

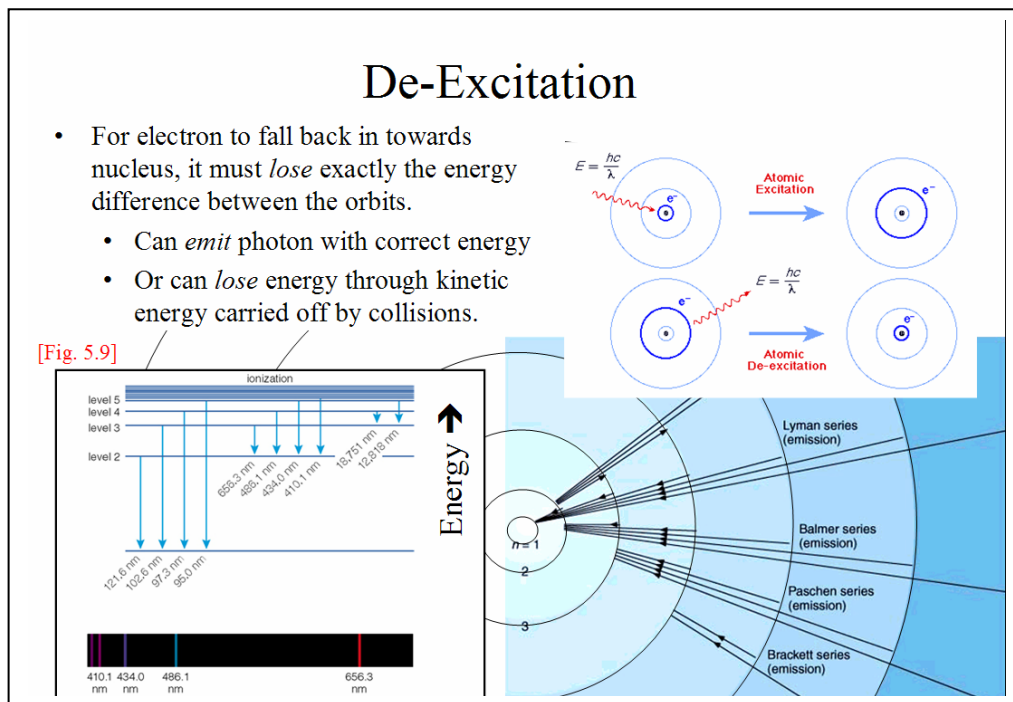
What would the spectrum of a star made out of pure hydrogen look like, as compared to the H emission line spectrum you saw on Friday night?

The (semi-) short answer.

The Emission Line Spectrum.

The emission lines that you saw on Friday night were caused by electrons falling from higher energy levels to lower energy levels in a tube full of pure hydrogen gas. Although quantum mechanics gives the full description, a simple model that pretty much works is that the electrons were falling in towards the nucleus of the atom, and so they had to get rid of some potential energy (due to the electrical attraction between the + charged nucleus and the - charged electron). They turned the energy into photons of light. The wavelength of the light is inversely proportional to the energy of the photon, and there are only a certain set of fixed differences in energy between the energy levels in the atom, so the light came out in a series of emission lines with sharply defined wavelengths.

How did the electrons get into the higher energy levels in the first place? They were bumped up there by absorbing kinetic energy during a collision between 2 atoms, or between an atom and a free electron. The electrical arc provided the energy for the collisions.

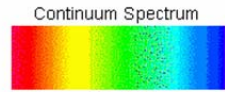
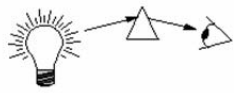


The Spectrum of a Star

In a star of a correct surface temperature (about 10,000°K), you see spectral lines from hydrogen at these same wavelengths, but now they are in absorption instead of in emission. They are wavelengths where energy has been removed from a background source that emits light at all wavelengths. To understand this, you need to picture the visible outer surface of a star as having two layers... a hotter inner layer (the "photosphere") that emits the continuous spectrum, and then a cooler outer layer (the "chromosphere") that produced the absorption lines.

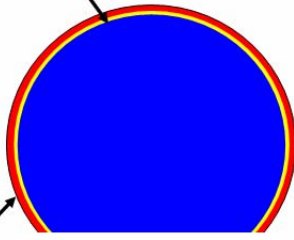
Stars vs. Gas Clouds

Continuum Spectrum



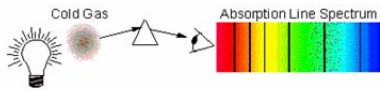
The Sun's photosphere)

Photospheres of stars

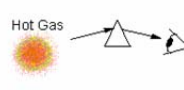
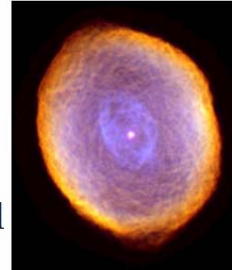


Outer, cooler layers

Absorption Spectrum



Emission spectrum:
Planetary nebula shell

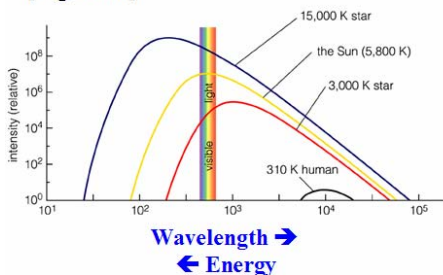


Continuous “thermal” radiation. The photosphere emits at all wavelengths because it is dense enough to be in “thermal equilibrium”, meaning that collisions of atoms with other atoms, and of atoms with photons, happen so frequently that every possible interaction will eventually take place. When we look into a star to the depth of its photosphere, we are looking past about 10^{21} atoms cm^{-2} ... that’s an awful lot of atoms. Each atom has some probability of absorbing or emitting light at any particular wavelength, through at least these three processes: (1) electron jumps between two different high energy levels; (2) an electron jumping between a bound orbit and a state in which it has been knocked free of the atom (or vice versa); or (3) an atom exchanging energy with a free electron which is just passing by. The sum of all these different interactions produces a very characteristic spectrum with light at all wavelengths, but with the exact distribution of energy vs. wavelength depending on the temperature of the gas. This is called a thermal spectrum, or more

archaically, a “black body” spectrum (where “black” refers to the ability to absorb and emit light at any wavelength).

Black-Body Spectrum

[Fig. 5.10]



- Characteristic shape
 - Narrow peak.
 - Sharp drop towards higher energy.
 - Slow drop towards lower energy.

- Peak wavelength given by **Wien Displacement Law**.

- $\lambda_{\text{max}} = 3 \times 10^6 / T$
- hotter objects have peak at smaller λ .

- Total energy emitted *per unit surface area* is given by

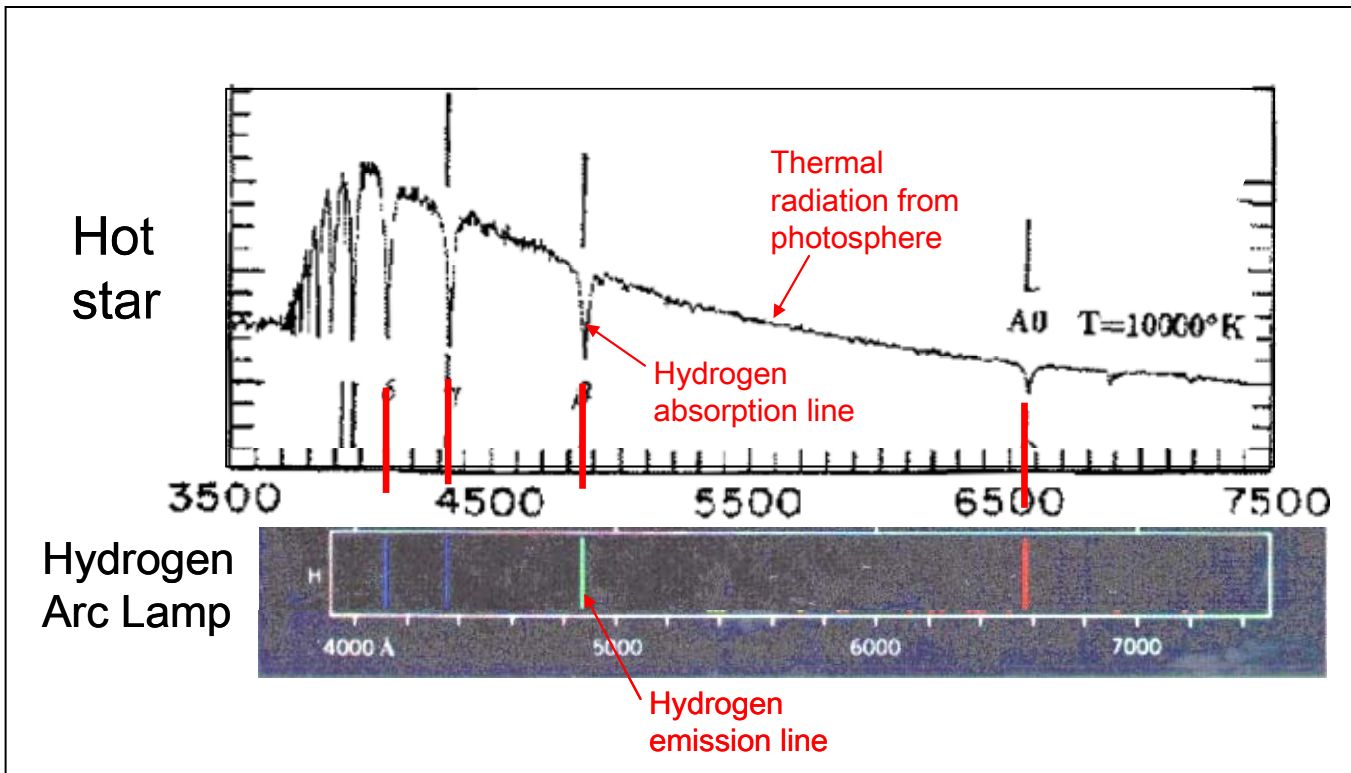
Steffan-Boltzmann Law: $E = \sigma T^4$

Slightly hotter objects put out way more energy per unit surface area:

| T | T^4 |
|---------|----------------------|
| 5800 | 1.1×10^{15} |
| 6800 | 2.1×10^{15} |
| 10,000 | 1.0×10^{16} |
| 100,000 | 1.0×10^{20} |

A star’s photosphere essentially emits a thermal (black-body) spectrum with a shape and energy cm^{-2} that is set by the star’s surface temperature. The second CLEA experiment you do will make use of this fact to work out the surface temperatures of stars by just measuring the overall shape of their spectra.

Absorption Line Spectra of Stars. A gas will produce absorption lines if it is in front of a source of continuous radiation that corresponds to a hotter gas. The photosphere discussed above serves as the hot background source. The cooler gas in the chromosphere then produces absorption lines. What is happening in each atom is that the electron is in a low-lying state, and can absorb only those photons which carry the exact amount of energy needed to move that electron up to a higher energy state. This is just the reverse of the process that produced the emission lines, so the absorption lines fall at the same wavelengths as the emission lines.



The above picture shows the spectrum of a star with a surface temperature of 10,000°K, which is just right for the hydrogen atoms to have had their electrons bumped up into the $n = 2$ energy level by collisions with other atoms. This means that photons with wavelengths corresponding to the energy difference between the $n=2$ level and a particular higher level can now be absorbed, so we see the series of H absorption lines as in the star's spectrum. To see a particular absorption line in the spectrum of a star, you need to have the chemical element present in the correct ionization state, and then have an electron sitting in the correct lower energy level to produce that absorption line. Stars with much hotter surface temperatures would have all of their hydrogen ionized, so there would not be any H absorption lines produced. For very cool stars, the electrons in the hydrogen atoms would all be sitting in the lowest possible energy level ($n=1$), so there would not be any in the $n=2$ energy level which is the starting point for absorbing the lines that we see at visible wavelengths.

The star shown here is not pure hydrogen, but it is the hydrogen absorption lines that are strong because the temperature is not correct to produce absorption lines of other elements in the visible pass band. The spectrum of a star made of pure hydrogen, with this same surface temperature, would look very similar.