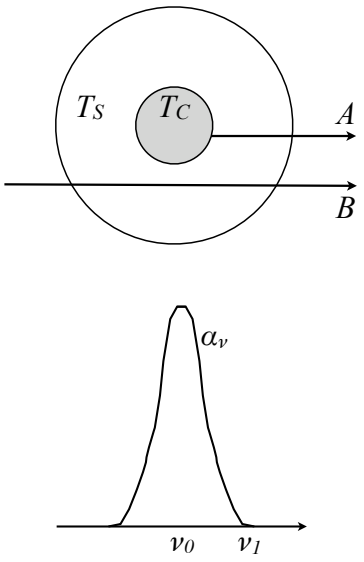
1 Shell around an object



Suppose a spherical and opaque object emitting as a blackbody at temperature T_c is surrounded by a spherical shell of material that is thermally emitting at a temperature T_s ($T_s < T_c$). This shell absorbs in a narrow spectral line, i.e. it absorption coefficient becomes large at the frequency ν_0 and is neglibly at other frequencies ν_1, $\alpha_{\nu_0} \gg \alpha_{\nu_1}$. The object is observed at ν_0 and ν_1 and along two different lines of sight A and B (see figure). Assume that the Planck function does not vary appreciably from ν_0 to ν_1.

1. At which frequency will the observed brightness be larger when observed along A? And along B?
2. Now assume $T_s > T_c$: answer the same question.

2 Forbidden lines vs. permitted lines

The optical spectra of laboratory plasma's are characterized by allowed transitions, while for interstellar plasma's, forbidden lines are prominent. HII regions are a case in point. Explain this difference. In what interstellar environment do you expect that allowed recombination lines will far outshine forbidden transitions?

3 Saha-Boltzmann equation

The LTE version of the Saha equation is

$$\frac{n_p n_e}{n_n} = (\frac{2\pi m_e kT}{h^2})^{3/2} \frac{1}{n^2} \mathrm{e}^{-\chi_n/kT} \ , \tag{1}$$

where $\chi_n = 13.6\mathrm{eV}/n^2$, and assume that $n_e = n_p$.

1. Evaluate the constants in this relation.
2. For hydrogen, for $T = 5000\,\mathrm{K}$, $10^4\mathrm{K}$, and $2 \times 10^4\mathrm{K}$, determine the ratio of populations in the $n = 1$ and $n = 100$ states with respect to the number of ions (i.e. the left hand side of the relation). From these results can you explain why the Orion nebula is fully ionized given that the temperature of the gas is 8000K?

4 Strömgren sphere (I)

The Strömgren spheres around two stars emitting 10^{47} and 10^{49} UV photons/s are observed to be in pressure equilibrium with their surroundings. What is the ratio of the interstellar gas densities around the two stars if the Strömgren spheres have identical radii? Assume that the temperature of the interstellar gas is the same in both cases.

5 Strömgren sphere (II)

Consider a Strömgren sphere of radius $R_S = 10\,\mathrm{pc}$ and internal density $n_e = 10^6\,\mathrm{m}^{-3}$ with a central ionizing source of 10^{49} photons/s.

1. How long will it take to become neutral once the ionizing star has switched off?
2. Suppose that the sphere expands at a rate equal to the sound speed in a fully ionized $10^4\,\mathrm{K}$ gas. How long will it take to expand to a size of $100\,\mathrm{pc}$?

6 HII regions

1. Describe qualitatively the ionization structure and energy balance of HII regions, focussing on the Strömgren sphere, the neutral fraction, the ionization front, and the effects of helium, trace species, and dust.

2. Describe the emission characteristics of HII regions.

3. Describe how the observed spectra of HII regions can be analysed to determine the physical characteristics of the gas and ionizing star. (See Figure 1 for an example spectrum.)