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EXCITATION MECHANISM
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4.1 Introduction:

The energy states of atoms in the discharge are populated by electron collisions (1, 2) and depopulated by collisions with slow electrons and walls. The states are populated and depopulated due to some radiative processes (3-6) also. The electrons passing through the discharge transfer their energies to the gas particles by two types of collisions i) Elastic collisions. ii) Inelastic collisions. In elastic collision the transfer of kinetic energy from one particle to the kinetic energy of other gas particle takes place in the process and kinetic energy of colliding particle is converted. In the elastic collisions in the discharge the energy is utilized to increase the temperature of electrons and particles in discharge tube. In fact only the elastic collisions are responsible for the heating of the laser plasma. In the second type of collision i.e. inelastic collision the kinetic energy of the electron is converted into potential energy of the target gas particles and the gas particles get excited. These particles in excited state either transfer their energy back to the electrons or the discharge tube walls or they undergo a transition emitting electromagnetic radiation. The rate of transfer of energy from the discharge electrons to the gas particles may be expressed as.

\[
\frac{dE}{dt} = N_g C_e N_e E_e + \sum_j N_{gi} N_e C_{in} E_j - \sum_j N_{gi} N_e C_{dex} E_i \quad (4.1)
\]

where,

\( N_s \) is number of gas particles

\( C_e \) is coefficient of elastic collisions

\( E_c \) is energy transferred in elastic collisions
$C_{in}$ is Rate coefficients of inelastic collisions.
$E_j$ is Energy of the $j^{th}$ state excited by inelastic collision.
$C_{dx}$ is deexcitation rate coefficient.
$E_i$ is energy of excited particles which transfer its energy to the electrons.

The sum runs over all possible energy states of the gas particles. The gas discharge loses the energy due to radiative emission and the collisions of the particles with the walls. The rate equation governing the population density of the laser states are discussed in article 3.3. All the processes, which can populate or depopulate the state, are listed and only the dominant ones are to be discussed in details.

4.2 Various excitation processes:

The He-Ne laser states are excited probably by the processes like,

1) Electron impact excitation from ground state of atom to the excited state of the atom. 2) Penning excitation i.e. transfer of energy from metastable state to the excited state of an active atom. 3) Duffenduck excitation i.e. the transfer of charge from the ion I having charge $z$ to another ion having charge $z$ so as to reduce charge from $z$ to $z-1$ and to increase the charge from $z$ to $z+1$.

4.3 Excitation Rate and rate coefficients:

The helium neon discharge exhibits laser action on about 8 transitions of the Ne ions and about eighteen electronic states of the neon ion are involved in the transitions. It is tedious to write the equations for all the electronic states so we have written one equation for all the upper laser states and one equation for all the lower laser states. The upper and lower states of laser are respectively populated with the rates.
\[
\frac{dN_u}{dt} = N_e R_u n_e + N_e N_{He}^* P_u + N_e N_{He} T_u + \sum_j A_{ju} N_j
\] (4.2)

\[
\frac{dN_l}{dt} = N_e R_l n_e + N_e N_{He}^* P_l + N_e N_{He} T_l + \sum_j A_{jl} N_j
\] (4.3)

The terms in the above equations stand for rate of excitation of states by different processes. The first terms in equations (4.2) and (4.3) stand for rate of excitation of the states by electron impact excitation from the ground state of NeI. The second terms are for excitation of states by penning process i.e. by transfer of energy by helium atoms in metastable states to the neon atoms in the ground states. The third terms are for excitation of states by Duffenduck process i.e. the transfer of energy from the helium ions to neon atoms in ground states. The fourth term stand for excitation of the states by cascading processes i.e. due to radiative decay of states, which lie energetically above the state involved in the laser transitions.

The excitation rate and excitation cross sections are entirely different from each other. When one particle is colliding with other particle there may be transfer of energy between them. The probability of transfer of energy in the collision is called as the transfer cross section. The number of collisions made by the species governs the total amount of energy transferred and the rate of transfer per second per particle is called as transfer rate coefficient. The different transfer rate coefficient and the transfer cross sections are discussed in detail.

4.4 Penning excitation rate coefficient:

The second terms \(N_{Ne} N_{He}^* P_u\) and \(N_{Ne} N_{He} P_l\) in the equation (4.2) and (4.3) are the penning excitation rates of the upper and lower laser states respectively. The excitation rates of the states by the penning process are
determined by the fractional abundance of NeI. The density of the helium atom in metastable states and the penning transfer cross section of the individual states of NeII. In the penning transfer of energy the excited electron of helium atoms comes to the ground state and the energy is transferred to the neon atom resulting in the excitation assisted ionization and excitation of the electronic states of neon. As the processes involve many sub processes the cross section is very small. The penning excitation rate coefficient may be obtained from the cross section using the equation,

$$P = < \sigma_p v_{He}>$$

(4.5)

where

\[ \sigma_p \] is the penning transfer cross section and

\[ v_{He} \] is the velocity of helium atoms relative to neon atoms.

The gas temperature determines the velocity of the helium atom. The velocity of helium gas follows the Maxwellian distribution as the density of the helium atoms is about \( 10^{16} \) and the plasma is highly collisional one. Thus for Maxwellian velocity distribution, the penning excitation rate coefficient may be expressed as

$$P = \frac{6.7 \times 10^{-7}}{86 (\theta)^{3/2}} \int_{0}^{\infty} \sigma_p E \cdot \exp \left( \frac{-E}{\theta} \right) dE \text{ cm}^3/\text{sec}$$

(4.6)

where

\[ \theta \] - is gas temperature in electron volt (eV) and

\[ E \] - is the energy of the helium atom in (eV)

The factor 86 comes because of the helium mass (4amu). The gas temperature is expressed in terms of electron volts. However, it is more convenient to express the gas temperature in degree Kelvin. Moreover, the Penning transfer cross section does not depend upon the velocity of colliding helium atoms (8, 9). Hence Penning transfer rate coefficient reduces to,
\[ P = 7.79 \times 10^5 \sigma_p (\theta)^{\frac{1}{2}} \text{ cm}^2/\text{sec.} \quad (4.7) \]

The total penning transfer cross section has been measured by Shearer and Padovani (7) for the mixture of helium and cadmium. However, in order to compute the excitation of the laser states by the Penning transfer the total cross section may not be utilized. In order to make it convenient to both the excitation of the individual state by the Penning process Inaba et al (8) in the year 1981 measured the penning excitation cross section of the individual levels of the 4416A and 3250A laser transitions by crossed beam method. Since the Penning excitation cross section of the neon is not available, we assume the Penning excitation cross-section of the neon to be same as that of the cadmium.

The total Penning transfer rate coefficient is obtained by putting \( \sigma_p = 4.5 \times 10^{-15} \text{ cm}^2 \) in the equation 4.7. The penning excitation rate coefficient for the individual NeII state may be obtained from the total rate coefficient by multiplying the appropriate factor obtained after few calculations. When the neon atom collides with the helium atom in the metastable state it is excited to one of the 5 states. Thus the rate of excitation of a state by Penning transfer must be less than the total Penning transfer rate coefficient of the neon by a factor of 5.

The density of the metastable state of helium governs the Penning excitation rate and the electron temperature. The population density of the metastable state is controlled by the several processes like electron impact excitation, the Penning collision, the electron impact de-excitation etc. The rate equation for the metastable density is written as

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\[
\frac{dN_m}{dt} = N_{He} R_{He} n_e - N_m N_{Ne^*} P - N_m n_e X
\]  

(4.8)

where \( R_{He} \) is the electron impact excitation rate coefficient of helium metastable state from the ground state. \( X \) is the electron impact deexcitation rate coefficient. When steady state is reached the rate of excitation and rate of deexcitation balance each other i.e.

\[
N_{he} n_e R_{he} = N_m N_{Ne^*} P + N_m n_e X
\]  

(4.9)

The electron impact excitation rate coefficient \( R_{he} \) is computed as a function of the electron temperature.

4.5 Electron Impact Excitation (EIE):

Electron impact excitation cross section of the Ne atom are of importance not only in the field of fundamental physics but also for the further understanding of discharge plasma such as in laser systems and the atomic processes in astrophysics. An electron having energy more than the excitation energy of electron rotating about an atom (or ion) collides with the atom (or ion) transfers its energy to the system and excites the rotating electron to a higher orbit. The probability of excitation depends upon the energy of exciting electron and the 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 function of electron temperature \( T_e \). The electron impact excitation rate coefficient is expressed in terms of the excitation Cross section \( \sigma \) and the electron velocity \( v_e \) as

\[
R = <\sigma v_e>
\]  

(4.10)
As we know that the plasma consist 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 of ion in ground state and accordingly the electron impact excitation (EIE) rate coefficients are defined as direct excitation and stepwise excitation respectively.

The experimental values of the integral cross section may be used and the excitation rate coefficient may be obtained. When an electron is incident on an atom (ion) electron transfers its energy to an electron rotating about the ion and the energy of the incident electron is shared by the incident electron and the electron rotating about the atom (ion). In the process of the excitation of the energy level the incident energy of the electrons is divided into three parts 1) part of energy is utilized in joining atom, 2) The another part is utilized in exciting the produced ion to the laser state and 3) The remaining part is kept by the incident electron itself.

When energy states of atom or ion are to be excited the energy of the incident electron is divided into two parts 1) A part is given to the electron rotating about atom (ion) and 2) The remaining part is kept by the incident electron itself. The former process may contribute towards the process of ionization and may indirectly excite the laser states. Obviously the contribution of the former processes is negligibly small. It has been shown by the computation of the excitation rate coefficients for some species of atoms that the two rate coefficients differ by four orders of magnitude.

If ions are participating in producing the laser action in the gas the stepwise excitation and direct excitation play different rolls. In He-Ne laser discharge the neutral neon is involved in the process of producing laser action and hence only direct electron impact excitation rate play important role. The
velocity of an electron is function of its energy and related to its energy $E$ by the relation

$$V_c = 5.9 \times 10^7 (E)^{1/2} \quad (4.11)$$

For Maxwellian distribution the number $dN$ of the electrons having energy between $E$ and $E + dE$ is given by the equation.

$$dN = N(2/KT_e) \times [E/\pi kT_e]^{1/2} \exp(-E/kT_e) \, dE \quad (4.12)$$

Thus the rate of excitation of energy levels by direct excitation is expressed as.

$$dR = N \left( \frac{2}{K T_e} \right) (E/\pi kT_e)^{1/2} \left( \sigma_V e \right) \exp(-E/kT_e) \, dE \quad (4.13)$$

The total excitation rate coefficient can be obtained by integrating above equation within the limits of energy from 0 through $\infty$. 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 (4.13) gives.

$$R = \frac{6.7 \times 10^3}{T_e^{3/2}} \int \sigma_V E \exp(-E/kT_e) \, dE \quad \text{cm}^3\text{sec}^{-1} \quad (4.14)$$

From this equation it is clear that if the values of excitation cross section are known at different values of the electron energies, the excitation rate coefficients may be obtained at different electron temperatures.

The semiempirical expressions for the electron Impact excitation rate coefficient of several kinds of electronic transitions were given by Drawin (10). The equation shows that the electron impact excitation rate coefficient is
directly proportional to the square root of electron temperature for forbidden transitions and cube root of electron temperature for allowed transitions. Moreover, the work on He-cd$^+$ laser (11) shows that the electron impact excitation rate coefficient is very nearly proportional to the square root of electron temperature for low electron temperature. Since the transitions of the neon atoms from the upper laser state and lower laser state to the ground state are almost forbidden. The electron impact excitation coefficient may be assumed to be directly proportional to the square root of the electron temperature. Drawin’s semiempirical formula may be employed for the calculation of electron impact excitation rate coefficient when the excitation cross section of the states of atoms are not known. In case of helium neon laser the electron impact excitation cross sections are measured by S. Tsurubuchi. et al (12, 13) for several energy levels of the neon atom.

4.6 Results and Discussion:

We compute the electron impact excitation rate coefficients of the electronic states of neon atom using equation (4.14). The excitation rate coefficients have been computed for the electron temperature ranging between 0 and 10 eV. Numeric trapezoidal computation method has been employed for performing the calculations. The results obtained are displayed in the figures 4.1 through 4.3.

The EIE (electron impact excitation) rate coefficients of the electronic states exhibit almost similar trend. Initially at low electron temperatures the rate of increase of EIE with temperature is high. When the temperature reaches about 2 eV the rate of increase of EIE with temperature becomes relatively less. At the electron temperatures of about 4 eV the EIE rate coefficients start showing saturation trends. It should be noticed that the EIE
rate coefficient reduces as the energy of the electronic state increases. With the help of computations is shown that EIE rate is more than the Penning excitation rate.
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Fig. 4.1 Electron Impact Excitation Rate Coeff. Of Neon 2P₂ And 2P₄ States As Function Of Electron Temperature
Fig 4.2 Electron Impact Excitation Rate Coeff. Of Neon $2P_6$, $2P_6$ And $2P_7$ States As Function Of Electron Temperature
Fig. 4.3 Electron Impact Excitation Rate Coeff. Of Neon 2P_{8}, 2P_{9}
And 2P_{10} States As A Function Of Electron Temperature