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A COLLISIONAL RADIATION MODEL FOR THE ARGON NEUTRAL SYSTEM

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Abstract : We present a collisional radiative model of the argon neutral system to calculate the population density of the 4p group and the total ionization coefficient. We also measured the density of the 4p and of higher groups in a highly ionized magnetically confined hollow cathode arc discharge at low pressure (10^{-3} torr). From this combined information the atom density n_a can be determined. The ratio (n_{4p}/n_a) is about 5.10^{-5} and the total ionization is about 1.2 times the direct ionization at the electron temperature T_e=3eV and density $n_e=10^{19}m^{-3}$. Overpopulations with respect to the Saha-Boltzmann relation vary from 350 (4p group) to 30-60 (higher groups).

Introduction : Katsonis /1/ published an extended model study on the neutral system, including about 125 levels. We carried out measurements of the 4p group density and established that these densities did not agree with the model calculations of Katsonis. It appeared that Katsonis first model for the stationary and homogeneous case is not appropriate to our plasma conditions (T_e=3eV, $n_e=10^{19}m^{-3}$) since this model leads to a ratio $(n_e/n_a)=10^3$ compared to an experimental value of ∿1-5. We have a plasma of radius R=10 mm surrounded by neutral gas (R=150 mm) which delivers in a great amount atoms in the ground state. Comparison with the $r_j^{(1)}$ coefficients of Katsonis second model for the inhomogenous and the optical transparent case (calculations for the optical opaque case are only available for $T_e<16.10^3$K) leads to disagreement, discussed in the results. Therefore we set up a simplified collisional radiative model (C.R.M.) which only contains a few number of groups of the argon neutral system. The purpose of the study is besides the determination of the 4p group density the calculation of the total ionization coefficient as functions of the electron temperature and density and the atom density. Our model which is far less complete than Katsonis model differs in a number of points from that of Katsonis : 1. we took into account the collisional excitation 3p (ground level)→4p with measured values /2/ instead of calculated values; 2. the four 4s levels have been considered as separate levels instead of two groups, each containing a resonance and a metastable level; 3. the absorption of the resonance radiation of the 4s groups has been taken into account by the introduction of a local escape factor G, according to Holstein's theory.

Model : The C.R.M. has been set up as a steady state model in which diffusion losses for excited levels (including metastable levels) can be neglected so that the continuity equation for an excited level j reduces to the term, containing the collisional and radiative processes. Recombination can be neglected due to the low ion density of $\sim 10^{19}m^{-3}$. Collisional excitation and de-excitation (principle of detailed balance) by electrons have been taken into account between the 3p ground level, the four 4s levels and the 4p group (4p is considered as one group). The ionization from these levels and groups has also been taken into account. An essential assumption in the model is that excitation from 4p to higher groups may be considered as to contribute to stepwise ionization for a great part (see also results). The cross-section for the 3p-4s $^1P_1$ (0.25 $10^{-20}m^2$ at 50 eV) and 3p-4s $^3P_1$ (0.08 10^{-20} m^2 at 50 eV) are derived from Ref. /3/ and for the 3p-4s $^3P_0$, $^3P_2$ transition (0.19 $10^{-20}m^2$ at 22 eV) from Ref. /4/. The total cross-section for the 3p-4p transition has been taken equal to 0.5 $10^{-20}m^2$ according to Peterson and Allen /2/. This value is 2.5-3 times smaller than other recent values but much more in agreement with the measurements of McConkey and Donaldson /3/. Values of the excitation rates between 4s $^3P_1$ and the 4p group and also 4s $^3P_2$ and 4p can be found in Ref. /5/. The same values have been taken for the $^3P_0$ and $^1P_1$→4p transitions. Ferreira and Delcroix /5/ also mention a coupling coefficient between the metastable $^3P_2$ and the resonance level $^3P_1$ The ionization coefficient from the 4s group is also from Ref. /5/. The de-excitation from the 4p group to higher groups $\langle\sigma v_e\rangle_{4p}\uparrow$has been taken from Ref. /6/ with the help of transition probability values of Ref. /7/. The cross-section for direct ionization from the atom ground level 3p is from Ref. /8/. All the data about collisions are collected in Fig. 1. The data for the spontaneous emission from 4s $^3P_1$ and $^1P_1$ and from 4p-4s are derived from /7/. As already mentioned the trapping of resonance radiation has been taken into account. The 4p levels are considered as one group. This consideration is supported by measurement of the densities of the 4p levels. They appear to be nearly the same per unit statistical weight apart from the $2p_1$ level (the $2p_{10}$ level has not been measured).

Results : One of the results of the C.R.M., a calculation of the parameter $\bar{n}_{4p}=(n_{4p}/n_a)$ as a function of (n_e,T_e), is shown in Fig. 2. It appears that the values $\bar{n}_{4p}$ are about one order of magnitude larger than found with the corresponding coefficient $r_j^{(1)}$of Katsonis. It permits us to calculate the atom density n_a from a value of n_{4p} measured with line intensities of the 4p group if n_e and T_e have been measured simultaneously. The determination of n_a in a low pressure (10^{-3} torr) hollow cathode arc cannot be carried out directly from a pressure measurement and the relation $p=\Sigma nkT$ since the mean free path of atoms is almost equal to the tube radius; ionization on the axis may take away a number of atoms and the electron and ion contribution in the pressure relation may play a dominant role. A check on the quality of the model at low values of n_e,T_e, at an atom temperature not far from room temperature and with a very low ionization

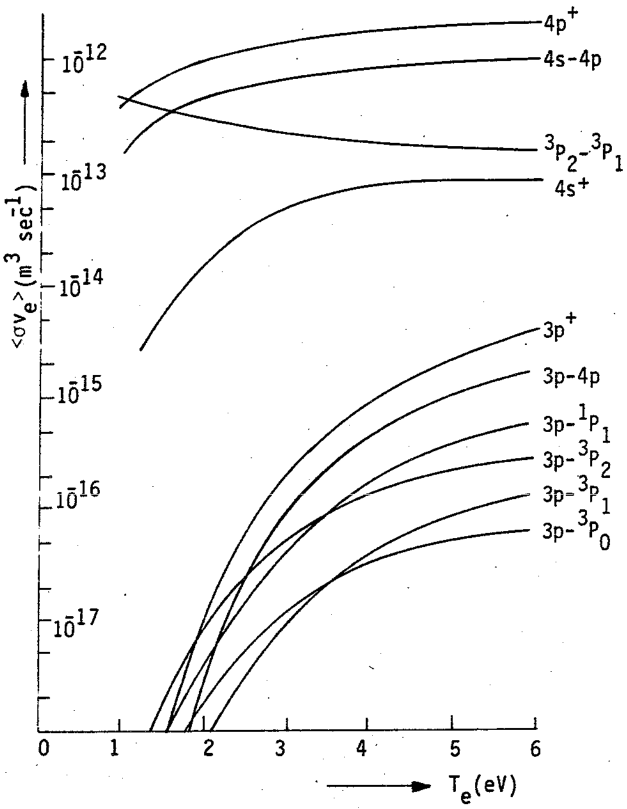

Fig. 1 The value $<\sigma v_e>$ for the various processes as a function of T_e.

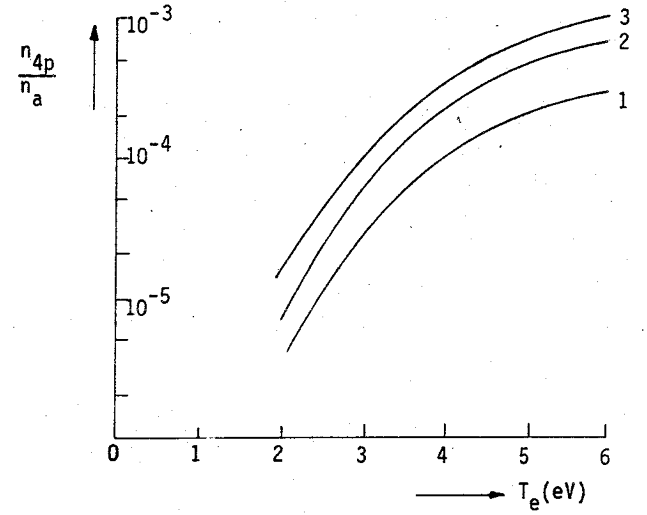

Fig. 2 The ratio (n_{4p}/n_a) as a function of n_e and T_e. 1:$n_e=10^{19}m^{-3}$; 2:$n_e=3.10^{19}m^{-3}$; 3:$n_e=9.10^{19}m^{-3}$.

rate and degree learned that deviations between the model and experiment are at the present state within 25% which is a surprising good agreement in view of the state of development of the model. The model is also set up to calculate the total ionization coefficient being : $<\sigma v_e>_{dir} + (n_{4s}/n_a)<\sigma v_e>_{4s}$ ion + $(n_{4p}/n_a)<\sigma v_e>_{4p}$ ion. The results for the extra ionization rate as function of (n_e,T_e) are found in Fig. 3. An experimental determination of the 4p group density delivered a value about 350 times larger than a density according to the Saha-Boltzmann relation applied with respect to the ion density. The measured density is about a factor 10 in disagreement with the calculated $r_j^{(1)}$ coefficient of Katsonis for inhomogenous plasma's. Higher groups as 5p, 6p, 4d, 5d etc appear to have densities which are 30-60 times larger than the Saha-Boltzmann relation predicts. From the ratio of overpopulation of the 4p group (350x) and of higher groups (30-60x) we took the conclusion that processes from 5p, 4d etc upward are more rapidly than back to 4p, so that they often lead to ionization. The $r_j^{(0)}$ and $r_j^{(1)}$coefficients of Katsonis predict population densities for these high groups which approach much more rapidly the Saha-Boltzmann relation. Probably, the excitation from the ground state is more important as suggested in Katsonis' model. It may be also that the de-excitation and recombination coefficients between high levels are too large. The total recombination rate (Katsonis /1/) at $n_e=10^{19}m^{-3}$ and T_e=3eV is $10^{19}m^{-3}sec^{-1}$ and the total excitation rate at these values is $5.10^{22}m^{-3}sec^{-1}$ (our model). It explains to our opinion that for a great number of groups densities have been found which are overpopulated with respect to the ion density and the Saha-Boltzmann relation.

Conclusion : Though the presented C.R.M. is not complete at this moment, the first results are encouraging so that it seems worthy to build out the system to a more complete one. One of the points for further investigation is the role of groups higher than 4p in the stepwise ionization processes.

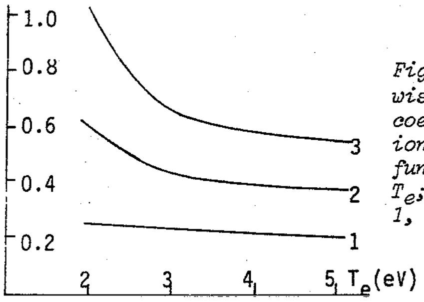

Fig. 3 The stepwise ionization coefficient/direct ionization as a function of n_e and T_e; see Fig. 2 for 1, 2 and 3.

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