Recombination of ionic species in the laser discharge as a function of electron temperature

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Abstract : The laser plasma consists of particles having different velocities. They undergo collision which intern give rise to various processes like ionization, excitation and recombination etc. Different types of recombination processes that can exist in the laser plasma have been studied. In particular theories proposed by Seaton, Breaton and Jorden have been considered in brief. The radiative, dielectronic and total recombination rate coefficients of different species of helium and cadmium has been computed as a function of electron temperature and some results are presented graphically

Key Word **- excitation, recombination, radiative recombination, dielectronic recombination, electron temperature.**

I. INTRODUCTION

When matter is heated to high temperature, the number of collisions made by the particles in the matter increases. During the collision process electrons are detached and the matter gets ionized, such an ionized matter at very high temperature is called plasma. The plasma is characterized by various parameters like electron temperature, electron density, ion temperature and ion density etc. and by the type of particles which are ionized. Beside the process of ionization and excitation another important reaction called as recombination takes place in laser plasma.

In the laser plasma discharge, when a positive ion come in contact with an electron, the ion tries to capture the electron and recombine to form an ion in which the positive charge of the ion gets reduced by unity. Probability of capturing the electron depends upon velocity of the electron relative to the ion, the distance between the ion and electron etc. During recombination process the positive ion may either be in the ground or excited state. Depending upon the initial state of positive ion the recombination process is divided into two types as Radiative recombination process and Dielectronic recombination process.

When an ion of charge z in the ground state captures an electron and recombines into one of the energy levels of an ion with charge z-1. During the process of electron capture, a continuum spectrum is emitted. This process is called as radiative recombination. The rate of radiative recombination depends upon the density of the ions of charge z in the ground state, density of the electrons and electron temperature. In dielectronic recombination two electrons are involved. One electron is used to excite the positive ion from the ground state to a resonance state. When this positive ion of charge z comes in contact with an electron then it recombine to form an ion of charge z-1. The dielectronic recombination rate depends upon density of ions with charge z in the excited state, the electron density and recombination rate coefficient.

The He-Cd^+ discharge consist of helium and cadmium ion with different fractional densities. The radiative recombination of these ions takes place according to following reactions.

He III + e ---------- He II* + hν
He III + e ---------- He II* + hν
Cd IV + e ---------- Cd III* + hν
Cd III + e ---------- CdI II* + hν
Cd II + e ----------- CdI I* + hν

The dielectronic recombination process takes place as follow.

He II* + e --------- He I* + hν (continuum)
Cd IV* + e -------- Cd III* + hν (continuum)
Cd III* + e -------- Cd II* + hν (continuum)
Cd II* + e --------- Cd I* + hν (continuum)

The star indicates that ions are in the excited state.

Radiative recombination rate coefficient

M J Seaton [1, 2] proposed a theory for the calculations of ionization and recombination rates in the solar corona. According to Seaton the recombination rates can be calculated by using the equation

$$\sigma_{z+1} = 1.3033 * 10^{-11} \left({Z^2}/{T} \right) \left({I_z}/{kT} \right)$$

Where z is the charge, T is the temperature and σ_{z+1} is a slowly varying function of I_z/kT. But the values of electron density and electron temperature in the laser discharge tube t optimum conditions are very large as compared to the values of electron density and electron temperature in solar corona. Thus Seaton's formula cannot be used for the calculations of recombination rate coefficients.

In general the employed formula which may be used for the calculations of radiative recombination rate coefficient in the plasma where the range of electron temperature is few electron volts and electron density is in between 10^{12} to 10^{13} $cm^3$is given by [3].

$$\sigma_{rz} = 2.6 * 10^{-14} (\alpha_1 + \beta_1)\, cm^3/sec$$

$$\text{where } \alpha_1 = z^2 \left({\mu}/{n^3} \right) exp \left({I_{z-1}}/{T_e} \right) E_1 \left({I_{z-1}}/{T_e} \right) \frac{I_H^{1/2}}{T_e^{1/2}} cm^3/sec$$

$$\beta_1 = \sum_{v=1} 2z^4/(n+v)^3 \left[\exp {z^2 I_H}/{(n+v)^2 T_e} \right] E_1(z^2 I_H/(n+v)^2 T_e)\, cm^3/sec$$

where I_H = 13.6 eV is ionization potential of H2 atom,

I_{z-1} is ionization potential of ion after recombination,
μ = (2n²-p) is the number of empty spaces in the valence shell, n is principal quantum number
and $E_1(X)$ exponential integral function.

Dielectronic recombination rate

Some workers from plasma physics [4-6] have calculated dielectronic recombination rate. If the electron density is neglected, then the rate coefficient may be expressed as

$$\alpha_{dz} = \frac{1}{Te^{\frac{3}{2}}} B_z \sum_j A_{(zj)} exp\left(-E_{zj}/T_e\right) cm^3/sec$$

The sum in the equation is extended over all possible resonance levels j of the recombining ion of charge z so that total recombination rate is obtained, E_{zj} is the energy of resonance transition j. The term $B_{(z)}$ and $A_{(zj)}$ for the given atomic species are functions of z. This equation may be used for the calculations of recombination rates of light and heavy ions also. The constants A and B are the functions of z and oscillator strength. They are obtained by using the equation

$$B_{(z)} = 6.5 * 10^{-10} \frac{z^{1/2}(z+1)^2}{(z^2+13.4)}$$

$$A_{(zj)} = \frac{f_{zj} E_{zj}^{\frac{1}{2}}}{1 + 0.105\chi_{zj} + 0.015\chi_{zj}^2}$$

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

$$\chi_{zj} = \frac{E_{zj}}{(z+1)I_H}$$

II. RESULTS AND DISCUSSION

We have computed the radiative, dielectronic and total recombination rate coefficients of HeI and HeII ions as a function of electron temperature. The total recombination rate coefficient is obtained by adding radiative and dielectronic recombination rate of the corresponding ions. When the electron temperature is low the results are displayed in figure 1. When the electron temperature is very low (nearly equal to zero eV), the electrons moves very slowly in the plasma. Thus the ions in the plasma can easily capture these slowly moving electrons and recombine with them. Thus there is a more probability of radiative recombination when the electrons are at low temperature. The probability of dielectronic recombination is very less at low electron temperatures because the rate of excitation of the resonant states is very low. At low temperatures the value of radiative recombination rate coefficient is about 10^{12} to 10^{13} cm^3/sec.

As the electron temperature is increased, there is an increase in the average kinetic energy of the electrons. Consequently the electrons moves with the high velocity and it becomes very difficult for the ions to capture the electrons moving with high velocities and therefore radiative recombination rate coefficient becomes low at higher temperatures. Whereas if the electron temperature is increased, the excitation rate of the resonant states also increases and the probability of the dielectronic recombination rate coefficient starts increasing.

If the electron temperature is increased further then the dielectronic recombination rate coefficient starts rising continuously and it saturates at some particular value of the temperature. The radiative recombination rate coefficient starts to decrease as the electron temperature is increased. In general at high electron temperatures radiative recombination rate is very less than dielectronic recombination rate.

The total recombination rate coefficient is obtained for CdII, CdIII and CdIV as a function of electron temperature and the results are displayed in figure 2. At very low temperature the entire contribution to the total recombination rate coefficient is due to radiative process. As the electron temperature is further increased, the radiative recombination rate decreases and it reaches a minimum value near 1.5 eV. With further increase in electron temperature the dielectronic recombination rate starts increasing. At low temperatures the contribution of dielectronic recombination rate to the total recombination rate is very small and it can be neglected. If the electron temperature is further increased the contribution of radiative recombination rate coefficient decreases and the contribution of contribution of dielectronic recombination rate coefficient becomes considerable. Therefore total recombination rate coefficient starts to increase and it saturates at some value of the electron temperature. Still further if we increase the electron temperature the radiative recombination rate coefficient becomes very less and the dielectronic recombination rate coefficient becomes dominant and hence total recombination rate coefficient is almost equal to the dielectronic recombination rate coefficient. At very high electron temperature the probability of both the radiative and dielectronic recombination decreases and hence total recombination rate coefficient also decreases.

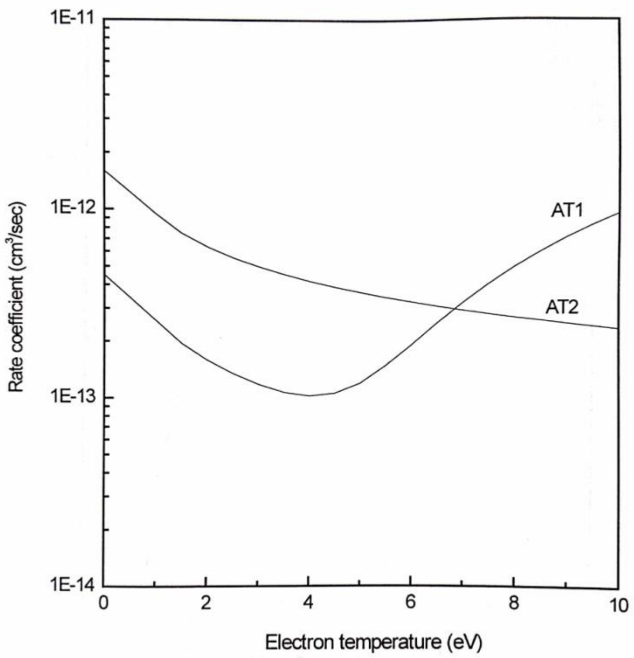

Fig1: Total Recombination rate coefficients of HeI(AT1) and HeII(AT2) as a function of electron temperature

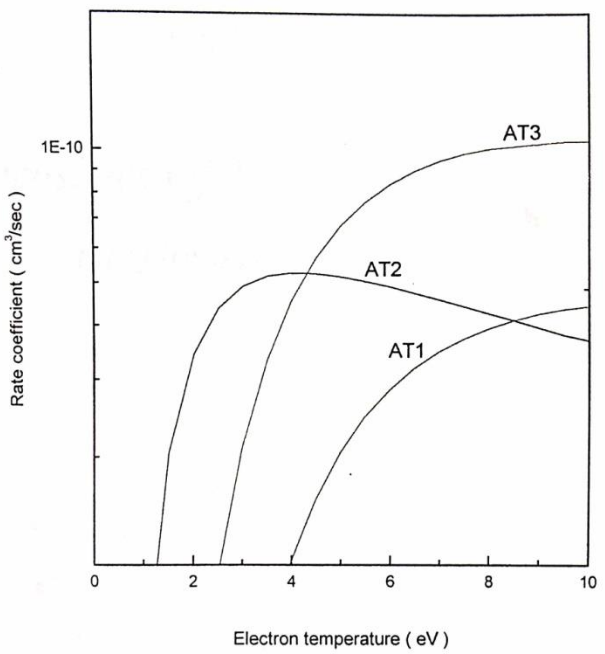

Fig2: Total Recombination rate coefficients of CdI(AT1),CdII(AT2) and CdIII(AT3) as a function of electron temperature

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