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Study the effect of the reducing electric field and nitrogen gas concentration on electronic distribution function and transfer parameters of a mixture (N_2-Xe)

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Abstract:

In this research, we studied the effect of applying the reduced electric field E/N on the electronic distribution function and on the electronic transfer parameters (electron energy rate , characteristic energy , electron drift velocity , electron mobility , electron diffusion coefficient) for pure nitrogen gas (N_2) and gas Noble xenon (Xe) and their mixtures in different concentrations. The main transfer parameters mentioned above were studied as a function of the reduced electric field E/N for different values. Changing the concentration of xenon gas in the mixture causes a change in the distribution function EEDF and as a result, a change occurs in the electronic transfer parameters. The data obtained from the EEDF program was plotted using the (MATLAB) program. The operations were conducted under constant standard conditions, where gas pressure ,temperature, and the electron concentration are 760 Torr, 273 K, 1×10^9 cm $^{-3}$, respectively.

Keywords: (EEDF) prog., Boltzmann eq., N_2 Gas, Xe Gas, Electronic transfer parameters .

دراسة تأثير المجال الكهربائي المختزل وتركيز غاز النيتروجين على دالة التوزيع الإلكتروني ومعاملات النقل لخليط (N_2-Xe)

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البحث مستل من رسالة ماجستير للباحث الاول

مستخلص:

تم في هذا البحث دراسة تأثير تطبيق المجال الكهربائي المخفض E/N على دالة التوزيع الإلكتروني وعلى معاملات النقل الإلكتروني (معدل طاقة الإلكترون ū، الطاقة المميزة ، سرعة انجراف الإلكترون ، تنقلية الإلكترون ، انتشار الإلكترون معامل لغاز النيتروجين النقي N_2 ولغاز الزينون النبيل (Xe)) ومخاليطها بتركيزات مختلفة. تمت دراسة معاملات النقل الرئيسية المذكورة أعلاه كدالة للمجال الكهربائي المخفض E/N لقيم مختلفة. يؤدي تغيير تركيز غاز الزينون في الخليط إلى تغير في دالة التوزيع EEDF ونتيجة لذلك يحدث تغيير في معاملات النقل الإلكتروني. تم رسم البيانات التي تم الحصول عليها من برنامج EEDF باستخدام برنامج (MATLAB) أجريت العمليات تحت ظروف قياسية ثابتة، حيث بلغ ضغط الغاز ودرجة الحرارة وتركيز الإلكترون Torr 760 ، K 273 ، 1×10^9 cm $^{-3}$، على التوالي.

الكلمات المفتاحية: برنامج EEDF ، معادلة بولتزمان، غاز N_2، غاز Xe ، معادلة نقل الالكترون.

Introduction:

In an elastic collision, if the electron does not have enough energy to excite the heavy body (molecule or atom), it can exchange momentum with its counterpart, and a small portion of the electrons possess kinetic energy that exceeds the excitation limit [1]. According to the distribution function f (u), elastic collisions are predominant, and consequently, the effect of inelastic collisions as Ionization or excitation on the distribution function is insignificant [2].

When the electrons are provided with sufficient energy from the electric field, the kinetic energy of the electron is transferred to the neutral atoms and raises them to an excited level. In this case, the kinetic energy is not conserved and the collisions are inelastic.

In monatomic gases, such as the noble gases, at high energies, inelastic collisions are important for the purpose of determining the behavior of the electron, and in molecular gases, such as nitrogen gas, elastic and inelastic collisions are important.

Xenon has the greatest chemical activity compared to other noble gases [3]. Adding a noble gas like xenon to nitrogen gas leads to enhancing the concentration of active species through the processes of ionization and agitation. Therefore, the collision processes and plasma reactions in the mixture can be explained by knowing the plasma parameters [4]. There are many Among the programs and techniques that are used to obtain electron transfer properties, one of these programs is the EEDF program. This program gives electron transfer coefficients in a mixture of gases by solving the Boltzmann equation [5]. This program describes how electrons gain energy from the electric field and then lose it in collisions. Inelastic [6]. In our research, the electron energy distribution function (EEDF) was studied for both pure xenon and nitrogen gases and for their mixtures. And also to study the electron transfer coefficients, which include the drift speed, the mobility of the electrons, the energy rate of the electrons, the characteristic energy of the electrons, and the electron diffusion coefficient. The MATLAB program was used to show the graphs of the calculations, and the study was carried out under constant standard conditions such as a pressure of Torr 1 = P and a temperature of K = 300T.

Theory:

In the plasma model, the Boltzmann equation (BE) describes phenomena that are relevant to some important applications such as engineering and technology. The general form of Boltzmann equation [7].

$$\left(\frac{\partial}{\partial t} + v.\nabla r + \frac{eE}{m}.\nabla v\right) f(r, v, t) = \left(\frac{\partial f}{\partial t}\right)_{coll} \quad (1)$$

The left side of the equation describes how the function f(r·v·t) changes due to independent motion without collisions, while the right side of the equation describes how the function changes as a result of bilateral collisions of charged particles with neutral particles.

The expression (v·∇_r) represents that part of the change as a result of the external force v.

e/m is the ratio of an electron's charge to its mass, which indicates the acceleration of electrons as a result of the applied electric field, E.

f (r.v.t) is the distribution function in spatial location r, velocity v, and time t. For a particle moving in three-dimensional space, the phase space consists essentially of all points [8].

The code is restricted to a standard value to terminate the iterating actions. And The function f_0^{n+1} is the solution. In this program, the number of iterations is limited by the value Mmax, which is set by the user of the program [9]. And by using the distribution function $f_0(u)$, we can get the electron transfer coefficients such as electron drift velocity (v_d) , and electron energy rate $(\bar{u})$[10].

$$v_d = -\frac{1}{3}\sqrt{\frac{2}{m}\frac{eE}{N}}\int_0^\infty \frac{1}{q_m(u)}\frac{df_0}{d\epsilon} u\, du \qquad (2)$$

where (u) is the electron energy in (eV), (N) gas density in (cm^{-3}), (E/N) the reduced electric field in (V.cm^2), (q_m) the momentum transfer cross-section measured in (cm^2) [11].

$$\bar{u} = \int_0^\infty u^{3/2} f_0(u)\, du \qquad (3)$$

The ability of electrons to move in a medium under the influence of an electric field is called electron mobility (μ_e), and it can be found from the following relationship [11]:

$$\mu_e = \frac{v_d}{E} = -\frac{1}{3}\sqrt{\frac{2}{m}\frac{e}{N}}\int_0^\infty \frac{1}{q_m(u)}\frac{df_0}{du} u du \quad (4)$$

The relationship between the distribution function and the electronic diffusion coefficient (D_e) is illustrated by the equation below:

$$D_e = \frac{1}{3}\frac{2}{m}\int_0^\infty \frac{u^{3/2}}{\nu_m(u)} f_0 du \qquad (5)$$

where (ν_m) is the momentum transfer collision frequency.

The characteristic energy (E_k) , represents the ratio between the electronic diffusion coefficient to the electron mobility, which is shown in the following relationship.

$$E_k = e\frac{D_e}{\mu_e} \qquad (6)$$

Results and discussion

Calculating the distribution function EEDF versus the electron energy u (eV) by solving the binomial approximation of the Boltzmann equation in the molecular gas N_2 and pure xenon gas for different values of the reduced electric field E/N = (10-100) Td shown in the figure (1).

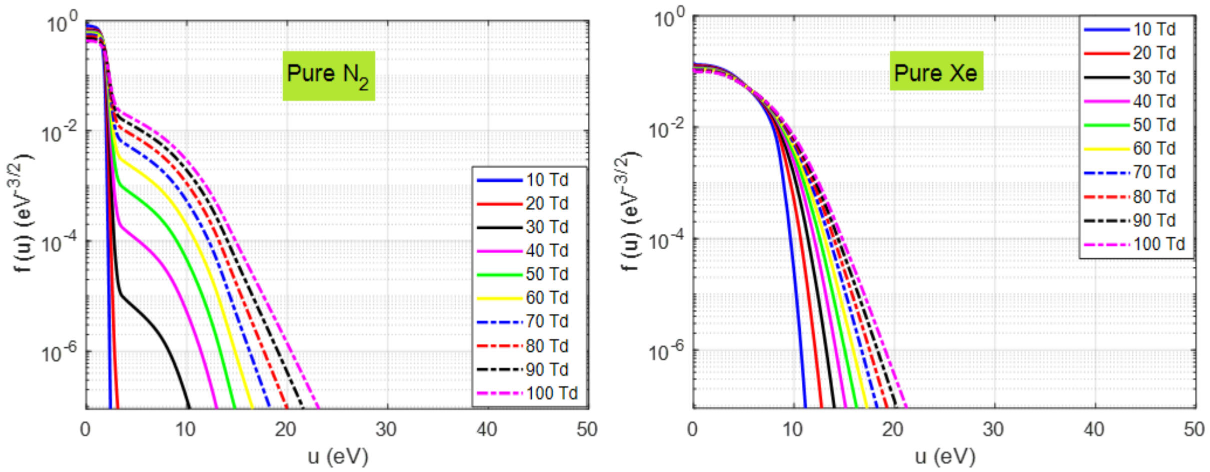

Figure (1) Electron energy distribution function versus electron energy for pure nitrogen N_2 and xenon Xe

In Figure (2) When adding molecular gas N_2 to Xe gas leads to a decrease in the EEDF curves towards the low energy tail, which is attributed to inelastic collisions of electrons with N_2.

If the concentration of N_2 in the mixture increases and at E/N < 30 Td, the EEDF curves decrease quickly and approach the origin of the energy field, which is attributed to the increase in the cross-section of the interaction, which results in an increase in inelastic collisions of electrons with N_2 on the one hand, and the electrons gain little energy. By applying E/N on the other hand. As the concentration of N_2 in the mixture increases and the reducing electric field increases (E/N > 30 Td), the EEDF decreases slowly and does not approach the origin of the energy field, which is attributed to the balance of energy gain and loss of the electrons as a result of the application of the reducing electric field on the one hand and the increase in inelastic collisions

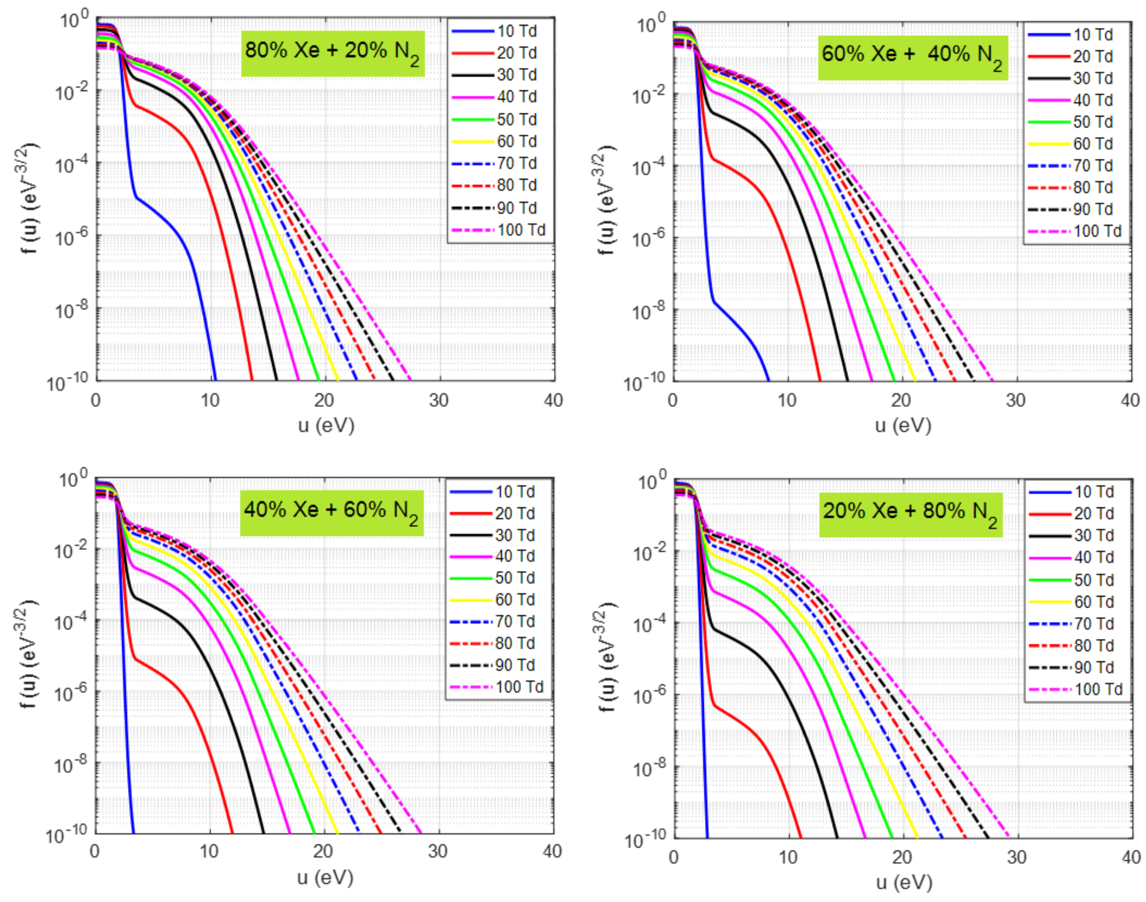

Figure (2) Electron energy distribution function as a function of electron energy for mixtures (Xe + N_2) with different concentrations

on the other hand. Second hand. with increasing E/N.

Varied behavior in Figure (3(a)) for the average electron energy u as a function of the reduced electric field E/N for the (N_2+Xe) mixture. u increases with increasing E/N.

When E/N < 200Td, reducing the nitrogen concentration in the mixture leads to raising the electron energy rate, and when E/N > 200Td, increasing the nitrogen concentration in the mixture leads to raising the electron energy rate u.

In the figure (3(b)) the characteristic energy versus the reduced electric field E/N for pure xenon gas, nitrogen gas, and their mixtures at different concentrations. The figure shows the difference in the behavior of each mixture depending on the concentration of

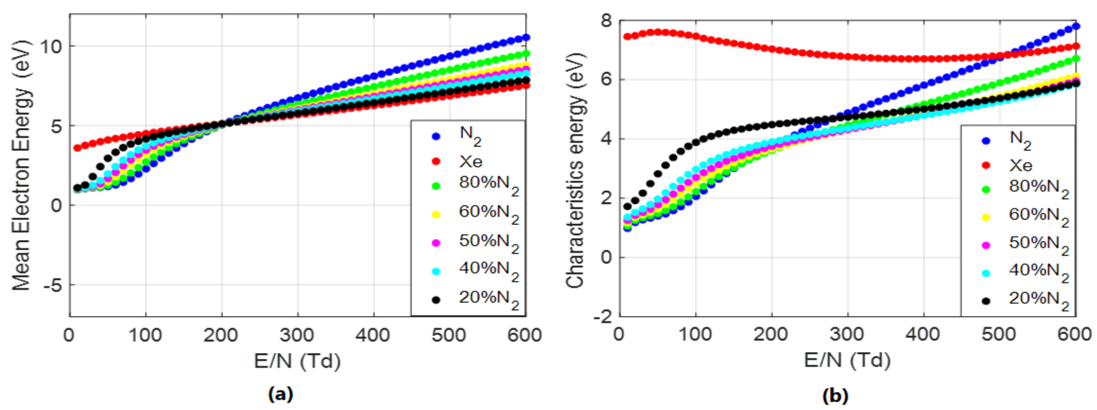

Figure [3(a,b)] Average electron energy and characteristic energy versus the reduced electric field for a mixture (N_2 + Xe).

gases in that mixture.

Figure (3(a)) expresses the relationship of the drift velocity to the reduced electric field E/N at different concentrations of xenon gas After this value, increasing the nitrogen concentration in the mixture leads to raising more.

The decrease in the concentration of nitrogen in the mixture (N_2 + Xe) increasing the electric field (E/N > 100 Td), the mobility gradually decreases with increasing E/N. As shown in Fig-

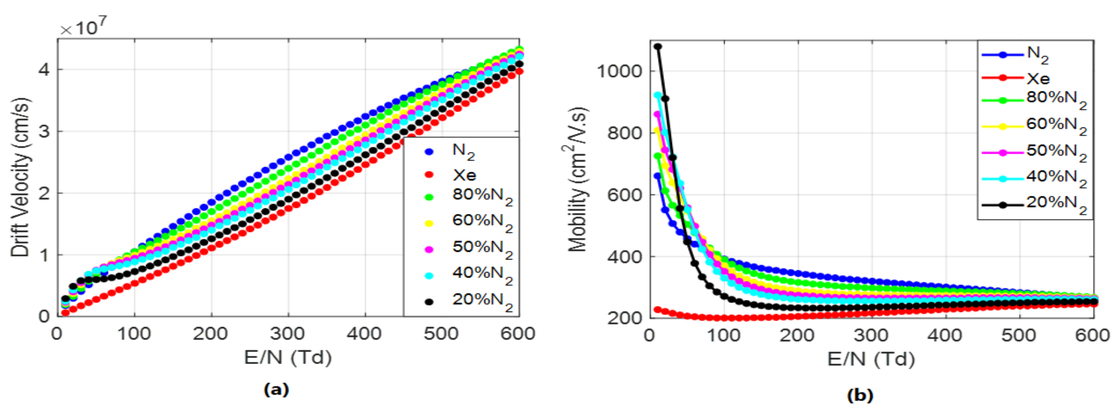

Figure [4 (a,b)] Electron drift speed and mobility versus the reducing electric field for a mixture (N_2 + Xe)

ure (4(b)).

Figure (5) shows the electronic diffusion coefficient De versus the reduced electric field E/N for a mixture (N2+Xe), which shows the behavior of each mixture varying with the concentration of gases in the mixture.

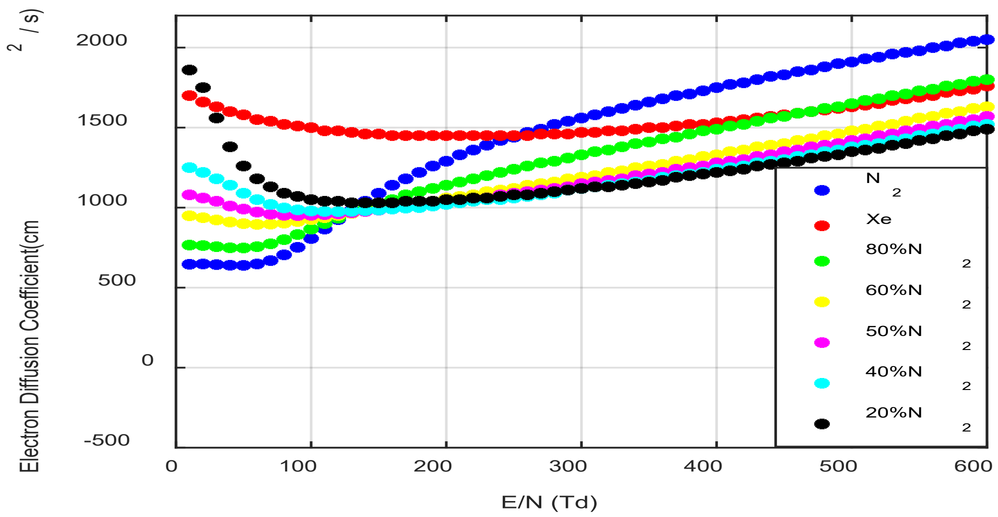

Figure (5) Electronic diffusion coefficient versus the reduced electric field for a mixture (N_2 + Xe)

Conclusion:

Decreasing the nitrogen concentration in the mixture (N_2+Xe) plays a different role depending on E/N. As a result, there is a change in the electron transport parameters (electron energy rate, characteristic energy, drift velocity, electron mobility, electron diffusion coefficient). Therefore, we notice that the EEDF is greatly affected by changing the reduced electric field E/N and then the electron transport parameters are affected by it. Also, increasing E/N leads to the evolution of the EEDF towards the high energy tail as a result of the electrons gaining energy.

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