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Mean Drift Length During a Semi Wave of the CW Radio-Frequency Field

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Abstract

In this work we study mean drift length during a semi wave of the CW radio-frequency field the behavior of the diffusion particles in the pure Helium gas whose plays important role in production of the lam ps such as glow lamps and gas lasers through the calculation of the transport parameters which are w, μ, and D by solving numerically transport equation and feeding it to computer program which is construction to calculate the following parameters: E/P_{300}, S, DN, Dp, ν, $\bar{c}$, λ, ω, a, S_E, $(f\nu_1P)$, $(f\nu_1P)^{-1}$, ω/π and π/ω for energy ranges $0.121\times10^{-18} \leq E/N \leq 0.303\times10^{-16}$ V.cm^2 at temperature 300°K.

These parameters represented as functions for their variables whose shows a good agreement with experimental and theoretical data.

Keywords: Boltzmann transport equation, Boltzmann relation (plasma physics, radio wave).

معدل طول الانجراف خلال شبه موجة الترددات الراديوية المستمرة

الخلاصة

تم في هذا العمل حساب معدل طول الانجراف خلال شبه موجة الترددات المايكروية المستمرة التردد التصادمي للجسيمات المنتشرة في غاز الهليوم الذي يلعب دوراً مهماً في إنتاج المصابيح مثل مصابيح التوهج وليزرات الغاز ... الخ وذلك من خلال حساب معلمات الانتقال وهي سرعة الجرف والحركية ومعامل الانتشار وذلك بحل معادلة الانتقال عددياً، حيث تم تغذية هذه المعلمات إلى برنامج تم بناؤه لحساب المعلمات الآتية: E/P_{300}، S، DN، DP، ν، $\bar{c}$، λ، ω، a، S_E، $(f\nu_1P)$، $(f\nu_1P)^{-1}$، ω/π، π/ω، للقيم المحصورة بين $0.121\times10^{-18} \leq E/N \leq 0.303\times10^{-16}$ فولت . سم^2 وعند درجة حرارة 300 كلفن.

تم رسم هذه المعلمات كدوال لمتغيراتها حيث أظهرت تطابقاً عند مقارنتها مع النتائج العملية والنظرية المنشورة.

الكلمات المرشدة: معادلة الانتقال لبولتزمان، علاقة بولتزمان (فيزياء البلازما، الموجات الراديوية).

1-Introduction

The procedure is to find one or more transport coefficients for an assembly of electrons in the gas. In experimental conditions are chosen to ensure a very large number of collisions in the collision chamber rather than a single collisions, this collisions occur between the neutral

Particles and electrons having a relatively wide distribution of energies; this electrons received theenergy from, such as, electric field or x-ray, etc., which is produces

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ionization inside diffusion chamber containing gas.

We can using the approach through the solution of the Boltzmann equation for the motion of an electron swarm drifting and diffusing through a gas in the presence of an electric field has been discussed by many authors.

In general, the energy distribution of the swarm is determined by the ratio E/N, the gas temperature T, and the elastic and inelastic collision processes between the electrons and the molecules of the gas, which is, the swarms of electrons absorb the energy to produce electronic excitation. The collision processes controlling the energy distribution were therefore limited to an exchange of kinetic energy between the electrons and helium atoms so that the momentum transfer cross section alone determined the distribution.

The using of the computer techniques to the analysis of the results of electrons swarms is the factor chiefly responsible for the greatly increased accuracy that can now be claimed for the calculations of the diffusion parameters. Accurate formulae for the energy distribution and for drift and diffusion of an electron swarm moving through a gas in the presence of a uniform electric field have been known for many years. But before the availability of computers the only practical approach to the problem of extracting collision parameters from the transport data was through the use of somewhat drastic assumptions. In the earlier approach (e.g. Huxley and zaazou 1949; Crompton and Sutton 1952) formulae for diffusion and drift were developed on the assumption that the energy–dependent momentum transfer cross section could be replaced by an effective mean value for any given energy distribution corresponding to a particular value of the ratio E/N of the electric field strength to gas number density [1-8].

2-Theory Deduction

We know the total number n of electrons contained in the diffusion chamber over spatial coordinates is given by [9]:

$$n = n_{01} e^{\frac{-t}{t_{11}}} \qquad (1)$$

where t_{11} is related to the radius of the chamber, R and height H of the chamber by the expression:

$$\frac{1}{t_{11}} = D\left[\left(\frac{p}{H-2S}\right)^2 + \left(\frac{2.405}{R}\right)^2\right] \qquad (2)$$

where H-2S is the effective height for diffusion since the electrons within a layer of width S at both electrodes are immediately captured, if S represents the mean drift length during a semi wave of the CW radio-frequency field:

$$S = \frac{2W}{w} \qquad (3)$$

where W refers the drift velocity to the maximum value reached by the sinusoidal electric field in a period $2p/w$, which is the (capture by any electrode of the electrons contained in an adjacent layer of thickness S) and w is the semi wave of the CW radio-frequency field.

We can deduce the reduced diffusion coefficient, D from the equation (2) which is:

$$D_{1N} = DN \qquad (4)$$

or we can find the DN values obtained by multiplying the D/m data by the corresponding mN, which is [10]:

$$mN = \frac{W}{E/N} \qquad (5)$$

where:

$$DN = \frac{D}{m} \times mN \qquad (6)$$

substitute Eq.(5) into Eq.(6) yields:

$$DN=\frac{D}{m}\frac{W}{E/N} \qquad (7)$$

therefore, by using the same procedure for DN we can find DP;

$$mP=\frac{W}{E/P} \qquad (8)$$

hence:

$$DP=\frac{D}{m}\times mP \qquad (9)$$

substitute Eq.(8) into Eq.(9) yields:

$$DP=\frac{D}{m}\frac{W}{E/P} \qquad (10)$$

where D/m is the characteristic energy of the gas and E is the electric field strength.

From the expression of drift velocity W in the case of a Maxwellian distribution and $dl/dc=0$, we can find the n values, which is:

$$W=0.85\frac{e}{m}\frac{l}{c}=0.85\frac{e}{mn} \qquad (11)$$

and

$$n=\frac{\bar{c}}{l} \qquad (12)$$

where e is the electronic charge, m is the electronic mass, l is the electron mean free path n is the collision frequency, $\bar{c}$ is the mean speed of the electron in the swarm whose defined by the formula [1]:

$$\bar{c}=5.93\times10^{7}\left(\frac{D}{m}\right)^{\frac{1}{2}} \qquad (13)$$

The drift velocity of the electron is obtained according to the assumptions:

One the velocity variation Δc_E between two successive collisions, due to the accelerating field E, are small with respect to the thermal velocity c, i.e., $\Delta c_E << c$.

Two the inelastic collision frequency n_{in} is small with respect to the elastic collision frequency n_{el}, i.e., $n_{in} << n_{el}$. The drift velocity is obtained by two successive steps: (a) theories deducing W(c) from the first-order expansion of F(c,v) which is define by the expression:

$$W=\int_0^p\int_0^\infty c\cos v\,F(c,v)\,dc\,dv \qquad (14)$$

where c is the magnitude of the velocity v is the angle between c and electric field E, W is the drift velocity and F(c, v) is the velocity distribution function of the electrons in a gas. (b) theories deducing W(c) from the study of generic electron motion.

Three the mean free path (l) is independent of the thermal velocity c. Theories of type (a) make use of lorentic treatment of electric conduction in metals. According to the a treatment above, first, two, and third, give us:

$$W=\frac{2a}{3}\frac{l}{c} \qquad (15)$$

since;

$$a=\frac{eE}{m} \qquad (16)$$

where a is the acceleration of an electron (or ion) of charge e and mass m, and subjected to an electric field E.

Drude derive the expression for obtained the drift velocity which is [11]:

$$W(c)=\frac{a}{2}\frac{l}{c} \qquad (17)$$

The first theory of Langevin who assumed for the mean displacement S_E in the direction of E, the expression corresponding to the equation (17), in the case of a generic path S which is define by [12]:

$$S_E=(\frac{1}{2}a)t^2=\frac{1}{2}a\frac{S^2}{c^2} \qquad (18)$$

The Langevin averaged over the distribution of free paths whose defined by:

$$P(s)ds = -\frac{dn}{n} = \frac{1}{l} e^{-\frac{S}{l}} ds \qquad (19)$$

where dn is the number of electrons colliding between s and s+ds. And multiplied by the mean collision frequency $\frac{\bar{c}}{l}$ (he assumed l = const. and $\Delta c_E << c$; obtained: $W(c) = al/c$

From the above, the drift velocity values have been calculated by using the solution of numerically transport equation, in this situation, indeed, there is other condition which is equivalence between oscillating and constant fields, this condition implies a relationship between CW radio-frequency field period and thermalization time $(fn\ P_0)^{-1}$, this time we can derive below.

An energy balance equation is:

$$de = -nfedt + eEWdt \qquad (20)$$

Since $v = \frac{\bar{c}}{l}$ is the collision frequency, l is the mean free path, e represent the mean kinetic electron energy and f is the fractional loss of kinetic energy per collision. By integration the Eq.(20) through the time t_2-t_1, and the mean value of the energy interval $(e_1 + e_2)/2$ gives:

$$t_2 - t_1 = \frac{1}{fn_1P_0}\left[\ln\left(\frac{eWE}{P_0} - fn_1e_2\right) - \ln\left(\frac{eWE}{P_0} - fn_1e_1\right)\right]$$

$$t_2 - t_1 = \frac{1}{fn_1P_0} \ln \frac{\frac{eWE}{P_0} - fn_1e_2}{\frac{eWE}{P_0} - fn_1e_1} \qquad (21)$$

Since P_0 is gas pressure at temperature 0°C, n_1 is collision frequency at P_0=1 Torr and fn_1 is deduced from Eq.(20) in equilibrium equation condition and assuming a Maxwellian distribution:

$$fn_1 = \left(\frac{eEW}{P_0 e}\right)_{eq} = \frac{2}{3}\left(\frac{WE/P_0}{D/m}\right)_{eq} \qquad (22)$$

$$fn_1P = \left(\frac{eEW}{e}\right)_{eq} = \frac{2}{3}\left(\frac{WE}{D/m}\right)_{eq} \qquad (23)$$

$$(fn_1P)^{-1} = \frac{1}{\frac{2}{3}\left(\frac{WE}{D/m}\right)} \qquad (24)$$

where $(fn_1P)^{-1}$ is called a relaxation time constant, which is required by fast electrons (produced, such as, by x-rays) to reach practical equilibrium energy.

From the above therefore, when the condition $\frac{W^2}{v^2} \le 10^{-2}$ is satisfied the sinusoidal field is equivalent to a rectified full wave field (in order to heat electrons). It is sufficient that the thermalization time constant be not smaller than a half period p/w of the alternating field

$$\frac{1}{fn_1P} \ge \frac{p}{w} \qquad (25)$$

to obtain an energy ripple of (7.5%).

When the oscillating field is equivalent to a constant field E of amplitude equal to the effective value $E_0/2^{1/2}$ of the sinusoidal field. If this condition is always assumed, then

$$\frac{w^2}{n^2} \le 10^{-2} \qquad (26)$$

Where w is angular frequency which is define by the equation:

$$w = 2pn \qquad (27)$$

$$\frac{w}{n} \le 0.1 \qquad (28)$$

from Eq.(25) and Eq.(27) imply:

$$\frac{1}{fn_1 P} \geq \frac{p}{w}$$

$$fn_1 Pp \leq w$$

$$0.1pn_1 P \leq w$$

$$fn_1 P \leq \frac{w}{p} \leq \frac{0.1n_1 P}{p} \qquad (29)$$

Where the fractional loss f of kinetic energy is:

$$f \leq 0.1p \qquad (30)$$

3-Transport Equation solution

The evaluating of the drift velocity of the electron in the electric field based on the mathematical theory in pure gas and/or gaseous mixture which is the physical theory depend on the mathematical relation for Boltzmann transport equation, this relations are resultant for numerically solving to this equation, the transport parameters are result for above and had be obtained:

$$W = \frac{P}{En_0} \qquad (31)$$

where W is the drift velocity, P is the time rate which is the electron acquire the energy from the electric field E and n_0 is the total electrons density, which is equal 2.5146×10^{19}.

$$m = \frac{W}{E} \qquad (32)$$

where m is the electron mobility.

$$D = \frac{1}{3}\left(\frac{2}{m}\right)^{\frac{1}{2}} \sum_k \frac{e_k f_k \Delta e}{\sum_k q_s s_s(e_k)} \qquad (33)$$

$$< e >= \sum_k e_k n_k \Delta e / n_0$$

where D is diffusion coefficient, m is electron mass, q_s is the concentration of samples N_s , s_s is elastic scattering cross section and f_k is distribution function, e_k is the characteristic energy and $<e>$ is the electron average energy[13]. The above parameters are obtained by solved numerically transport equation solution [14] as in table (1).

The units of using of the above parameters are practical units which is for drift velocity is cm/sec, mobility is cm^2/V.sec, diffusion coefficient is cm^2/sec, average energy $\Delta\varepsilon$ and characteristic energy, e_k are eV, the distribution function is $eV^{-3/2}$ and s_s is cm^2.

4- Calculations

After we solved numerically transport equation and obtained the above parameters as in table (1). This parameters fed to the computer program (appendix A), which constructed to this purpose to calculate the following, which are:

1- The ratio of electric field strength to the gas pressure E/P_{300} is calculated from the equation:

$$\frac{E}{P_{300}} = \frac{E}{N} \times 966.951\times10^{16} \frac{1}{T} \qquad (34)$$

where E/N in unit of (V cm^2) and E/P in unit of (V cm^{-1} $Torr^{-1}$).

2- The mean drift length during a semi wave of the CW ratio – frequency field S is calculated from the Eq.(3).
3- The reduced diffusion coefficient DN is calculated from the Eq.(7).
4- The reduced diffusion coefficient DP is calculated from the Eq.(10).
5- The collision frequency n is calculated by:

It is possible to state that the correct factor is 2/3 multiplied by the ratio between the average of 1/c over, as assumed, a Maxwellian distribution, and the mean velocity $\bar{c}$, which gives 1.275. The result is:

$1.275\times\frac{2}{3}=0.85$. For the factor 2/3, for example see [11] PP. 287.

From the above, we can say, from the Eq.(11):

$$W = 0.85\frac{e}{m}\frac{l}{c} = 0.85\frac{e}{mn}$$

$$nmW = 0.85e$$

$$n = 0.85\frac{e}{m}\frac{1}{W}$$

$$n = 0.85\frac{1.602\times10^{-19}c}{9.109\times10^{-31}kg}\frac{1}{W}$$

$$n = 0.85\times1.759\times10^{11}ckg^{-1}\times\frac{1}{W}$$

$$n = 0.85\times1.759\times10^{8}cgm^{-1}\times\frac{1}{W} \qquad (35)$$

6- The mean speed of the electric $\bar{c}$ is calculated from the Eq.(13).
7- The electron mean free path l is calculated from the Eq.(12).
8- The angular frequency w is calculated from the Eq.(27).
9- The acceleration of an electron or ion (a) is calculated from Eq.(16).
10- The mean displacement S_E of the electron in the direction of E is calculated from Eq.(18).
11- The relaxation time constant (fn_1P) is calculated from Eq.(23).
12- The relaxation time constant $(fn_1P)^{-1}$ is calculated from Eq.(24).
13- The value of $\frac{w}{p}$ and $\frac{p}{w}$ are calculated from the Eq.(27).

The units of using are practical units which are: E/P_{300} in unit of Vcm^{-1} $Torr^{-1}$, S in unit of cm, DN in unit of $cm^{-1}sec^{-1}$, DP in unit of cm^2 Torr sec^{-1}, n in unit of sec^{-1}, $\bar{c}$ in unit of cm sec^{-1}, l in unit of cm, w in unit of sec^{-1}, a in unit of cm sec^{-2}, S_E in unit of cm, (fn_1P) in unit of μsec^{-1}, $(fn_1P)^{-1}$ in unit of μsec, $\frac{w}{p}$ in unit of μsec^{-1}, and $\frac{p}{w}$ in unit of μsec.

The physical quantities are obtained from the above are tabulated in tables (2-4) and represented as a functions for their variables as seen in figures (1-38).

5-Results and Discussion

In this work the results obtained by using the Finite-Difference method to solve the transport equation in gaseous medium, e. g. Helium gas are agreement with practical data, [9].

Figure (1) show the mean drift length during a semi wave of the CW radio-frequency field as a function of the radio applied electric field to gas total number density **E/N** and gas pressure **E/P$_{300}$** in a pure helium gas, which is increasing the layer thickness up to 0.1×10^2 cm because the electrons acquires the more energy from the applied electric field, but after this thickness the increasing is linear.

Figure (2) shows the layer thickness during a semi wave of the CW radio-frequency field as a function of the drift velocity **W** in a pure helium gas, which is, the relation between them is linear.

Figure (3) shows the layer thickness during a semi wave of the CW radio-frequency field as a function of the angular frequency in a pure helium gas, which is the layer thickness reduces with angular frequency increasing.

Figure (4) shows the diffusion coefficient increasing up to 0.1×10^{23} (cm^{-1} sec^{-1}) with drift velocity is constant but after this value, the increasing is exponential with velocity.

Figure (5) shows the increasing of the diffusion coefficient with characteristic energy.

Figure (6) show the reduced diffusion coefficient is constant up to 0.1×10^{23} (cm^{-1} sec^{-1}) but after this value, the DN increases with E/N. Notice the good agreement with experimental values [9].

Figures (7-9) show the reduced diffusion coefficient as a function of the (E/N, E/P_{300}, W and D/μ), from the curves we can see the exponential relations for increasing the DP with their variables. Notice the good agreement with experimental values [9].

Figure (10) shows the collision frequency reduced in linear form with drift velocity increasing.

Figure (11) appear collision frequency reducing with a function increasing E/N and E/P_{300}.

Figure (12) appear electron mean speed increasing with E/N and E/P_{300} is exponentially.

Figure (13) shows the electron mean speed increases in rapid form and at final becomes stable with increasing of the D/μ.

Figure (14) appears the mean free path increase with increasing of the E/N and E/P_{300} in linear form.

Figure (15) shows the mean free path increase with drift velocity, i.e., the distance of the travel by electron becomes large.

Figure (16) shows the angular frequency is reducing with E/N and E/P_{300}.

Figure (17) shows the angular frequency is reducing in linear form with drift velocity increasing.

Figure (18) shows the linear relation for the increasing of the electron acceleration with E/N and E/P_{300}.

Figure (19) shows at low values for electric field, the electron acceleration increases, but at large values for electric field, the electron acceleration stable nearly.

Figure (20) shows at low values for E/N up to 0.455×10^{-18} V cm^2, the mean displacement is very low, but at E/N=(1.214-4.55)× 10^{-18} V cm^2, the mean displacement is gradually increase and at E/N=(12.14-30.3)× 10^{-18} V cm^2, the mean displacement is rapidly increase.

Figure (21) shows the electron mean displacement is increasing with increasing of electron acceleration.

Figure (22) show at E/N=(0.121-0.455)× 10^{-18} V cm^2, the relaxation time constant of the electrons is low but at E/N=(1.214-30.3) × 10^{-18} V cm^2, the relaxation time constant is very large.

Figure (23) shows when the electron average energy increases from 0.04898 eV (corresponding, $E/P_{300}=0.39\times10^{-2}$ V cm^{-1} $Torr^{-1}$) to 1.6298 eV, the relaxation time is increasing until 1.6298 eV corresponding, $E/P_{300}=97.663\times10^{-2}$ V cm^{-1} $Torr^{-1}$.

Figure (24) shows the applied electric field to gas total number density **E/N** and gas pressure $\mathbf{E/P_{300}}$ as a function of relaxation time constant of electron, starting from E/N=30. 3 × 10^{-18} V cm^2 & $E/P_{300}=97.663\times10^{-2}$ $V.cm^{-1}$ $.Torr^{-1}$.

Figure (25) shows the electron average energy as a function of relaxation time constant of electron, starting from $<e>$=1.6298 eV.

Figure (26) shows the relaxation time of electron angular frequency starts from $w/p=11.222\times10^{-3}$ μsec^{-1} and take decay form to the ending.

Figure (27) shows the relaxation of electron angular frequency starts from $p/w=0.002\times10^{3}$ μsec^{1} corresponding to E/P_{300}=97.663 ×10-2 V cm^{-1} $Torr^{-1}$ and take decay form.

6- Conclusions

1- The drift velocity W is given by $W=\int_0^\infty W(c_0)f_0(c_0)dc_0$ [11] is not subjected to the simplifying assumption used by the previous theories sec.2, where $W(c_0)$ refers the drift velocity of electrons having initial velocity c_0 and $f_0(c_0)$ is initial distribution function. The quantity $W(c_0)$ compared with $W(c)$ Eq.(17) obtained by the various theories mentioned is sec.2, and gives the same result. The validity of Eq.(17) not only for low fields but also for high fields and can be extended even to inelastic collisions by simply considering l as the actual mean free path corresponding to the total (Elastic + Inelastic) collision cross section, which is fed as input data to solve numerically transport equation.

The electron density sampling method [9] was measured the drift velocity W and of the mobility $m=W/E$ and of the ratio D/m, from which $D=m(D/m)$.

2- This above quantities and others obtained by using Finite-Difference method and compared with it, i.e., the calculated values are agreement with experimental values.

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Table (1): The calculated transport parameters for pure – Helium at 300°K

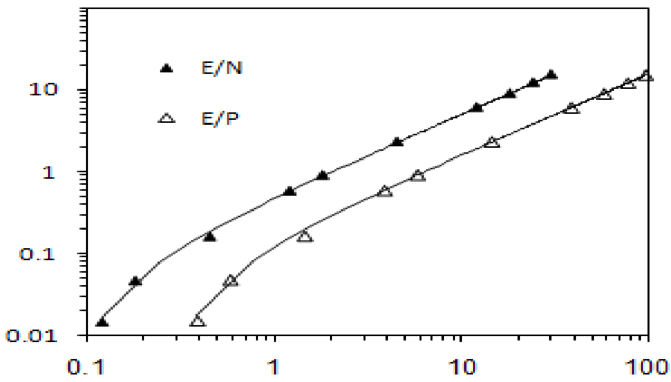
E/N (V.cm^2) $\times 10^{-18}$	E (V/cm) Eq.(31)	W (cm/sec) $\times 10^5$ Eq.(31)	D/μ (eV) Eqs.(32 +33)	<ε> (eV)
0.121	3.041	0.267	0.034	0.0489
0.182	4.575	0.473	0.035	0.0518
0.455	11.428	0.877	0.043	0.0609
1.214	30.519	1.666	0.075	0.1103
1.82	45.754	2.074	0.100	0.129
4.55	114.38	3.307	0.208	0.2796
12.14	305.19	5.342	0.519	0.6638
18.2	457.54	6.500	0.759	0.9678
24.3	610.90	7.571	1.015	1.3093
30.3	761.74	8.454	1.250	1.6298

Table (2): The calculated physical quantities

E/N V cm^2 $\times 10^{-18}$	**E/P$_{300}$** Vcm^{-1} Torr^{-1} $\times 10^{-2}$	n sec^{-1} $\times 10^3$	w sec^{-1} $\times 10^3$	**S** cm $\times 10^2$	**DN** cm^{-1} sec^{-1} $\times 10^{23}$	**DP** cm^2 Torr /sec $\times 10^7$
0.121	0.390	5.610	35.262	.015	.074	.023
0.182	0.586	3.158	19.850	.0476	.090	.028
0.455	1.466	1.705	10.712	.1636	.082	.025
1.214	3.912	0.897	5.638	.5908	.103	.011
1.82	5.866	0.720	4.525	.9166	.114	.035
4.55	14.665	0.452	2.841	2.3282	.151	.047
12.14	39.129	0.279	1.753	6.0941	.228	.070
18.2	58.661	0.230	1.445	8.9962	.271	.084
24.3	78.323	0.197	1.238	12.230	.316	.098
30.3	97.663	0.176	1.106	15.287	.348	.108

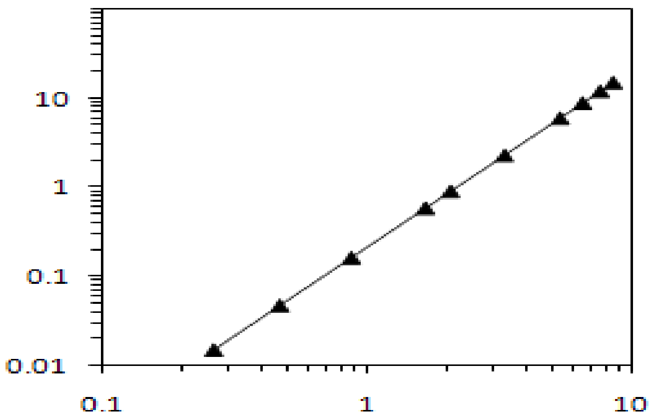
Table (3): The calculated physical quantities

E/N V.cm^2 $\times 10^{-18}$	**E/P$_{300}$** V.cm^{-1}. Torr^{-1} $\times 10^{-2}$	(fn_1P) µ sec$^{-1}\times 10^{-6}$	$\frac{w}{p}$ * µsec^{-1} $\times 10^{-3}$	$(fn_1P)^{-1}$ µsec $\times 10^{6}$	$\frac{p}{w}$ ** µsec $\times 10^{3}$
0.121	0.390	1.6032	11.222	0.623	.00008
0.182	0.586	4.1835	6.317	0.24	.0001
0.455	1.466	15.583	3.41	0.064	.0002
1.214	3.912	45.0669	1.794	0.022	.0005
1.82	5.866	63.1962	1.44	0.015	.0006
4.55	14.665	120.8935	0.904	0.008	0.001
12.14	39.129	209.244	0.557	0.004	0.001
18.2	58.661	261.1494	0.459	0.003	0.002
24.3	78.323	303.688	0.394	0.003	0.002
30.3	97.663	343.5957	0.352	0.002	0.002



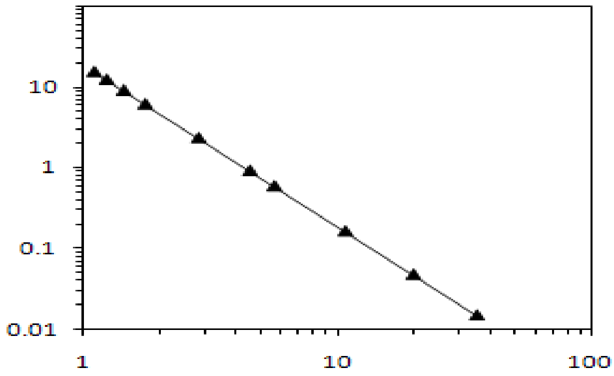
E/N (V cm^2) × 10^{-18}
E/P$_{300}$ (Vcm^{-1}Torr^{-1}) ×10^{-2}

Figure (1): The mean drift length during a semi wave of the CW radio-frequency field as a function of the E/N & E/P$_{300}$ in a pure helium gas.



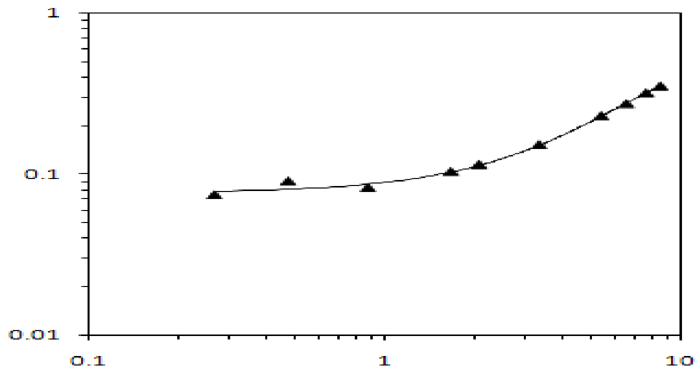
Drift velocity W (cm/sec) × 10^5

Figure (2): The layer thickness during a semi wave of the CW radio-frequency field as a function of the drift velocity W in a pure helium gas



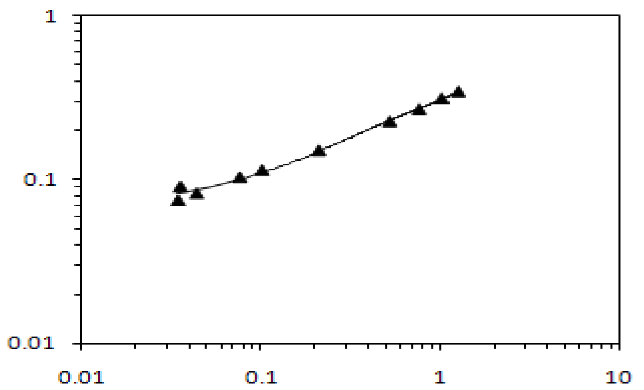
Angular frequency w (sec-1) ×103

Figure (3): The layer thickness during a semi wave of the CW radio-frequency field as a function of the angular frequency in a pure helium gas.



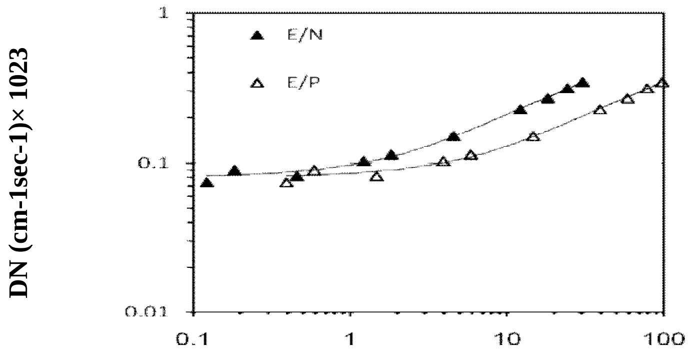
Drift velocity W (cm/sec) × 105

Figure (4): The diffusion coefficient as a function of the drift velocity in a pure helium gas.



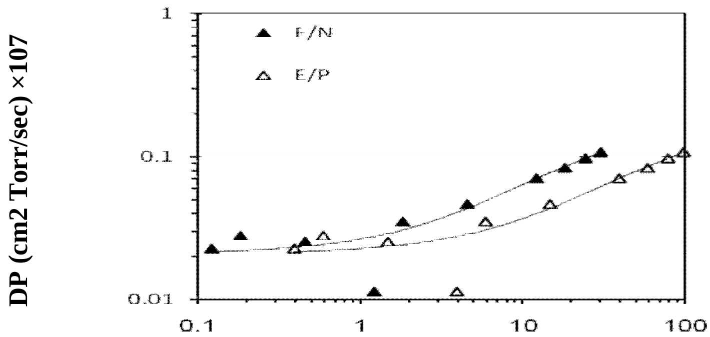
D/m (eV)

Figure (5): The electron reduced iffusion coefficient DN as a function of the diffusion coefficient to the electron mobility ratio in a pure helium gas.

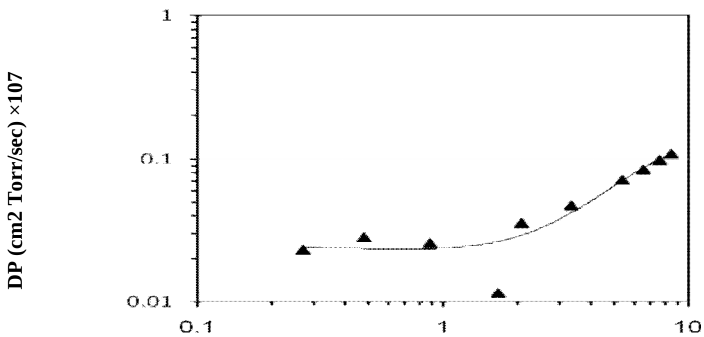


E/N (V cm2) × 10-18
E/P300 (Vcm-1Torr-1) ×10-2

Figure (6): The electron reduced diffusion coefficient versus E/N & E/P300. Notice the good agreement with experimental va[9]. lues



E/N (V cm2) × 10-18
E/P300 (Vcm-1Torr-1) ×10-2
Figure (7): The electron diffusion coefficient versus E/N & E P300. Notice the good agreement with experimental alues [9].



Drift velocity W (cm/sec) × 105
Figure (8): The electron diffusion coefficient as a function of the drift velocity in a pure helium gas.

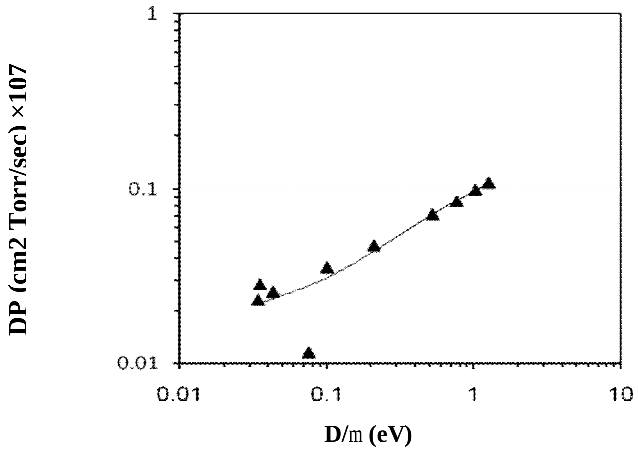


Figure (9): The electron diffusion coefficient as a function of the electron mobility ratio in a pure helium gas.

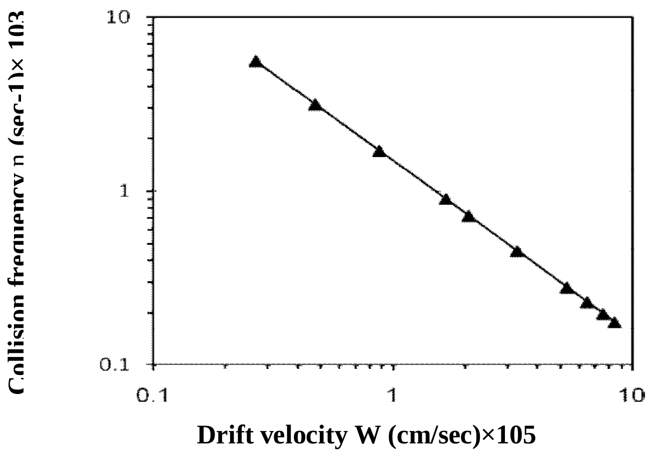


Figure (10): The Collision frequency as a function of drift velocity in a pure helium gas.

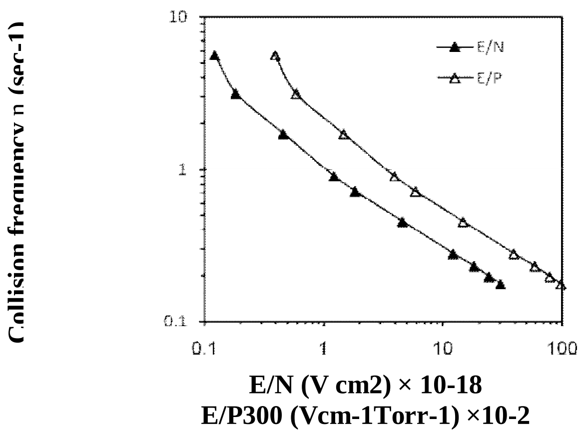


Figure (11): The Collision frequency as a function of the E/N & E/P300 in a pure helium gas.

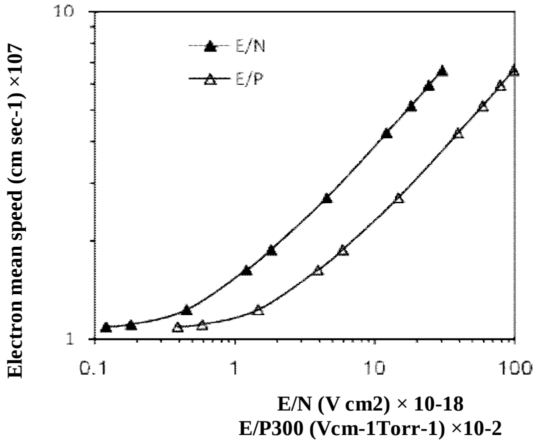
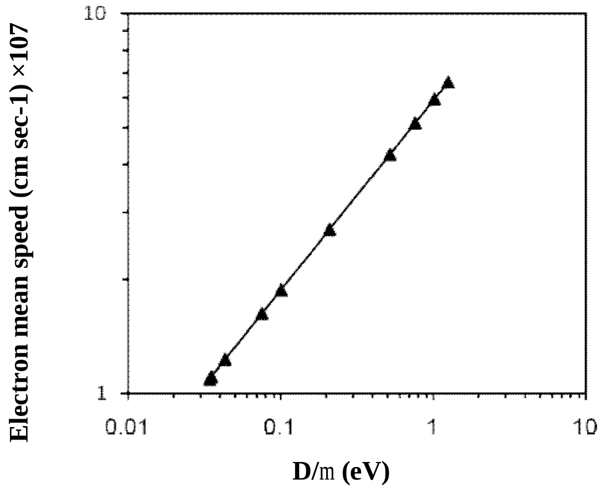


Figure (12): The mean speed of the electron as a function of the E/N & E/P300 in a pure helium gas.



Figure(13): The mean speed of the electron as a function of the electron mobility ratio in a pure helium gas.

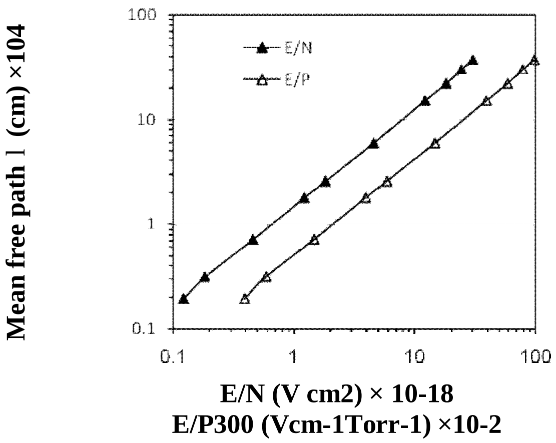


Figure (14): The mean free path of the electron as a function of the E/N & E/P300 in a pure helium gas.

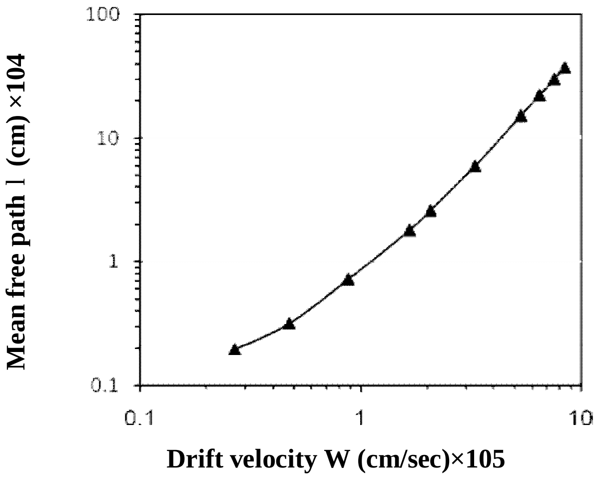
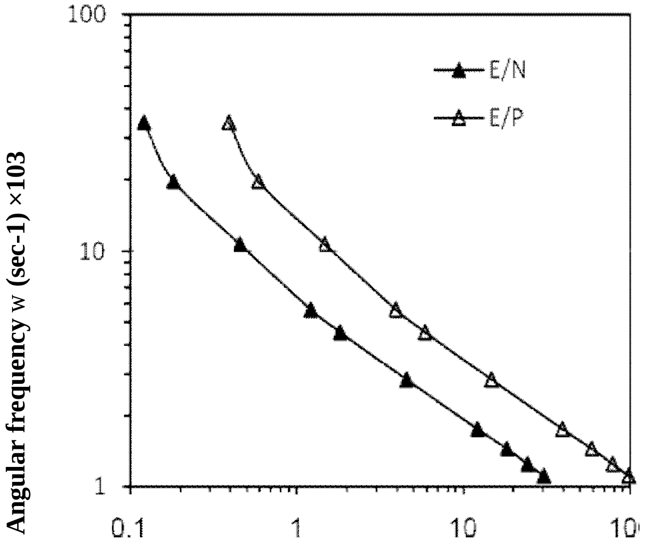
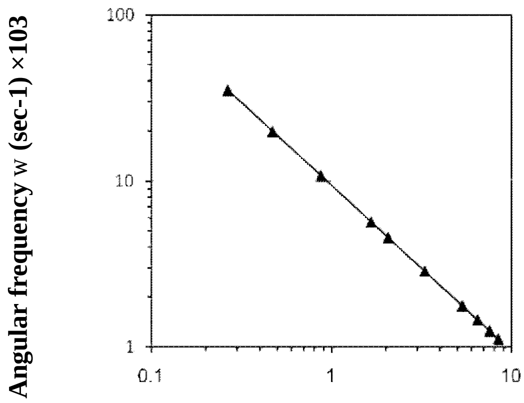


Figure (15): The mean free path of the electron as a function of drift velocity in a pure helium gas.

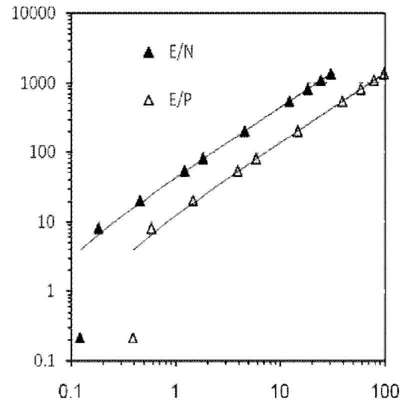


E/N (V cm2) × 10-18
E/P300 (Vcm-1Torr-1) ×10-2
Figure (16): The semi wave of the CW radio-frequency filed as a function of the E/N & E/P300 in a pure helium gas.



Drift velocity W (cm/sec)×105
Figure (17): The semi wave of the CW radio-frequency filed as a function of drift velocity in a pure helium gas.

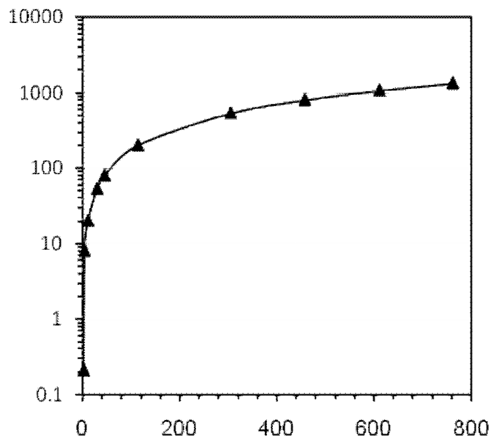
Electron acceleration a (cm sec-2) ×108



E/N (V cm2) × 10-18
E/P300 (Vcm-1Torr-1) ×10-2

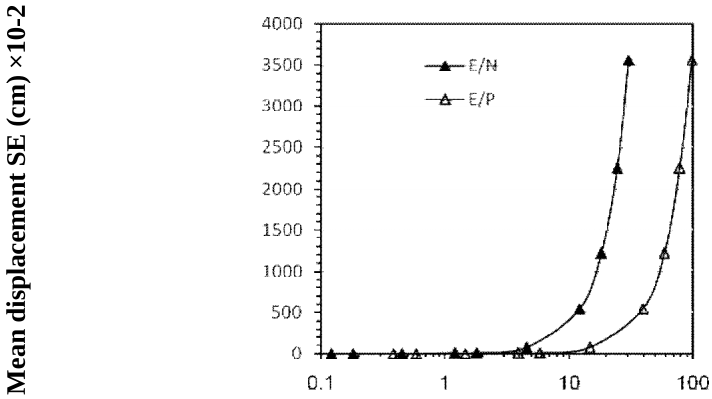
Figure (18): The acceleration of an electron as a function of the E/N & E/P300 in a pure helium gas.

Electron acceleration a (cm sec-2) ×108



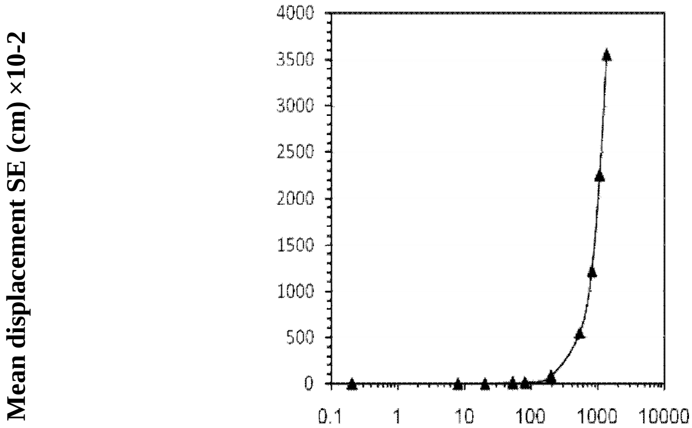
E (V cm-1)

Figure (19): The acceleration of an electron as a function of electric field strength in a pure helium gas.



E/N (V cm2) × 10-18
E/P300 (Vcm-1Torr-1) ×10-2

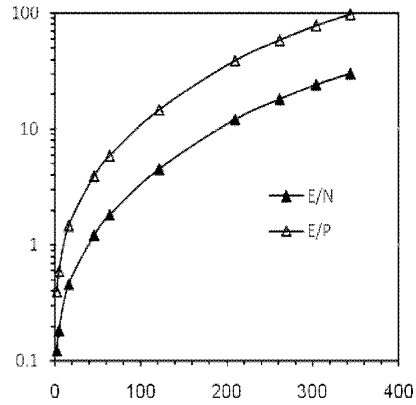
Figure (20): The mean displacement of an electron as a function of E/N & E/P300 in a pure helium gas.



Electron acceleration a (cm sec-2)×108

Figure (21): The mean displacement of an electron as a function of the electron acceleration in a pure helium gas.

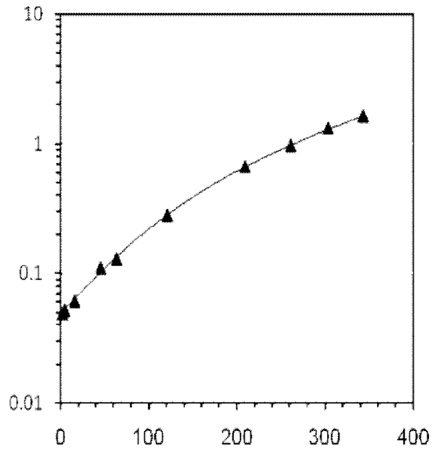
E/N (Vcm2) × 10-18
E/P300 (Vcm-1Torr-1) ×10-2



Relaxation time cons.(fn1P) (msec-1)×10-6

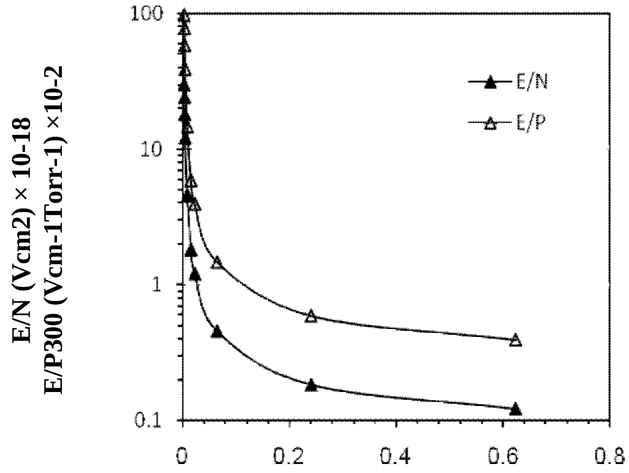
Figure (22): The E/N & E/P300 as a function of the relaxation time constant in a pure helium gas.

Electron average energy<e> (eV)

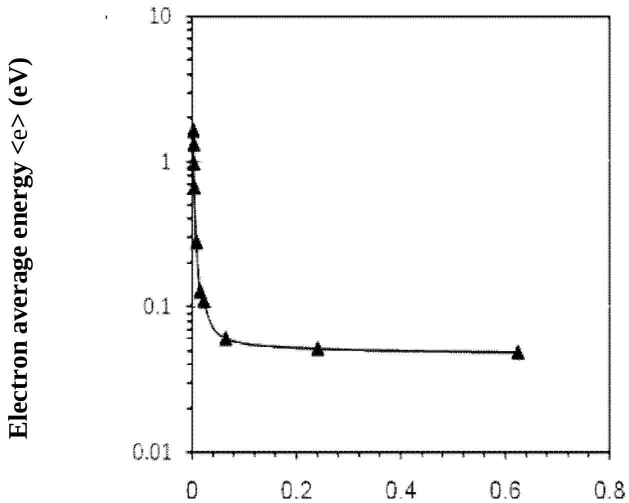


Relaxation time cons.(fn1P) (msec-1)×10-6

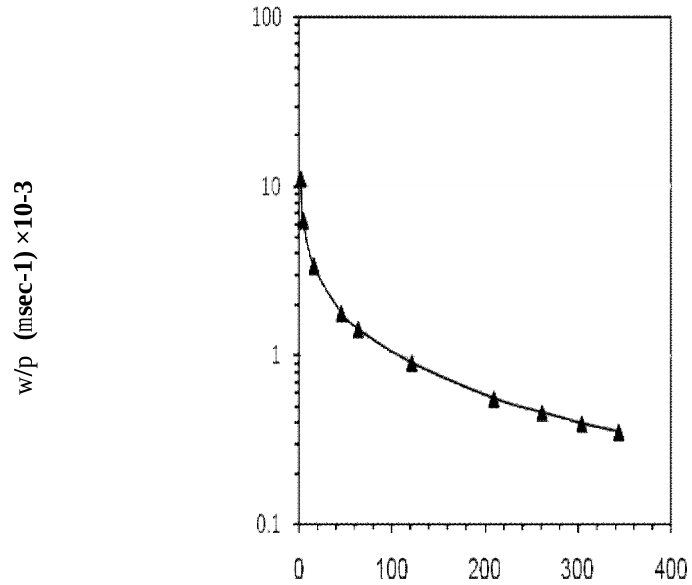
Figure (23): The Electron average energy as a function of the relaxation time constant in a pure helium gas.



Relaxation time cons. (fn1P)-1 (msec-1)×106
Figure (24): The E/N & E/P300 as a function of the relaxation time constant in a pure helium gas.

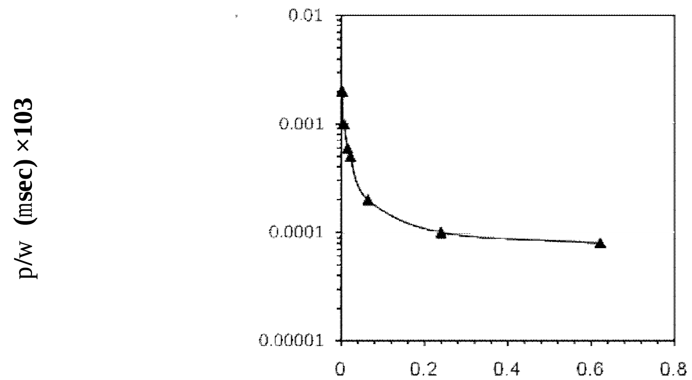


Relaxation time cons. (fn1P)-1 (msec-1)×106
Figure (25): The Electron average energy as a function of the relaxation time constant in a pure helium gas.



Relaxation time cons.(fn1P) (msec-1)×10-6

Figure (26): The ratio of w/p as a function of the relaxation time constant in a pure helium gas.



Relaxation time cons. (fn1P)-1 (msec-1)×106

Figure (27): The ratio of p/w as a function of the relaxation time constant in a pure helium gas.

Appendix A

Computer program (Fortran language) for CW radio-frequency calculation

```
     dimension EN(10), DU(10), E(10),W(10), E(10),EE(10), V(10),
        W1(10),DN(10),S(10),DP(10),EP(10),C(10), H(10), A(10), SE(10), F(10), F1(10),
        T(10), T1(10)
     real K,K1
     data EN/0.121E-18,0.182E-18,0.455E-18,1.214E-18,1.8E-18,4.55E-18, 12.14E-18,18.2E-
          18,24.3E-18, 30.3E-18/
     data E/3.041,4.575,11.438,30.519, 45.754, 114.387,305.199,457.548, 610.902,761.742/
     data W/0.2665E+05,0.4774E+05,
          0.8767E+05,1.6657E+05,2.0739E+05,3.3073E+05,5.3415E+05,6.4998E+05,7.5708E
          +05,8.4541E+05/
     data DU/0.0337,0.0348,0.0429,0.0752, 0.1001,0.20862,0.5194,0.7592,1.0153,1.2495/
     DATA EE/0.0489,0.0518,0.0609,0.1103, 0.1290,0.2796,0.6638,0.9678,1.3093,1.6298/
     Tg=300.0
!e (S ) Electronic Charge
!k      Boltzmann Constant
!Tg     Gas Temperature
!E  The Applied Electric Field (V**-1      cm**-1)
!W      The Drift Velocity (cm sec**-1)
!E/N (EN) The Ratio of Applied Electric Filed To Total Number Density of Molecules (or
          Atoms) of Gases
!D/U (DU) The Ratio of Diffusion Coefficient To The Mobility (eV)
!E/P300 (Ep) The Ratio of Applied Electric Field to Gas Pressure (V cm**-1 Torr**-1)
!V      Collision Frequency
!W1     Angular Frequency
!S      Mean Drift Length
!DN     Diffusion Coefficient
!DP     Reduced Diffusion Coefficient
!C      Mean Speed of The Electron
!H      Mean Free Path of The Electron
!A      Acceleration of The Electron
!SE     Mean Displacement In The Direction of The Applied Electrical Field E
!F      Relaxation Time Constant
!F1     Inverse of Relaxation Time Constant
!T      Ratio of Angular Frequency To Pi
!T1     Ratio of Pi To Angular Frequency
    open (6,file='f:\xx1.dat')
     write(6,*)'          Table (1)        '
     write(6,*)'          ------------        '
     write(6,1)
1    format(/,5x, 'E/N',9x, 'E',10x, 'W',    9x,'D/U',8x,'<e>')
     write(6,2)
2    format(/2x,' _______',2x,' _______', 2x, '_______',2x,'_______',2x,'_______')
      do 3 I=1,10
3    write(6,4)EN(I),E(I),W(I),DU(I),EE(I)
4    format((5(2X,E9.3))
     write(6,5)
5     format(/)
!calculation of the ratio of applied electric field to gas pressure (V cm**-1 Torr**-1)
    do 6 I=1,10
6   EP(I)=966.951E+16*EN(I)/Tg
!calculation of collision   frequency
```

```
    do 7 I=1,10
7   V(I)=0.85*1.759E+08/W(I)
!calculation of angular frequency
    do 8 I=1,10
8   W(I)=2.0*3.14*V(I)
!calculation of mean drift length during a semi wave of the CW radio-frequency field
    do 9 I=1,10
9   S(I)=2.0*W(I)/W1(I)
!calculation of diffusion coefficient
    do 10 I=1,10
10  DN(I)=DU(I)*W(I)/EN(I)
!calculation of reduced    diffusion coefficient
    do 11 I=1,10
11  DP(I)=DU(I)*W(I)/EP(I)
    write(6,12)
12 format(32X,'Table (2)',/,32X,'-----------')
    write(6,13)
13  format(/, 13X,'Collision', 3X, 'Angular', 4X,'Mean drift', 4X,'Diffusion', 6X, 'Reduced')
    write(6,14)
14  format(3X, 'E/P300',4X, 'Frequency', 2X,'Frequency',5X,'Length',8X,'Coeff.',5X,'Diff. Coeff.')
   write(6,15)
15 format(/2x, '_______',2x, '_______' , 2x, '_______',2x,'_______',2x,'_______',2x,' _______')
    do 16 I=1,10
16 write(6,17) EP(I),V(I), W1(I), S(I),DN(I),DP(I)
17 format(3(2X,E9.3), 2(4X, E9.3), 5X,E9.3)
!calculation of mean speed of the electron
    Do 18 I=1, 10
18 C (I) =5.93E+07*DU (I) **0.5
!calculation of mean free path of the electron
    DO 19 I=1, 10
19 H (I) =C (I)/V (I)
!calculation of acceleration of the electron (or ion)
    Do 20 I=1, 10
20 A (I) =1.759E+08*E (I)
!calculation of mean displacement in the direction of the applied electrical field e
   Do 21 I=1, 10
21 SE (I) =0.5*A (I)*S (I) **2/(C (I) **2)
    Write (6, 22)
22 format (/, 22X,'Table (3)', /, 25X,'---------', /)
    Write (6, 23)
23 format (4X, 'Electron', 5X, 'Electron', 8X,'Mean', 10X,'Electron')
    Write (6, 24)
24 format (2X,'Acceleration', 2X, 'Mean Speed', 3X,'Displacement', 4X, and 'Mean Free Path')
    Write (6, 25)
25 format(/2x, '_______',2x, '_______', 2x, '_______',3x,'_______')
    Do 26 I=1, 10
26 write(6,27)A(I),C(I),SE(I),H(I)
27 format(3X,E9.3,5X,E9.3, 5X, E9.3, 7X,E9.3)
! Calcul. Of relaxation time constant (thermalization time)
    Do 28 I=1, 10
28 F (I) =(2.0/3.0)* ((W(I)/1.0E+06)*E(I)/ (DU(I))
!calculation of inverse of relaxation time constant
    Do 29 I=1, 10
```

```
29 F1 (I) =1.0/F (I)
! Calcul. Of the ratio of the angular frequency to f1
    Do 30 I=1, 10
) =7.0*(W1 (I)/1.0E+6)/22.0       30
!calculation of the ratio of pi to the angular
     frequency
    Do 31 I=1, 10
31 T1 (I) =1.0/T (I)
    Write (6, 32)
32 format (/, 25X,'Table (4)',/,25X,'---------')
   Write (6, 33)
33 format (/, 3X,'Relaxation', 5X,'Inverse')
   Write (6, 34)
34 format (6X,'time', 6X,'Relaxa. Time',
    3X,'Ang. Freq./Pi',4X,'Pi/Ang. Freq.')
   Write (6, 35)
35  format(/2x, '_______',2x, '_______', 2x,
    '_______',3x,'_______')
   do 36 I=1,10
   write(6,37)F(I),F1(I),T(I),T1(I)
37 format (3X, E9.4, 4X, E9.4, 5X, E9.4, 7X,
    and E9.4)
   Stop
   End
```