Universitetet i Oslo

Det matematisk-naturvitenskapelige fakultet

Midtveiseksamen i AST4310
Radiative processes in astrophysics

Date of exam: Monday 5 October 2015
Time of exam: 10:00 - 13:00
This exam consists of 3 pages (Problems 1–3).
Attachments: none
Allowed materials: pocket calculator

Please answer in English if possible. Answers in Norwegian are permitted.

Check if the set of exercises is complete before you begin to answer!

selected constants:
speed of light $c = 2.99792 \times 10^{10}$ cm s^{-1}
Planck constant $h = 4.135667 \times 10^{-15}$ eV s
Boltzmann constant $k = 8.61734 \times 10^{-5}$ eV K^{-1}
electron mass $m_e = 9.10939 \times 10^{-28}$ g

nr.	element	solar abundance	χ_1	χ_2	χ_3	χ_4
1	H	1	13.598	–	–	–
2	He	7.9×10^{-2}	24.587	54.416	–	–
6	C	3.2×10^{-4}	11.260	24.383	47.887	64.492
7	N	1.0×10^{-4}	14.534	29.601	47.448	77.472
8	O	6.3×10^{-4}	13.618	35.117	54.934	77.413
11	Na	2.0×10^{-6}	5.139	47.286	71.64	98.91
12	Mg	2.5×10^{-5}	7.646	15.035	80.143	109.31
13	Al	2.5×10^{-6}	5.986	18.826	28.448	119.99
14	Si	3.2×10^{-5}	8.151	16.345	33.492	45.141
20	Ca	2.0×10^{-6}	6.113	11.871	50.91	67.15
26	Fe	3.2×10^{-5}	7.870	16.16	30.651	54.8
38	Sr	7.1×10^{-10}	5.695	11.030	43.6	57

Table 1: Solar abundances (relative to H) and ionisation energies (in eV) for selected elements.

1. Discuss briefly
   (a) the difference between brightness temperature and effective temperature
   (b) the difference between (i) natural broadening, (ii) Doppler broadening, and (iii) collisional broadening of spectral lines
   (c) the difference between flux and intensity.

2. The Boltzmann distribution is given by

$$\frac{n_{r,s}}{N_r} = \frac{g_{r,s}}{U_r} e^{-\chi_{r,s}/kT}$$

and the Saha distribution is given by

$$\frac{N_{r+1}}{N_r} = \frac{1}{N_e} \frac{2U_{r+1}}{U_r} \left(\frac{2\pi m_e kT}{h^2}\right)^{3/2} e^{-\chi_r/kT}$$

and the partition function U_r is given by

$$U_r \equiv \sum_s g_{r,s} e^{-\chi_{r,s}/kT}$$

(a) Describe the meaning of each symbol in these expressions and discuss the meaning and use of the Boltzmann and Saha distributions.

(b) The Balmer α line of hydrogen (Hα) at 656.3 nm is one of the strongest spectral lines in the visual part of the solar spectrum. The Ca II K line of singly ionised calcium at 393.3 nm is even stronger. Explain qualitatively why a spectral line from a *minority species* (see Table 1) can be stronger than a spectral line from the most abundant element, hydrogen.

(c) Neutral sodium has two *resonance lines* (i.e., transitions with the ground state as the lower level) near 589 nm: the Na I D lines. Using Table 1, argue whether these lines are (a) stronger than Hα and comparable to Ca II K, (b) similar in strength as Hα, or (c) much weaker than both Hα and Ca II K.

3. Figure 1 shows an incomplete series of graphs that can be used to give a schematic illustration of spectrum formation in an astrophysical medium.

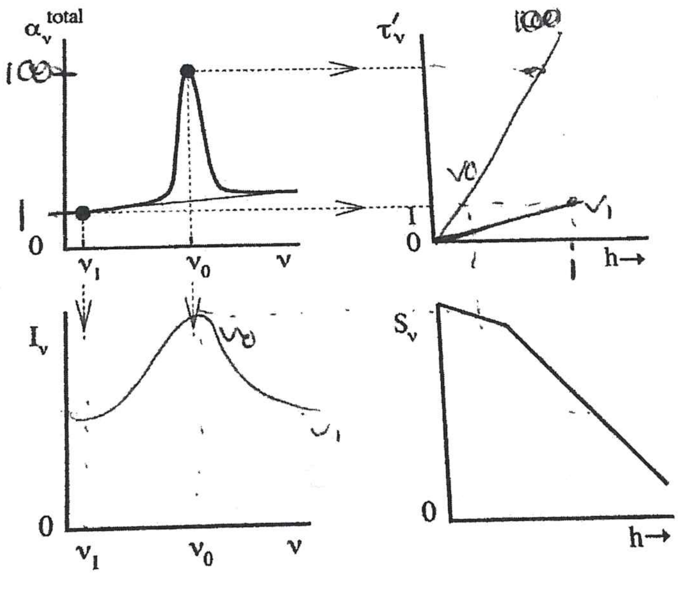

Figure 1:

(a) The top left panel shows a typical extinction profile as a function of frequency for a bound-bound (bb) transition. Describe the 3 radiative bb processes. Draw cartoons to illustrate the processes.

(b) Describe the three pairs of bb transitions that result in (i) photon destruction, (ii) photon creation, and (iii) photon scattering. Draw simple cartoons to illustrate the processes.

(c) Describe the process of photon conversion. Draw a simple cartoon to illustrate the process.

For Figure 1, we assume that the extinction is constant with height h. The source function S_ν as a function of height is shown in the bottom right panel, with height increasing to the right. The bb and continuum source functions are assumed to be equal $S_\nu^{\text{bb}} = S_\nu^{\text{cont}} = S_\nu$.

(d) Copy the four panels and fill out the missing lines and arrows that are needed to make a sketch of the intensity profile I_ν in the lower left panel. Describe in detail what you do and what assumptions are made.