Atomic processes – other transitions

Forbidden transitions
Electron transition with emission of single photon not allowed due to *usual* selection rules, but may be allowed at higher levels of approximation where lifetime in excited state is very long, so at high densities de-excitation occurs via collision

Fine transitions
Splitting of states with principal quantum number *n*, due to electron spin and relativistic corrections to classical theory

Hyperfine transitions
Splitting of states due to interactions of electron with nucleus

All the above produce important emission lines in astronomy for cooling and diagnostics of physical conditions

Look over your atomic physics notes…!

Selection rules: bound-bound transitions

- In simplest hydrogen-like atoms (H, He^+ etc) energy levels depend only on *n*
- Most real atoms of interest are not hydrogen-like
- Electron transitions are not possible between arbitrary energy levels
- Must obey *selection rules* for their different configurations n, l, m_l, m_s

Selection rules

- The outer shell electrons define
  - a total orbital angular momentum $L=\Sigma l_i$
  - a total spin angular momentum S
  - the total angular momentum J
- A given *configuration* can re-arrange its angular momentum to give more than one *term L, S, J*
- *Selection rules* ($\Delta l=\pm 1$, $\Delta L=0,\pm 1$, $\Delta J= 0,\pm 1$ and $\Delta S=0$) arise because photons carry angular momentum, which must be conserved in any emission or absorption process

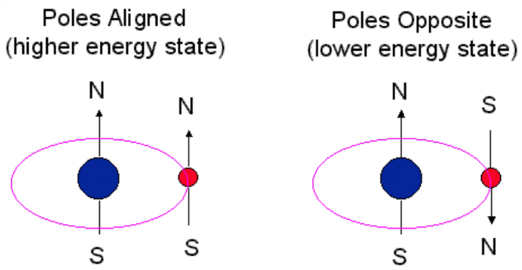
Forbidden bound-bound transitions

- *Permitted transitions*: allowed by the selection rules
  - (rates A_{21}~10^9 s^{-1}).
- *Forbidden transitions*: too slow to be observed under laboratory conditions due to collisional de-excitation
  - (transition rates A_{21} ~ 0.02 s^{-1}).
- They may be:
  - *Genuinely impossible*. e.g., electron in the n=2, l=0 state of hydrogen (2*s*) cannot decay to ground state (1*s*) by single photon emission. Only *collisions* or *two-photon emission* allow decay from 2*s* to 1*s*.
  - Forbidden only in some *approximate description* of the transition. Transition can occur, but rate A_{21} is slow. The energy level may be *metastable*.
- Forbidden transitions become important in low-density astrophysical environments. In nebulae an atom can stay in an excited state for a long time without suffering a collision, e.g., nebular [OIII] emission lines at 5007Å and 4959Å.

Fine bound-bound transition

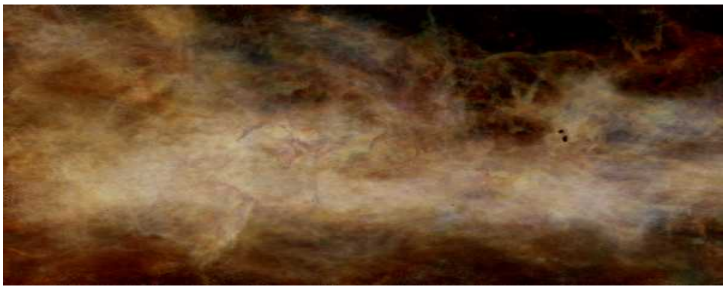
- *Fine structure*: levels with the same *n* have different energies due to
  - spin-orbit interaction, coupling the electron's spin with the orbital angular momentum having same *L* and *S* but different *J*. These *forbidden* emission lines, e.g., [OIII] at 52µm and 88µm, have low transition rates of 10^{-4} s^{-1}. Observed under low densities found in gaseous nebulae
  - relativistic corrections to the kinetic energy. This leads to splitting of spectral lines, e.g., the neutral Sodium D lines (5895Å and 5889Å).

Hyperfine bound-bound transition



- Hyperfine structure: The energy when spins of electron and nucleus are aligned differs from when they are not aligned. This coupling splits even the ground state of hydrogen which consists of 2 states between the spins of electron and proton. Transitions between these levels involve photons of wavelength 21cm (frequency of 1420 MHz) in the radio part of the spectrum.
- Although the transition is very slow (lifetime ~ 3×10^{14} s), the neutral hydrogen is very abundant and thus can be observed.

Galactic plane in 21cm emission



Canadian Galactic Plane Survey mapped a large area near the Galactic plane at 21 cm. (Taylor et al, 2003, *Astronomical Journal*, 125, 3145)

- Use radio observations of 21 cm line to measure distribution of gas in the Galaxy
- Useful because radio is not absorbed by dust
- Study impact of star formation on environment e.g., "chimneys" where supernovae have blown holes in the ISM
- Investigate formation of molecular clouds → next generation of stars
- In other galaxies, measure rotation curves

Lecture 14 revision quiz

- Why can't hydrogen de-excite from 2*s* to 1*s* via emission of a single photon?
- What is the sum of photon energies emitted by hydrogen in the two-photon 2*s* to 1*s* transition?
- Describe the physical mechanism that produces the 21cm line from the ground state of hydrogen. Describe two of its astrophysical uses.
- How hot does the HI gas have to be for collisions between atoms to excite the 21cm transition?
- Compare the 3×10^{14} s mean lifetime of the excited state to the age of the Universe. Why do we see the 21cm line at all?
- Calculate the natural broadening of the 21cm line and compare it to the thermal broadening of HI gas at 10K.