Atomic processes

Radiation can be emitted or absorbed when electrons make transitions between different states:

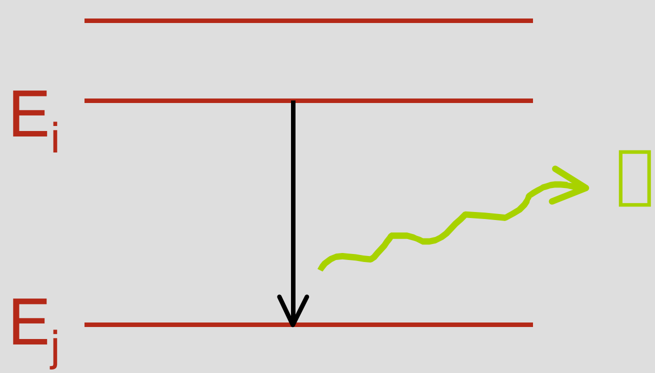
Bound-bound: electron moves between two bound states (orbitals) in an atom or ion. Photon is emitted or absorbed.

Bound-free:
- Bound -> unbound: **ionization**
- Unbound -> bound: **recombination**

Free-free: free electron gains energy by absorbing a photon as it passes near an ion, or loses energy by emitting a photon. Called **bremsstrahlung**.

Bound-bound transitions

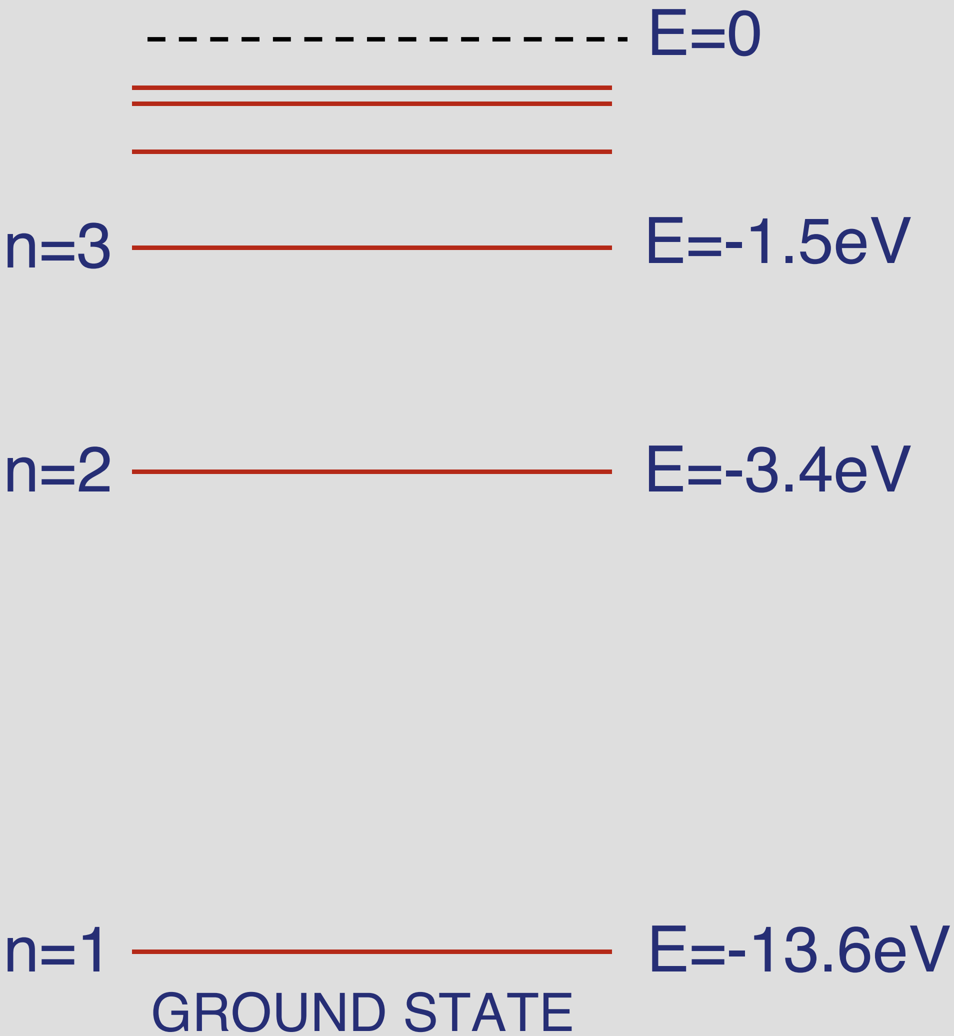
Transitions between two atomic energy levels:



Energy of the emitted / absorbed photon is the difference between the energies of the two levels:

$$h\nu = \left| E_i - E_j \right|$$

Hydrogen energy levels



Energy levels are labeled by n - the *principal quantum number.*

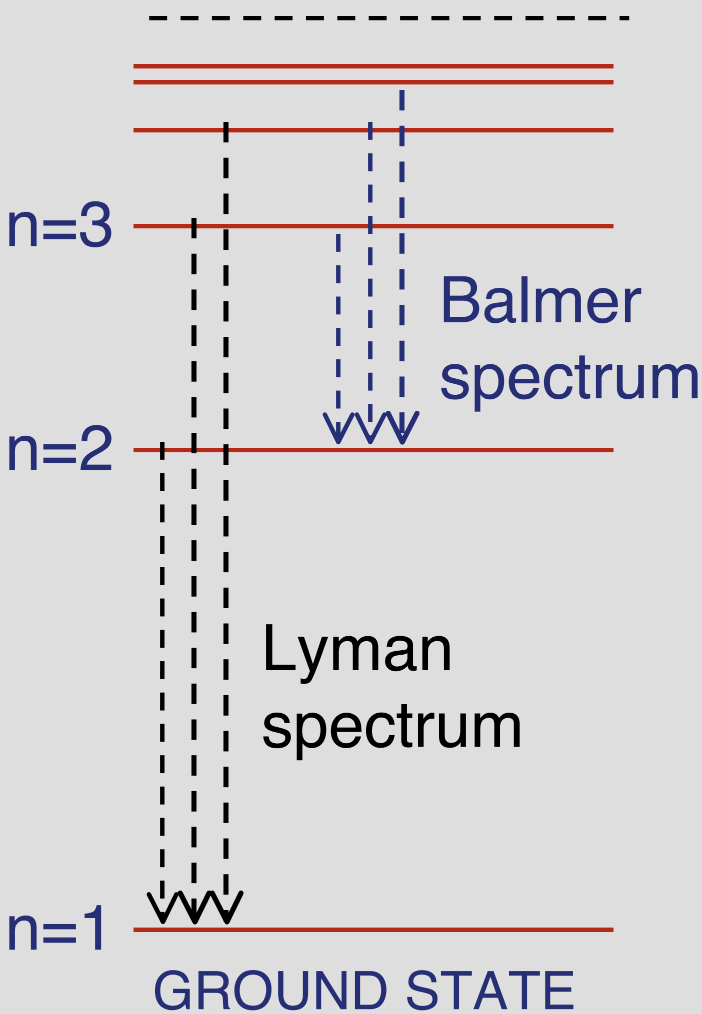
Lowest level, n=1, is the ground state.

$$E_n = -\frac{R}{n^2}$$

where R=13.6 eV is a constant.

n-th energy level has $2n^2$ quantum states, which are degenerate (same E).

Hydrogen spectrum



Terminology:

- Transitions involving n=1,2,3,4 are part of the *Lyman, Balmer, Paschen, Brackett* series.
- Different transitions are labeled with Greek letters - e.g. the Lyman □ line arises from the n=2 to n=1 transition.
- Balmer series includes H□, H□ etc.

Even for H - simplest atom - huge number of pairs of energy levels with different ΔE and hence different ν. How do we decide which lines we will see?

- At particular T, some levels will have a higher probability of being occupied than others.
- Probability of some transitions is greater than others.
- Not all transitions are possible (*selection rules*).

↓

Because of conservation laws - e.g. since a photon carries angular momentum cannot make a transition between two states with zero angular momentum by emitting one photon.

Boltzmann's Law

Calculating the populations of energy levels is difficult if the gas is not in local thermodynamic equilibrium (LTE). In LTE, very easy.

At temperature T, populations n_1 and n_2 of any two energy levels are:

$$\frac{n_2}{n_1} = \frac{g_2}{g_1} e^{-(E_2 - E_1)/kT}$$

g_1 and g_2 are the statistical weights of the two levels - allow for the fact that some energy levels are degenerate. For hydrogen:

$$g_n = 2n^2$$

21cm radiation

Ground state of hydrogen (n=1) has $2 \times 1^2 = 2$ states.

Correspond to different orientations of the electron spin relative to the proton spin.

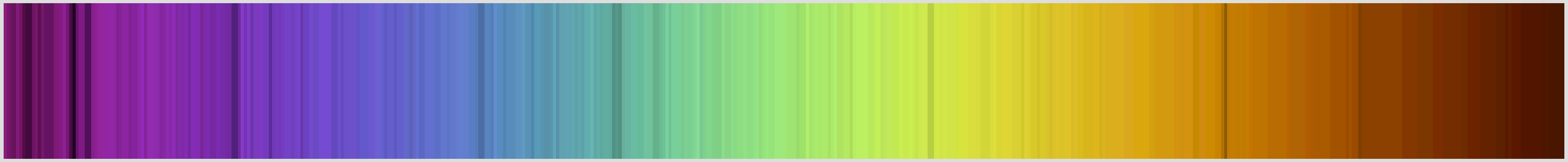
Very slightly different energies - *hyperfine splitting*.

Energy difference corresponds to a frequency of 1420 MHz, or 21cm wavelength.

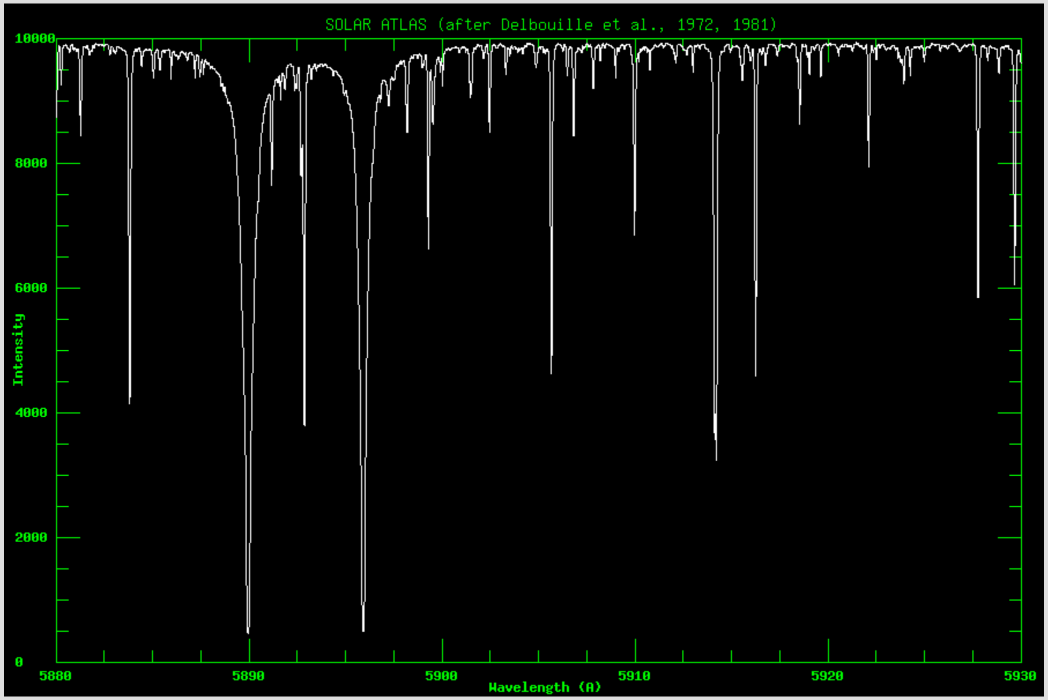
Very important for radio astronomy, because neutral hydrogen is so abundant in the Universe.

Absorption line and emission line spectra

Temperature of the Solar photosphere is ~6000K. Lots of spectral lines of different elements at this T.



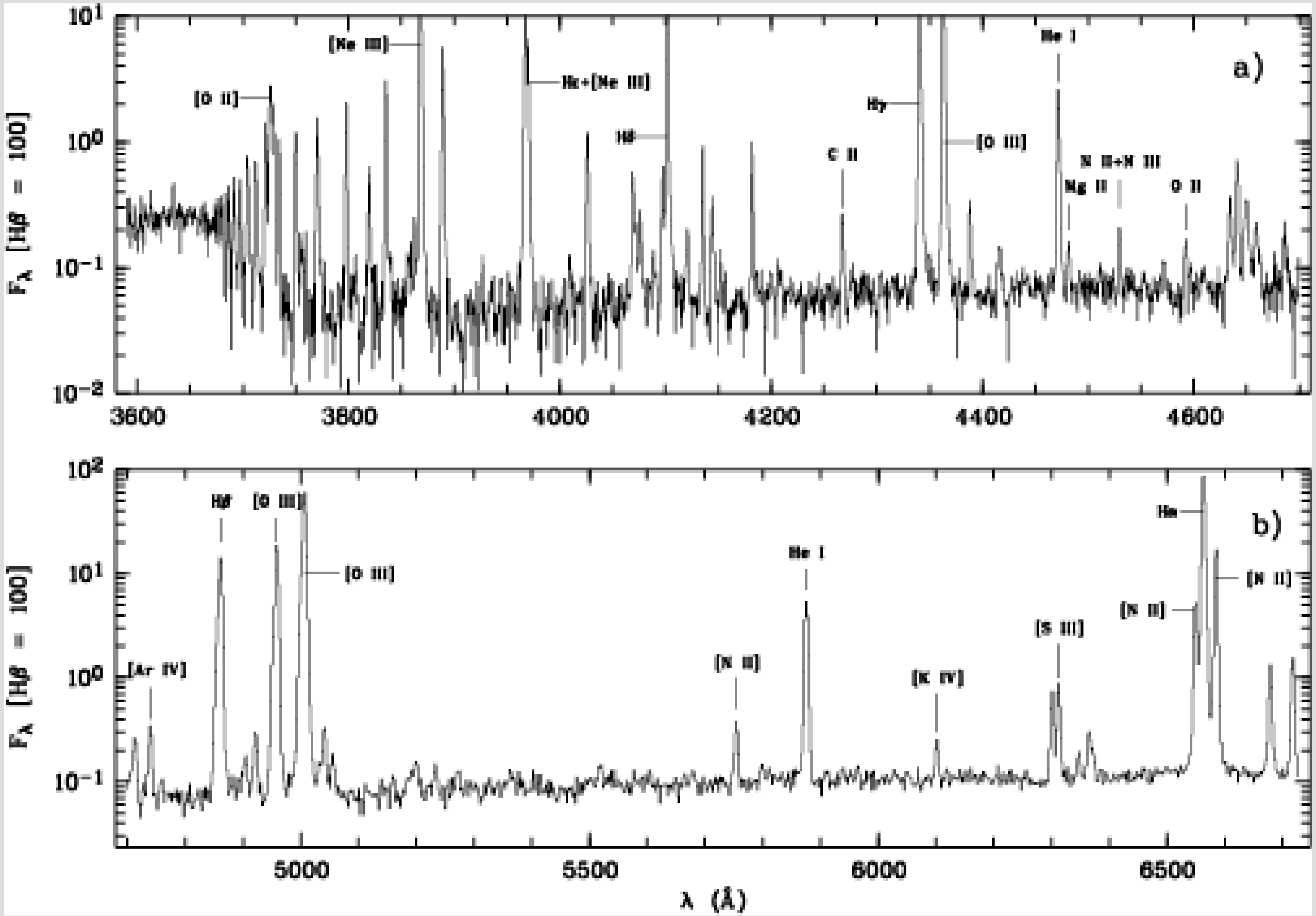
Optical spectrum is an **absorption line spectrum** - see dark absorption lines superimposed on a bright continuum.



Small section of the Solar spectrum showing two strong lines due to sodium.

Nebulae of different sorts typically show **emission line spectra**:

Spectral lines are **stronger** than the continuum



Why this difference?

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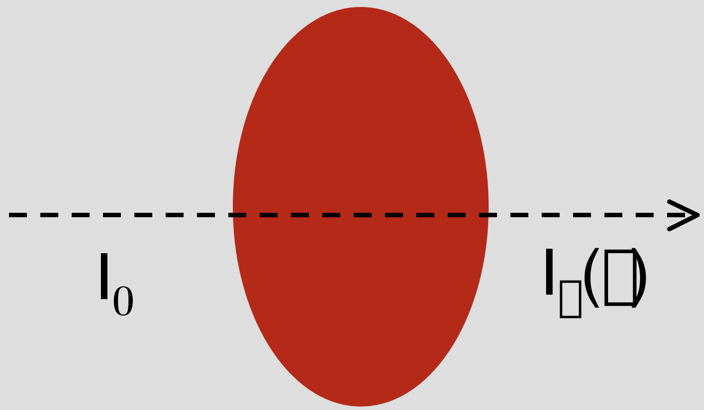
Use result we derived last time - consider radiation passing through a hot cloud of gas in thermal equilibrium:



Found:

$$I_\nu(\tau_\nu) = I_0 e^{-\tau_\nu} + B_\nu(1 - e^{-\tau_\nu})$$

Suppose no intensity entering the cloud, $I_0 = 0$. If the cloud is very optically thin:

$$e^{-\tau_\nu} \approx 1 - \tau_\nu$$

$$I_\nu(\tau_\nu) = B_\nu(1 - 1 + \tau_\nu) = \tau_\nu B_\nu$$

Optical depth is related to the absorption coefficient via:

$$\tau_\nu = \kappa_\nu \Delta s \qquad \text{(for constant } \kappa\text{)}$$

Means that:

$$I_\nu = \tau_\nu B_\nu \propto \kappa_\nu B_\nu$$

Intensity is large at frequencies where the absorption coefficient is large.

For a hot gas, absorption coefficient is large at the frequencies of the spectral lines.

For an optically thin medium such as a nebula, expect an emission line spectrum with large intensity at the frequencies where κ_ν is large.