Stellar Atmospheres, Ht 2003
Problem Set 1

Due date: Tuesday, 9 September 2003

1. LTE assumptions

(a) Define and compare thermodynamic equilibrium (TE), local thermodynamic equilibrium (LTE), non-local thermodynamic equilibrium (NLTE), and statistical equilibrium (SE). Include a discussion of how temperature is defined.

(b) Where in the solar atmosphere would you expect the strongest deviations from LTE, and why? In which kinds of stars do you think deviations from LTE will be most important for the photosphere?

(c) How does the relation between matter and radiation differ between LTE and NLTE? What must be done differently in NLTE computations?

2. Nasty notation

The different notation used by different authors can be confusing for the reader. This is mirrored in the course texts, too: Rob Rutten's lecture notes use the same designations in the radiative transfer equation as we do, but David Gray's book does not.

Review the definitions and cgs units for I_ν, α_ν, κ_ν, σ_ν, j_ν and S_ν from last semester (see chapter 2 of Rutten if necessary). Then look at how Gray defines I_ν, κ_ν, j_ν and S_ν in chapter 5 and α in chapter 8. Show how they are related to our usual quantities, e.g.,

$$(\kappa_\nu)_{\text{Gray}} = \cdots \tag{1}$$

Summarize your results in a list or table.

3. Einstein coefficients

(a) How are the different Einstein coefficients defined, and what are their units? (Use Rutten's definitions but explain also how Gray's differ.)

(b) Consider the simple case of a system with only two discrete energy levels ℓ and u. You may assume thermodynamic equilibrium. This implies, among other things, that detailed balance holds for each atomic process at each frequency. Derive the Einstein relations

- $B_{\ell u}/B_{u\ell} = g_u/g_\ell$
- $A_{u\ell}/B_{u\ell} = 2h\nu^3/c^2$
- $C_{u\ell}/C_{\ell u} = g_\ell/g_u \, e^{E_{\ell u}/kT}$

(c) Which of the Einstein relations hold generally, even outside of thermodynamic equilibrium? Why is that?

4. Radiative equilibrium

(a) Explain what is meant by flux constancy. Why is it generally, but not always, used as a requirement in models of stellar atmospheres?

(b) Use flux constancy and the radiative transfer equation to derive the Strömgren equation:

$$\int_0^\infty \alpha_\nu J_\nu \, d\nu = \int_0^\infty \alpha_\nu S_\nu \, d\nu \qquad (2)$$

In the derivation, be sure to note which assumptions you needed to make at each step!

(c) Can one also say that $J_\nu = S_\nu$? Explain what the right-hand and left-hand sides of the Strömgren equation mean in terms of the energy balance at each depth in the atmosphere. (Hint: recall the definition of S_ν.)