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INVESTIGATION OF ELECTRONS DIFFUSION COEFFICIENT DEPENDENCE ON TEMPERATURE IN PLASMA GAS CO2, N2, HE AND MIXTURES

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Abstract

The evolution of the μNth value at different temperatures was achieved through the drift velocity of electron. The results were show when the temperature was increased, the number of the electrons will be decreased because using the momentum transfer cross section for CO_2 molecules through collisions. The calculation of the diffusion coefficient was used to deduce the μNth values of CO_2 electrons at temperature between 288 to 573 k by utilization numerically the Boltzmann equation solution. The results were appearing the agreement with the theoretical and experimental data.

Keywords: Diffusion Coefficients, Boltzmann Equation, Swarms Parameters, Energy Distribution Function.

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1. Introduction

The electron energy distribution was performing the evaluation of momentum transfer cross section through the drift velocity measurement. For CO, CO2, H2O and NH3, … etc. were found that the electron drift velocity was linearly changing with the lowest of E/N (where E/N is the applied electric field strength to the total gas number density, Vcm2) and also the electrons distribution function was Maxwellian changing as a function of the temperature oT, and then the value of μN was obtained, since μ represents the electron mobility in unit of (cm2 sec-1 V-1) at small value of E/N for many[1-3]. Therefore, at the temperatures between 193 and 573 Kelvin, electron drift velocity values had be brought out that μNth values were decreasing when the temperature was increased according to the above when using the momentum transfer cross section σm to calculate the electron mobility μ from below forma, then there is the conflicting trend for the expected, which is [3,4]:

$$\mu N_{th} = -\left(\frac{2}{m}\right)^{1/2} \frac{e}{3} \int_0^{\infty} \frac{\epsilon}{\sigma_m} \frac{df_M(\epsilon)}{d\epsilon} d\epsilon \qquad (1)$$

where σm represent the momentum transfer cross section (cm2), fM(ε) represents the Maxwellian energy distribution function, ε is the electron energy (eV), e and m are the electric charege,1.6×10-19 coulomb and m represent the electron mass 9.109×10-28 gm. Equation (1) was showing the performance of CO2 lasers because the electron scattering cross section from CO2 molecules. The collision by CO2 molecules in the first vibrational state with total momentum transfer cross section could be leads to the difference in the theoretical and experimental data for μNth values against temperature oT [1-4]. This a large temperature, are extrapolate to E/N= 0 at 573 K for the electron drift velocity, this mean, at thermal equilibrium with CO2 molecules, any one could be obtain the electron swarm parameter, which is μNth value [5]. By measuring the coefficient of thermal electrons diffusion through the alternative experimental method was obtained the μNth value but this value changes with oT, and by using the Nernst-Townsend or Einstein formula, we can find [6]:

$$\mu N_{th} = ND_{th} \frac{e}{kT} \qquad (2)$$

Where Dth is represent the coefficient of the electrons diffusion, and k is represent the Boltzmann constant, 1.380662 x 10-23 J/oK, this work was achieved in the present work.

Computational procedures of Boltzmann equation:

The main purpose of Boltzmann transport equation solution was to obtain the electron distribution function f(r,c,t) volume part dr dc in the locus r with spatial velocity C, which is f(r,c,t)drdc [6,7]. The electrons distribution in energy, the number of electrons in the volume element dr dc in position r and velocity C space and time have important role in the electron's collisions with pure gas and/or mixture gases [3]. Consider the function f was detachable which:

$$f = n(r,t)F_o(\epsilon) \qquad (3)$$

Whereas n is total electron gas number density as a function of the space and time, Fo refers to the electron distribution as a function of the energy ϵ. if the diffusion of electron was omitted in analogy to the drift velocity then Fo is was not depend on r in this case. Furthermore, in the time-of-flight experiment the distribution function Fo was not depend on t was too right. The Boltzmann transport equation was whereupon, yielding that the function Fo was [8,9]

$$\frac{d}{d\epsilon}\left(\frac{e^2 E^2 \epsilon}{3NQ_m(\epsilon)} \frac{d}{d\epsilon} F_o(\epsilon)\right) + \frac{2m}{M}\frac{d}{d\epsilon}\left(\epsilon^2 NQ_m(\epsilon) F_o(\epsilon) + kT\frac{d}{d\epsilon}F_o(\epsilon)\right) + \sum_j\left[(\epsilon+\epsilon_j)F_o(\epsilon+\epsilon_j)NQ_j(\epsilon+\epsilon_j) - \epsilon F_o(\epsilon)NQ_j(\epsilon)\right] + \sum_j\left[(\epsilon-\epsilon_j)F_o(\epsilon-\epsilon_j)NQ_{-j}(\epsilon-\epsilon_j) - \epsilon F_o(\epsilon)NQ_{-j}(\epsilon)\right] = 0 \qquad (4)$$

Whereas e and m are the electronic charge and electron mass respectively, E represent the electric field strength, Vcm-1, N is the total gas number density, cm-3, Qm is the momentum collision cross-section for the electron-atom reaction, ϵ is the energy of the electron, eV, Qj(ϵ) represent the excitation cross section for the energy loss at the jth level, and Q-j(ϵ) represent the de-excitation cross section for the energy gain at the jth level.

The defining of the normalization of the energy distribution which is:

$$\int_0^\infty \epsilon^{\frac{1}{2}} F_o(\epsilon)d\epsilon = 1 \tag{5}$$

This mean, the number of the electron in the velocity spatial is equal unity.

$$\frac{\partial n}{\partial t} = D_o\left(\frac{\partial^2 n}{\partial x^2}+\frac{\partial^2 n}{\partial y^2}\right) - V_o\frac{\partial n}{\partial z} + D_o\frac{\partial^2 n}{\partial z^2} \tag{6}$$

From equation (4) the drift velocity, Vo was represented by:

$$V_o = -\frac{E}{3}\left(\frac{2e}{m}\right)^{\frac{1}{2}}\int_0^\infty \frac{\epsilon}{NQm}\frac{\partial}{\partial\epsilon}F_o(\epsilon)d\epsilon \tag{7}$$

And the diffusion coefficient is Do is:

$$D_o = \frac{1}{3}\left(\frac{2e}{m}\right)^{\frac{1}{2}}\int_0^\infty \frac{\epsilon}{NQm}F_o(\epsilon)d\epsilon \tag{8}$$

Where Do represent the isotropic diffusion coefficient. Thus, the mobility of the electron was depending on the momentum transfer cross section Qm and according to equation (1) then change with energy.
Calculation of the momentum transfer cross section and other inelastic cross sections using the theoretical procedure [10,11] for the electron diffusion coefficients are in accordance with the experimental data at the E/N range as seen in table 1. The diffusion coefficient Dth was obtained through solution of the Boltzmann equation (4) using the finite difference method [12].

Table (1) The diffusion coefficient Dth for thermal electron, of CO2, He, N2, CO2 2.5% He 45% N2 52.5%, CO2 5% He 55% N2 40%, CO2 10% He 50% N2 40%, CO2 40% He 40% N2 20% per temperature respectively

T(oK)	E/N (V.cm2)				
	1X10-19	1X10-18	1X10-17	1X10-16	1X10-15
	Dth				
288	0.641205	0.6413157	0.6527003	55.80812	1125.326
	962.9183	1030.482	1276.677	1688.517	1942.529
	716.3343	926.2188	2055.901	4905.108	5147.747
	560.6482	642.5728	1218.0570	2030.296	2949.049
	422.6324	476.4736	1041.3120	2148.4210	3291.5490
	292.3365	322.3814	739.5884	2140.4900	3083.4600
	102.8016	107.5506	173.9630	2348.4300	3331.9950
295	0.6543124	0.6544229	0.6658024	56.1411	1125.328
	963.6191	1030.568	1276.729	1688.516	1942.538
	721.0577	928.7944	2056.67	4905.084	5147.761
	561.8684	643.012	1218.213	2030.268	2949.065
	423.7426	476.7802	1041.454	2148.419	3291.539
	293.1899	322.553	739.6628	2140.491	3198.516
	103.1916	107.7229	174.0066	2348.436	3331.999
300	0.6634301	0.663506	0.6749308	56.37617	1125.329
	964.11779	1030.629	1276.765	1688.51	1942.504
	724.4133	930.634	2057.221	4558.147	4727.046
	562.7126	643.3265	1218.324	2030.267	2949.004
	424.5057	477.0001	1041.556	2148.419	3291.563
	293.772	322.6763	739.7257	2140.49	3198.507
	103.4558	107.8423	174.0377	2348.438	3332.007
355	0.7532429	0.753359	0.7654265	58.89149	1125.331
	969.482	1031.27	1277.17	1688.513	1942.542
	760.3594	950.8555	2063.277	4558.23	4727.054
	570.8629	646.827	1219.55	2030.263	2949.078
	431.6627	479.4533	1042.677	2148.413	3291.514

	299.0499	324.0323	740.3545	2140.484	3198.467
	105.7673	108.9913	174.3798	2348.451	3331.981
411	0.8313772	0.8315054	0.8448762	61.3143	1125.331
	974.6279	1031.878	1277.582	1688.511	1958.557
	795.2512	971.391	2069.460	4558.266	4727.019
	577.7792	650.4571	1220.8	2030.256	2949.104
	437.4537	482.015	1043.821	2148.41	3291.545
	303.0693	325.4193	740.9968	2140.484	3198.414
	107.4063	109.9346	174.7281	2348.461	3332.001
468	0.9028273	0.9029675	0.9179955	63.65308	1125.329
	979.4141	1032.463	1278.000	1688.510	1958.574
	829.1594	992.2019	2075.769	4558.417	4727.063
	584.019	654.2033	1222.071	2030.251	2949.045
	442.4822	484.6823	1044.988	2148.403	3291.567
	306.3793	326.8379	741.6523	2140.478	3198.485
	108.6633	110.7402	175.0827	2348.479	3331.983
500	0.9405903	0.9407436	0.9568003	64.91903	1125.333
	981.8737	1032.779	1278.234	1688.509	1958.573
	847.5436	1003.833	2079.314	4196.310	4306.503
	587.296	656.3226	1222.784	2030.25	2949.054
	445.0583	486.2039	1045.644	2148.4	3219.576
	308.0136	327.6374	742.0203	2140.475	3198.488
	109.2513	111.143	175.2817	2348.482	3331.992
573	1.022642	1.02282	1.041422	67.69096	1125.334
	986.8624	1033.476	1278.769	1688.507	1958.609
	887.8846	1030.197	2087.426	4196.364	4306.508
	594.3775	661.1843	1224.413	2036.02	2949.052
	450.4985	489.7335	1047.143	2148.392	3291.611
	311.3408	329.4702	742.8627	2140.472	3198.494
	110.382	111.9648	175.7356	2348.5030	3332.005

Evaluation procedure of diffusion coefficient Dth:

Through the Boltzmann equation (4) solution by finite difference method was deduced the function of the electron distribution function Fo(ϵ) [13,14], then obtained diffusion of the thermal electrons for single gases, such as CO2, He, N2 gases and their as seen in table (1).

μNth calculation:

When the diffusion coefficients Dth where calculated after solution the Boltzmann equation (4) whereupon, Dth values were substituted into equation (2), in addition to values of the temperatures (288, 295, 300, 355, 411,468, 500 and 573), then, obtained the μNth values need as shown in Figures (1-6).

Results and Discussion:

The changing of the momentum transfer cross section Өm(ϵ) with energy ϵ was permit to find the transport parameter Dth [15, 16]. The calculated results of Boltzmann equation solution to obtain the parameter Dth as shown in table (1), its permitted to determine the μNth values at (1x10-19 – 5x10-15) Vcm2 for CO2, He, N2, and its mixtures, these values were compared with experimental data [10, 13].

From figure (1) it's obvious that, the electron component μNth as a function for the percentage of electric field strength to the whole gas number density of E/N of CO2. The value of μNth does not depend on E/N for low values from 1x10-19 to 8x10-17 Vcm2, and becomes zero at 1x10-16 Vcm2. The values of μNth increased rapidly until 3x10-16 Vcm2, then at 2x10-16 Vcm2 the values of μNth will be constant during increasing of temperature, but in the case of He gas, the value of μNth will be constant and undependable on temperature. From figure (3) it obvious that the value of μNth increase gradually with E/N. Figures (4-7) were show that the increase of CO2 percentage in the mixture will reduces the value of μNth and E/N to zero and similar to figure (1) which is the case of unique gas and CO2 the values of μNth will increased with E/N from 1x10-19 to 2x10-17 Vcm2 and will be increased rapidly from 2x10-17 to 1x10-15 Vcm2, but, after these values, the behavior of μNth going to be constant. from above its clear that all figures in agreements with practical values [4]. The current values are sufficiently taken at low values of E/N which makes the electron swarm approach to thermal equilibrium with gas molecules. The values of μNth are imaginary and undependable and in contrast with the value of E/N, making an extrapolation to zero E/N an accurate procedure. The values of μNth has been obtained and shown in figures (8-12) are a function of temperature, hence, reveals a contrast with it and compared with reference [4]. The values of μNth current work reveals a coincidence with results in references [2, 4, and 10] for the familiar temperature range (288-573) oK as shown in figure (13). From figures above its known that when E/N values are low, then the values of μNth becomes coincidence due to ionizing small molecules particles, conversely, the values of μNth will be in contrast if the temperature increased T, due to high molecules ionization, and this agrees the change of μNth with T derived from reference [4].

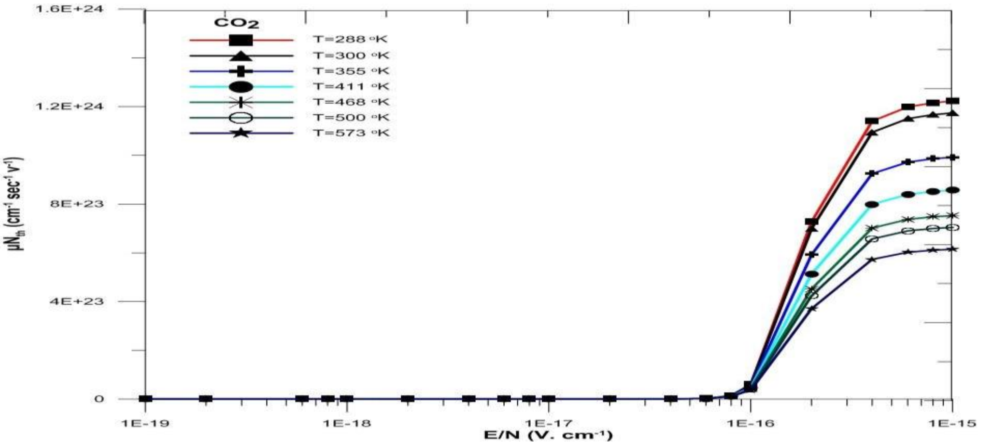

Fig. 1 The μN values of the function of the E/N in CO2 gas at many temperatures.

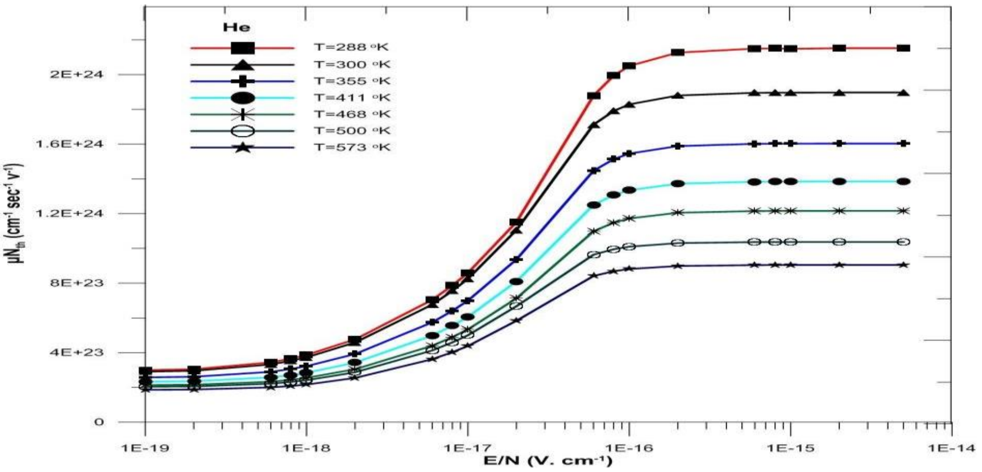

Fig. 2 The μN values of the function of the E/N in He gas at many temperatures.

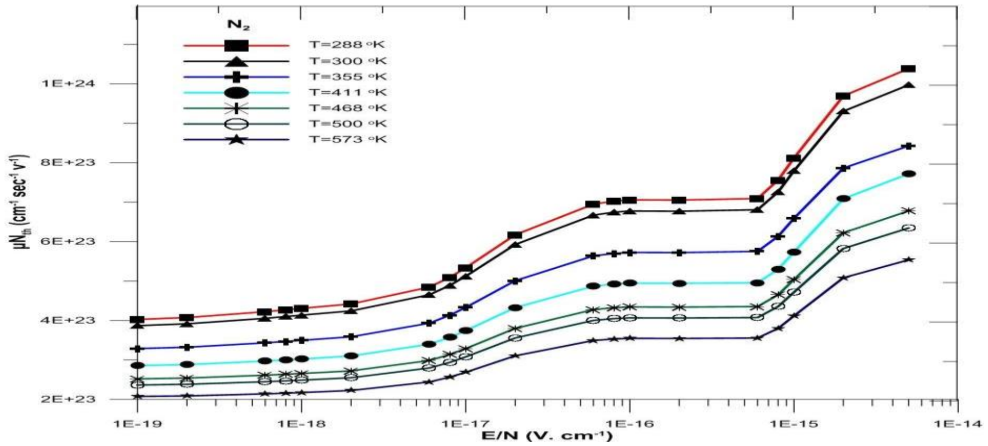

Fig. 3 The μN values of the function of the E/N in N2 gas at many temperatures.

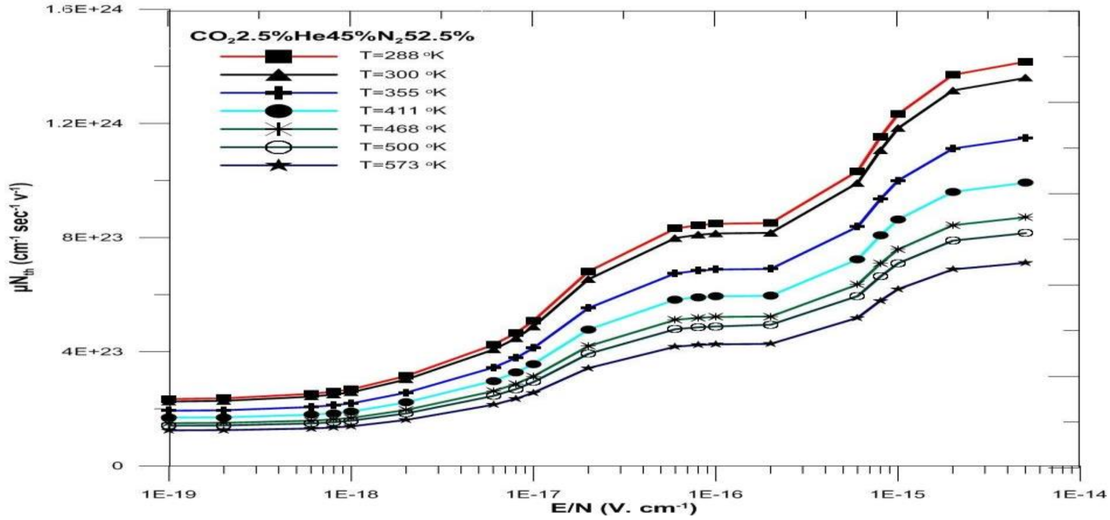

Fig. 4 The μN values of the function of the E/N in CO2 2.5% He 45% N2 52.5% gas mixture at many temperatures.

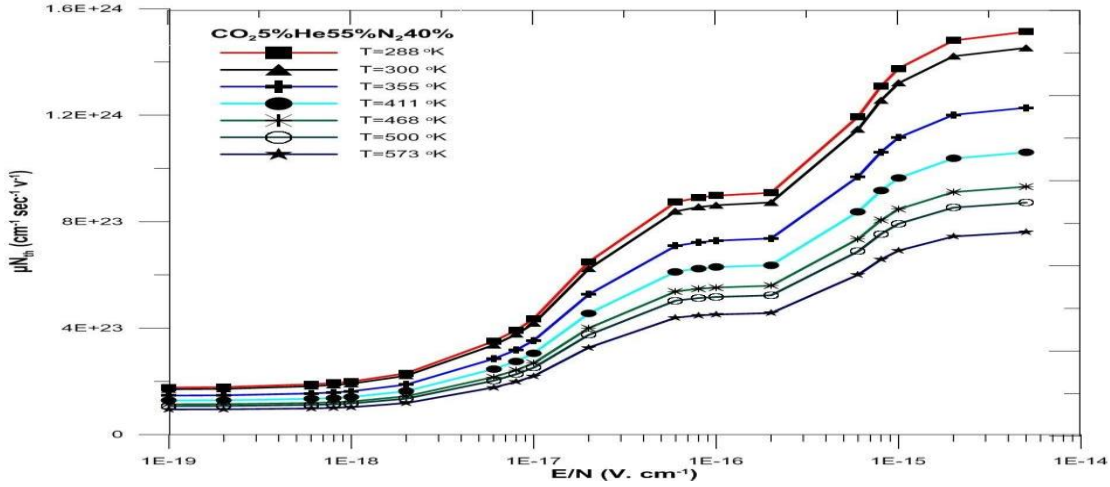

Fig. 5 The μN values of the function of the E/N in CO2 5% He 55% N2 40% gas mixture at many temperatures.

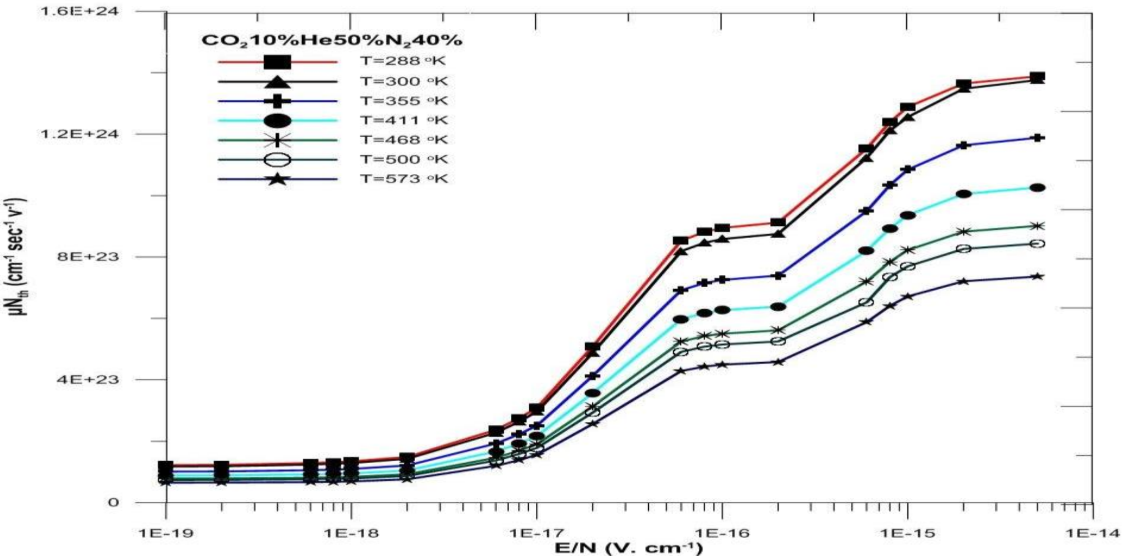

Fig. 6 The μN values of the function of the E/N in CO2 10% He 50% N2 40% gas mixture at many temperatures.

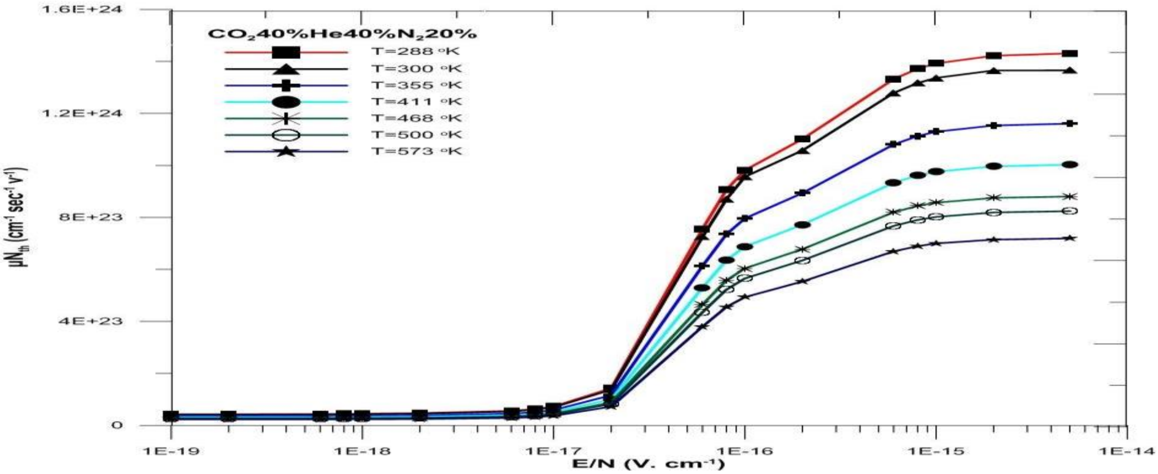

Fig. 7 The μN values of the function of the E/N in CO2 40% He 40% N2 20% gas mixture at many temperatures.

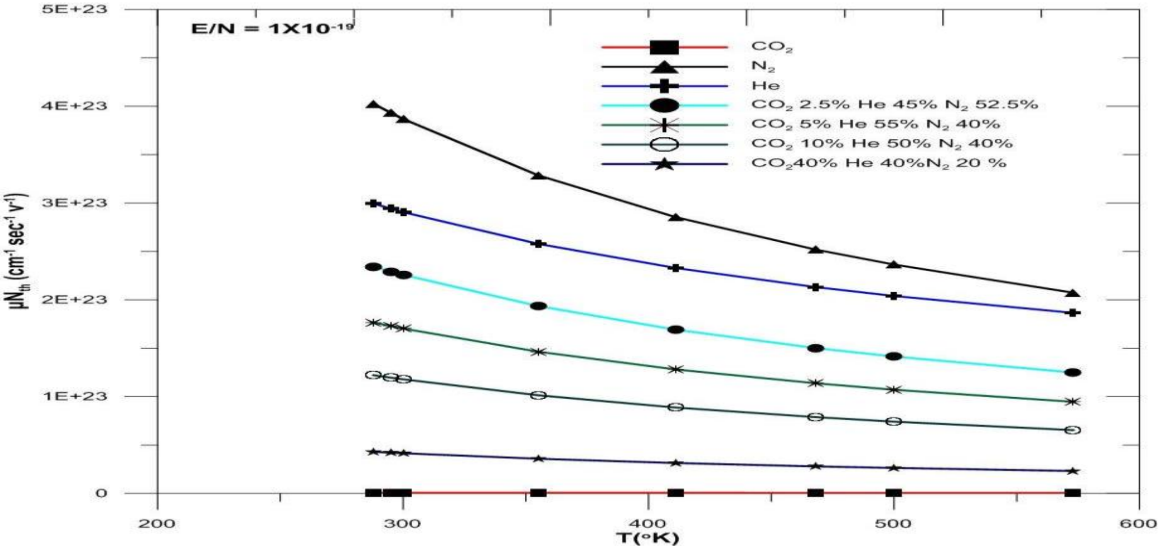

Fig. 8 The μN values of the function of the E/N in CO2, N2 and He and their mixture at E/N = 1X10-19 V.cm2

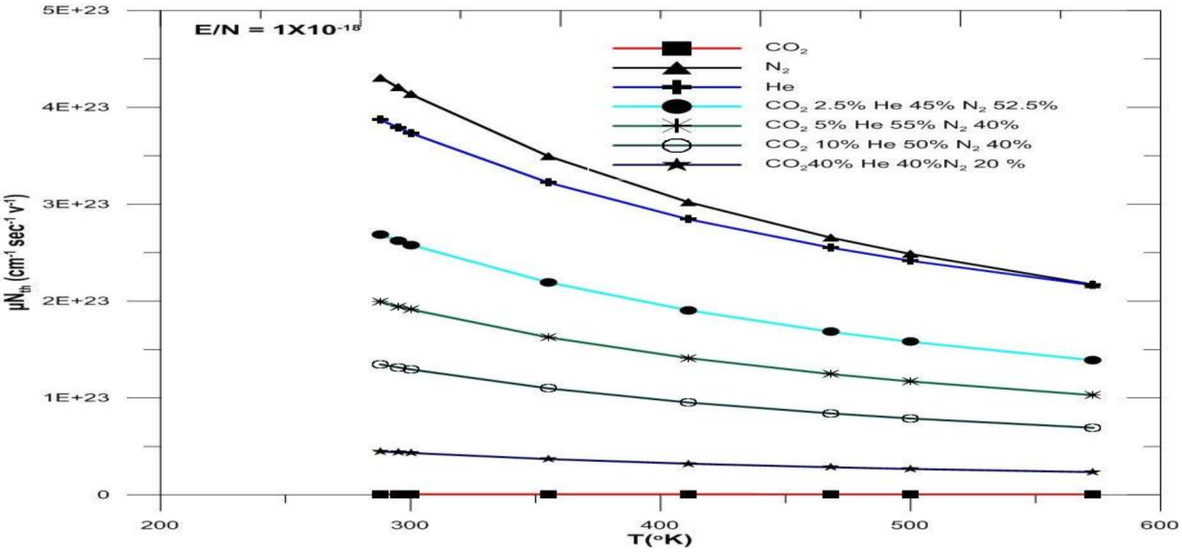

Fig. 9 The μN values of the function of the E/N in CO2, N2 and He and their mixture at E/N = 1X10-18 V.cm2

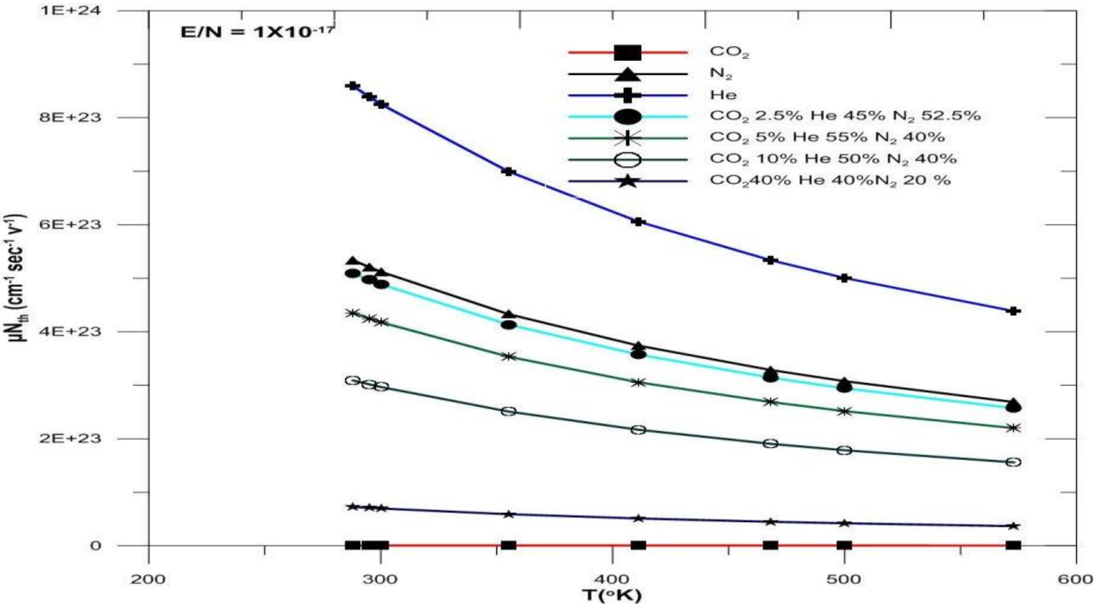

Fig. 10 The μN values of the function of the E/N in CO2, N2 and He and their mixture at E/N = 1X10-17 V.cm2

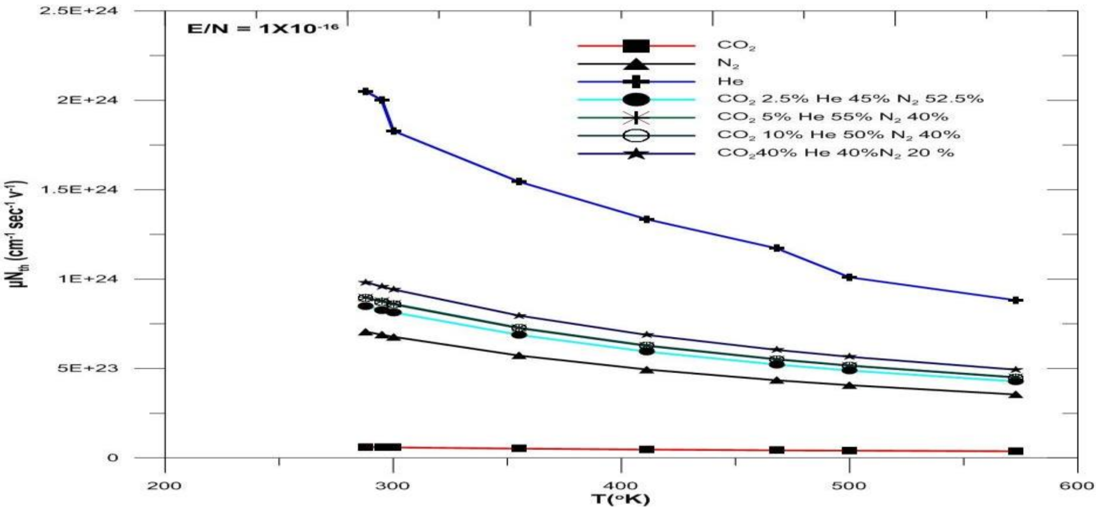

Fig. 11 The μN values of the function of the E/N in CO2, N2 and He and their mixture at E/N = 1X10-16 V.cm2

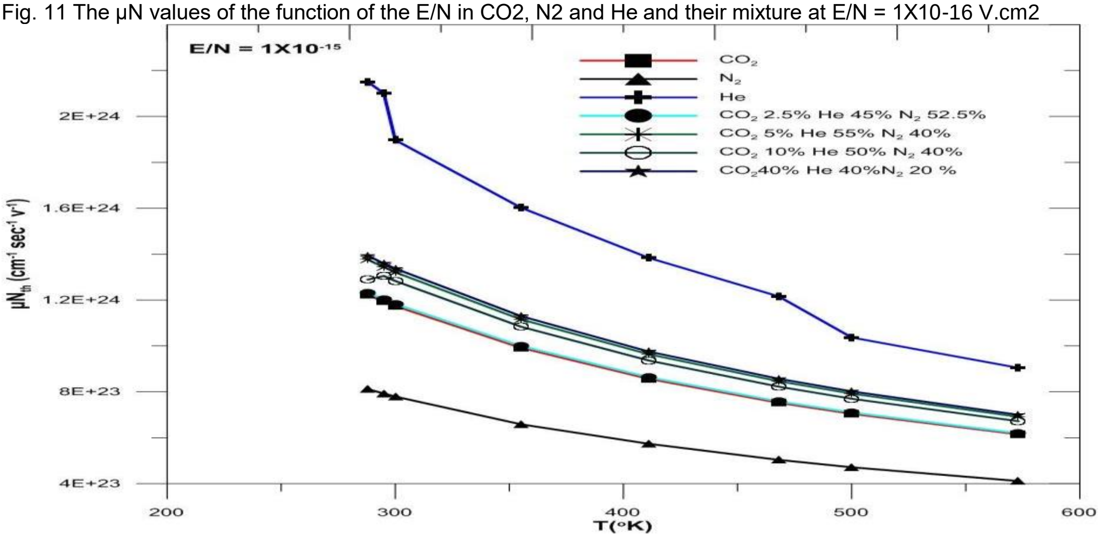

Fig. 12 The μN values of the function of the E/N in CO2, N2 and He and their mixture at E/N = 1X10-15 V.cm2

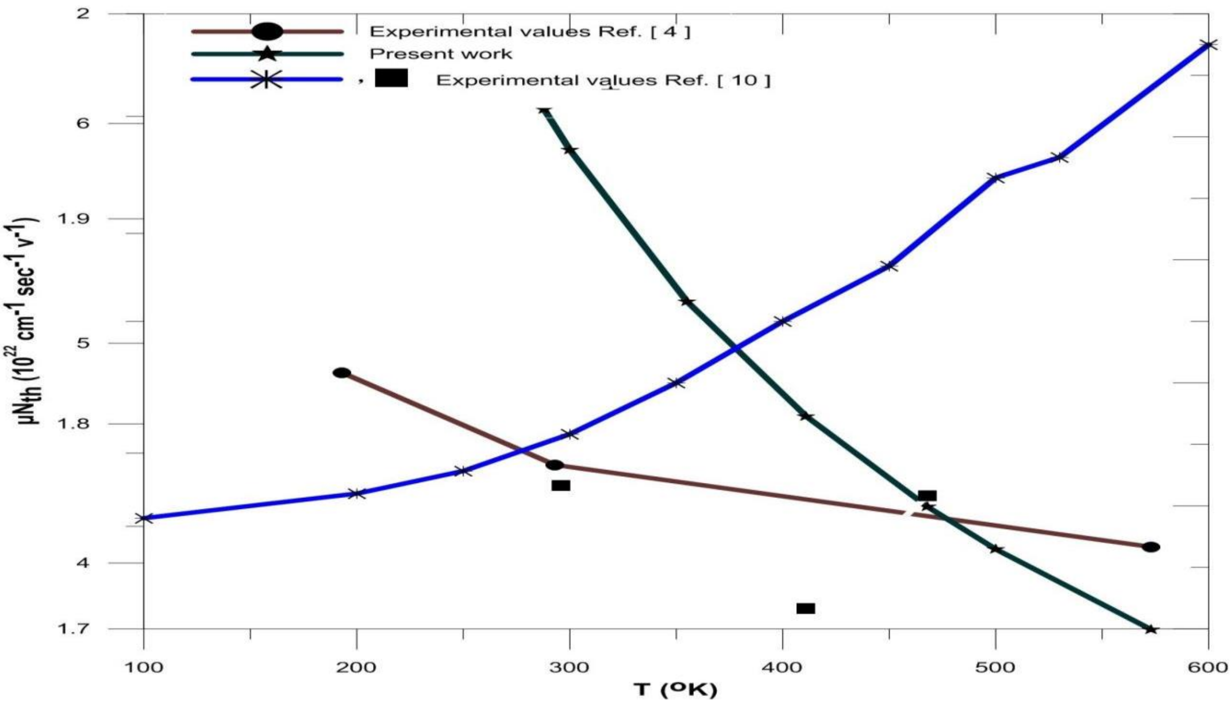

Fig. 13 comparison between the present work for the values of the μNth versus gas temperature of electrons in CO2 gas with the experimental values

Conclusion:

The present result investigates the μNth change with gases temperatures which was deduced by [2] and extend the temperature range to 573 oK. The μNth versus T change had been serve as rigorous check on the derived momentum transfer cross sections. The value of μNth at 573 oK is not congenial with the momentum transfer cross section deduced using 239 oK data [15].

The indicated references reveals to significant levels of impurities were not introduced by outgassing of the cell, the associated ballast, etc. The purification procedure is found to be necessary to avoid the values of the measured time constant increasing over the initial period of the data accumulation.

There is no dependence on gas pressure. The values of μNth decrease with temperature at E/N > 1×10-17 V cm2.

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