



EXCITATION RATE COEFFICIENTS OF MOLYBDENUM ATOM AND IONS IN ASTROPHYSICAL PLASMA AS A FUNCTION OF ELECTRON TEMPERATURE

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ABSTRACT:

In present work Excitation rate coefficients of the states of Molybdenum ions have been obtained using widely utilized standard formulae proposed by Breton [1] based on Bethe Born approximation. The excitation rate coefficients of Molybdenum ions in Astrophysical plasma are determined as a function of electron temperature and are presented graphically. From graphs it shows that, the Excitation Rate Coefficient is a very sensitive function of electron temperature before it reaches its peak value and becomes very slow varying function of Electron Temperature near its saturation value.

KEYWORDS: Excitation Rate Coefficient, Electron Temperature, Stepwise excitation, Electron Impact excitation, Inelastic collisions.

1. INTRODUCTION

It is well known that energy states of atoms and ions in the plasma are populated by electron collisions and depopulated by collisions of ions with slow electrons. Besides the collisional processes the atomic and ionic states are populated and depopulated due to some radiative processes also.

Electrons passing through the plasma transfer their energy to the plasma particles by two types of collisions, i) Elastic collisions ii) Inelastic collisions.

In elastic collisions the transfer of kinetic energy of electron in to the kinetic energy of the plasma particles (atoms or ions) takes place. In this process the kinetic energy of the colliding particles is conserved. This type of collisional process is responsible to the heating of the plasma particles to some extent. In fact the second type of collision i.e. inelastic collisions are mainly responsible

for the excitation of atoms and ions in the plasma. Any collision in which the internal energy of excitation of a particle is changed is referred to as inelastic collision. In this type of collision the kinetic energy of electron is converted into potential energy of colliding plasma particles and the plasma particles get excited. These particles in excited states either transfer their energy back to the electron or they undergo a transition giving radiative emission. The rate of transfer of energy from the electrons to the plasma particles may be written as,

$$\frac{dE}{dt} = N_g C_e N_e E_c + \sum_j N_{g_i} N_e C_m E_j - \sum_j N_{g_i} N_e C_{dex} E_i \quad (1)$$

where,

N_g is number of gas particles.

C_e is coefficient of elastic collision.

E_c is energy transferred in elastic collisions.

C_{in} is rate coefficient of inelastic collisions.

E_j is energy of the j^{th} state excited by elastic collision.

C_{dex} is de-excitation rate coefficient.

E_i is energy of excited particles which transfers its energy to the electrons. The sum runs over all possible energy states of the plasma particles.

2. EXCITATION PROCESSES

The processes which can populate or depopulate the states of plasma particles are listed below.

- i) Stepwise excitation ii) Direct excitation
- iii) Penning excitation iv) Duffenduck excitation

2.1 ELECTRON IMPACT EXCITATION (EIE)

In this case the energy from the high energy electrons is transferred to the colliding atoms or ions in the plasma. When an electron having energy more than the excitation energy of an electron rotating around nucleus of an atom / ion collides with the atom / ion may transfer its energy to the system and this may result in excitation of the rotating electron to a higher orbit. The probability of excitation depends upon energy of exciting electron and cross section of excitation at that particular energy. The excitation rate depends upon the excitation cross section and the number of effective collisions made by the electron. The number of effective collisions is function of electron velocity, which in turn is a function of electron temperature (T_e).

As we know that the plasmas consists of atoms, ions and electrons, there can be two types of electron impact excitation processes depending upon whether the colliding particles are atoms in ground state or ion in ground state.

2.1.1 DIRECT AND STEPWISE EXCITATION

The EIE rate coefficient is expressed in terms of excitation cross section σ and electron velocity V_e as $\langle \sigma V_e \rangle$. Now for the two types of electron impact excitations we can write,

$$R = \langle \sigma_s V_e \rangle \quad (2)$$

and

$$D = \langle \sigma_d V_e \rangle \quad (3)$$

where,

R is EIE rate coefficient due to stepwise excitation.

D is EIE rate coefficient due to direct excitation.

σ_s is EIE cross section for states from ground state of ions.

σ_d is EIE cross section for the states from ground state of neutral atom.

The velocity of an electron is function of its energy and related to its energy E by the relation,

$$V_e = 5.9 \times 10^7 (E)^{1/2} \quad (4)$$

The number dN of the electrons having energy between E and $E+dE$ is given for Maxwellian distribution by equation,

$$dN = N \times (2 / KT_e)^{3/2} \times \exp(-E / KT_e) dE \quad (5)$$

Thus the rate of excitation of energy levels by stepwise and direct excitation are respectively expressed as,

$$dR = N \times (2 / KT_e)^{3/2} \times \int (\sigma_s V_e) \times \exp(-E / KT_e) dE \quad (6)$$

and

$$dD = N \times (2 / KT_e)^{3/2} \times \int (\sigma_d V_e) \times \exp(-E / KT_e) dE \quad (7)$$

The total excitation rate coefficient can be obtained by integrating above equation within the limits from 0 to ∞ .

As the excitation process does not occur if the energy of incident electron is less than the threshold energy E_s , the excitation cross section is zero for energy less than E_s . Therefore the lower limit of integration is taken as E_s instead of zero.

Further it is convenient to express the electron temperature and electron energy in eV. If T_e , E and dE are all in eV and cross section values are in cm^2 , the equation (6) and equation (7) be written as,

$$R = \frac{6.7 \times 10^7}{(T_e)^{3/2}} \int_{E_i}^{\infty} \sigma_s E \text{EXP}(-E / KT_e) dE \text{ cm}^3 \text{ sec}^{-1} \quad (8)$$

and

$$D = \frac{6.7 \times 10^7}{(T_e)^{3/2}} \int_{E_i}^{\infty} \sigma_d E \text{EXP}(-E / KT_e) dE \text{ cm}^3 \text{ sec}^{-1} \quad (9)$$

respectively.

These equations clearly show that if the values of the excitation cross section are known at different values of the electron energy, the excitation rate coefficients may be obtained at different electron temperatures.

2.2 PENNING EXCITATION

Excitation energy can be exchanged between neutral atoms. In particular, an excited atom can get ionized by virtue of its excitation energy, if the later is larger than the required ionization energy. Such a process is made more probable if the excited atom is in metastable state and has thus longer lifetime in which the particle may undergo an effective collision. When one of the colliding atoms is in metastable state and the other one is in ground state, there is a probability of ionizing second atom and getting excited to the excited state depending upon the energy of the metastable atom. Such a process is referred to as penning excitation.

2.3 DUFFENDUCK EXCITATION

The process in which an ion having charge z in a ground state, when collide with the other ion having charge z' in ground state, transfers its energy to the colliding partner and the other ion gets ionized. This process of ionization and excitation of one ion and recombination of other ion is known as duffenduck excitation or charge transfer.

For computation of excitation rate coefficients, we have used the formula proposed by Breton [1] which is useful for

computation of excitation rate coefficient of heavy atoms like iron and molybdenum as a function of electron temperature. The formula proposed by Breton is based on the Bethe-Born approximation for optically allowed transitions [2] which is given below.

$$Q = 1.6 \times 10^{-5} e^{-\beta} \times \frac{f \bar{g}(\beta) (\beta)^{1/2}}{(\Delta E)^{3/2}} \quad (10)$$

where Q is in $\text{cm}^3 \text{ sec}^{-1}$, ΔE is the excitation energy in eV. $B = (\Delta E / T_e)$

where, T_e the electron temperature in eV. f is the absorption oscillator strength.

$\bar{g}(\beta)$ is the average effective Ground factor.

The expression for $\bar{g}(\beta)$ which is proposed by Mewe [3] and is given below.

$$\bar{g}(\beta) = A + (B\beta - C\beta^2 + D)e^{\beta} E_1(\beta) + C\beta.$$

where A , B , C and D are adjustable parameters. This formula may also include optically forbidden monopole or quadrapole transitions (for example H - like ions, the $1s \rightarrow ns$ or $1s \rightarrow nd$ transitions respectively) and spin exchange transitions (for example singlet-triplet transitions in He like ions). In these cases, f in equation (10) assumes the f values of the allowed transitions to the level with the same principle quantum number. This means for example, for the transition

$1s \rightarrow ns$ and $1s \rightarrow nd$ in the H - like sequence the f value of $1s \rightarrow np$ is chosen: for $1s2^1S \rightarrow 1s 2s^3S$ in the He like sequence, that of $1s2^1S \rightarrow 1s 2p^1P$ is used.

The molybdenum transition that are included in excitation rate coefficient computations together with wavelengths λ , the excitation energies ΔE and the f values, we used the values in C. Breton et al [1]. The isoelectronic sequences and transitions considered are the same as for Iron ; the wavelength λ were either taken from calculations [6] or elsewhere obtained by extrapolation. The absorption

oscillator strength f were taken from [4 to 7] otherwise, we used the systematic trends of f in isoelectronic sequences [4] as a function of nuclear charge Z_n , starting from the values for Iron. Thus for $\Delta n = 0$ transitions, we used $f \sim (f_1/Z)$: for $\Delta n \neq 0$ transitions $f \sim (f_0 + f_1/Z)$. In this second case we have assumed that $f_1/Z < f_0$ and have taken for Mo the same values as for Fe (this is justified by the fact that, in all cases considered in [5], the variations of f between Fe and Mo are smaller than 5%).

The excitation rate of an energy level of an ion is given by,

$$\frac{dN_u}{dt} = N_e N_z R_{zu} \quad (11)$$

where,

N_e is the electron density.

N_z is the fractional density of the ion of charge z

R_{zu} is the electron impact excitation rate coefficient of the state of ion of charge z .

The excited states in the plasma are dexcited by radiative transitions. Therefore we may write,

$$\frac{dN_u}{dt} = \frac{-N_u}{\tau} \quad (12)$$

where τ is the radiative life time of the state.

When the plasma is in steady state the excitation rate of a state would be equal to dexcitation rate. Therefore,

Rate of excitation = Rate of dexcitation.

The energy states of the ions dexcite only because of the radiative decay and therefore we may write,

Rate of excitation is equal to Rate of dexcitation by radiative decay. In other words, we can write, Rate of excitation is directly proportional to Rate of photon emission.

Thus, Rate of excitation is directly proportional to Intensity of Radiation.

Therefore, Intensity of radiation is directly proportional Rate of photon

emission and Rate of excitation of the energy states.

3. RESULTS AND DISCUSSION

The excitation rate coefficient is very useful function in computing the contribution functions of various spectral lines. In present work, to study the excitation rate coefficient of different ionic species of molybdenum, we have computed excitation rate coefficients of Mo XXV through Mo XLII using Bretons formula [1] as a function of electron temperature. To study the behavior of excitation rate coefficient, We have computed excitation rate coefficient of all the molybdenum ions and results for Mo XXV to Mo XXVIII and Mo XXXV to Mo XXXVIII are displayed in figure (1) and figure (2) respectively as a function of electron temperature.

In all figures it is observed that the general behavior of the curves is almost similar for all the molybdenum ions. From the nature of the graph, it is seen that, initially, as the electron temperature is increased from lower value, the excitation rate coefficient increases linearly. But as the electron temperature approaches to a value at which the excitation rate coefficient becomes maximum, the excitation rate coefficient increases non-linearly. The non linearity in the curve increases as excitation rate coefficient approaches towards saturation. Further; the electron temperature increases, the value of electron temperature at which excitation rate coefficient saturates, the excitation rate coefficient decreases but rate of decrease in excitation rate coefficient will be very slow. From all the graphs in figure (1) and (2), it shows that the excitation rate coefficient (ERC) is very sensitive function of the electron temperature before it reaches its peak value but the variation of the function becomes very slow varying function of electron temperature near its saturation value. For example in figure 6.3, the ERC for Fe XV increases linearly upto electron temperature 9 eV. The curve proceeds

nonlinearity till the ERC reaches to saturation. ERC reaches to saturation at electron temperature 135 eV.

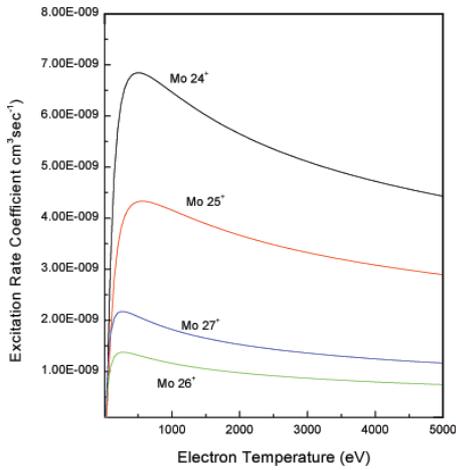


Fig.1 Excitation Rate Coefficient As A Function Of Electron Temperature.

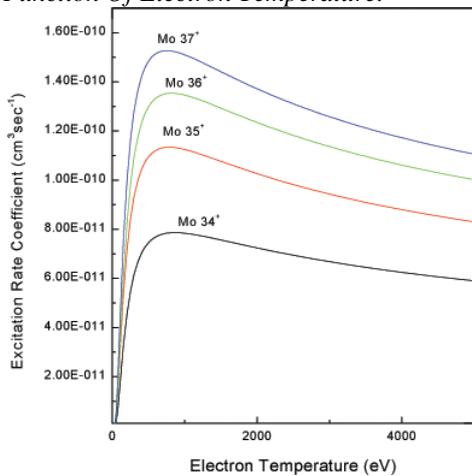


Fig. 2 Excitation Rate Coefficient As A Function Of Electron Temperature.

Excitation rate coefficient (ERC) is very sensitive function of the electron temperature before it reaches its peak value but the variation of the function becomes very slow varying function of electron temperature near its saturation value.

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4. CONCLUSION