The transport parameters of an electron swarm and electron energy distribution in Xe, He and (Xe-He) mixtures using Boltzmann equation

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Abstract

The Boltzmann transport equation is used to calculate the electron energy distribution function (EEDF) and the transport parameters in pure Xe, He and their mixtures. The electron swarm parameters are evaluated in the range ($1\times10^{-18} \le E/N \le 2\times10^{-15}$) V.cm^2. These parameters namely are: mean electron energy and drift velocity. The calculated distribution function is found to be remarked non-Maxwillian that has energy variations which reflect the import electron-molecule energy exchange processes.

Keyword : Plasma and Electron Discharges, Swarm Parameter, Kinetic and Transport Theory of Gases

Introduction

A study of the electron energy distribution function in the mixture of Xenon and Helium is presented, using the numerical code kinema-Elendif (Morgan et al., 1990).

It is important to understand the plasma chemistry of gas mixtures and the discharge influence in the deposition processes. This code is used to calculate the electron energy distribution function for pure xenon, pure helium and xenon –helium mixtures. Elastic and inelastic processes are considered for both gases.

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Theory

1. Boltzmann equation

The general form of the Boltzmann equation is (Jiang et al., 1993):

$$\left(\frac{\partial}{\partial t}+V.\nabla_r-\frac{eE}{m}.\nabla_V\right)f\left(r,v,t\right)=\left(\frac{\delta}{\delta t}\right)_{coll.}$$

(1)

Where f(r,v,t) is the electron velocity distribution function (EVDF) at time t and spatial location r.

of electron charge to its mass which is refers to the acceleration due to applied electric field (E) ($V.cm^{-1}$).

∇_V is the gradient in v-space.

And $\left(\frac{\delta}{\delta t}\right)_{coll.}$ is the collision integral which accounts for electron energy transferred in elastic and inelastic collision (Willett, 1974).

2. Transport parameters

It is well known that the swarm parameters of electrons and collision cross-sections with molecules are related to each other's through the medium of the velocity distribution function of the swarm.

The electron mean energy is, (Wang *et al.*, 1999):

$$\varepsilon=\frac{2}{3}\int_0^\infty u^{3/2}f_o(u,E/N,T)du$$

(2)

Where (ε) is expressed in electron volts.

Values of $f_o(u)$ are calculated from Boltzmann's equation using all collision cross-sections.

The drift velocity V_d, is (Morgan, 2002):

$$V_d=-\left(\frac{2e}{m}\right)^{1/2}\left(\frac{E/N}{3}\right)\int_0^\infty\frac{u}{\sum\delta_S Q_{sm}(u)}\frac{df_o}{du}du$$

(3)

Where u is the electron energy in (eV), δ_S is the number density of molecules of species S divided by gas number density N ($\delta_S=\frac{N_S}{N}$),

$Q_{sm}(u)$ is the momentum transfer cross-section for elastic collisions of electron with energy u with molecules of species S.

3. The cross-section

A. Pure Xe

The calculation has been made using a set of previously measured and calculated cross sections.

The momentum transfer $Q_{sm}(u)$ cross section for elastic collision is taken from (Kucukarpaci *et al*., 1979).

B. Pure He

For He, atom the momentum transfer cross-section Q_m is taken from (Hilke, 2010). The excitation cross-section to the metastable state Q_{ex} is taken from (Nikolay *et al*., 2001). The electronic excitation to [P_1^2, P_3^2] are taken from (Christophorou *et al*., 1990).

Result and discussion

The distribution function is defined such that $\int_0^\infty u^{1/2} f(u) du = 1$ clearly, the calculated distribution function are markedly non-Maxwillian, having energy variations which reflect the dominant electron-Molecule energy exchange processes as in figures (1, 2 & 3).

Fig (1) is representing the electron energy distribution function for pure Xe as a function for several values of E/N, in this figure at lower E/N=1x10^{-19}V.cm^2 the electron energies are thermal and the energy distribution is Maxwillian, in which represent by the straight line variation, However for E/N=1x10^{-15}V.cm^2 the distribution is non-Maxwillian.

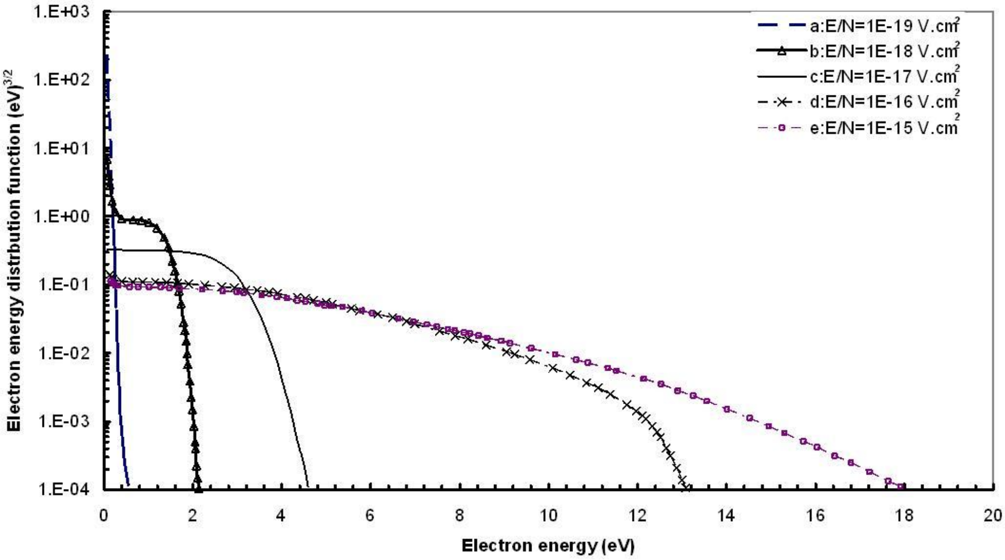

Figure (1) the electron energy distribution function in pure Xenon for several values of E/N

Fig (2) is represent the electron energy distribution function as a function of E/N value for pure He. In this figure the influence of different discharge parameters on the electron distribution function are demonstrated in, and also it shown that, for E/N=1x10^{-17}V.cm^2 the distribution is Maxwillian .While for E/N= (4x10^{-17}V.cm^2, 6x10^{-17}V.cm^2) the distribution is clearly non-Maxwillian. It differs from the inert helium gas that has vibrational levels, and one electronic level that the electron cross-section for elastic and inelastic are explained in previous section.

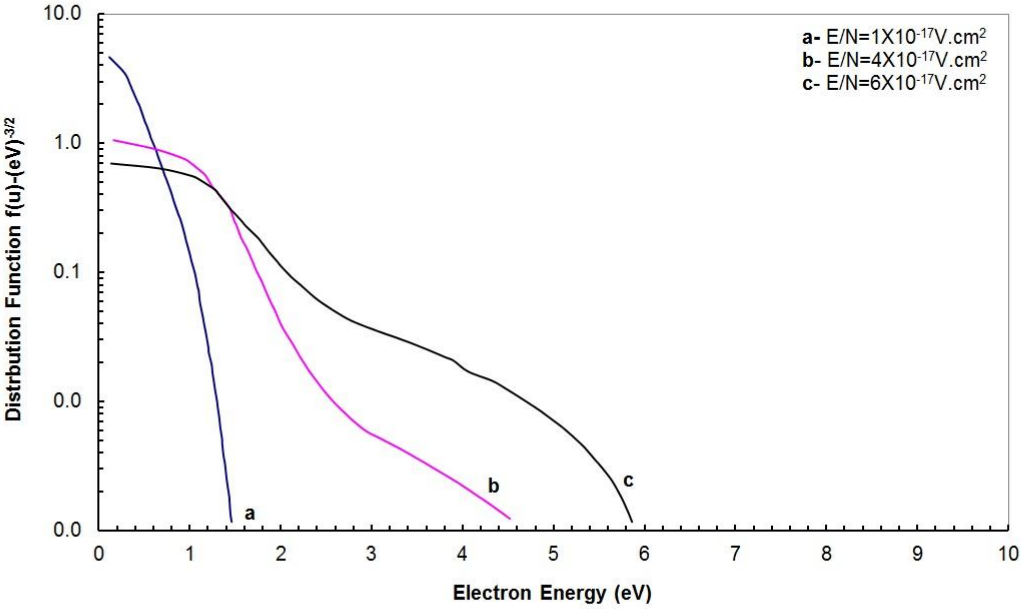

Figure (2)The electron energy distribution function in pure He for several value of E/N

Fig (3) represents the electron energy distribution function as a function of E/N value for Xe-He mixtures. The electron distribution function (EDF) strongly affected by changing the parameters E/N, The distribution functions are clearly non- Maxwillian having distinct varying curvatures at all electron energies. The pronounced dip in the distribution function are emphasized at low electron temperatures occur as a result of the very large cross-sections for vibrational excitation of (Xe, He) in this electron-energy range.

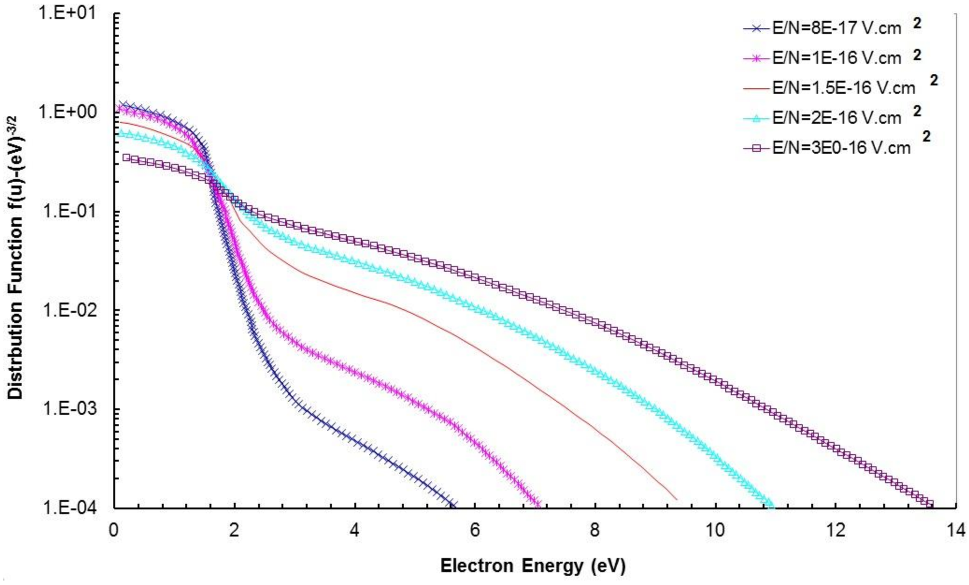

Figure (3)The electron energy distribution function for (Xe-He) (0.15:0.85) for several value of E/N

Table (1) contains the data of figure (3) which represent the electron energy distribution function as a function of electron energy for several (E/N) values of (Xe-He) mixed by (0.15:0.85).

Table (1) The data of the (electron energy distribution function) as a function of (electron energy) for several (E/N) values of (Xe-He) mixed by (0.15:0.85)

Electron Energy (eV)	E/N=8x 10^{-17} V.cm	E/N=1x 10^{-16} V.cm	E/N=1.5x 10^{-16} V.cm	E/N=2x 10^{-16} V.cm	E/N=3x 10^{-16} V.cm
0.20	1.140000	1.030000	0.774000	0.606000	0.344000
0.40	1.090000	0.952000	0.724000	0.570000	0.320000
0.60	0.991000	0.912000	0.673000	0.535000	0.309000
0.80	0.885000	0.813000	0.601000	0.509000	0.291000
1.00	0.831000	0.710000	0.531000	0.457000	0.272000
1.20	0.673000	0.613000	0.465000	0.399000	0.245000
1.40	0.458000	0.405000	0.398000	0.346000	0.221000
1.60	0.243000	0.224000	0.242000	0.252000	0.197000
1.80	0.072500	0.113000	0.173000	0.182000	0.163000
2.00	0.025700	0.052200	0.105000	0.131000	0.129000
2.20	0.009990	0.022100	0.103000	0.069200	0.110000
2.40	0.004650	0.012200	0.074900	0.049900	0.091600
2.60	0.002800	0.008020	0.064800	0.039200	0.084700
2.80	0.001840	0.005800	0.056600	0.031300	0.077900
3.00	0.001220	0.004980	0.049700	0.027100	0.070200
3.20	0.000963	0.003990	0.044300	0.022100	0.065700
3.40	0.000814	0.003490	0.041100	0.020800	0.061200
3.60	0.000665	0.003070	0.037800	0.018500	0.057200
3.80	0.000579	0.002700	0.033900	0.016500	0.053300
4.00	0.000502	0.002380	0.031400	0.014800	0.049900
4.20	0.000407	0.002100	0.029000	0.013700	0.046500
4.40	0.000352	0.001840	0.025900	0.012600	0.042300
4.60	0.000284	0.001610	0.024200	0.011300	0.040200
4.80	0.000246	0.001400	0.021900	0.010000	0.036500
5.00	0.000212	0.001220	0.019500	0.008790	0.032900
5.20	0.000170	0.000985	0.017400	0.007680	0.031200
5.40	0.000135	0.000856	0.015400	0.006680	0.028200
5.60	0.000116	0.000741	0.013500	0.005840	0.026000
5.80		0.000590	0.012000	0.005070	0.023900
6.00		0.000466	0.011200	0.004400	0.021400
6.20		0.000368	0.009670	0.003540	0.019200
6.40		0.000268	0.008110	0.003060	0.017000
6.60		0.000210	0.007090	0.002460	0.016100
6.80		0.000152	0.006200	0.002120	0.014300
7.00		0.000119	0.005400	0.001690	0.012800
7.20			0.004710	0.001460	0.011400
7.40			0.004100	0.001160	0.010100
7.60			0.003290	0.000926	0.009520
7.80			0.002860	0.000740	0.008420
8.00			0.002490	0.000635	0.007450
8.20			0.002160	0.000505	0.006570
8.40			0.001740	0.000400	0.005780
8.60			0.001500	0.000315	0.005080
8.80			0.001200	0.000249	0.004460
9.00			0.001040	0.000196	0.003910

9.20			0.000824	0.000156	0.003420
9.40			0.000653		0.002980
9.60			0.000520		0.002610
9.80			0.000411		0.002280
10.00			0.000325		0.001860
10.20			0.000256		0.001620
10.40			0.000203		0.001410
10.60			0.000160		0.001230
10.80			0.000127		0.001060
11.00					0.000859
11.20					0.000746
11.40					0.000648
11.60					0.000563
11.80					0.000454
12.00					0.000394
12.20					0.000342
12.40					0.000297
12.60					0.000240
12.80					0.000208
13.00					0.000181
13.20					0.000146
13.40					*0.000126*

Fig (4) represent the mean kinetic energy of electron (ε) as a function of E/N for pure Xe which have been calculated using eq. (2) and it is show clearly that the (ε) is increases from 0.2eV at E/N=1x10^{-19}V.cm^{2} to 5.75eV at E/N=2x10^{-15}V.cm^{2} this is because that the growth of the inelastic collisions of electrons, and also there is a good agreement over the entire E/N range by comparing the results with the data of (Dujko S. *et al.*, 2011).

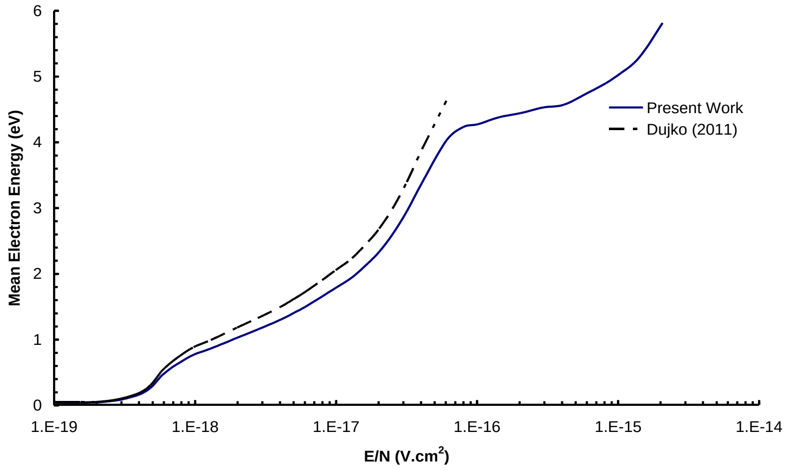

Figure (4) The mean electron energy as a function of E/N for pure Xe

Table (2) contains the data of figure (4) which is representing the mean electron energy as a function of (E/N) for pure Xenon.

Table (2) The calculated transport parameters for pure Xenon

E/N (V/cm^2) $x10^{-17}$	V_d (cm/sec) $x10^4$	$\langle \varepsilon \rangle$ (eV)	E/N (V/cm^2) $x10^{-17}$	V_d (cm/sec) $x10^4$	$\langle \varepsilon \rangle$ (eV)
0.01	0.375	0.04	4.00	20.734	3.395
0.02	0.815	0.045	6.00	32.594	4.027
0.04	2.898	0.157	8.00	46.628	4.215
0.06	6.2	0.455	10.00	60.628	4.295
0.08	7.832	0.656	20.00	124.373	4.435
0.10	8.535	0.768	40.00	246.277	4.593
0.20	9.794	1.029	60.00	364.92	4.744
0.40	11	1.302	80.00	485.814	4.888
0.60	11.817	1.492	100.00	607.69	5.039
0.80	12.475	1.646	150.00	926.568	5.409
1.00	13.048	1.78	200.00	1266	5.755
2.00	15.541	2.33	4.00	20.734	3.395

Fig (5) is represent the (ε) of pure He as a function of E/N values, which have been also calculated using eq. (2). The (ε) increases with increasing E/N values, as a results of different mechanism of electron energy dissipation through the inelastic collision in this gas, There is a good agreement between the present results and the evaluated data of (Nakamura K. *et al*., 2010).

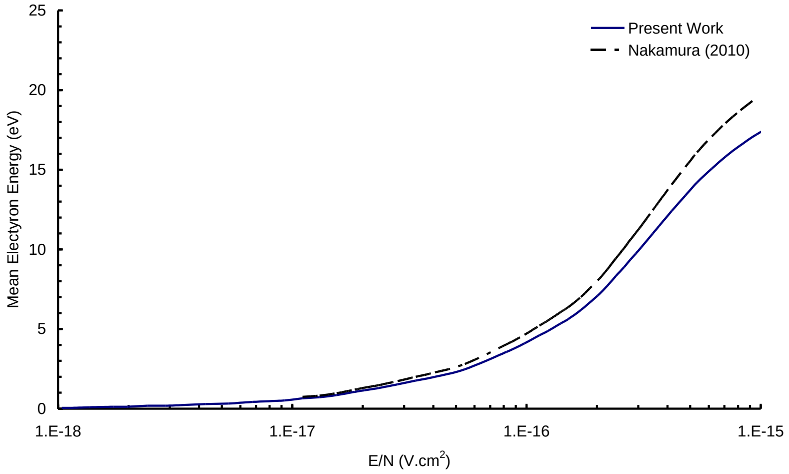

Figure (5) The mean electron energy as a function of E/N for pure He

Table (3) contains the data of figure (5) which is representing the mean electron energy as a function of (E/N) for pure Helium.

Table (3) The data of the (mean electron energy) as a function of (E/N) for pure Helium

E/N (V.cm^2)	$\langle \varepsilon \rangle$ (eV)	E/N (V.cm^2)	$\langle \varepsilon \rangle$ (eV)
1E-18	0.00	6E-17	2.67
2E-18	0.12	7E-17	3.11
3E-18	0.15	8E-17	3.46
4E-18	0.24	9E-17	3.82
5E-18	0.30	1E-16	4.14
6E-18	0.33	2E-16	7.03
7E-18	0.39	3E-16	9.86
8E-18	0.45	4E-16	12.07
9E-18	0.51	5E-16	13.63
1E-17	0.54	6E-16	14.87
2E-17	1.10	7E-16	15.79
3E-17	1.58	8E-16	16.38
4E-17	1.96	9E-16	16.91
5E-17	2.26	1E-15	17.38

Figure (6) is represents the drift velocity of pure Xenon as a function of E/N which have been calculated using eq. (3). The data have been recorded in (Table 2).

The drift controlled by inelastic collisions and proportional to E/N, and it takes higher value with increasing of E/N, since the elastic scattering cross section decreases strongly with the energy in this range of E/N.As shown in this figure, E/N increases rapidly for wide E/N range($1\times10^{-19} \le E/N \le 6\times10^{-19}$) V.cm^2, which is due to the reduction of the number of collisions as the energy of the swarm coincides with the sharply decreasing part of momentum transfer cross section Q$_m$.

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. By comparing the present work with the data of (Dujko S. et al., 2011) it can see clearly a very sensitive agreement between them.

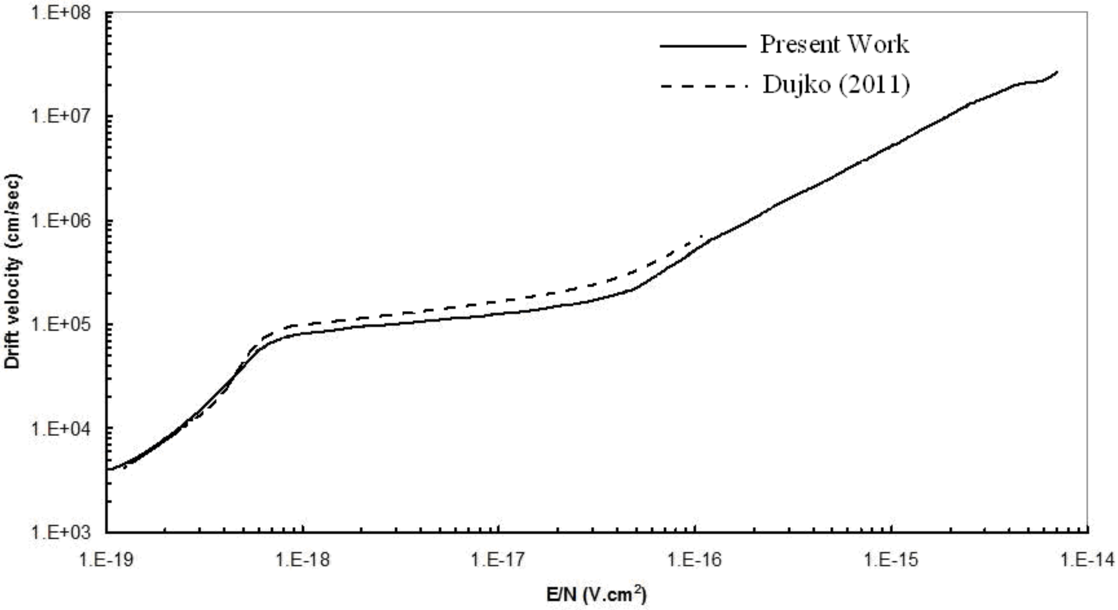

Figure (6) The drift velocity as a function of E/N value for pure Xe

Fig (7) is represent the drift velocity as a function of E/N value in pure He. The velocity calculations have been made using equation (3) too in order to overlap with the values calculated from Boltzmann equation. The computations are very sensitive to the magnitude and shape of the variation cross-sections. The gradient of V_d should be larger than elsewhere; on the other hand the energy moves on the increasing parts of Q_m the slope of the drift velocity will be much smaller, the present result values are shown to be in a good agreement with experiment values of (Schlummer T. et al., 2011).

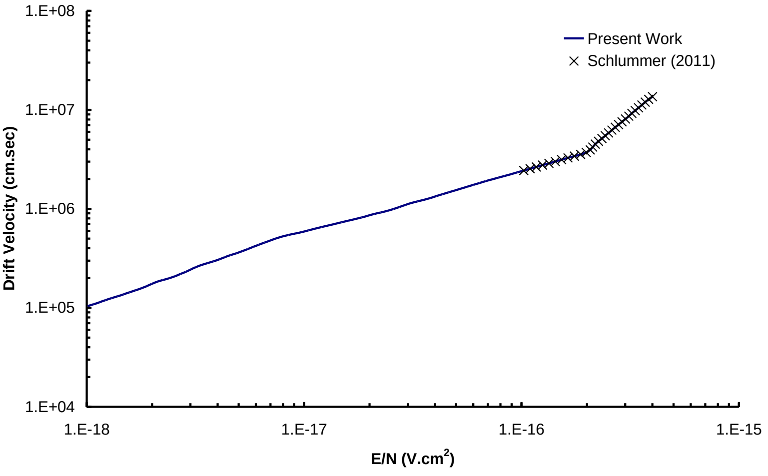

Figure 7: The drift velocity as a function of E/N value for pure

He

Table (4) contains the data of figure (7) which is representing the drift velocity as a function of (E/N) for pure Helium.

Table (4) The data of the (Drift velocity) as a function of (E/N) for pure Helium

E/N (V.cm^2)	V_d (cm.sec)	E/N (V.cm^2)	V_d (cm.sec)
1E-18	1.01E+05	3E-17	1.09E+06
2E-18	1.72E+05	4E-17	1.30E+06
3E-18	2.39E+05	5E-17	1.49E+06
4E-18	2.96E+05	6E-17	1.71E+06
5E-18	3.53E+05	7E-17	1.88E+06
6E-18	4.20E+05	8E-17	2.04E+06
7E-18	4.73E+05	9E-17	2.20E+06
8E-18	5.11E+05	1E-16	2.33E+06
9E-18	5.42E+05	2E-16	3.65E+06
1E-17	5.74E+05	3E-16	7.80E+06
2E-17	8.31E+05	4E-16	1.32E+07

Finally, fig (8) is representing the drift velocity of (Xe-He) mixtures as a function of E/N, This figure shows that energy level coincidences to do exist between the lowest helium metastable level and levels of neutral Xenon so that atom –atom excitation transfer from Helium to Xenon, as the metastable levels of Helium are higher in energy than the Xenon ground state, any observed increase in electron concentration when Helium is added to Xenon discharge could possibly be accounted. The present results in a good agreement with (Schlummer T. *et al.*, 2011)

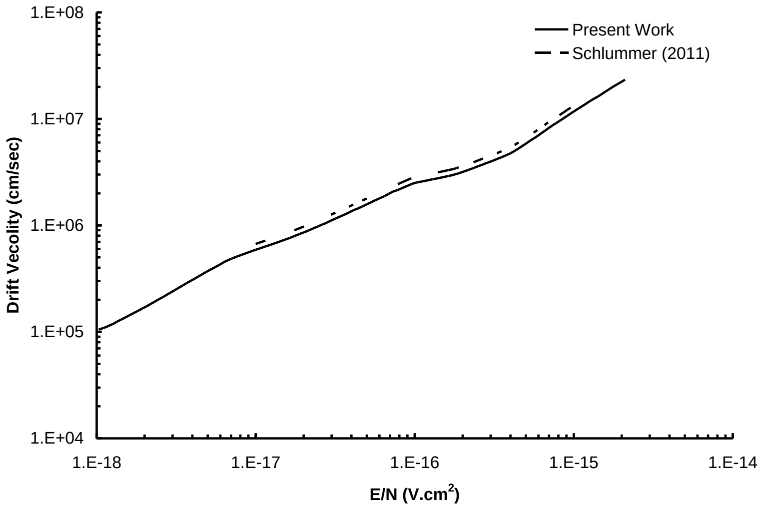

Figure (8) The Drift velocity as a function of E/N for (Xe- He) (0.2:0.8) mixture

Table (5) contains the data of figure (8) which represent the drift velocity as a function of (E/N) for Xe-He mixture mixed by (0.20-0.80).

Table (5) The data of the (Drift velocity) as a function of (E/N) for (Xe-He) mixture mixed by (0.20-0.80)

E/N (V.cm^2)	*D.V. (cm.sec)*	*E/N (V.cm^2)*	*D.V. (cm.sec)*
1E-18	1.06E+05	7E-17	1.96E+06
2E-18	1.65E+05	8E-17	2.12E+06
3E-18	2.34E+05	9E-17	2.29E+06
4E-18	3.02E+05	1E-16	2.43E+06
5E-18	3.60E+05	2E-16	3.06E+06
6E-18	4.29E+05	3E-16	3.87E+06
7E-18	4.73E+05	4E-16	4.70E+06
8E-18	5.21E+05	5E-16	5.71E+06
9E-18	5.52E+05	6E-16	6.81E+06
1E-17	5.85E+05	7E-16	7.95E+06
2E-17	8.47E+05	8E-16	9.12E+06
3E-17	1.09E+06	9E-16	1.02E+07
4E-17	1.33E+06	1E-15	1.15E+07
5E-17	1.55E+06	2E-15	2.19E+07
6E-17	1.78E+06		

Conclusion

The behavior of electron swarms in gases has been studied employing a Boltzmann equation. The calculating electron energy distribution function for pure Xe, He and their mixtures with different concentrations has been described.

Where the inelastic collision cross-section is relatively large (because of vibrational excitation), A strong anisotropy was observed.

The behavior of the swarm parameters, which are drift velocity and mean kinetic electron energy dependence on the ratio of the mixture components, can very probably, be explained by a preferential weighting of the elastic and inelastic scattering of the electrons on xenon and helium molecules at different values of E\N, also the results were in good agreement with the computational work.

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معلمات الأنتقال لحشد الألكترونات و دالة التوزيع الطاقي في غازي الزينون و الهيليوم و خليطيهما باستخدام معادلة بولتزمان

كولاله محمد فرج

كلية التربية / قسم الفيزياء / الأقسام العلمية – جامعة صلاح الدين

الخلاصة

تم استخدام معادلة الأنتقال الطاقي لبولتزمان لحساب و استنباط علاقات رياضية لمعلمات انتقال الألكترون و دالة التوزيع الطاقي للألكترون في الغازين (Xe ,He) و خليطيهما. تم استخراج معلمات الحشد الألكتروني ضمن المدى ($1\times10^{-18} \le E / N \le 2\times10^{-15}$) فولت.سم٢. ومن هذه المعلمات:متوسط طاقة الاكترون و سرعة الأنجراف كدالة لنسبة شدة المجال الكهربائي الى الكثافة العددية للغازات، و قد وجد بأن دوال التوزيع هي لاماكسويلية و تمتلك اختلافات في الطاقة تعكس دور عمليات تبادل طاقة الأكترون الجزيئي.