Radiative Recombination Coefficients in Plasmas of Low Density

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Radiative recombination coefficients for Ne, A, Kr, Xe, N, and O in plasmas of low density are calculated in the temperature range $10-10^4$ K.

A quantum mechanical calculation for radiative recombination was carried out by Stueckelberg and Morse [1] for hydrogen ions. This method is not applicable in general. Recombination to any state may be computed alternatively by the methods of Burgess [2], Seaton [3], Burgess and Seaton [4], Bates and Dalgarno [5], Bates [6], Callaway [7], Chandra and Narain [8] using the standard relation of Milne [9] in which only the photoionization cross sections and the ionization potentials are required.

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Table I. Values of the parameters.

Target	I (eV)	g_a	g_i	A *
Ne	21.559	1	6	1.60
A	15.755	1	6	4.32
Kr	13.996	1	6	—
Xe	12.127	1	6	4.99
N	14.540	4	9	8.75
O	13.614	9	4	6.86

* in 10^{-13} cm^3 s^{-1} deg$^{1/2}$/eV.

Here radiative recombination coefficients for the process

$$X_i^+(n^{2S+1}L) + e \rightarrow X_a(n^{2S'+1}L') + h\nu, \qquad (1)$$

where the recombining ions and the recombined atoms are in their ground states, have been determined using photoionization cross sections of Dalgrano et al.[10], Samson and Cairns [11], and Samson [12].

The radiative recombination coefficient R (in cm^3 s^{-1}) for the process (1) occurring in a low density plasma is given by the standard expression of Milne [9, 5].

$$R = 65.48 \frac{g_a}{g_i} \frac{\exp\{I/t\}}{t^{3/2}} \int_I^\infty (h\nu)^2 Q(\nu) \cdot \exp\{-h\nu/t\}\, \mathrm{d}(h\nu) \qquad (2)$$

in which g_a and g_i are the statistical weights of X_a and X_i^+ respectively, and $t = KT$. I is the ionization potential of X_a, T the temperature, K the Boltzmann constant and $Q(\nu)$ the photoionization cross section (in cm^2) for the inverse process

$$X_a(n^{2S'+1}L') + h\nu \rightarrow X_i^+(n^{2S+1}L) + e. \qquad (3)$$

The photoionization cross sections $Q(\nu)$ needed for the evaluation of the integral in Eq. (2) are taken from Samson [12]. They may be fitted to an accuracy of 10 per cent to simple analytic expressions.

On substituting the values of g_a, g_i and I (Table 1) and the expressions for $Q(\nu)$ in Eq. (2)

Table II. Radiative Recombination Coefficients (in cm^3 s^{-1}).

Temperature (K)	Ne	A	Kr	Xe	N	O
10	1.068^{-12}	1.894^{-12}	3.182^{-12}	1.997^{-12}	3.924^{-12}	2.698^{-12}
20	7.571^{-13}	1.391^{-12}	2.311^{-12}	1.409^{-12}	2.774^{-12}	1.908^{-12}
30	6.183^{-13}	1.139^{-12}	1.930^{-12}	1.148^{-12}	2.266^{-12}	1.558^{-12}
50	4.791^{-13}	8.856^{-13}	1.563^{-12}	8.853^{-13}	1.756^{-12}	1.207^{-12}
70	4.051^{-13}	7.517^{-13}	1.377^{-12}	7.453^{-13}	1.483^{-12}	1.021^{-12}
100	3.392^{-13}	6.329^{-13}	1.219^{-12}	6.197^{-13}	1.242^{-12}	8.541^{-13}
200	2.404^{-13}	4.569^{-13}	9.740^{-13}	4.289^{-13}	8.788^{-13}	6.048^{-13}
300	1.967^{-13}	3.808^{-13}	8.263^{-13}	3.425^{-13}	7.181^{-13}	4.945^{-13}
500	1.530^{-13}	3.068^{-13}	5.884^{-13}	2.539^{-13}	5.572^{-13}	3.839^{-13}
700	1.299^{-13}	2.689^{-13}	4.451^{-13}	2.074^{-13}	4.717^{-13}	3.253^{-13}
1000	1.094^{-13}	2.358^{-13}	4.951^{-13}	1.721^{-13}	3.957^{-13}	2.732^{-13}
2000	7.912^{-14}	1.845^{-13}	2.196^{-13}	1.505^{-13}	2.821^{-13}	1.957^{-13}
3000	6.606^{-14}	1.596^{-13}	2.092^{-13}	1.537^{-13}	2.322^{-13}	1.553^{-13}
5000	5.352^{-14}	1.326^{-13}	2.236^{-13}	1.548^{-13}	1.829^{-13}	1.288^{-13}
7000	4.358^{-14}	1.176^{-13}	1.953^{-13}	1.499^{-13}	1.571^{-13}	1.138^{-13}
10000	4.224^{-14}	1.043^{-13}	1.705^{-13}	1.401^{-13}	1.346^{-13}	1.080^{-13}

* The superscript denotes the power of 10 by which the number is to be multiplied.

and carrying out the elementary integrations, explicit expressions for the recombination coefficients may be obtained.

The calculated recombination coefficients, for the temperature range $10-10^4$ K are displayed in Table 2.

Since the present coefficients have been calculated by fitting the photoionization cross sections by simple expressions with reasonable accuracy over a wide range of photon energies, they are expected to be fairly accurate.

It is obvious from Table 2 that the coefficients for all atoms except Kr decrease monotonically as the temperature increases. An examination reveals that this exception is due to the behaviour of the photoionization cross sections of Kr.

Bates and Dalgrano [5] show that in many cases of interest the coefficients may be expressed in terms of threshold photoionization cross sections. We find that this is not valid for Krypton at temperatures above 50 K. The difference between the present results and those using the expression given by Bates and Dalgarno for Krypton oscillates with the temperature. For other cases the difference increases monotonically with the temperature. However, all the coefficients except those for Kr may be represented by the following simple formula (for Xe and A upto 1000 K only).

$$R = A\, I/T^{1/2}$$

with parameters A presented in Table 1.

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1 E. C. G. Stueckelberg and P. M. Morse, Phys. Rev. **36**, 16 [1930].
2 A. Burgess, Mon. Not. Roy. Astron. Soc. **118**, 477 [1958].
3 M. J. Seaton, Mon. Not. Roy. Astron. Soc. **119**, 81 [1959].
4 A. Burgess and M. J. Seaton, Mon. Not. Roy. Astron. Soc. **121**, 76 [1960].
5 D. R. Bates and A. Dalgrano, in Atomic and Molecular Processes, edited by D. R. Bates, Academic Press, New York 1962, p. 245.
6 D. R. Bates, in Case Studies in Atomic Physics, edited by M. R. C. McDowell and E. W. McDaniel **4**, 57 [1974].
7 J. Callaway, Phys. Lett. **48 A**, 359 [1974].
8 S. Chandra and U. Narain, Prog. Theor. Phys. **55**, No. 2, 1 [1976].
9 E. A. Milne, Phil. Mag. **47**, 209 [1924].
10 A. Dalgarno, R. J. W. Henry, and A. L. Stewart, Planet, Space Sci. **12**, 235 [1964].
11 J. A. R. Samson and R. B. Cairns, J. Opt. Soc. Amer. **55**, 1035 [1965].
12 J. A. R. Samson, in Advances in At. and Molec. Phys. edited by D. R. Bates and I. Estermann, **2**, 177 [1966].