Lec #21: 10 OCT 11 Spectral Line Strengths, 4.3.5, 4.4

Last Time: What Transitions Are Possible?

Today: What Can We Determine From Line Strength?

- measuring line strength
- luminosity in a line; number of absorbers in beam
- abundance, temperature, and density

Wednesday: What Can We Determine From Line Profiles?

- lifetime of level
- physical conditions (e.g. local gravity)
- systematic and random motions
- number of absorbers

Spectroscopic "Terms" and Terminology

- "term" $^{(2S+1)}L_J$
  - $S=\sum m_s$ $L=\sum l$ and $J=L+S$ (vector sums)
  - (2S+1) gives "multiplicity of state"
  - use same letters for L (but capitalized: SPDF)
- L-S (spin-spin + orbit-orbit coupling) selection rules:
  - $\Delta S = 0$
  - $\Delta L = -1, 0, 1$
- $\Delta J = -1, 0, 1$ (but not J=0 to J=0)
- in heavier atoms (Z>30), jj coupling (spin-orbit)

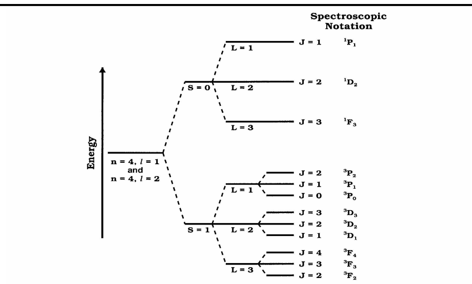


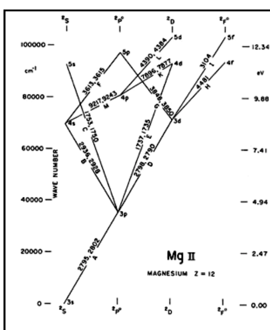
Figure I-6: Hund's rules demonstration: Example of energy splitting in the LS coupling scheme.

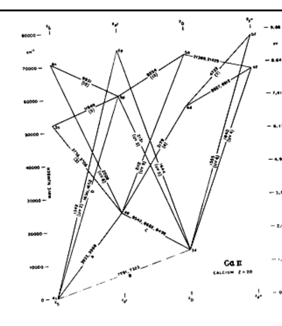
higher S & higher L for same S -> lower E

higher J -> higher E if shell < 1/2 full; else lower E

- *Resonance* Line (e.g. Ca II λ3934): "allowed" transitions involving ground state
- *Semi-Forbidden* Line (e.g. C II] λ2325): ΔS *or* ΔL violated
- *Forbidden* Line (e.g. [O III] λ5006): ΔS *and* ΔL violated
- *Metastable* state: no "allowed" connection to ground --> very long lifetimes (recall $\Delta E \Delta t \sim h_b$)

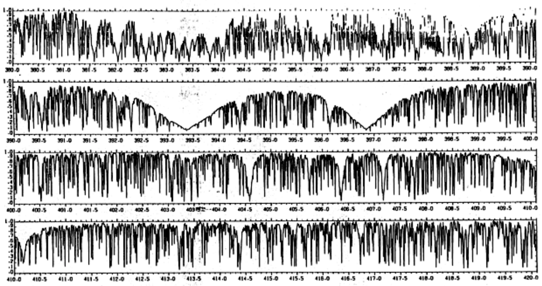
- *Intersystem (or Intercombination)*: transitions within subshell; never "allowed", but often diagnostic (e.g. O III] λ5006 - nebular line)
- *Fine Structure*: transitions within ground state multiplet (always forbidden)
- *Hyperfine* lines: electron spin flip (e.g. 21 cm line)
- [note: vacuum v. air wavelengths]
- Grotrian diagrams...





Mg II h+k Ca II H+K

cool web link: physics.unl.edu/~tgay/content/grotrian.html

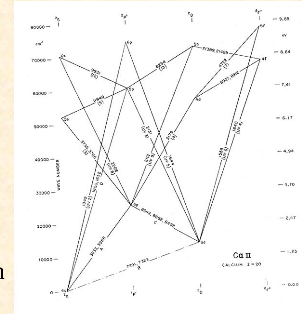


Solar spectrum from 3800-4200 Å

What Can We Determine From Line Strength?

- Elemental *Abundances*
  - relative to Hydrogen
- Local electron *Density*
- Local *Temperature*

- Relative strengths -> relative probability of transitions + population of levels (n, T)



ned.ipac.caltech.edu/level5/Ewald/Grotrian/grotrian.html

Luminosity in a Line (e.g Lyα)

- L_ν (erg/s) = transitions/sec * Energy of transition
  - $\Delta E = (E_2 - E_1) = h\nu = hc/\lambda$
  - transitions per second = N_2/τ_2
    - where τ_2 = lifetime of excited state
    - and N_2 = # of electrons in excited state
- $N_2/V = n_2 \quad N_H/V = n_H$
  - $N_2 = N_H(n_2/n_1) = n_H V\,(n_2/n_1)$
  - so it reduces to finding (n_2/n_1)
  - in thermal equilibrium, this is easy!
- Boltzmann distribution of level populations...

Bound-Bound Transitions

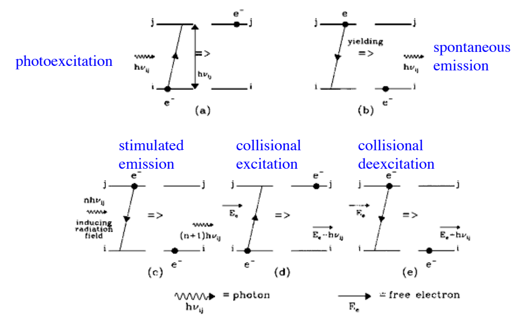


Figure I-4: The 5 processes involving bound-bound transitions. For each subframe, the left side represents "before" the interaction, and the right side, "'after" the interaction.

Bound-Bound Rate Coefficients

(see 4.3.5 in LeBlanc)

- Excitation
  - B_{12} (photoexcitation)
  - C_{12} (collisional excitation)
- De-Excitation
  - A_{21} (spontaneous emission) s^{-1}
  - B_{21} (stimulated emission)
  - C_{21} (collisional de-excitation)

- *B* depends on mean intensity of radiation field, J_ν
- *C* depends on density of colliders (mostly n_e) and kinetic temperature