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Abstract

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ASTRONOMY

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ON AN APPROXIMATE ESTIMATE OF THE DECREMENT OF N III LINES IN THE SPECTRA OF PLANETARY NEBULAE

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The estimation of the relative intensities of spectral lines is of great interest: it makes it possible to judge both the mechanism responsible for the appearance of emission lines and the physical parameters of the envelope in which they arise. For hydrogen, and to a lesser degree for helium, under the assumption of the recombination character of the spectrum, this problem has been considered in sufficient detail; the situation is less satisfactory for heavy elements: there is only one work ([1]), in which only certain particular aspects of the problem are considered.

In studying the recombination spectra of heavy elements it is necessary to bear in mind the following difficulties:

1. The absence of any sufficiently reliable values of transition probabilities and absorption coefficients for a number of the levels under investigation, especially highly excited ones.
2. Possible inhomogeneities of the spectral scheme in passing from lower to higher levels.
3. The necessity, in some cases, of taking into account effects due to the multiconfiguration approximation.
4. Allowance for effects associated with the complex character of the distribution of recombining ions over the energy levels of the ground state.
5. In individual cases, excitation of inner electrons and the related effect of autoionization may change the degree of ionization of one or another element, which in turn may introduce certain changes into the recombination processes.

6. The great number of levels and of lines associated with these levels for elements of the iron group does not permit, in a number of problems, investigation of each separate level. In these cases, apparently, it is necessary to use statistical methods—as in nuclear theory. In the present work, which is a continuation of investigations ([2]), a particular problem is considered. The theoretical recombination spectrum of N III is calculated and compared with observations, under the assumption that the emitting envelope is opaque in the lines of the principal series $2s^2 2p^2 P$—$2s^2 nsd^2 SD$.

The stationarity equation in the case considered has the form

$$\sum_{n''>n} F(n''l \mp 1;\, nl) + F(kl \pm 1;\, nl) = \sum_{n'<n} F(nl;\, n'l \pm 1). \tag{1}$$

$F(n''l \pm 1;\, nl)$ is the number of spontaneous transitions from the level $n''l + 1$ to the level nl; $F(kl + 1;\, nl)$ is the number of recombinations to the level nl; $F(nl;\, n'l \pm 1)$ is the number of spontaneous transitions from nl to $n'l \pm 1$, where $n'l \pm 1 \neq 2p$. System (1) was solved for $T_e = 5 \cdot 10^3$ and $T_e = 10^4$ for the following terms: $2s^2 3p^2 P$, $2s^2 3d^2 D$, $2s^2 4s^2 S$, $2s^2 4p^2 P$, $2s^2 4d^2 D$, $2s^2 4f^2 F$, $2s^2 5s^2 S$, $2s^2 5p^2 P$, $2s^2 5d^2 D$, $2s^2 5f^2 F$,

$2s^2 5g^2 G$. The expressions entering into (1) are given by the following formulas:

$$F(kl' - nl) = n^+ n_e \frac{h^3}{(2\pi m k T_e)^{3/2}} \frac{4\pi^2 e^2}{mc^3} \frac{\omega_{nl}}{2z^2 R} e^{\chi_{nl}/kT_e} \int_{\nu_{nl}}^{\infty} \nu^2 e^{-h\nu/kT_e} f_{nk} k^3 \, d\nu; \tag{2}$$

$$F(nl - n'l') = b_{nn} n^+ n_e \frac{h^3}{(2\pi m k T_e)^{3/2}} \frac{4\pi^2 e^2}{mc^3} \omega_{n'l'} \nu_{nn'}^2 f(n'l' - nl) e^{\chi_{nl}/kT_e};$$

b_n is the required parameter determining the population of the level nl; the other notations are standard (see (3)); $f(n'l' - nl)$ and f_{nk} are oscillator strengths for transitions between discrete states and into the continuum. For the terms calculated, they are defined in (2).

The solution of system (1) for the terms whose transitions give the most intense multiplets is given in Table 1.

Table 1

Transition	$\bar{\lambda}$	$f_{n'n}$	$A_{nn'}$	Upper term. $T_e = 5 \cdot 10^3$	Upper term. $T_e = 10^4$
$3s^2S$—$3p^2P$	4100	0,95	$1,2 \cdot 10^8$	$2,4 \cdot 10^{-17}$	$1,7 \cdot 10^{-8}$

Transition	$\bar{\lambda}$	$f_{n'n}$	$A_{nn'}$	Upper term. $T_e = 5 \cdot 10^3$	Upper term. $T_e = 10^4$
$3p^2P$—$3d^2D$	4640	0,56	$1,1 \cdot 10^8$	$4,4 \cdot 10^{-15}$	$1,3 \cdot 10^{-7}$
$4f^2F$—$5g^2G$	4379	1,54	$4,3 \cdot 10^8$	$1,5 \cdot 10^{-7}$	$7,8 \cdot 10^{-5}$

Estimates of the relative intensities of the multiplets considered in Table 1 have the following values:

$$\frac{I(3s^2S - 3p^2P)}{I(3p^2P - 3d^2D)} \simeq 2; \qquad \frac{I(4f^2F - 5g^2G)}{I(3p^2P - 3d^2D)} \simeq 0,10; \qquad T_e = 5 \cdot 10^3;\ 10^4. \quad (3)$$

Observations of the laboratory spectrum (4), the spectra of some stars (5), and also theoretical calculations (6) have shown that, owing to interconfiguration effects from the $2s^2 3p^2P$ level in C II, N III, O IV, a transition to the $2s2p^2\,{}^2SPD$ levels is possible. The probability of such a transition for N III is $\sim 10^8$ (all the lines are in the ultraviolet with λ from 1000 to 690 Å). If in the stationarity equations (1) the transition $2s2p^2\,{}^2SPD$—$2s^2 3p^2P$ is taken into account, then

$$\frac{I(3s^2S - 3p^2P)}{I(3p^2P - 3d^2D)} \simeq 1,5;\ 1; \qquad T_e = 10^4;\ 5 \cdot 10^3.$$

Let us make a certain comparison of the theoretical decrement for N III with the observed one in the case of planetary nebulae. The observed intensities (7) are corrected for interstellar reddening by the method of (8). The results of the calculations are given in Table 2, where I_1 refers to λ4100 Å, I_2 to 4640 Å, I_3 to 4379 Å, all relative to H_β.

Table 2

Nebula	Observed I_1	Observed I_2	Observed I_3	Corrected I_1	Corrected I_2	Corrected I_3	$\frac{I_1}{I_2}$	$\frac{I_3}{I_2}$
NGC 6791	4,5	6,0	–	8,0	6,9	–	1,2	–
NGC 7662	4,5	6,0	0,7	5,2	6,2	0,8	0,8	0,13
NGC 6572	2,0	1,7	0,3	2,5	1,8	0,3	1,4	0,16
NGC 7027	3,0	4,0	0,40	4,4	4,4	0,5	1,0	0,11
NGC 5219	4,5	4,5	1,0	6,9	5,0	1,3	1,4	0,26

Nebula	Observed I_1	Observed I_2	Observed I_3	Corrected I_1	Corrected I_2	Corrected I_3	$\frac{I_1}{I_2}$	$\frac{I_3}{I_2}$
I. C 2165	0,30	0,60	–	0,38	0,64	–	0,6	–

The N III line λ4101 is strongly blended with the hydrogen line H_δ; therefore its intensity was estimated from the observed intensity of another line of the same multiplet, λ4097 Å, and the corresponding multiplet formulae. Comparison of the data in Table 2 with the estimates (3) and (4) shows that there is satisfactory agreement between theory and observations, taking into account the accuracy of determining the atomic and physical parameters entering into the problem.

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