The Diffusion Dependence on the Geometry of a Laser discharge containing a mixture of CO & N2 Gases

Gulala Mohammad Faraj
Department of Physics, College of Science-Education,
University of Salahaddin, Erbil, Iraq.

اعتماد الانتشار على التصميم الهندسي في مفرغات الليزر المحتوية على خليط من الغازين أول أكسيد الكربون و النيتروجين

كولالة محمد فرج
قسم الفيزياء/ كلية التربية للعلوم/ جامعة صلاح الدين-اربيل ,العراق

الخلاصة:
تم في هذا البحث اخذ خليط غازي مؤلف من غازي النتروجين و أول أكسيد الكربون و بنسبة 9:1 . السبب في هذا الخلط هو تقارب الوزن الجزيئي لهدين الغازين من بعضيهما البعض . ان معامل الانتشار هو المعلم الاساسي في البحث اضافة الى الثوابت المتعلقة بالحسابات الرئيسية التي تمثلت في عملية التفريغ البلازمي التماثل الثرموديناميكي اجريت تحت ضغط (3mb) ودرجة حرارة (45k) . كانت النتائج منطقية ومتماثلة مع القيم العملية . تم تهيئة عملية التماثل لتحضير وسط فعال دي جزيئات عالية القدرة للغاز المستخدم في الليزر.

Abstract
In this study a gas mixtures [CO+N2] are mixed with a specified ratio of 9:1 (N2:CO).The reason for this mixing is that the molecular weight are very close to each other.The main parameters in question to be studied are the diffusion coefficient of the discharge and the related constants to it. The main calculations held that were concerned the plasma discharge operation of optimum thermodynamic constants [Total pressure of *3mb* and the discharge temperature of *450Ko*]. The results were consistent and very optimum compared with their experimental values, and the

optimum circumstance was prepared to use them as an active medium for a high power molecular gas laser.
Key word: Plasma-Discharge, Ionization,
Lasers, Diffusion parameters.

Theory

From early kinetic theory of gases, the transport phenomenon is caused by the transport of a molecule from one place to another [1]. The mean free path of a molecule is directly proportional with the average molecular – speed measured from C.M. of the system, where C.M. refers to the center of mass of the molecule witch is the axial center of the molecule showing the symmetry about axis of rotation.
then:

$$\lambda = \langle \upsilon \rangle \tau ....(1)$$

where τ is the collision life-time in sec $(= \frac{1}{\nu_c})$.

and ν_c, being the collision frequency related to the collision cross-section as:

$$\nu_c = N\sigma\langle \upsilon \rangle ....(2)$$

N is the number density of electrons. The Boltzmman transport equations a key equation to describe the motion of free particle in a relatively high temperature, where the gas is charged in to what is called the cold plasma where $\mathbf{(T_{Atom} N(400 \square 450) k)}$. The plasma parameters in question are:

1. The collisional cross-section.
2. The electric field intensity/ number density=E/N
3. Atom and the electron characteristic energy $(\varepsilon_a, \varepsilon_e)$ respectively.
4. The drift velocity (υ_d) These quantities could be combined together to produce the following equation. [as in [2]].

The diffusion coefficient *D*, is a factor of proportionality representing

$$\frac{E}{N} = \frac{3m^2\sigma^2\upsilon_d^2(\varepsilon_e - \varepsilon_a)}{Me^2} \,..........(3)$$

the amount of substance diffusing across a unit area through a unit concentration gradient in unit time and it is combined to diffusion cross section. In a mixture of gases, each gas has the three coordinating degree of freedom for diffusion (along x, y and z axis), thus the flux of labeled 2 molecules thought a unit area parallel to xy plane is:

$$\Phi_y = -D\frac{\partial \widehat{N}}{\partial y} \,..........(4)$$

□

If the flux is multiplied by volume element ($A\Delta t$) then we get:

$$\Phi_y = -\frac{1}{3}\langle \upsilon_d \rangle \lambda \frac{\partial \widehat{N}}{\partial y} \,..........(5)$$

where ***N*** is the number density flowing across (A); where A is a cross section area. Comparing (4) and (5) we get:

$$D = \frac{1}{3}\langle \upsilon \rangle \lambda \,..........(6)$$

Substituting for *N* and ג from above equation we have:

$$D = \frac{2}{3\sigma N\sqrt{\pi}}\sqrt{\frac{kT}{\mu}} \,..........(7)$$

where ***k*** is Boltzmman constant, ***T*** is absolute temperature of the medium and (µ) is the mass of one molecule.

Diffusion length:

The only problem remaining to solve the diffusion equation in a laser active medium is the relation between the diffusion coefficient and the diffusion length. Many investigators, and among them Langmorur [3], found that the square of the reciprocal of the diffusion length (*Λ*) is proportional to the square of the reciprocal of the plasma discharge length (*L*) and radius (*R*), such as:

$$\frac{1}{\Lambda^2} = \frac{C_1}{L^2} + \frac{C_2}{R^2} \,..........(8)$$

where *Λ* is the diffusion length, and it is a dimensionless parameter depending on the geometrical dimensions of the plasma tube and represent the range thought witch the gas diffusion occurs as minimum. Many experiments have been performed for different gases by taking value of *D* from equation (7), then the best fitting values from *C1* and *C2* were π^2 and *(2.505)2* respectively.

$$\therefore \frac{1}{\Lambda^2} = \frac{\pi^2}{L^2} + \frac{(2.405)^2}{R^2} \ldots\ldots(9)$$

Distribution of molecular decay

If an excited state of a molecule have its own number density *no* in any time period, the decay rate is [4]:

$$n(t) = n_o e^{-t\Gamma} \ldots\ldots\ldots(10)$$

where Γ is the decay constant and it is the reciprocal of the life time of the state.

$$\Gamma = \frac{1}{\tau}$$

Having saying this we can combine the three fundamental quantities *Γ*, ***D*** and Λ as:

$$\Gamma = \frac{D}{\Lambda^2} \ldots\ldots\ldots(11)$$

The literature

The object of the work is to prepare a plasma mixture at the glow discharge temperature of about *450Ko*, optimum, for a ratio mixture 9:1 for nitrogen/carbon monoxide in order to make of them an active medium for a gas laser, whose out-put parameters are determined by specifying the engine3 ering and physical properties of what is known as **"*Optical Resonator*".**

The important process is to fi the plasma tube's length and diameter.
Also the total pressure of the mixture has to be taken is to account, and for most purposes it is traditional to fixit at
3mbar.
Table (1), is survey for numerical valves of some important physical and chemical properties obtained from sources [4] and [5]. The individual values are constants and the mixed values are calculable from mentioned equations.

Table (1): The plasma parameter of CO and N2 and there mixtures.

Property	Gas		Mix ratio 9:1
	CO	N_2	
Density at *0C°*(gm/Liter)	1.25	1.251	1.2505
Concentration of molecules-,*N*(cm^{-3})	$1.6863x10^{22}$	$1.6877x10^{22}$	$1.68685x10^{22}$
Molecular mass, μ (gm)	$4.653x10^{-23}$	$4.6511x10^{-23}$	$4.6519x10^{-23}$
Drift velocity (cm/sec)	$7x10^{5}$	$4.091x10^{5}$	$4.382x10^{5}$
Weight	28.01	28.02	28.015
Cross-section, σ(cm^2)	$3.21x10^{-16}$	$312.638x10^{-16}$	$2.06x10^{-16}$
Number density, n_o	$1.11x10^{11}$	$3x10^{11}$	

The plasma tube length wasfixed at 12cm and the internal diameter (2r) was fixed at 4mm.
Figure (1): Represents the variation of diffusion length (Λ) as the function of discharge diameter. This shows a sharp depletion from the beginning reaching the minimum of about (1.5cm).
This means that the laser discharges are workable in fact when they are almost capillary tables. When the discharge length is charged, then the diameter should be fixed at 0.4cm [or r=0.2cm], as in figure (2). The length was changed from 100mm to 200mm.
The drastic dependence of D on the thermodynamic properties of the materials make us to fix few parameters in question for substance [N2 and CO], as the collision crosssection (σc), the temperature and the pressure [P]. In equation (7), it is clear that σ is so chosen that it have all standard circumstances. Then it was found that their values were [312.638 x10-16 cm2, 3.21x10-16 cm2 & 2.06x10- 16cm2] for pure N2, pure CO and their mixture respectively.

Calulations:

From equation (11), it is clear that the value of (Γ) depend on Λ2 and from equation (7) D depends on (σ), and on the temperature of the system. As we have mentioned earlier, let us fix T on 450Ko, and introducing the values of μ and N from table (1).

The diffusion length Λ was found table: (0.0831 and 0.0552) for CO and N2 respectively. But this is not working for the laser operation in a plasma tube 4 having the dimensions mentioned above. Instead, equation (10) is used for different time intervals (in micro seconds) and the values of (no) are as given in table (1) for both N2 and CO.

The result are shown in figure (1) where the discharge length is kept at (120mm) for both gases. The specific decay schemes for both gases are shown in figure 2. The concentration of meta species have been taken from experiments performed by Langmuir [3]. Finally, the concentration dependence on (t) is shown in figure 2 keeping (Γ) constant.

The diffusion dependence on the geometry of the plasma tube have been studied, using equation (9), the values of (Λ) were found keeping (r) constant (r=2mm) and changing the value (L) from (120mm to 180mm). The results are the same for both gases and are shown in table (2). Then the values are drawn with corresponding values of Dm (variables) depending on (T) from 250Ko to 450Ko in 5Ko intervals from equation (7) and the results are shown in figure (3).

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Table (2): The Plasma discharge length as a function of Diffusion length.

L(m)	Λ (m)	L(m)	Λ (m)
0.120	0.0014	0.152	0.0021
0.122	0.0014	0.154	0.0022
0.124	0.0015	0.156	0.0022
0.126	0.0015	0.158	0.0023
0.128	0.0015	0.160	0.0023
0.130	0.0016	0.162	0.0024
0.132	0.0016	0.164	0.0024
0.134	0.0017	0.166	0.0025
0.136	0.0017	0.168	0.0025
0.138	0.0018	0.170	0.0026
0.140	0.0018	0.172	0.0026
0.142	0.0019	0.174	0.0027
0.144	0.0019	0.176	0.0027
0.146	0.0020	0.178	0.0028
0.148	0.0020	0.180	0.0028
0.150	0.0021		

Table (2): The corresponding value of D_m depending on temperature in (K^o) for CO & N_2.

Temperature (K^O)	D_m (CO)/$cm^2.sec^{-1}$ $x10^{-7}$	D_m(N_2) /$cm^2.sec^{-1}$ $x10^{-9}$	Temperature (K^O)	D_m (CO)/$cm^2.sec^{-1}$ $x10^{-7}$	D_m(N_2) /$cm^2.sec^{-1}$ $x10^{-9}$
0	0	0	230	5.740384	5.890234
10	1.196953	1.228199	240	5.863848	6.01692
20	1.692747	1.736935	250	5.984765	6.140993
30	2.073183	2.127302	260	6.103286	6.262609
40	2.393906	2.456397	270	6.21955	6.381907
50	2.676468	2.746336	280	6.333679	6.499016
60	2.931924	3.00846	290	6.445789	6.614052
70	3.16684	3.249508	300	6.555981	6.727121
80	3.385494	3.47387	310	6.664352	6.838321
90	3.590859	3.684596	320	6.770988	6.947741
100	3.785097	3.883905	330	6.875971	7.055464
110	3.969844	4.073474	340	6.979375	7.161567
120	4.146366	4.254605	350	7.081269	7.266121
130	4.315675	4.428333	360	7.181717	7.369192
140	4.478588	4.595498	370	7.28078	7.470841
150	4.635779	4.756793	380	7.378513	7.571125
160	4.787812	4.912795	390	7.474968	7.670098
170	4.935163	5.063993	400	7.570195	7.76781
180	5.078241	5.210805	410	7.664238	7.864308
190	5.217397	5.353594	420	7.757141	7.959637
200	5.352936	5.492671	430	7.848945	8.053837
210	5.485127	5.628313	440	7.939687	8.146948
220	5.614207	5.760762	450	8.029404	8.239007

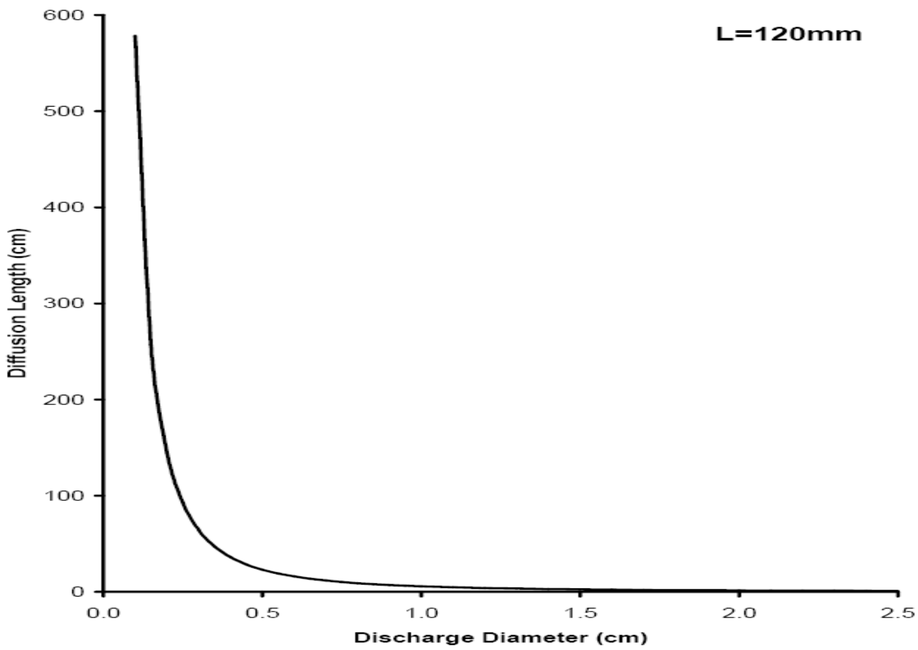

Figure 1: Variation of Diffusion length (⊗) as a function of Discharge Diameter.

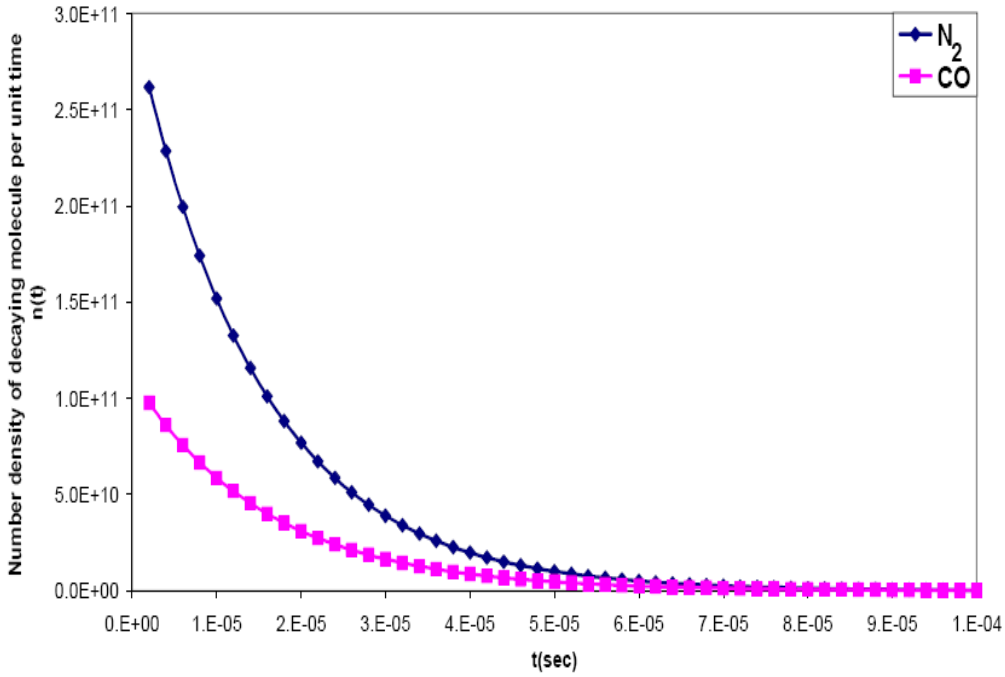

Figure 2: Variation of number density as a function of time decay for N_2 and CO gases.

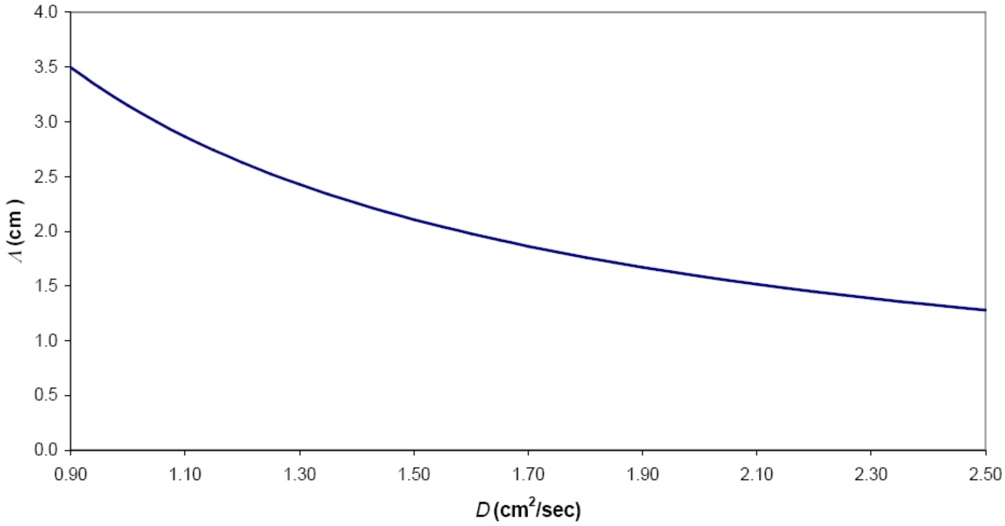

Figure 3: The variation of diffusion length (Λ) as a function of Diffusion coefficient (D).

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