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EXCITATION TEMPERATURE FUNCTIONS OF SOME Kr SPECTRAL LINES

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The excitation temperature functions of the following spectral lines of Kr atom/ion have been calculated: Kr I 3679.58; Kr I 4273.97; Kr II 3783.13; Kr II 4369.69; Kr III 3268.48; Kr III 6310.22; Kr IV 2609.5; Kr IV 3934.29 Å. The total pressure has been taken 1 atm. The results can be used for the determination of plasma temperature distribution in space and time.

Introduction

For the determination of the temperature of an axially or spherically symmetrical plasma in local thermodynamic equilibrium the method of astrophysics [1, 2] basing on a comparison of the measured real profiles of intensities with theoretically calculated excitation functions appears very convenient. The calculated excitation functions are usually normalized to unity at the maximum. In the case of electrical discharges this method of determining the radial distribution of temperature is known as that of Larenz [3, 4]. It can also be applied in the cases when there is a temperature gradient with a corresponding appearance of the maxima of the intensities as function of time of plasma heated to a high temperature. Depending on the rate of heating and cooling and on the available technique for the time resolution of the spectra, it is possible to examine the course of the temperature both as regards the heating and the cooling of the plasma.

In the present study the excitation temperature functions are calculated for a series of Kr-lines up to the fourth ionization stage at a pressure of 1 atm. We consider the knowledge of these exitation temperature functions as particularly important for practical spectroscopy.

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Two groups of sufficiently intense spectral lines were selected, and grouped into two different ranges of the spectrum; this makes it possible to apply the respective methods of determining the plasma temperature when utilizing a spectrograph with either quartz or glass optical components.

Mathematical basis of calculation

For the calculation of the intensity of a spectral line as a function of temperature the method given by Fowler and Milne [1, 2] has been used. It is discussed in detail by Unsöld [5]. The procedure is based on the Boltzmann and Saha equations given as follows

$$\frac{n_{r,s}}{n_r} = \frac{g_{r,s}}{U_r} - e^{-\frac{eU_{r,s}}{kT}} \tag{1}$$

$$\frac{n_{r+1}}{n_r} P_e = \frac{u_{r+1}}{u_r} 2 \frac{(2\pi m_e)^{3/2}(kT)^{5/2}}{h^3} e^{-\frac{eU_r}{kT}} \tag{2}$$

where $n_{r,s}$ is the number of atoms per cm^3 in the s level of the r-times ionized atoms; $n_r(n_{r+1})$ is the number of atoms per cm^3 in the ground state of the $r\,(r+1)$-times ionized atoms; $g_{r,s}$ is the statistical weight of the s level of the r-times ionized atom; $u_r(u_{r+1})$ is the partition function of the $r(r+1)$-times ionized atom; e is the charge of the electron; $U_{r,s}$ is the excitation potential of the s level of the r-times ionized atom; k is the Boltzmann constant; T is the temperature; P_e is the partial pressure of electrons; m_e is the mass of the electron; h is Planck's constant; and U_r is the ionization potential of an ion belonging to the ionization level r.

So if P_e is known, then according to Fowler and Milne the intensity of a spectral line as a function of temperature can be calculated by using the Boltzmann and Saha equations. The partial pressure of electrons can be calculated as follows

$$P_e = \frac{x+r}{1+x+r_r} P \tag{3}$$

where x is the degree of ionization, P is the total pressure (1 atm) and $r = 0, 1, 2, \ldots$ the stages of ionization. Using the Saha equation

$$\frac{(x+r)x}{(1+x+r)\,(1-x)} = \frac{u_{r+1}}{u_r} 2 \frac{(2\pi m_e)^{3/2}(kT)^{5/2}}{h^3 P} e^{-\frac{U_r}{kT}} \equiv f(T) \tag{4}$$

P_e can be written as follows

$$P_e = \frac{\frac{r}{2} + \sqrt{\frac{r^2}{4} + \frac{1+r}{1+\frac{1}{f}}}}{1+\frac{r}{2} + \sqrt{\frac{r^2}{4} + \frac{1+r}{1+\frac{1}{f}}}} - P. \tag{5}$$

Using the equation (5) the first of all P_e has been calculated as the function of temperature. Subsequently the intensity of a spectral line as a function of temperature has been computed according to Fowler and Milne.

Results

Table I shows all the Kr lines, for which the excitation temperature functions were calculated. The transitions which correspond to these lines, as well as the data which were utilized in the calculations, are also shown. In the last two columns the calculated electronic pressure corresponding to maximum temperature and the maxima of the excitation temperature functions are given.

TABLE I

Element	λ, Å	Transition	$\frac{Ur+1}{Ur}$	$e\,Ur$	$\frac{gr,s}{Ur}$	$e\,Ur,s$	P_e *bar*	$T_{\max}$ °K
Kr I	4273.97	$5s[1^1/_2]^0_2-6p[1^1/_2]_2$	6	13.999	8	12.82	5.065×10^5	1.4×10^4
	3679.58	$5s[1^1/_2]^0_2-7p[2^1/_2]_{3,2}$	6	13.999	8	13.28	5.065×10^5	1.4×10^4
Kr II	4369.69	$5p^1\,{}^2F^0_{5/2}-4d''\,{}^2D_{3/2}$	$^9/_6$	24.570	$^{14}/_6={}^7/_3$	21.33	6.753×10^5	2.6×10^4
	4355.47	$5s^4\,P_{5/2}-5p^4\,D^0_{7/2}$	$^9/_6$	24.570	$^{12}/_6=2$	16.83	6.753×10^5	2.6×10^4
	3783.13	$5p\,{}^4D^0_{7/2}-5d\,{}^4F_{9/2}$	$^9/_6$	24.570	$^{20}/_6={}^{10}/_3$	20.11	6.753×10^5	2.6×10^4
Kr III	6310.22	$4d''\,{}^3D^0_1-5p'\,{}^3P_2$	$^4/_9$	36.947	$^{15}/_9={}^5/_3$	24.56	7.597×10^5	3.8×10^4
	3268.48	$5s'\,{}^3D^0_1-5p'\,{}^3F_2$	$^4/_9$	36.947	$^{15}/_9={}^5/_3$	24.03	7.597×10^5	3.8×10^4
Kr IV	3934.29	$4d\,12_{3/2}-5p^4P^0_{1/2}$	$^9/_4$	52.5	3	25.78	8.104×10^5	4.4×10^4
	2609.5	$5s^4p_{5/2}-5p^4D^0_{7/2}$	$^9/_4$	52.5	$^{12}/_4=3$	26.13	8.104×10^5	4.4×10^4

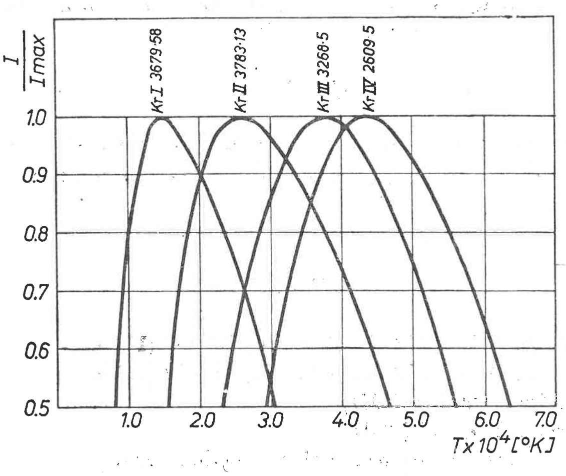

Fig. 1. Excitation temperature functions of Kr lines

For the calculations a computer was used. The data for the calculation of each line were taken from the works of Allen and Unsöld, and the tables of Striganov and Swentitzky [5–7]. In the calculations such values of temperature were selected which gave the excitation temperature function of the respective spectral line around its maximum. All the excitation temperature functions are normalized to unity. The excitation temperature functions are shown in Figs. 1–2. Fig. 1 depicts Kr I 3679.58, Kr II 3783.13, Kr III 3268.5 and Kr IV 2609.5 and Fig. 2 Kr I 4273.97, Kr II 4369.69, Kr III 6310.22 and Kr IV 3934.29. As can be seen from these curves the maxima of the individual lines of each group are located within a sufficiently wide temperature range. This enables us to utilize these curves, or more precisly the values of the temperatures of these functions for the evaluation of the temperature change for various discharges, in which we have a time or space temperature gradient.

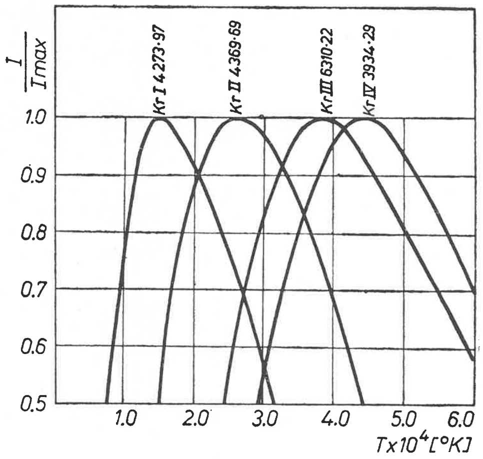

Fig. 2. Excitation temperature functions of Kr lines

Conclusion

The excitation temperature functions of 8 Kr spectral lines have been calculated to 4-stages of ionization for the determination of plasma temperature distribution in space and time.

REFERENCES

[1] R. H. Fowler and E. A. Milne, *Not. R. Astr. Soc.*, **83**, 403 (1923).
[2] R. H. Fowler and E. A. Milne, *Not. R. Astr. Soc.*, **84**, 499 (1924).
[3] R. W. Larenz, *Z. Phys.*, **129**, 343 (1951).
[4] R. W. Larenz, *Z. Phys.*, **129**, 327 (1951).
[5] A. Unsöld, *Physik* der Sternatmosparen, Springer, Berlin, 1955.
[6] S. W. Allen, *Astrophysical Quantities*, Sec. Ed., Univ, of London 1963.
[7] A. R. Striganov, N. S. Swentitsky, *Tabilitsy Spektralnikh linii*, Atomizdat, Moskva 1966.