SOME ESTIMATES OF THE INTENSITIES OF HELIUM LINES IN THE SPECTRA OF NONSTATIONARY STARS

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Abstract

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ASTRONOMY

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SOME ESTIMATES OF THE INTENSITIES OF HELIUM LINES IN THE SPECTRA OF NON-STATIONARY STARS

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In the spectrum of the Sun, as well as of other stars, the helium lines associated with the metastable level 2^3S change their intensity with time rather rapidly. Approximately, these changes may be divided into two groups: changes proceeding quasistationarily, and rapid changes over several minutes or hours with a shallow maximum. On the basis of data ([1]), the following figures may be given, characterizing the change of the line $\lambda 10830$ (2^3S—2^3P) in the spectrum of the Sun, which apparently arises in the chromosphere.

Time, min.	0	2	6	11	13	18
Intensity, Å	0.107	0.597	0.665	0.338	0.336	0.150

In the spectrum of the Sun quite a number of helium lines are observed in emission, and their intensities do not change noticeably with time.

It is natural to suppose that the change of the line $\lambda 10830$ in absorption is to some extent due to the fact that its lower level 2^3S is metastable, and therefore such external agents as radiation and collisions with electrons can noticeably change the population of this level. Since the atoms of hydrogen and of other elements have ionization potentials from their upper levels approximately the same as that of helium from the level 2^3S, while the intensities of the lines of these elements do not undergo large changes, one may expect that the population of the level 2^3S will depend appreciably on the electron density.

For a quantitative estimate, let us consider the following model: suppose that at some instant of time, in a thin shell in which "shell"spectra can arise, the electron density has suddenly increased. We shall determine how, as a consequence of this, the intensities of the helium lines associated with the level 2^3S will change. On the one hand, they should increase as a result of an increase in the number of recombinations, and on the other hand decrease as a result of an increase in the number of collisions of the second kind, transferring helium atoms from the state 2^3S to 1^1S.

Let us assume that at the instant t there will be n_2 helium atoms in the state 2^3S, n_1 in 1^1S, and n^+ in the ionized state. The metastability of the level 2^1S is not taken into account. The changes of n_2 and n_1 are then determined by the equations

$$\begin{aligned} \frac{dn_2}{dt} &= -wn_2\varphi(T_2) + n^+n_e f(T_e) - n_2 n_e \lambda(T_e), \\ \frac{dn_1}{dt} &= -wn_1\theta(T_1) + n^+n_e f_1(T_e) + n_2 n_e \lambda(T_e). \end{aligned} \tag{1}$$

The first terms are the number of ionizations from the corresponding levels under the action of radiation of temperature T and dilution w; the second terms are the number of recombinations to all triplet and singlet levels, respectively; the last term is the number of transitions from 2^3S to 1^1S under the action of collisions of the second kind.

From system (1), taking into account that $n_1 + n_2 + n^+ \equiv n$ is a constant quantity, we obtain the equation

$$\frac{d^2n_2}{dt^2} + \frac{dn_2}{dt}(a + a_1) + n_2(aa_1 - bb_1) + bc_1 - a_1c = 0; \tag{2}$$

a, a_1, etc. are known coefficients determined from (1).

Let us prescribe the initial conditions in accordance with the assumptions made above. They will have the form:

$$t = 0, \qquad n_2 = n_0, \qquad \left(\frac{dn_2}{dt}\right)_{t=0} = \beta = \delta n_0 w\varphi(T_2); \tag{3}$$

δ is the relative increase of the electron density at the initial instant (thereafter it remains constant), and before this instant a stationary state existed for the level $2\,^2S$.

With these initial data we find:

$$n_2 = \left[\frac{k_2(n_0 - \alpha) - \beta}{k_2 - k_1}\right] e^{k_1 t} + \left[\frac{\beta - k_1(n_0 - \alpha)}{k_2 - k_1}\right] e^{k_2 t} + \alpha; \tag{4}$$

$$k_{1,2} = -\frac{(a + a_1) \mp \sqrt{(a - a_1)^2 + 4bb_1}}{2}; \qquad \alpha = \frac{a_1c - bc_1}{aa_1 - bb_1}; \tag{5}$$

k_1 and k_2 are always negative; we shall assume that $n_0 > \alpha$. Formulas (4) and (5) make it possible to estimate approximately the relaxation time of the process under consideration. Since $|k_1| > |k_2|$, in (4) the term containing k_2 in the exponent will be significant. The time T_c for establishment of the stationary state is determined by the formula

$$|k_2 T_c| \simeq 1.$$

Depending on the electron density, T_c may vary from several seconds to a year and more in envelopes with a very small dilution coefficient.

In formula (4) the coefficients at the exponentials will have different signs. At some value $t = t_{\text{cr}}$ the population of the level $2\,^3S$ will be maximal, with

$$t_{\text{cr}} = \ln\left(\frac{1-\gamma_2}{1-\gamma_1}\right)^{\frac{1}{k_2-k_1}}; \qquad \gamma_1 = \frac{\beta}{k_1(n_0-\alpha)}; \qquad \gamma_2 = \frac{\beta}{k_2(n_0-\alpha)};$$

$$n_{2\text{cr}} = (n_0-\alpha)(1-\gamma_2)\left(\frac{1-\gamma_2}{1-\gamma_1}\right)^{\frac{k_2}{k_2-k_1}}. \tag{6}$$

If we assume that $a_1 \sim a$; $n_e \sim 10^4$–10^6; $T_e \sim 10^4$, and, according to ([2]), $\lambda(T_e) \sim 10^{-9}$, then t_{cr} will lie in the range from 10^2 to 10^4 sec. In the more general case the electron density n_e may vary with time. The system of equations (1) is then not solvable in general form; however, some approximate solutions can be found. Let

$$n_e = \frac{A}{Ce^{kt}-1}. \tag{7}$$

This is the law of variation of n_e in an envelope in which at $t = 0$, $n_e = A$, but then an instantaneous ionization of hydrogen occurred, after which the ionization source disappeared.

For the quantity n_2, under the initial conditions $t = 0$, $n_2 = 0$, $n_1 = n$, with $n_1 \gg n_2$, one can obtain from (1) and (7) the formula

$$n_2 = \left\{B\left[\frac{\tau_1}{(de^{kt}-1)^{\delta}} - \frac{\lambda}{(de^{kt}-1)^{\chi}}\right]\right\}; \tag{8}$$

$B,\ d,\ \tau,\ \lambda$ are known constants. For this case one can also find t_{cr} and $n_{2\text{cr}}$.

If one sets $T_e \sim 10^4$ and $A \sim 10^4$, then $t_{\text{cr}} \sim 10^5$ sec.; if $A \sim 10^8$, then $t_{\text{cr}} \sim 20$ sec.

Under these conditions $n_{2\text{cr}}$ will be of the order of $\sim 10^3$—10^4.

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CITED LITERATURE

[1] O. Mohler, Ap. J., **115**, No. 2 (1952); O. Mohler, L. Goldberg, Ap. J., **124**, No. 1 (1956). [2] H. Zirin, Ap. J., **123**, No. 3 (1956).

Note: Figure translations are in progress. See original paper for figures.