National Conference on Recent Trends in Synthesis and Characterization of Futuristic Material in Science for the Development of Society (NCRDAMDS-2018)
In association with
International Journal of Scientific Research in Science and Technology

Investigation of Ionization Recombination and Fractional Abudances of Different Ionic Spieces

A. P. Pachkawade
Rajarshee Shahu Science College, Chandur Rly, Amravati, Maharashtra, India

ABSTRACT

We obtained the ionization and recombination rate coefficients of the ions of Zn, Mg, Cd, Na, K, Se, Cu, Zr, Li, Ba, and Ni. From the knowledge of the ionization and recombination rate coefficients the fractional abundance's of different ionic species of the elements have been obtained. Displays of fractional abundances show that singly ionized elements (alkali metals and alkaline earth metals) may play very important role in the discharges. The singly ionized species show its appearance over very wide range of electron temperature. Further doubly ionized Magnesium also shows its appearance over very wide range of electron temperature.

Keywords: Laser radiation, inversion density, ionization and recombination, dimensions of the laser plasma.

I. INTRODUCTION

M.H.Elghazaly etal. (2007) have studied [1], the most important rate coefficients for electron collisions in noble gases, electron-neutral ionization and electron impact excitation [1]. S W Simpson et al. (1990) have studied ionization and recombination rates in argon plasmas [2]. They presented approximate model for treating multi-step ionization and recombination in inert gas plasmas [2].

The glow discharge consists of the electrons and the ions with different charges. The collisions between the atoms, ions of different charges and electrons result in ionization. At the same time the ions may capture the electrons and result in formation of ions of lower charge. The ionization and recombination processes compete each other so that the ionization rate and recombination rates reach; each to a certain value and the equilibrium is attained. As long as the electron temperature is not changed the equilibrium remains in a particular state. A change in electron temperature results in changing the densities of ions and electrons. Thus the densities of ions and electrons are completely dictated by the electron temperature. The discharge emission depends upon the fraction of the total density of a species remaining in a particular ionized state, the electron density and the electron temperature.

Fractional"The amount of the fraction of the total density of a species remaining in a particular ionized state is called as fractional abundance of that ion".

.

The concepts of fractional abundances have been widely used in order to explain the experimental results in Tokmak plasma discharge. Mathematically it may be expressed as [3,4,8]

$$F_{Z'} = \frac{N_{Z'}}{\sum_{Z} N_Z} \qquad (1)$$

where $F_{z'}$ is the fractional abundances of the ion with charge z'

1) **$N_{z'}$ is the density of ion with charge z' Lotz cross section for electron impact ionization rate coefficient may be written as**

$$S_Z = 6.7x10^7 \sum_{i=1}^{N} \left(\frac{q_i \xi_i}{T_e^{3/2}} \right) \cdot \left(\frac{1}{\left(\frac{P_i}{T_e} \right)} \right) \cdot \int_{P_i/T_e}^{\infty} \frac{e^{-x}}{x} dx \quad \text{cm}^3\text{sec}^{-1} \; (2)$$

Where, T_e - electron temperature in eV.

P_i - number of equivalent electrons in the subshell. ζ_1 is the number of equivalent electrons in this subshell.

Lotz formula for obtaining the cross-sections, works with all types of velocity distributions of the discharge electrons.

II. RECOMBINATION RATES AND RATE COEFFICIENTS

The recombination processes are divided into two categories depending on the initial states such as I) Radiative recombination and ii) Dielectronic recombination. The total recombination rate of an ion is the sum of these two rate coefficients.

1. Radiative Recombination Rate

Breton et at [4] suggested the formula for the calculation of recombination rate in plasma having above range of parameter values and it is expressed as

$$\alpha_{TZ} = 2.6X10^{-14}(\alpha_1 + \alpha_2) \quad cm^3 sec^{-1} \quad (3)$$

Where,

α_1 and α_2 for Maxwellian distribution of electron density are given as

$$\alpha_1 = Z^2\left(\frac{I_H}{T_e}\right)^{1/2}\frac{\mu}{n^3}\left(\frac{I_{Z-1}}{T_e}\right)e^{I_{Z-1}/Te}.E_1\left(\frac{I_{Z-1}}{T_e}\right) \mathrm{cm^3sec^{-1}}$$

and

$$\alpha_2 = \sum_{v=1}\left(\frac{2}{(n+v)^3}.Z^4\right)\left(\frac{I_H}{T_e}\right)^{3/2}\exp\left(\frac{Z^2 I_H}{(n+v)^2.T_e}\right)E_1\left(\frac{Z^2 I_H}{(n+v)^2.T_e}\right) \mathrm{cm^3sec^{-1}}$$

where

I_H is ionization potential of hydrogen i.e. 13.6 eV,

n is principle quantum number,

I_{z-1} is ionization potential of ion after recombination,

μ is the number of empty places in the valence shell,

$E_1(x)$ is the exponential integral function.

The function E(x) is known as an exponential integral function and it is expressed in the form

$$E_1(\times) = \int_0^{\infty}\frac{e^{-x}}{x}dx \qquad (6)$$

2. Dielectronic Recombination Rate

The dielectronic recombination rates of the ions existing in plasma have been investigated in details [5-7]. The electron density in plasma has some influence on the radiative recombination rate. If the influence of electron density is neglected, the dielectronic recombination rate coefficient of an ion with charge Z can be expressed as

$$\alpha_{dZ} = \frac{1}{T_e^{3/2}}B_{(Z)}\sum_j A_{(Z,j)}\exp\left(-\frac{E_{Zj}}{T_e}\right) \quad cm^3 \; sec^{-1} \quad (7)$$

The summation extends over all the resonance levels j of the recombining ions of charge Z so that the total recombination rate is obtained.

Where E_{zj} is total energy of the resonance transition j, and the terms B(z), A(z,j) are obtained as

$$B_{(Z)} = 6.5 \times 10^{-10} Z^{1/2} (Z+1)^2/(Z^2 + 13.4)^{1/2} \quad (8)$$

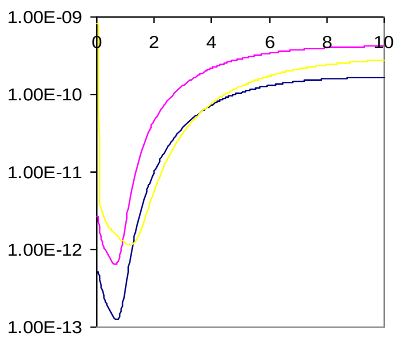
and

$$A_{(Z,j)} = \frac{f_{Zj}(E_{Zj})^{1/2}}{1 + 0.105\chi_{Zj} + 0.015\chi_{Zj}^{\;2}} \qquad (9)$$

where f_{zj} is the absorption oscillator strength of the resonant transition j of ion z and the factor χ_{zj} is given by

$$\chi_{zj} = \left(\frac{E_{zj}}{(Z+1)}\right).IH \qquad (10)$$

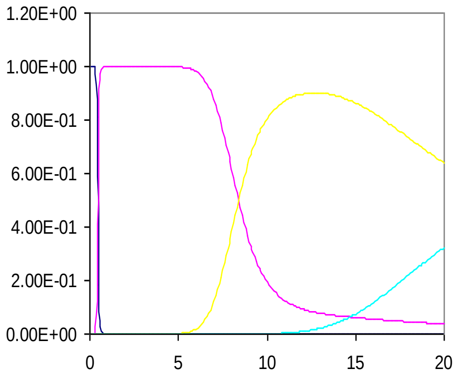
III. RESULT AND DISCUSSION



Electron temperature (eV)

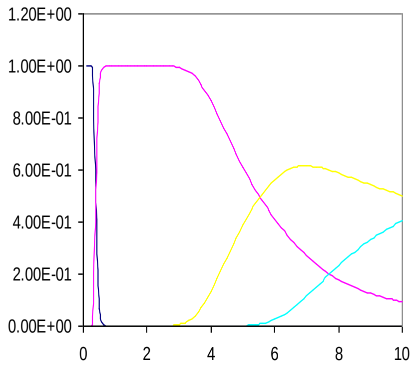
Figure 1. Total recombination rate coefficient of CuI,CuIII and CuIV as a function of electron temperature

We have computed the radiative recombination rate coefficient as well as dielectronic recombination rate coefficient of CuII, CuIII and CuIV in the discharge as a function of electron temperature from 0 through 10 eV. The total recombination rate coefficients are then obtained by adding the corresponding values of above two recombination rate coefficients. The radiative and dielectronic recombination rate coefficients for CuII, CuIII and CuIV are plotted as a function of electron temperature and the total recombination rate coefficients for these species are plotted as a function of electron temperature in figure 1. The curves in these figures clearly show that at low electron temperature the radiative recombination rate coefficient is of the order of (10^{-13}-10^{-12}) cm^3 sec^{-1}. When the electron temperature is near to zero the electron moves slowly in the plasma. The ions in plasma can very easily capture the slow moving electrons and recombine. Thus there is more probability of radiative recombination at electron temperature near zero.



Electronic temperature (eV)

Figure 2. Fractional Abundance of LiI,LiII,LiIII and LiIV as a function of Electron Temperature



Electronic temperature (eV)

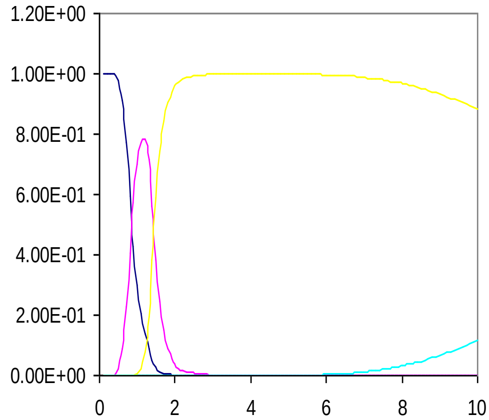
Figure 3. Fractional Abundance of NaI,NaII,NaIII and NaIVas a function of electron temperature

As the temperature increases the electrons move faster and it becomes difficult for an ion to capture the electron and therefore the radiative recombination rate coefficient decreases. At low electron temperature the dielectronic recombination is low as the rate of excitation of the resonant states of the ion is low. The increase of electron temperature increases the excitation rate of the resonant states and hence increasing the dielectronic recombination rate. It is found that the dielectronic recombination rate tends to saturate for electron temperature above 4 eV.

At low electron temperature the entire contribution to the total recombination rate is of the radiative recombination process. As the electron temperature is increased to about 1 eV the total recombination rate coefficient decreases and reaches a minimum value. As the electron temperature is further increased the total recombination rate increases. This is because of the increase in the dielectronic recombination rate coefficients. This increase continues and starts saturating at the electron temperature of about 2eV and becomes almost saturated at electron temperature of 4eV.

We obtained electron impact excitation rate coefficients, recombination rate coefficients and fractional abundances of the elements like Li, Na, Mg, K, Cu, and Zn, , as a function of electron temperature. The results are displayed in the figures 2 through 7 The results showed that at electron temperature very near to zero the entire species is in neutral form. As the electron temperature is increased the neutral atoms are converted into singly ionized species. Further increase in electron temperature converts singly ionized species into doubly ionized species. This implies that in order to get highly ionized species the electron temperature in the plasma column should be increased.

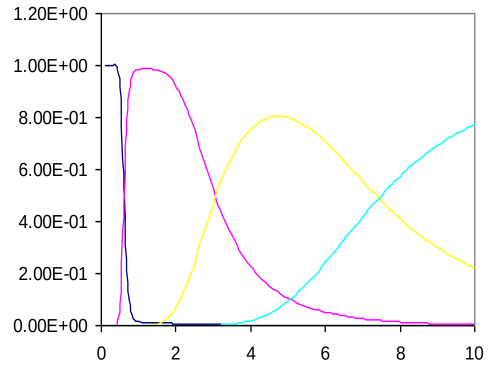
The keen observation of the displays of fractional abundances show that singly ionized elements (alkali metals and alkaline earth metals) may play very important role in the discharges. The singly ionized species show its appearance over very wide range of electron temperature. Further doubly ionized Magnesium also shows its appearance over very wide range of electron temperature. The results related to fractional abundances also show that the species like Li II, Na II, K II and Mg III may play the role of buffer gas in case of shorter wavelength Laser designs. The design of X-ray Laser can get some ideas about the operation of the Laser and operating temperature of discharge.



Electronic temperature (eV)

Figure 4. Fractional Abundance of MgI,MgII,MgIII and MgIV as a function of Electron Temperature

The species like Li II, Na II, K II and Mg III may play very important role in the penning ionization process in the glow discharge.



Electronic temperature (eV)

Figure 5. Fractional Abundance of CuI,CuII,CuIII and CuIVas a function of Electron Temperature

IV. REFERENCES

[1]. M.H.Elghazaly and S.Solyman, J. of Quantitative Spectroscopy and Radiative Transfer, Vol. 103,Issue 2, pp. 260-271, Jan 2007

[2]. S W Simpson, J.Phys. D: Appl. Phys. 22, pp.1161-1167, 1990

[3]. Ph.D. thesis, K.P.Kadam, , SGBAU, Amravati, 2008

[4]. C.Breton, C.DE Michelis and M.Mattioli,J.Quantitative Spectroscopy: Radiative Transfer Vol.19,pp.367, 1978.

[5]. A. Burgess, Astro. Phys. J. Vol.107,pp.6,1948

[6]. I.L.Beigman, L.A.Vainstien and R.A.Syunyaev, n Sov.Phys.Usp.Vol.11,pp.411,1968.

[7]. L.A.Vainstien, I.A. Sobelman and E,A, Yucou, Cross Section for excitation of atoms and ions by electrons, Nauka, Moccow,1973.

[8]. TFR Group, Nuclear Fusion 15, 1053,1975