# UNIVERSITY OF OSLO
## Faculty of Mathematics and Natural Sciences

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| Final exam in: | AST 4210 – Radiation I |
| Exam date: | Monday December 15th 2003 |
| Time for exam: | 14.30 – 17.30 |
| Question set is 2 pages. | |
| Attachments: | None |
| Allowed examination aids | All non-communicating aids |

*Control that the question set is complete*
*before you start answering the questions*

### Question 1

If we consider the Sun as a perfect black body of radius $R$, at a temperature $\mathcal{T}$ and located in vacuum:

a) Give the specific intensity $\mathcal{I}_\nu$ as a function of distance $r$ from the Sun, frequency $\nu$ and solid angle $\Omega$.

b) Give the ratio of the specific intensities $\mathcal{I}_\nu$, the ratio of the mean intensities $\mathcal{J}_\nu$ and the ratio of the outward directed unidirectional flux $\mathcal{F}_\nu^+$ at Jupiter (at a distance of 5.2 AU) and at the Earth.

### Question 2

The resonance line of Na I ($^{23}_{11}$Na I) is a doublet with doublet separation 6 Å. In the solar spectrum the two members of this doublet appear as two strong absorption lines, by Fraunhofer called the Na I D-lines.

a) Describe the atomic states of Na I involved in the formation of the resonance line. Which atomic states give rise to each of the two D-lines? Explain.

b) If the Na I atom is exposed to a magnetic field $B = .1$ T, describe in detail the splitting of the energy levels involved in the formation of the resonance line.

c) Describe the splitting with the corresponding polarizations of the two members of the resonance line. Explain your reasoning. How does the maximal magnetic splitting of each doublet line compare with the doublet separation?

d) The Na I atom is located in the solar atmosphere at a temperature $T = 6000$ K. What is the thermal Doppler width of the Na I spectral lines? Assuming ideal instrumentation, estimate the minimum magnetic field that can be measured based on the use of the Na I D-lines.

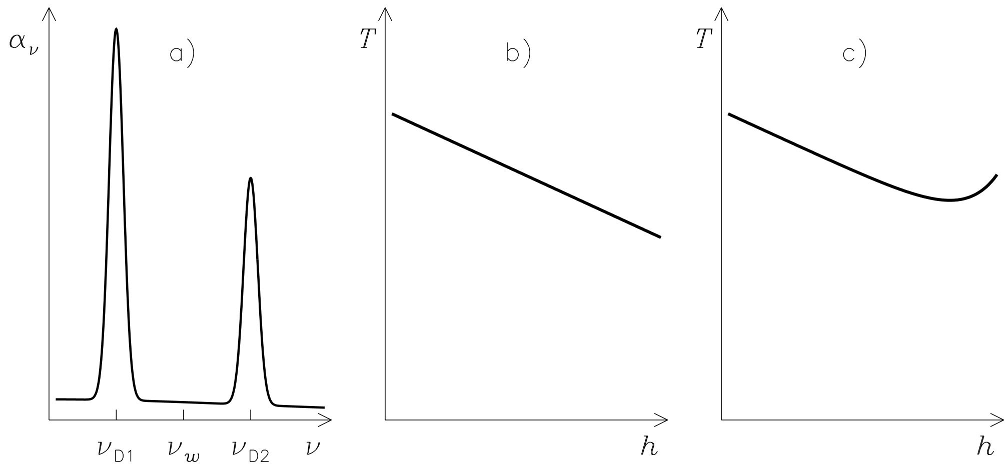


Figure 1: Extinction coefficient and temperature profile

Question 3

We want to explain the appearance of the Na I resonance line doublet as two absorption lines in the solar spectrum. The line extinction coefficient $\alpha_\nu$ in the frequency range of the resonance line consists of a slowly varying continuum component with two narrow, much higher line components (three orders of magnitude higher) superposed. A schematic plot of the line extinction coefficient is given in figure 1a. We notice that there is a factor of order 2 difference in the extinction coefficient between the two lines. We now assume the magnetic field to vanish, and we only consider radiation at normal incidence, $\mu = \cos\theta = 1$.

We first assume the LTE approximation to be valid and that the temperature $T$ in the height range of the formation of the resonance line is decreasing outward (see figure 1b).

a) What can you conclude about the radial optical depth $\tau'_\nu$ and the correspondent geometric depth $h$ at which the line centers $\nu = \nu_{\mathrm{D1}}, \nu_{\mathrm{D2}}$ and line wings, here represented with the frequency $\nu = \nu_w$ (see figure 1a), are formed? Explain your reasoning.

b) What is the source function $S_\nu$ under the above assumptions? Can you explain the appearance of the resonance line doublet as two absorption lines? What do you predict regarding the relative strengths of the two D-lines?

An investigation indicates that the formation of the center of each of the two D-lines takes place above the temperature minimum in the solar atmosphere (see figure 1c) and also that the LTE assumption may not be valid for these heights.

c) Comment on the claim: "The actual source function for the line centers are smaller than the LTE value". What are the consequences for the actual line shape compared to the line shape under LTE assumptions? The two D-lines appear in the solar spectrum as two absorption lines of approximately the same strength. Can you account for this fact – qualitatively?