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Electron energy distribution and swarm parameters in DC Argon, Chlorine discharge and their mixtures

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توزيع طاقة و معلمات الحشد الألكتروني لغازي الأركون و الكلور مع خليطيهما في مفرغات التيار المستمر

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الخلاصة

تم استخدام معادلة الأنتقال الطاقي لبولتزمان لحساب و استنباط علاقات رياضية لمعلمات انتقال الألكترون و دالة التوزيع الطاقي للألكترون في الغازين (Ar ،Cl_2) و خليطيهما بواسطة التفريغ في التيار المستمر. ومن معلمات الحشد التي تم حسابها: سرعة الأنجراف و معامل التأين كدالة لنسبة شدة المجال الكهربائي الى الكثافة العددية للغازات. تم استخدام بيانات المقاطع العرضية المعتمدة على طاقة ألألكترون. لقد وجد بأن دوال التوزيع هي لاماكسويلية و تمتلك اختلافات في الطاقة تعكس دور عمليات تبادل طاقة الأكترون الجزيئي، كما وجد ايضا بأن نسبة قليلة من غاز (Cl_2) لها تأثير مباشر على دالة توزيع طاقة الألكترون.

Abstract

A study of electron energy distribution function and some swarm parameters in a DC discharge of pure Argon and chlorine is presented using Boltzmann transport equation. Moreover, the electron swarm parameters namely are: drift velocity and ionization coefficient.

Reported electron cross-section data have been used in the calculation. The calculated distribution function are found to be remarked non-Maxwillian that have energy variations which reflect the import electron-molecule energy exchange processes

It is notes that a small quantity of Cl_2 affects the electron energy distribution function.

Theory

Electrical discharges using mixtures of reactive with rare gases have been a subject of great interest, because if their application.

The Boltzmann equation is the equation of continuity for electrons in a six-dimensional phase space and describes the time evolution of the electron energy distribution function $f(r.v.t)$. Electron transport and excitation coefficients are calculate as average of integral involving *f*. The electron energy distribution function contains all the information about the electron swarm and the calculated swarm parameters are average in the same sense that the experiments measure average quantities. The Boltzmann equation maybe written as [1]:

$$\frac{\partial f}{\partial t} + V.\nabla_r f - a \bullet \nabla_V f = C(f) \text{……….(1)}$$

Where f is the electron energy distribution function, ∇_r is the special gradient *in r*-dimension, a is the acceleration due to the applied field, $\vec{\nabla}_v$ is the gradient. The term on the right hand side of the equation is the collision integral, which accounts for electron energy transferred and inelastic collisions.[2] In a DC discharge the electron energy distribution function depends on the parameter E/N (The ratio of the local electric field E to the local total particle density in the discharge N) which is to a good approximation, equal to the neutral particle density and the plasma composition[3]

Calculation of swarm parameters

The swarm parameters are defined in terms of collision cross-section (σ) and the distribution function $f(\sigma)$ [4].

One can compute the drift velocity by:

$$V_d = -\sqrt{\frac{E}{3}\left(\frac{2e}{m}\right)} \int_0^{\infty} \frac{\varepsilon}{N\sigma_m} \frac{\partial f(\varepsilon)}{\partial \varepsilon} d\varepsilon \text{ ……………(2)}$$

Where V_d is the drift velocity, m is the electron rest mass, E is electric field, (ε) is the electron energy in (eV), N is the number density of molecules and (σ_m) is the momentum transfer cross-section for elastic collision of electron.

The ionization coefficient is:

$$\frac{\alpha}{N} = \frac{1}{V_d}\left(\frac{2e}{m}\right)^{1/2} \int_0^{\infty} \sigma_i(\varepsilon) f(\varepsilon) d\varepsilon \text{ …………………(3)}$$

Where α is proportional to the number density of molecules and $\sigma_i(\varepsilon)$ is the ionization cross-section [5].

Electron Collision cross-section for:

1- Argon (Ar)

The momentum transfer cross-section where taken from the work of *Ángel* [6], and it defined as:

$$Q_m = 2\pi\int_0^{\pi} (1-\cos\theta) I(\theta, v)\sin d\theta \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where $I(\theta,v)$ is the differential cross-section for the scattering of an electron with velocity v in to the range of angle $d\theta$ at angle θ in the center of mass coordinate system.

The ionization cross section σ_{ion}, having the onset energy (15.8eV), where it been calculated by using the formula [7]:

$$\sigma_{ion} = \frac{\pi e^4}{J^2} f(\frac{\varepsilon}{J}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where e is the electron charge, ε is the electron energy, J is the ionization potential and $f(\varepsilon/J)$ is the framework of the approached witch had been employed.

The sets of excitation cross-section ($^3P_1$, $^1P_1$, $^3P_0$+$^3P_2$) were taken from measured value of *Mariotti and Maguire* [8].

2- Chlorine (Cl_2)

For the chlorine discharge, electron collisions with both atomic and molecular chlorine where taken into account. The purpose was to investigate the effect of gas composition on the electron transport [9].

Various kind of elastic processes such as excitation, ionization play an important role.

The chlorine molecules in the metastable state $C^1\pi$ is Dissociative excitation with a threshold of (3.12eV) and electronic excitations (molecular) to ($B^1\pi$, 2.49eV loss) and ($2^1\pi$, $2^1\sum$ and 9.25eV loss) and electronic excitations (atomic) with threshold of (8.9, 10.4, 10.9, 11.8, 12.0 and 12.4) eV.

The vibrational excitation plays an important role at intermediate values of E/N as given by [10] with energy loss (0.0689) eV. Molecular ionization with energy loss of (11.47) eV and also atomic ionization with energy loss of (12.99) eV are given by [9].

Results and discussions

Boltzmann transport equation (1) have been used to calculate the Electron Energy Distribution function and the electron swarm parameters in pure argon within the E/N range (0.01-800) Td or ($1\times10^{-19} - 8\times10^{-15}$) V.cm^2 where Td is a standard unit for E/N determined from analysis of an Argon discharge lamp with length of (40 in) and pressure of (3mb).

The convergence property of the velocity distribution function in the spherical harmonic expansion is directly investigated at energies near the Ransaur Townsend minimum from analysis of the Boltzmann eq. (1).

Figure (1) show the electron energy distribution function $f(\varepsilon)$ as a function of electron energy in pure Argon, for the lowest E/N values (1×10^{-19} and 1×10^{-18}) $V.cm^2$. The electron energy is thermal and the electron distribution is Maxwillian $f(\varepsilon)=f_o\exp\left(-\varepsilon/(K_BT)\right)$ was observed to be nearly constant with a slop of $(-1/(K_BT))$. However, for higher E/N values (1×10^{-17} and1×10^{-16}) $V.cm^2$ the distribution is clearly non Maxwillian, having electron molecular energy exchange processes

Fig (2) shows the modulation of EEDF for reduced field of E/N =200Td for Cl_2 gas. The distribution function is modulated strongly.

Fig (3) show the electron energy distribution function for mixtures with 95%Ar, 5% Cl_2 when E/N=27Td ,it can be noted that plasma with pure argon have EEDF with a longer tail ,A small quantity of chlorine modifies this function because Chlorine has several vibration and excitation levels with threshold energies well below 10 eV . These processes result in a displacement of the tail of EEDF, The pressure has very little influence in the EEDF.

To obtain the differed swarm parameters the E/N values were chosen to yield mean electron energies in the range (0.36-12.48) eV with a knowledge of the energy distribution function, electron swarm parameters (drift velocity ,ionization coefficient) have been calculated for the range ($1\times10^{-19}\leq E/N\leq 8\times10^{-15}$) $V.cm^2$.

Electron in an ordinary case, have an ordinary movement that is define as thermal motion, but with increasing *E/N* value. The speed of electrons will increase too; this will lead to another kind of motion known as the drift motion.

The electron drift velocity V_d calculation for pure Ar and pure Cl_2 have been made down as shown in figure (4&5) using equation (2) in order to over lap with the values calculated from Boltzmann equation .the computation are very sensitive to the magnitude and shape of the variation cross-section . Fig (6) is representing the value of drift velocity that evaluated from equation (2) too, for (Ar-Cl_2) (90:10) mixture ratio.

The drift velocity which depends on the ratio of the mixture component can very probably be explained by a preferential weighting of the elastic and the inelastic scattering of the electrons on argon atom and Chlorine molecules at different value of E/N .since at lower values of E/N, the effect of elastic scattering prevails over the other due to low energy transfer cross-section of Argon gas.

The ionization coefficient (α/N) have been calculated in figure (7) for pure argon using equation (3) for the range ($6\times10^{-17}\leq E/N\leq 8\times10^{-15}$) $V.cm^2$.The results are shown us the behavior of ionization coefficient which increase with increasing of E/N . The result of high E/N are sensitive to the inelastic collision , This means that the electrons acquire enough energy from the applied field to reach the ionization level, In this case, the number of energetic electrons, which cause the ionization increase with increasing E/N according to the ionization cross-section of pure Argon.

And also in figure (8) which represent the ionization coefficient of pure Cl_2 over the entire E/N rang it agree with the data of Bozin [11] the increasing of mean energy causes the increase of α/N. The behavior of ionization coefficient as a function of E/N for (Ar-Cl_2) mixtures (90:10) is shown in figure (9) which is calculated by eq. (3) .In this fig as E/N value increase the differences in ionization coefficient value decrease .This behavior is due to the increase in the number of electron that causing the ionization . This behavior is also related to the stability of ionization state and also to the electronic excitation of Argon.

Conclusion

Using the numerical solution of the Boltzmann Equation in a tow-term spherical harmonic approximation by the set of cross-sections it was possible to investigate the behavior of the electron energy distribution function in a plasma with Argon and Chlorine and with their mixtures, The swarm parameters .Generally, The accuracy of the calculation depends on the accuracy of the electron-molecule cross-section sets. Calculations of the electron energy distribution function for discharge processes of Ar, Cl_2 and their mixtures have shown that the distribution is highly non-Maxwillian.

The process of mixing an inert gas such as Argon gas with Chlorine molecule , causes a noticeable increase in the values of electron drift velocity this accompanied by a decrease in E/N value .The main advantage of Ar/Cl_2 mixtures is to reach the ionization state with less electron energy.

Acknowledgment

I wish to acknowledge the invaluable help of my dear husband Mr. Kasim Fawzy for his scientific notices and offering facilities.

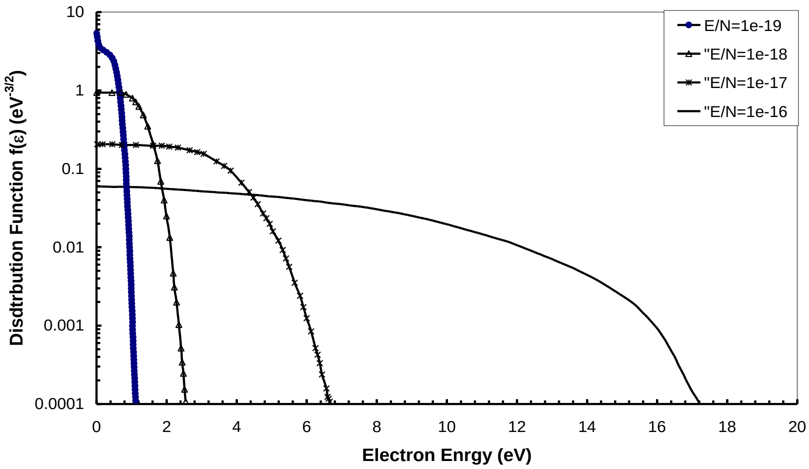

Figure 1: The electron energy distribution function as a function of electron energy in pure argon for several values of E/N.

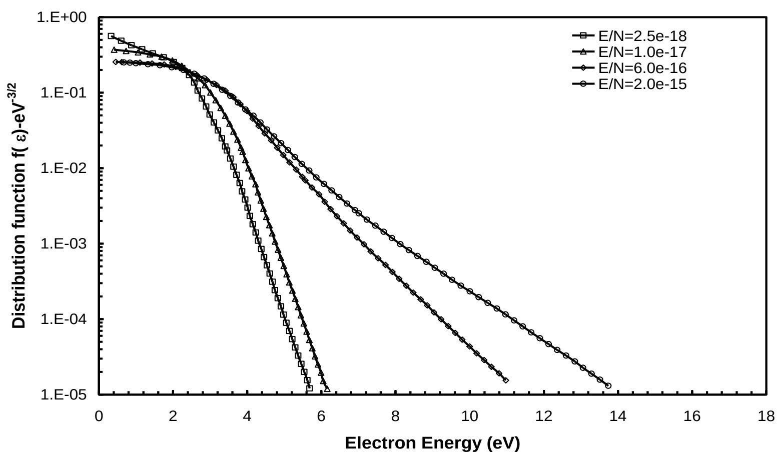

Figure 2: The electron energy distribution function as a function of electron energy in pure Cl_2 for several values of E/N.

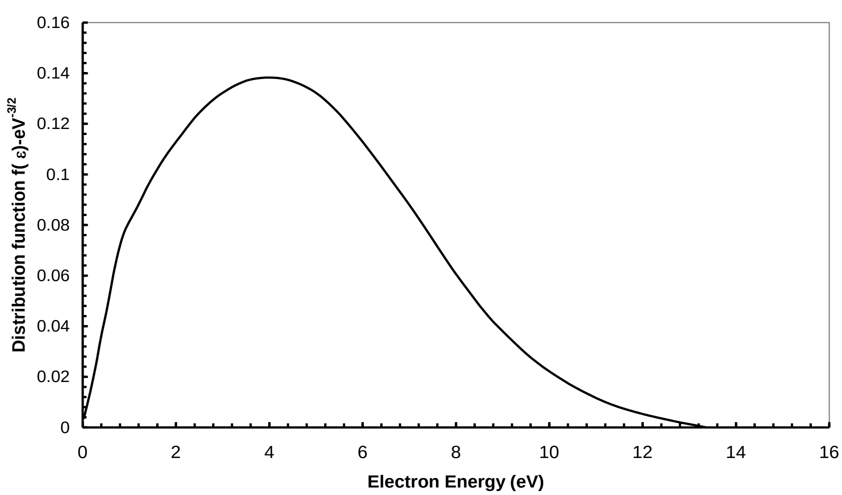

Figure 3: The electron energy distribution function as a function of electron energy for Ar- Cl_2 mixture (95:5) for E/N=27 Td.

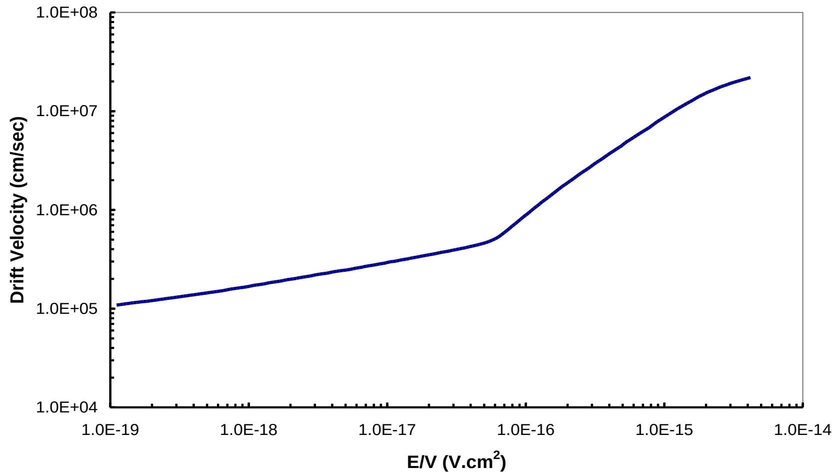

Figure 4: The drift velocity of electrons as a function of E/N in pure Argon.

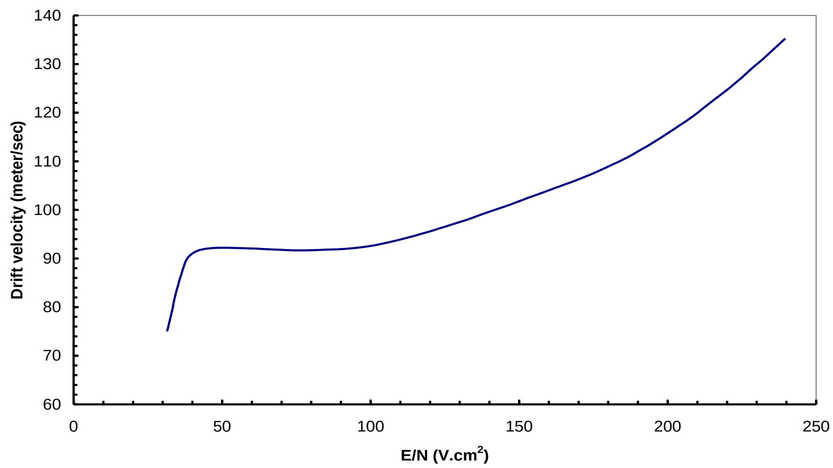

Figure 5: The drift velocity of electrons as a function of E/N in pure Cl_2.

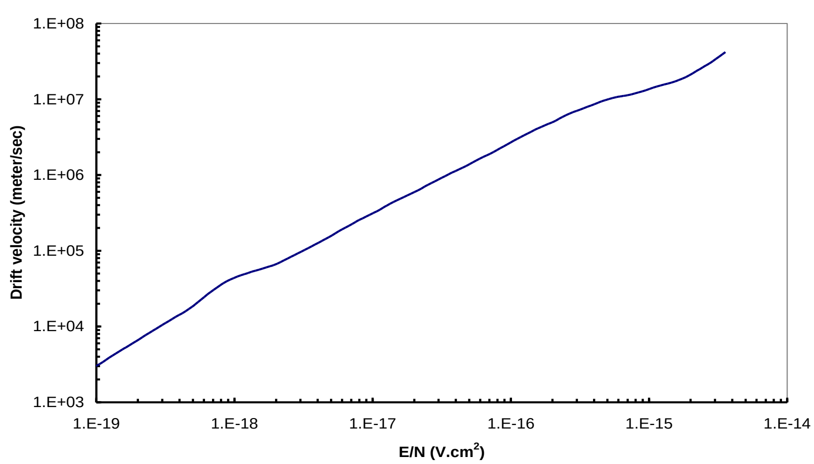

Figure 6: The drift velocity of electrons as a function of E/N for (Ar - Cl_2) (90:10) gas mixtures ratio.

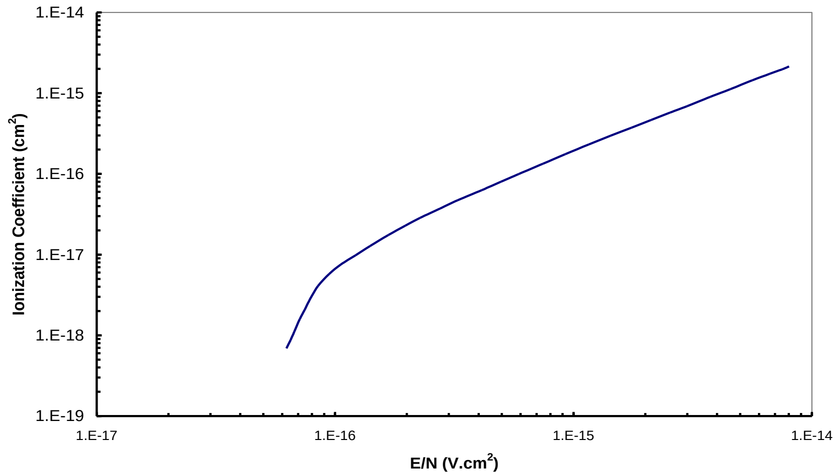

Figure 7: The ionization coefficient of electron as a function of E/N in pure Argon.

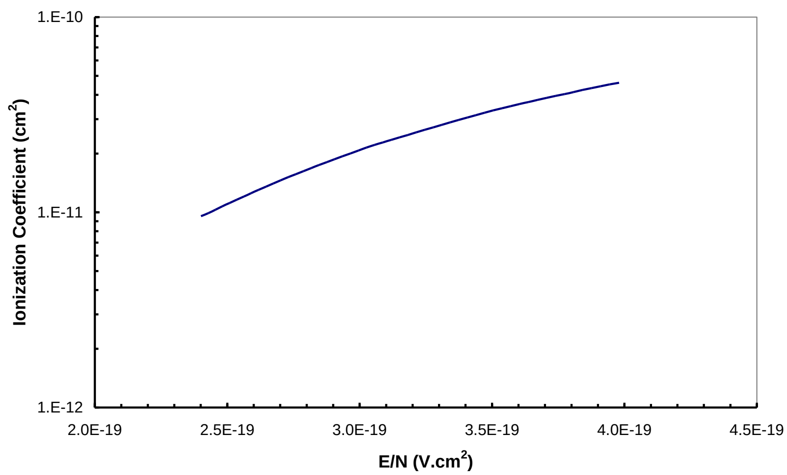

Figure 8: The ionization coefficient of electron as a function of E/N in pure Cl_2.

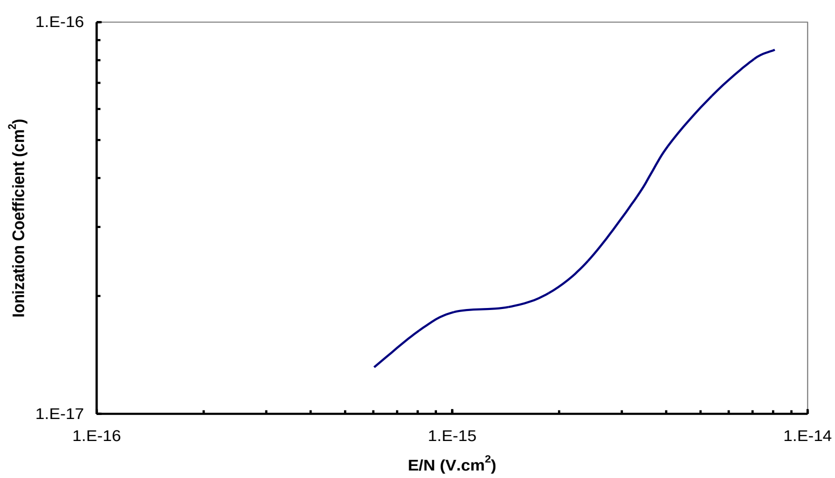

Figure 9: The ionization coefficient of electron as a function of E/N for (Ar-Cl_2) (90:10) gas mixtures ratio.

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