper sheet only,
- ☐ highly legible,
- ☐ written on **ruled**, **white** paper, without "burstable" sides or spiral notebook holes.
- ☐ Please also provide sufficient space **between** lines for my comments.

Homework judged illegible will be returned ungraded.

Academic Conduct Standards & Collaboration:

It is important that students submit for evaluation homework that is properly executed and attributed. I encourage you to study together, but require that you write up and submit your homework assignments separately. You may help each other to discover how to solve a problem, but you must present your own discussion of the steps needed to achieve the solution. Do not copy from another student or from another student's work (including students not in this class).

Students are reminded that their behavior is governed by the Graduate School Academic Discipline Procedure (see:

http://www.bu.edu/cas/students/graduate/forms-policies-procedures/academic-discipline-procedures/

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<u>Meeting Plan:</u>

Caveat emptor: The following meeting plan represents and expression of course goals – the actual schedule will likely depart somewhat from this plan
[Legend: B = Blinder; R&S = Ratner & Schatz]

Day/Date / Time	Topics	Readings; **Homework**
1: Wed, Sept 5 2-3:30pm	Lecture #1: Intro, syllabus, failures of classical physics, waves, dispersion relations, wave equations	Ch 1 B; Ch 1 R&S
2: Thurs, Sept 6 **9:30-11am** ***NOTE DAY/TIME***	Lecture #2: Schrödinger eqn, operators, eigenvalues, free particle, orthogonality of wave functions	***HW#1 Assigned*** Ch 2,3 B; Ch 2 R&S
Monday, Sept 10th **No Lecture**	**No Lecture: Clemens on Travel**	
3: Wed, Sept 12 2-3:30pm	Lecture #3: Particle in 1D box	Ch 3 B; Ch 3 R&S
4: Mon, Sept 17 9:30-11am	Lecture #4: π-bonds, 3-D box, zero point energy	**HW #1 due;** ***HW #2 Assigned*** Ch 4 B
5: Wed, Sept 19 2-3:30pm	Lecture #5: Wave function continuity, Heisenberg uncertainty, QM postulates	Ch 5 B; Ch 4 R&S
Monday, Sept 24th **No Lecture**	**No Lecture: Clemens on Travel**	
6: Wed, Sept 26 2-3:30pm	Lecture #6: Dirac <> notation, Harmonic oscillator	**HW #2 due;** ***HW #3 Assigned*** Ch 5, 7 R&S
7: Mon, Oct 1 9:30-11am	Lecture #7: SHO, raising & lowering functions, Hermite polynomials, variational principle	Ch 4A B; Ch 15 R&S
8: Wed, Oct 3 2-3:30pm	Lecture #8: Time independent perturbation theory, anharmonic corrections to SHO	**HW #3 due**; ***HW #4 Assigned***
Monday, Oct 8th **No Lecture**	**No Lecture: Holiday**	
9: Tues, Oct 9 **9:30-11am** ***NOTE DAY/TIME***	Lecture #9: Time-dependent perturbation theory, Fermi's Golden Rule, quantum theory of radiation	
10: Wed, Oct 10 2-3:30pm	Lecture #10: Perturbation theory for degenerate states	Griffiths, Chapter 6
11: Mon, Oct 15 9:30-11am	Lecture #11: Particle in a ring, rigid rotors, central potentials, spherical harmonics	Ch 6 B; Ch 4 R&S
12: Wed, Oct 17 2-3:30pm	Lecture #12: Spectra of Rigid Rotor molecules; angular momentum operators.	**HW #4 due**; ***HW #5 Assigned*** Ch 5 R&S
13: Mon, Oct 22 9:30-11am	Lecture #13: Spin, central potential, radial eqn solution, energy quantization, radial nodes.	Ch 6 R&S

14: Wed, Oct 24 2-3:30pm	Lecture #14: Hydrogen atom, single wavefunction, reduced mass, radial solutions, radial density function, hydrogenic orbitals, p & d state mixes	**HW #5 Due;** ***HW #6 Assigned*** Ch 7 B
15: Mon, Oct 29 9:30-11am	***MIDTERM EXAM – Closed Book***	
16: Wed, Oct 31 2-3:30pm	Lecture #15: Spin-orbit coupling, J & m_J, spectroscopic notation for states, fine structure, hydrogen transitions for low levels. **(Booooo….!)**	Ch 9 B; Ch 7, 9 R&S Ch 9 R&S
17: Mon, Nov 5 9:30-11am	Lecture #16: Fine structure lines, hyperfine structure, Helium	
18: Wed, Nov 7 2-3:30pm	Lecture #17: Indistinguishability, exchange energy, Slater determinants.	**HW #6 Due;** ***HW #7 Assigned***
19: Mon, Nov 12 9:30-11am	Lecture #18: Angular momentum vector coupling, Hunds rule, building up.	Ch 10, 11 B; Ch 10 R&S
20: Wed, Nov 14 2-3:30pm	Lecture #19: Electric dipole radiation, selection rules, Hamiltonian for electron in EM field	**HW #7 Due;** ***HW #8 Assigned*** Ch 11 B
21: Mon, Nov 19 9:30-11am	Lecture #20: Electric quadrupole selection rules, magnetic dipole selection rules. Molecules, Born-Oppenheimer approximation	Ch 10, 11 R&S
Wednes., Nov 22 No Lecture	**No Lecture: Holiday**	
22: Mon, Nov 26 9:30-11am	Lecture #21: "Cartoon Day" – Energy level diagrams and spectra from X-ray through optical/IR. Example applications of atomic and ionic spectra and levels.	
23: Wed, Nov 28 2-3:30pm	Lecture #22: "Cartoon Day" – II. Born-Oppenheimer method details.	Ch 14 B; Ch 4, 15 R&S
24: Mon, Dec 3 9:30-11am	Lecture #23: H_2^+ ion bonding, H_2^+, term symbols.	**HW #8 Due;** ***HW #9 Assigned*** Ch 10, 11 B; Ch 10 R&S
25: Wed, Dec 5 2-3:30pm	Lecture #24: Molecular orbital symmetry nomenclature, diatomic ground states, valence-bond theory	Ch 12 B; Ch 11 R&S
26: Mon, Dec 10 9:30-11am	Lecture #25: Excitation nomenclature, angular momentum coupling, selection rules, H_2 (non)formation, para & ortho, diatomic molecular rotation, rotation spectra	**HW #9 Due;** ***HW #10 Assigned*** Ch 7, 10, 11 Townes & Schawlow
27: Wed, Dec 12 2-3:30pm	Lecture #26: Molecular vibration, spectra Hund's coupling cases, symmetric top	Ch 9 Kwok Ch 2 Tielens; Ch 2 Kwok
28: Mon, Dec 17 3-5pm	***FINAL EXAM – 10-noon***	