AL-Qadisiyha Journal For Science Vol.21 No. 1 Year 2016
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Calculating the Temperature dependence Radiative recombination rate Coefficients for ions

Receved :8/2/2015 **Accepted :5/10/2015**

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Abstract

Radiative recombination rate coefficients (RRC) are presented for several ions with open and closed shells, (H I, He I, He II, N V, N VI, N VII) . The temperature of electron range 10-10^9 K is considered. The calculations have been performed in the framework of analytic fit parameters formula with no consideration of relativistic effects. Our results of RRC compared with the theoretical data available as a function of electron temperature, and the agreement was very good. Some data which had been depended showed a peak at high temperatures because of the influence of autoionizing resonance.

Keywords: Temperature, radiative recombination, rate coefficient.

Physics Classification QC717.6-718.8

Introduction

Matter is found in three phases: The solid phase, the liquid phase, and the gaseous phase. In the situation, where some degree of ionization has taken place, and we have a mixture of atomic and molecular ions and free electrons, this called the fourth phase of plasma[1].

The plasma can be reached either by having a very high temperature or by introducing some external ionization mechanism, such as an electrical discharge or irradiation with light with a photon energy exceeding a few eV (i.e. UV, X rays, and γ rays) [1].

When plasma has been formed an equilibrium situation can be reached:

$$X^{q+} + e^{-} \leftrightarrow X^{(q+1)+} + energy(e.g.\, photon)$$

Where X^{q+} denotes an ion in charge state (q^{+}). The process from right to left is ionization, while the inverse process is ion-electron recombination.

Nevertheless, the multipole and certain relativistic effect are usually neglected in consideration of phoionization and radiative recombination processes in plasma [2].

Recently, we published a paper [3] about the radiative recombination rate, but for electron temperature range 10-10^5 K, for Carbon ions. A number of calculations [4-7] have been carried out on the radiative recombination rate. In this paper we present RRC for (H I, He I, He II, N V, N VI, N VII) ions for temperature range 10-10^9K. astrophysical plasma are far from thermodynamic equilibrium, as a result their physical state resulting spectra are determined by the balance set by a host of microphysical processes. Total recombination rate coefficients are essential for the prediction of the ionization balance, among other things [8].

The work we have done represented by calculating RRC, for most ions it compared with Nahar and Nahar & Pradhan [9,10]. Nahar procedures are of two important inverse radiative processes of electron-ion recombination in an *ab initio* manner using unified method based on R-matrix method and close coupling approximation. The unified method includes both the radiative recombination RR and dielectronic recombination (DR) [9].

However, ion-electron recombination remains an essential feature of plasma physics. Plasmas, where these atomic physics processes are dominating, are well known in nature. They can be found in, e.g., stellar atmospheres and in interstellar nebulae; but also in the upper atmosphere of the earth, where the solar UV radiation leads to ionization. In fact, some of the first experimental investigations of ion-electron recombination were performed as an attempt to understand the number densities of atomic ions in the upper atmosphere [1].

Theory

This paper presents the using of the analytic fits to the radiative recombination rates, which gives the corrected threshold cross sections behavior based on OP (opacity project) data, and ensure accurate results by use of the fitting formula with the correct non-relativistic asymptote [8]:

$$\alpha_r(T) = \frac{a}{\sqrt{T/T_o}(1+\sqrt{T/T_o})^{1-b}(1+\sqrt{T/T_1})^{1+b}} \quad \ldots\ldots(1)$$

Where *a*, *b*, T_o , T_1 are fitting parameters, the T_o , T_1 are a certain quantities of temperatures had measured at specific circumstances. Table(1) give the value of these parameters. $\alpha_r(T)$ the radiative recombination rate coefficient (RRC). This formula ensure correct asymptotic behavior of the rate coefficients as well as at high temperatures: $\alpha_r(T) \propto T^{-0.5}$ at $T << T_o << T_1$, and $\alpha_r(T) \propto T^{-1.5}$ at $T >> T_1 >> T_o$.

Table(1): Fitting parameters for ions under investigation.

Ion	$a(cm^3 s^{-1})$	b	$T_o(K)$	$T_1(K)$
H I	7.982-11(*)	0.7480	6.793+2	7.036+5
He I	3.294-11	0.6910	1.611+2	3.676+7
He II	1.891-10	0.7524	9.015+1	2.774+6
N V	1.169-10	0.5470	6.793+2	1.650+7
N VI	3.910-10	0.6988	1.611+2	3.271+7
N VII	7.586-10	0.7563	9.015+1	3.338+7

(*) the number $7.982-11$ means 7.982×10^{-11}.

For the hydrogenic species, the researchers Arnaud & Rothenflug[11] recommended the formula of radiative recombination coefficient:

$$\alpha_r(Z,T) = 5.197\times10^{-14} Z\lambda^{1/2}[0.4288+0.5\ln(\lambda)+0.469\lambda^{-1/3}] \quad \ldots(2)$$

Where $\lambda = 157890Z^2/T(K)$. This formula is not valid at high $(T > 10^6 Z^2)$ temperatures.

Glassgold [12] used a formula to calculate the radiative recombination rate coefficient by determining the distribution of electrons and atomic energy levels in plasma:

$$\alpha_r(T) = \bar{v}\sigma_{rec}^{(1)}(1)2r(\frac{I_r}{KT})^2 e^{I_r/KT} E_1(\frac{I_r}{KT}) \quad \ldots(3)$$

This formula give the rate of direct radiative recombination of electrons into the r^{th} level.

Where $(\bar{v})$ the electron speed, $\sigma_{erc}^{(1)}$ the recombination cross section, (r) the electrons level, (I_r) the ionization potential.

In this study we also chose to compare our data calculations of RRC with Nahar [9] and Nahar & Pradhan [10], whom used the unified method which is based on the close coupling approximation and R-matrix method:

$$\alpha_r(E) = v\sigma_{RC}(E) \quad \ldots(4)$$

(*r*) is the photoelectron energy, $\sigma_{RC}(E)$ is the recombination cross section.

Results & Discussion

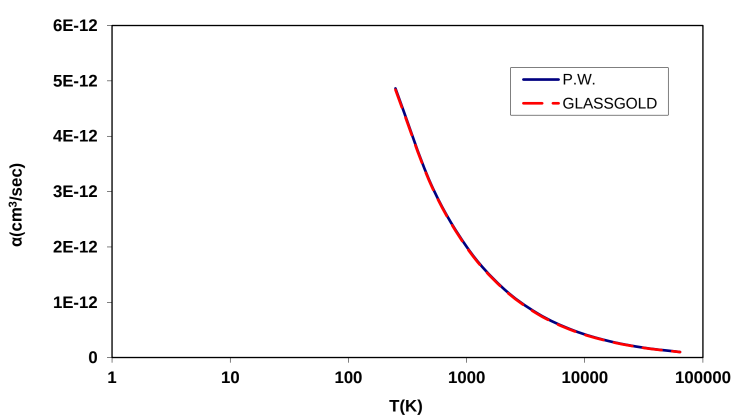
In this paper we deal with the interaction of electrons with (H I, He I, He II, N V, N VI, N VII) ions, to calculate the radiative recombination rate coefficient (RRC) as a function of electron temperature, we also compare the resulting calculations with the available data of other researchers.

In Figure(1) we compare our calculations of RRC for (H I) ion with the theoretical data of Glssgold[12] for temperature range $250K - 64\times10^3 K$, the agreement is nearly match. In figures (2) and (3) our results of RRC for (He I) and (He II) ions were compared with Nahar [9] data. HeI–ion showed a good agreement in the low temperature range until $10^5 - 10^6 K$, in this rage a disagreement had raised represented by a resonance . While He II-ion showed a good agreement between our calculations and Nahar's. In figures (4), (5), and (6) our calculations of RRC for (N V, N VI, and N VII) ions are all compared with the theoretical data of Nahar & Pradhan[10]. Both N V- ion and N VII showed a very good agreement, whereas for V II the RRC for the temperature range $10^6 - 10^9 K$ the disagreement begins to rise.

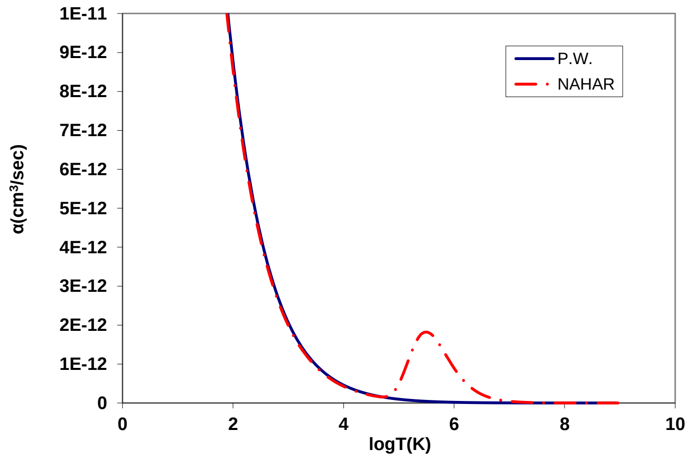
The reason of disagreement between our results of RRC and Nahar, Nahar & Pradhan data for (He I and N VI), return to that at low temperature RRC is high due to the dominance of RR in to an infinite number of high-n levels and decreases over a wide temperature range since the autoionization resonances do not appear until at high energy. Nahar, Nahar & Pradhan RRC forms a small "bump" at high temperature due to dominant DR process, and decays smoothly.

Conclusions

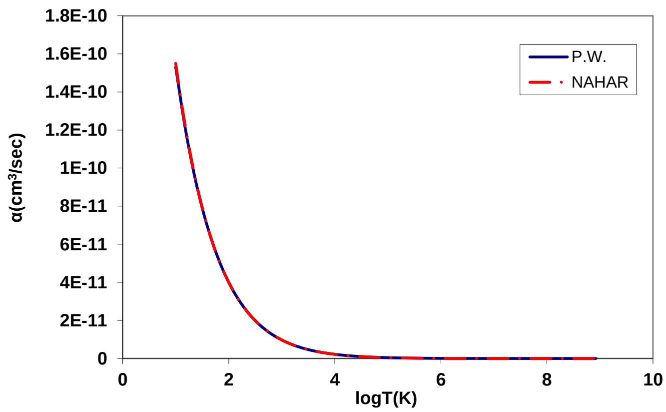
Radiative recombination rate coefficients have been studied for (Hydrogen, Helium and Nitrogen) ions. Most of the available comparison of RRC are non-resonant and there is a good agreement among the published results, as they all fall on the same curve in the region where RR is dominates. The DR rate coefficients peak around the same temperature, but the rates are slightly higher than the present values. Our formula doesn't consider interference between RR and DR, whereas Nahar used a method unified between RR and DR, and hence could be the possible reason for the difference or disagreement at high temperatures for some ions.



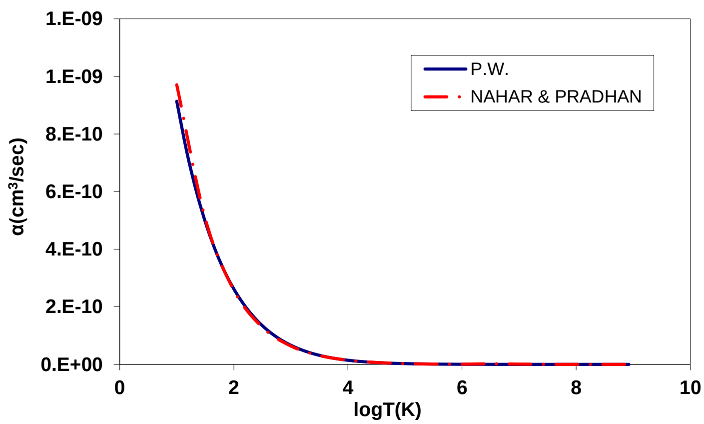
FIG(1):RADIATIVE RECOMBINATION RATE OF (H I)-ION.
THE PRESENT WORK(P.W.) COMPARED WITH GLASSGOLD.



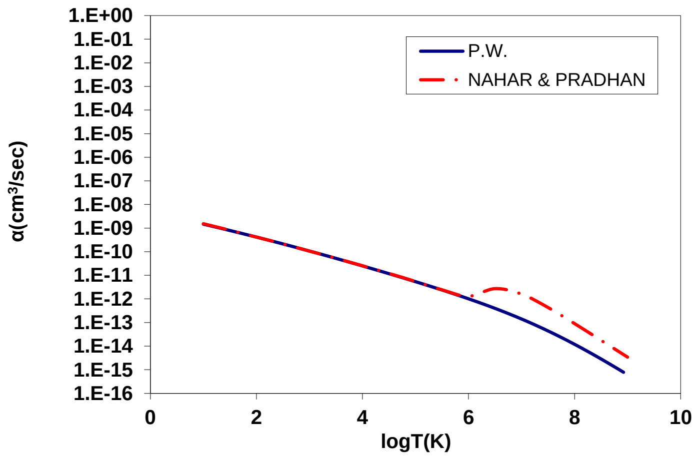
FIG(2):RADIATIVE RECOMBINATION RATE OF (He I)- ION.
THE PRESENT WORK(P.W.) COMPARED WITH NAHAR.



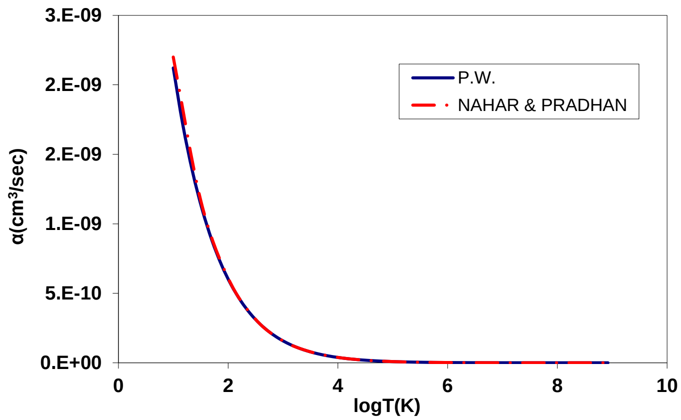
FIG(3):THE SAME AS FIG(2), EXCEPT FOR (He II)-ION.



FIG(4):RADIATIVE RECOMBINATION RATE OF (N V)-ION.
P.W. COMPARED WITH NAHAR & PRADHAN.



FIG(5):THE SAME AS IN FIG(4), EXCEPT FOR (N VI)-ION



FIG(6):THE SAME AS IN FIG(4), EXCEPT FOR (N VII)-ION

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حساب معاملات معدل اعادة الاتحاد المشع المعتمد على الحرارة للايونات

تاريخ الاستلام 2015/2/8 تاريخ القبول 2015/10/5

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ملخص

نتناول معاملات معدل اعادة الاتحاد المشع لعدد من الايونات ذات القشرات المغلقة والمفتوحة، (H I, He I, He II, N V, N VI, N VII) وتمت الدراسة لمدى درجة حرارة الالكترون $10-10^9$ كلفن. اجريت الحسابات في اطار استخدام صيغة معاملات التلائم التحليلي من دون تضمين التأثيرات النسبية في الصيغة المستخدمة. قورنت النتائج المستحصلة لمعاملات اعادة الاتحاد كدالة لدرجة الحرارة مع المتوافر من القراءات النظرية حيث اظهرا المقارنة توافق جيد جدا. بعض القراءات التي تمت المقارنة معها اظهرت قمم عند درجات الحرارة العالية سببها تأثيرات الرنين على تصرف معاملات اعادة الاتحاد.

كلمات مفتاحية: الحرارة، معامل اعادة الاتحاد المشع.