Magnetic Field Calculation in Gaseous Medium

Harith AbdulRazzaq Hasan Ibrahim Gitan Faiadh
Muhammad Hameed Abed
Ministry of Science and Technology,Materials Research Directorate
Baghdad - Iraq

Abstract
In this work, we derive an equation for magnetic field calculation B with related another parameters, such as, Townsend's energy factor K_1, magnetic field B, the ratio of the magnetic field to the electric field B/E, the ratio of the magnetic field to the gas pressure B/P, the ratio field number density B/N and the ratio of the electric field to the gas pressure E/P, with nitrogen gas presence moved under electric field effect perpendicular to magnetic field E×B, at 300 °K and the value limits are between $(0.5 \leq E/N \leq 5\times10^{-16})$ V cm^2.
We constructed "Computer Program" to calculate above equations, which this program receive input data from the program solved numerically transport equation. This results had be tabulated and graphically, which appeared an agreement with experimentally and theoretically literature.
Key words: Boltzmann transport equation, Atomic and molecular transport data, Numerical modeling and Fluid dynamics.

حساب المجال المغناطيسي في وسط غازي

حارث عبد الرزاق حسن إبراهيم كيطان فيّاض محمد حميد عبد
وزارة العلوم والتكنولوجيا - دائرة بحوث المواد
بغداد – العراق

الخلاصة
تم في هذا العمل اشتقاق معادله لحساب المجال المغناطيسي B، وما يتعلق به من معادلات منها عامل طاقة تاون سيند K_1، نسبة المجال المغناطيسي إلى المجال الكهربائي B/E، نسبة المجال المغناطيسي إلى ضغط الغاز B/P، نسبة المجال المغناطيسي إلى الكثافة العددية للغاز B/N ونسبة شدة المجال الكهربائي إلى ضغط الغاز E/P وبوجود غاز النتروجين الذي يتحرك تحت تأثير المجال الكهربائي والمتعامد مع المجال المغناطيسي E×B ، وعند درجة حرارة 300 كلفن، وان حدود القيم المستخدمة هي $(0.5 \leq E/N \leq 5\times10^{-16})$V cm^2.
تم استخدام برنامج لحل معادلة الانتقال عدديا حيث يغذي برنامج تم بنائه لغرض حساب المعاملات أعلاه. إن النتائج التي تم الحصول عليها تمت جدولتها ورسمها كدوال، حيث أظهرت تطابقا جيدا مع المنشورات العملية و النظرية.
الكلمات المفتاحية: معادلة انتقال بولتزمان، بيانات الانتقال الذرية والجزيئية، النمذجة العددية و حركية المائع.

Introduction

In crossed fields E×B can afford valuable information about the energy dependence of the momentum transfer cross section or from energy distribution (Taflove and Hagness 2005; Tkachev and Yakovlenko 2006). The electron swarms moves in crossed electric and magnetic fields have been investigated for many years, the first experiments being used as a method of measuring electron drift velocities more recently detailed examinations of the motions of electron swarms under these conditions have shown that the electron drift velocity cannot be deduced in a simple way from the results of such measurements.

The magnetic drift velocity was determined from measurements of the deflection of an electron swarm in a week magnetic field, with the increasing precision of measurements of electron transport coefficients, now the magnetic drift velocity (W_M) has been calculated by Townsend and Bailey by the relation:

$$W_M = (E/B) \tan \theta$$

Where, θ is the angle through which a stream of electrons is deflected in a magnetic field B perpendicular to the electric field (E). As far as many of the transport properties are concerned, the electrons then behave in the presence of a transverse magnetic field as though the actual gas pressure (P) has been increased to a value (P_e) and the magnetic field B has been reduced to zero.

The equivalent pressure concept for molecular hydrogen studies by the measurement values of the primary ionization coefficient α/P in E×B with those values predicted on the basis of the increase in gas pressure mentioned above. The magnetic field is used to measure the deflection of electron swarms, drifting in steady D.C. electric fields at right angles to the electric field date back to the pioneering work of Townsend (Bagnall 1965; Jory 1965; Lafta 2005; Boris 2003 and Smirnov 2001).

Derivation of the Equation

The general Bailey formula is used to measure the current ratio Re, which is, (Aldo Gilardini, 1972):

$$\mathrm{Re} = \psi\left(\frac{W}{Dd}\right)\exp(-\eta d) \qquad (1)$$

Where, Re is a coefficient which is to measure the ratio of the current passing through slit to that arriving and collect at collector, ψ is a function, W is a drift velocity, D is a diffusion coefficient, d is a distance between the slit and collector, and η is a lost energy of electron per collision through uniform electric field E, but with the addition of a magnetic field parallel to the electric one. If diffusion in the field direction can be neglected compared to the drift motion, in this case we can write equation (1) in form:

$$\mathrm{Re} = \psi\left(\frac{W_{11}}{D_T d}\right)\exp(-\eta d) \qquad (2)$$

Where, W_{11} is a drift velocity parallel to the magnetic field, D_T is the transverse diffusion coefficient.

In case of magnetic field, we can write:

$$W_{11} = \mu_{11} E \quad (3)$$

Where, μ_{11} is a mobility parallel to the field, E is a electric field. Substitute equation (3) into equation (2) yield:

$$\mathrm{Re} = \psi(\frac{\mu_{11} E}{D_T d}) \exp(-\eta d) \quad (4)$$

In case of absent the magnetic field yield:

$$W = \mu E \quad (5)$$

Substitute equation (5) into equation (1) yields:

$$\mathrm{Re} = \psi(\frac{\mu E}{D d}) \exp(-\eta d) \quad (6)$$

Where:

$$\frac{D}{\mu} = \frac{K T_g}{e} \quad (7)$$

Where T_g is gas temperature and e represent electron charge:

$$\frac{\mu}{D} = \frac{e}{K T_g} \quad (8)$$

Substitute equation (8) into equation (6) yield:

$$\mathrm{Re} = \psi(\frac{eE}{K T_g d}) e^{-\eta d} \quad (9)$$

By equating equation (9) with equation (4) and obtain for the case of the magnetic field to the value:

$$\frac{D_T}{\mu_{11}} = \frac{K T_g}{e} \quad (10)$$

We can define the Townsend's energy factor (K_1):

$$K_1 = \frac{e}{K T_g} \frac{D}{\mu} \quad (11)$$

$$\frac{K T_g}{e} = \frac{D}{K_1 \mu}$$

Substitute equation (11) into equation (10) yields:

$$\frac{D_T}{D_{11}} = \frac{1}{K_1} \quad (12)$$

From define of the diffusion coefficient D_{11} parallel to the magnetic field as:

$$D_{11} = \frac{1}{3}(\frac{\upsilon^2}{\nu_m}) \quad (13)$$

Therefore, the transverse diffusion coefficient (D_T) as:

$$D_T = \frac{1}{3}(\frac{\nu_m \upsilon^2}{\nu_m^2 + \omega_b^2}) \quad (14)$$

Where, υ is a Represents the electron velocity, ν_m is the momentum transfer collision frequency and ω_b is the cyclotron frequency.

By division equation (13) on equation (14) yield:

$$\frac{D_{11}}{D_T} = 1 + \frac{\omega_b^2}{\nu_m^2} = 1 + (\frac{\omega_b}{\nu_m})^2 \quad (15)$$

We can define the cyclotron frequency ω_b as:

$$\omega_b = \frac{eB}{m} \quad (16)$$

Where, e is a represents the electron charge, m is an electron mass. Substitute equation (16) into equation (15) yields:

$$\frac{D_{11}}{D_T} = 1 + \left(\frac{eB}{m \nu_m}\right)^2 \quad (17)$$

Where:

$$\mu = \frac{e}{m \nu_m} \quad (18)$$

Where, μ is a represent of the mobility. Substitute equation (18) into equation (17) we obtain:

$$\frac{D_{11}}{D_T} = 1 + (\mu B)^2 \quad (19)$$

By Simplification yields:

$$\mu = \frac{1}{B} \left(\frac{D_{11}}{D_T} - 1\right)^{\frac{1}{2}} \quad (20)$$

Substitute equation (20) into equation (5) yields:

$$W = \mu E = \frac{E}{B} \left(\frac{D_{11}}{D_T} - 1\right)^{\frac{1}{2}} \quad (21)$$

From equation (12) we can obtain the value of K_1, like this:

$$K_1 = \frac{D_{11}}{D_T} \quad (22)$$

Substitute equation (22) into equation (21) yields:

$$W = \frac{E}{B}(K_1 - 1)^{\frac{1}{2}} \quad (23)$$

$$B=\frac{E}{W}(K_1-1)^{\frac{1}{2}} \qquad (24)$$

By squaring the two sides of equation (24) and arrange it, yields:

$$\frac{B}{E}=\frac{1}{W}(K_1-1)^{\frac{1}{2}} \qquad (25)$$

Multiplying the two sides of equation (24) by the factor 1/P, where P represents the gas pressure, yields:

$$\frac{B}{P}=\frac{E(K_1-1)^{\frac{1}{2}}}{pW} \qquad (26)$$

Where the equation no (26), represents the magnetic field in term of pressure. From the mathematical relation (Aldo Gilardini, 1972), we can find:

$$N=3.54\times10^{16}\times\frac{273.15P}{T} \qquad (27)$$

$$P=\frac{NT}{3.54\times10^{16}\times273.15} \qquad (28)$$

Substitute equation (28) into equation (26) yield:

$$\frac{B}{N}=\frac{E(K_1-1)^{\frac{1}{2}}}{NW} \qquad (29)$$

From the ratio of the electric field to the gas number density, E/N (Charles Chien 2001), we can find the following relation. Substitute equation (27) to the above ratio, which is:

$$\frac{E}{N}=\frac{E}{3.54\times10^{16}\times\frac{273.15\,P}{T}}$$

Simplified the equation yield:

$$\frac{E}{P}=\frac{E}{N}\times966.951\times10^{16}\frac{1}{T} \qquad (30)$$

Where, e is a electron charge (1.602×10^{-19}) Coulomb, k is a Boltzmann constant (1.3805×10^{-23}) J/°K, J is Joule unit, E/N In unit of (Td),1 Td = 10^{-17} V cm^2,°T is the gas temperature in unit of Kelvin (°K), and P is the gas pressure of unit of Torr and 1 Torr = 1 mm Hg.

Determination of the transport coefficients

The purpose of solution numerically Boltzmann transport equation is to get electron transport motion coefficients as in table (1). This equation may be written as (Saham Zyhro Abaas 2010):

$$\frac{\partial f}{\partial t}+V\cdot\nabla_r f+a\cdot\nabla\vartheta f=\sum_j\iint\begin{bmatrix} f(\vartheta',r,t)F_j(V_j,r,t)-f(\vartheta,r,t)\times \\ F_j(V_j,r,t)V_{rj}\sigma_j(\theta,\vartheta_{rj})d\Omega_j dV_j\end{bmatrix} \qquad (31)$$

whereas $\partial f/\partial t$ defines that $f(\vartheta,r,t)$ changes with time at fixed values of V and r,V refers the velocity of the charged particles, a refers particle acceleration, F_j refers the velocity distribution function of the neutral species j, $\vartheta_{rj}=|\vartheta-V_j|$ refers the relative velocity of charged particle with respect to the neutral To calculate the above equations, we constructed the "computer program" which is the list of program indicates in Flowchart of program. species of gas j,V_j refers the velocity of neutral species $j,\sigma_j(\theta,\vartheta_{rj})$ refers the differential microscopic cross section of the interacting charged particles with V_j is the velocity of neutral species j, and $d\Omega=\sin\theta\, d\theta\, d\Phi$ refers the element of solid angle, where θ and Φ are the polar and azimuthally angles, respectively.

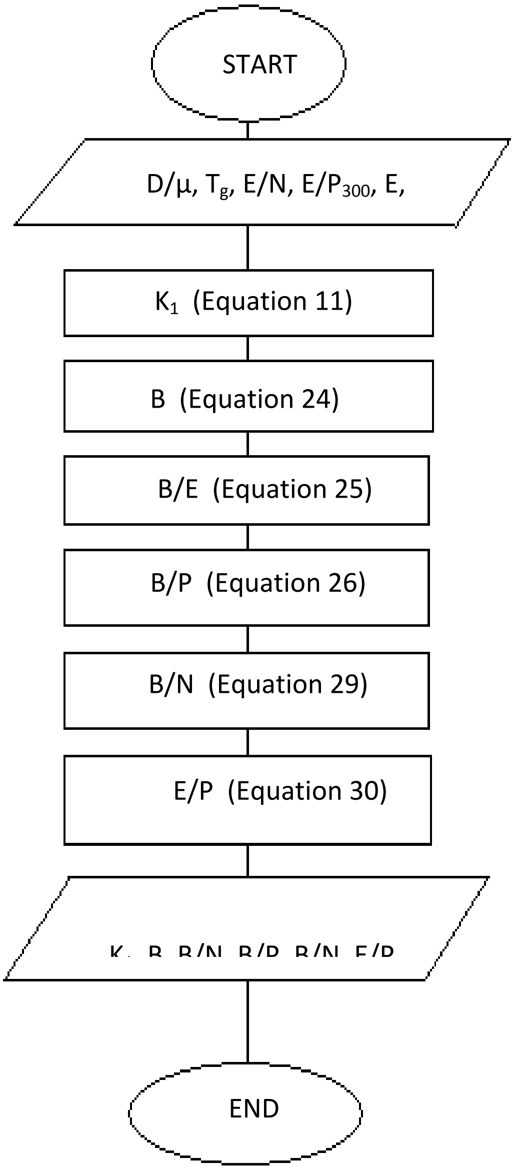
This program receives data such as: (electric field E, drift velocity W, characteristic energy D/μ) as seen in table (1) from the Nomad program which it's solve the numerically transport equation (S. D. Rockwood 1980 Farhan Lafta 2005).

The output data from our "computer program" are tabulated and had represented by figures.

Results and Discussion

After solving numerically the transport equation, we obtained the transport parameters which proposed in table (1), this parameters had been feed to our constructed program to calculate the parameters K_1 equation (11) and E/P_{300} equation (30) as show in table (2). In table (3) we calculate the parameter B from equation (24),in table (4) we calculate the parameter B/E equation (25) and in the table (5) we calculate the parameters B/P_{300} equation (26) and B/N equation (29) respectively.

The energy lost by low-energy electrons in collisions with molecular gasses is much greater than that expected from the recoil of the molecule in an elastic collision. The results obtained in the present work for $0.5x10^{-20} < E/N < 5x10^{-20}$ V m^2; $1.61x10^{-4} < E/P_{300} < 16.1x10^{-4}$ V m^{-1} $Torr^{-1}$ are shown in figures (1-24).



Flowchart of program

The results obtained for K_1 as a function of E/N, E/P and D/μ are shown in figures (1-3). In comparing the results of these calculations various and also in attempting to correlate the behavior of electrons in nitrogen gas with that in dry air. From the figures, we can see the increasing of the Townsend's energy factor when the E/N, E/p and D/μ are increased because more excitation for electrons which gained the energy from the applied electric field. A good agreement with the literature (Rees and Jory, 1964).

Figures (4 and 5) are shown the calculated values of characteristic energy D/μ as a function of the E/N and E/P300 for nitrogen gas at 300 °K, this show that D/μ is proportional to E/N and E/P by increasing the energy of the electron which received from the applied electric field, this appeared a good agreement with experimental data (Frost 1962).

Figures (6 and 7) are shown the magnetic field as a function of the ratio applied electric field: to the total number density E/N and to the gas pressure E/P_{300} in a pure nitrogen gas, this figures appeared increasing the magnetic field when the applied electric field increased this mean increasing in the electron motion in a gas.

Figure.(8) is represented the magnetic field versus a drift velocity, you can see from the figure a simple increasing for magnetic field with increasing of drift velocity, but after the value 8010 V/m, there is a large increasing in the magnetic field.

Figures (9 and 10) are shown the magnetic field as a function of the Townsend's energy factor K_1 and the applied electric field E, which is the magnetic field increased when the K and E increase, this mean the magnetic field is proportional with K_1 and E as seen from the equations of magnetic field.

Figures (11 and 12) are represented the ratio of magnetic field to the applied electric field B/E as a function of: the ratio applied electric field to the gas total number density E/N and the ratio applied electric field to gas pressure E/P_{300} at gas temperature 300°K respectively, these figures had been seen decreasing the ratio B/E with increasing of the value of ratio

E/N but it decreasing with increasing E/P_{300} like linear.

Figures (13 and 14) are shown the ratio of the magnetic field to the applied electric field B/E as a function of the : drift velocity W and the Townsend's energy factor K_1 respectively, the decreasing of the ratio B/E with increasing of the drift velocity is linear, for instant, when the electrons gained the energy from the applied electric field diffuse toward the anode, and the decreasing of B/E with increased of Townsend's energy factor K_1 is too linear, but at value 48.0 eV the decreasing in B/E is very little with increasing K_1.

Figures (15 and 16) are shown the ratio of the magnetic field to the gas pressure B/P at 300 °K as a function of the: ratio of the applied electric field to the gas total numbers density E/N and of the ratio of the applied electric field to the gas pressure E/P respectively, these figures had been seen exponenationally increasing in ratio B/P_{300} with increasing of E/N and E/P_{300} respectively as the result of the transverse diffusion of the electrons.

Figure (17) is shown the ratio of the magnetic field to the gas pressure as a function of the applied electric field, this figure is increasing in ratio B/P_{300} with increasing of applied electric field because the electron gains the energy from the field.

Figure (18) is shown the ratio of the magnetic field to the gas pressure, B/P, as a function of the drift velocity W, the value of B/P_{300} is increasing exponentially with increasing of drift velocity, i.e., the gained energy by electrons from the electric field lead to increase the electron drift velocity.

Figure (19) is represented the ratio of the magnetic field to the gas pressure as a function of the Townsend's energy factor, from the figure we can see when the average energy of the electron is increasing; the ratio of B/P_{300} is increases.

Figure (20) is represented the ratio of the magnetic field to the gas total number density as a function of the ratio of applied electric field to the gas total number density, which is seen from the figure that there is a rapid increasing of the ratio B/N with increasing of E/N.

Figure (21) is show the ratio of the magnetic field to the gas total number density as a function of the ratio of the applied electric field to the gas pressure when the ratio of the E/P_{300} increased, the ratio of B/N but at value 0.645E-3 (V m^{-1} $Torr^{-1}$) lead to the rapid increasing in the ratio of B/N.

Figure (22) is shown the ratio of the magnetic field to the gas total number density as a function of the applied electric field, the increasing applied electric field means the electrons are gain more energy, this lead to increase the value of B/N.

Figure (23) is shown the ratio of the magnetic field to the gas total number density as a function of the drift velocity, from the figure we can see the increasing in the ratio of the B/N with drift velocity increasing, but at value 0.306E+5 m/sec there is a rapid increasing in the value of B/N.

Figure.(24) is shown the ratio of the magnetic field to the gas total number density as a function of the Townsend's energy factor, from the figure we can see a rapid increasing in the value of B/N when the Townsend's energy factor increased, i.e., the gained electron average energy from the applied electric field are large.

Conclusions:

1- Calculation of the transport coefficients, such as, D/μ, E and W by solving the numerically transport equation, Eq. (31) in N_2 gas under the influence of the electric field and magnetic field, E×B.
2- Calculation the factor K_1.
3- Derivation the magnetic field, B.
4- Determination the magnetic field, B in terms of the electric field E, gas pressure, P, and total gas number density, N, furthermore had be calculate the ratio of E/P.

Table (1):Electron Transport Motio Cofficients in Pure N2 Ga

E/N (V m^2) × 10^{-20}	E(V/m) × 10^2	W (m/S) × 10^3	D/μ (eV)
0.5	1335	10.887	0.785
1.0	2670	17.813	0.984
2.0	5340	30.596	1.144
3.0	8010	41.765	1.246
4.0	10680	50.803	1.352
5.0	13350	57.519	1.477

Table(2):Calculated Physical Quntitiek in Pure N2 Gas

E/N (V m^2) ×10^{-20}	E/P_{300} (V m^{-1} $Torr^{-1}$) × 10^{-4}	D/μ (eV)	K_1 (eV)
0.5	1.61	0.785	30.3
1.0	3.22	0.984	37.9
2.0	6.44	1.144	44.1
3.0	9.66	1.246	48.0
4.0	12.89	1.352	52.1
5.0	16.1	1.477	57.0

Table(3):Calculated Physical Parameters B in Pure N2 Gas

E/N (Vm^2) × 10^{-20}	E/P_{300} ($Vm^{-1}Torr^{-1}$) × 10^{-4}	E (V/m) × 10^2	W (m/S) × 10^3	K_1 (eV)	B (Sherif I. I. 1984) (G)×10^{-1}
0.5	1.61	1335	10.887	30.3	663.753
1.0	3.22	2670	17.813	37.9	910.515
2.0	6.44	5340	30.596	44.1	1145.816
3.0	9.66	8010	41.765	48.0	1314.828
4.0	12.89	10680	50.803	52.1	1502.769
5.0	16.1	13350	57.519	57.0	1736.856

Table(4):Calculated Physical Parameters B/M in Pure N2 Gas

E/N (V m^2) × 10^{-20}	E/P_{300} (V m^{-1} $Torr^{-1}$) × 10^{-4}	W (m/S) × 10^3	K_1 (eV)	B/E (G V^{-1} m) × 10^{-3}
0.5	1.61	10.887	30.3	0.497
1.0	3.22	17.813	37.9	0.341
2.0	6.44	30.596	44.1	0.214
3.0	9.66	41.765	48.0	0.164
4.0	12.89	50.803	52.1	0.140
5.0	16.1	57.519	57.0	0.130

Table (5):Calculated Physical Parameters . B/P300 and B/N in Pure N2 Gas

B/N (G m^3)×10^{-23}	B/P_{300} (G $Torr^{-1}$)×10^{-7}	K_1 (eV)	W (m/S)×10^3	E (V/m)×10^2	E/P_{300} (V m^{-1} $Torr^{-1}$)×10^{-4}	E/N (V m^2)×10^{-20}
0.298	0.800	30.3	10.887	1335	1.61	0.5
0.341	1.098	37.9	17.813	2670	3.22	1.0
0.428	1.378	44.1	30.596	5340	6.44	2.0
0.492	1.584	48.0	41.765	8010	9.66	3.0
0.560	1.804	52.1	50.803	10680	12.89	4.0
0.650	2.093	57.0	57.519	13350	16.1	5.0

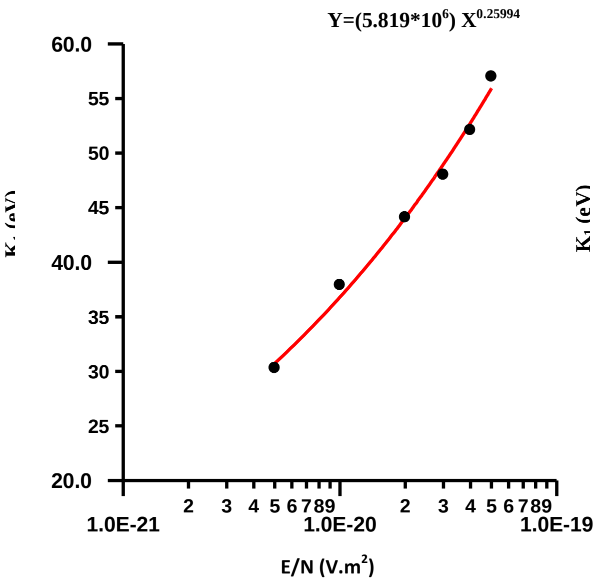


Figure (1): The Townsend's energy factor as a function of the ratio of the applied electric field to the total number density in a pure nitrogen gas

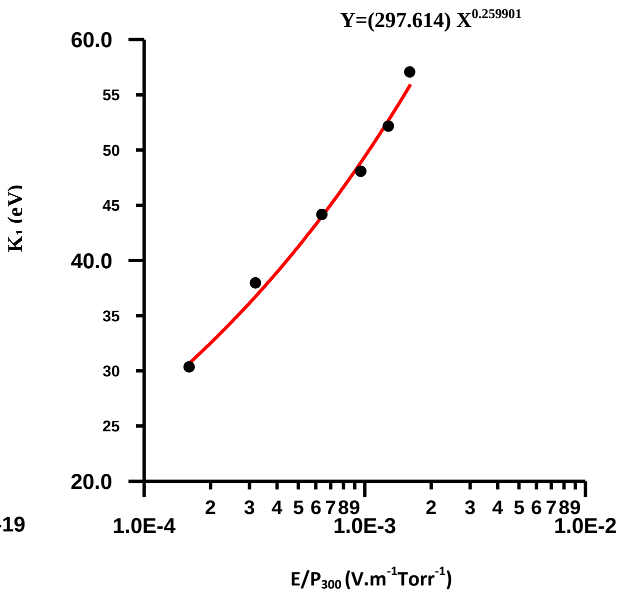


Figure (2): The Townsend's energy factor as a function of the ratio of the applied electric field to the gas pressure in pure nitrogen

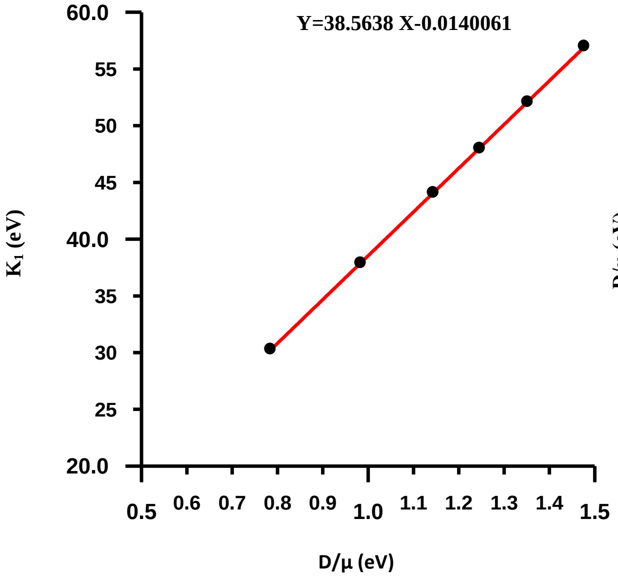


Figure (3): The Townsend's energy factor as a function of the ratio diffusion coefficient to the mobility in a pure nitrogen gas.

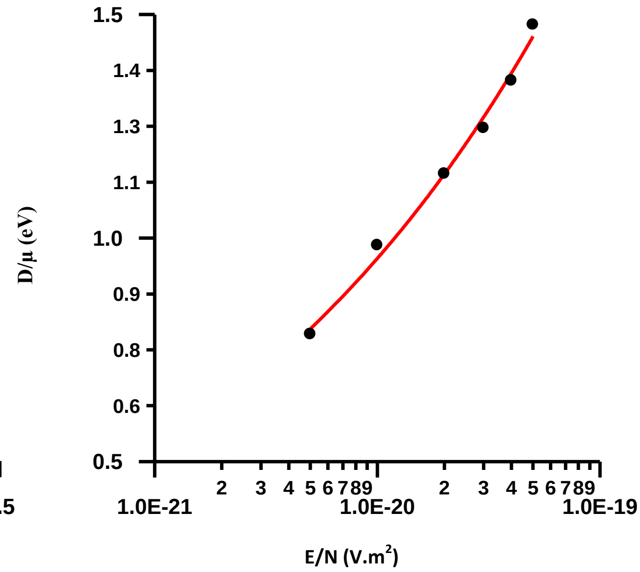


Figure (4): The characteristic energy as a function of the ratio applied electric field to the gas total number density in a pure nitrogen gas

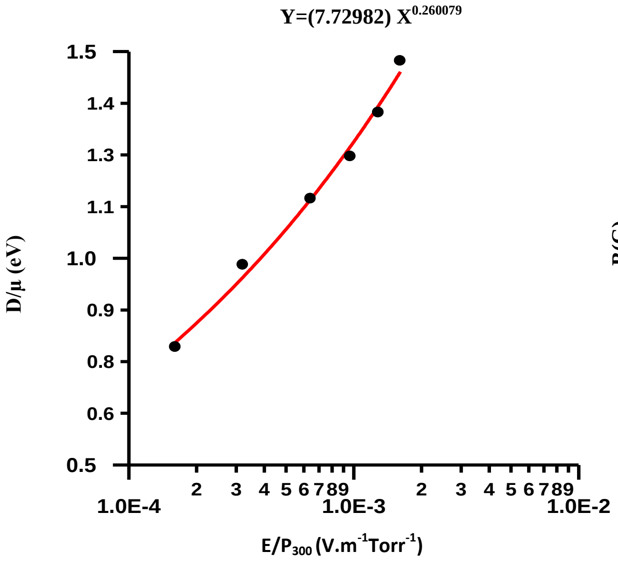


Figure (5): The characteristic energy as a function of the ratio applied electric field to the gas pressure in a pure nitrogen

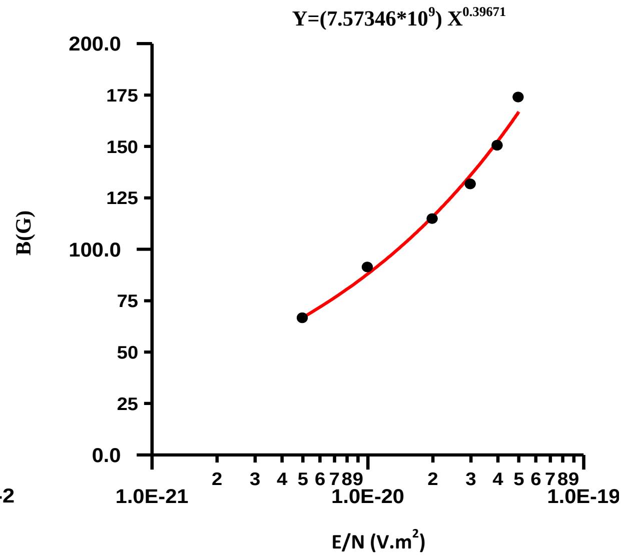


Figure (6): The magnetic field as a function of the ratio applied electric field to the total number density in pure

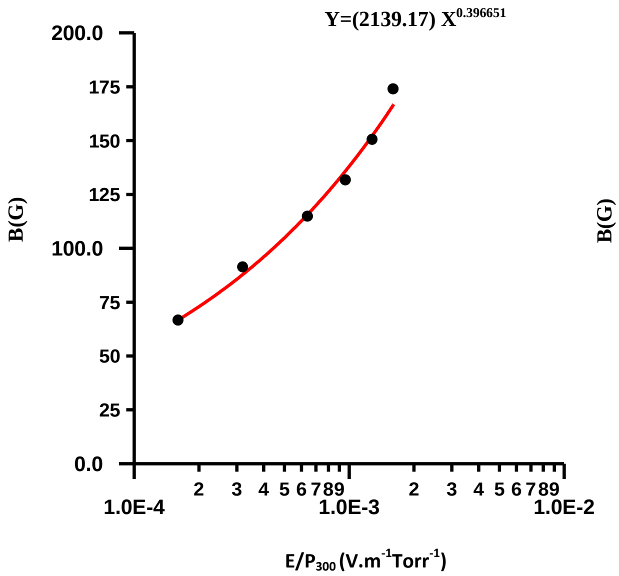


Figure (7): The magnetic field as a function of the ratio applied electric field to the gas pressure in a pure nitrogen gas.

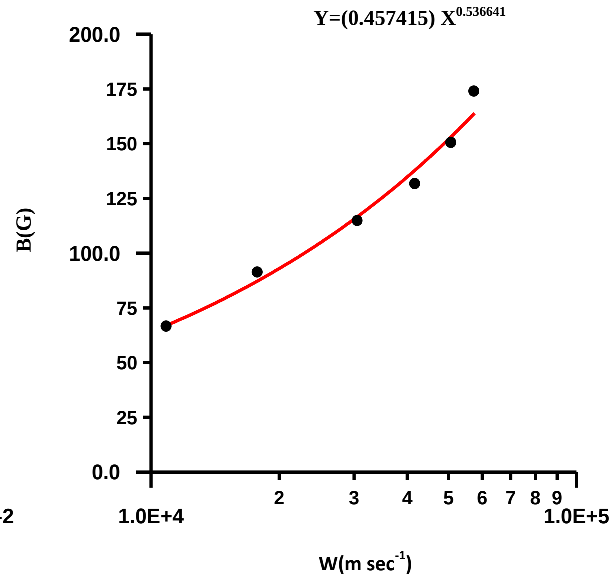


Figure (8): The magnetic field as a function of the drift velocity in pure nitrogen gas.

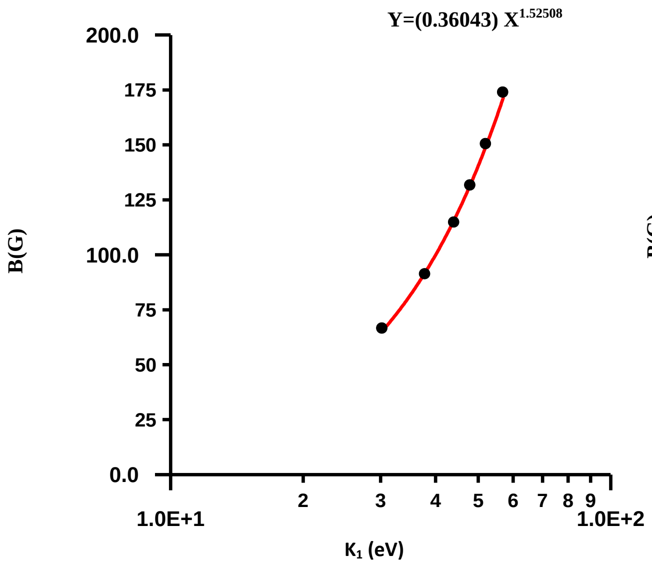


Figure (9): The magnetic field as a function of the Townsend's energy factor in a pure nitrogen gas.

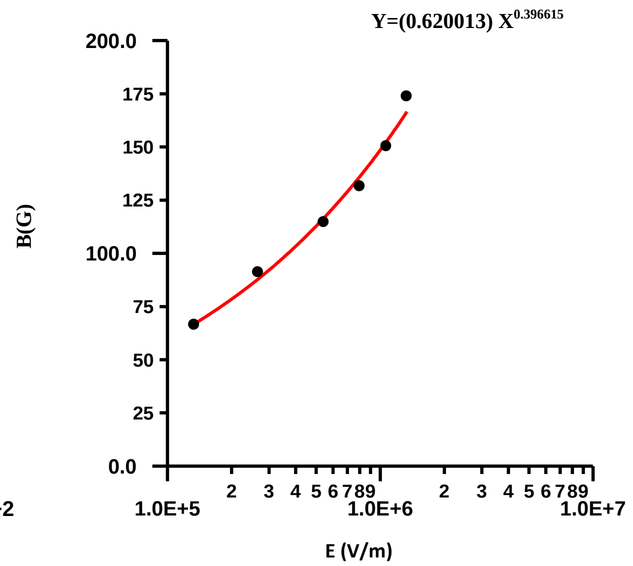


Figure (10): The magnetic field as a function of the applied electric field in a pure nitrogen

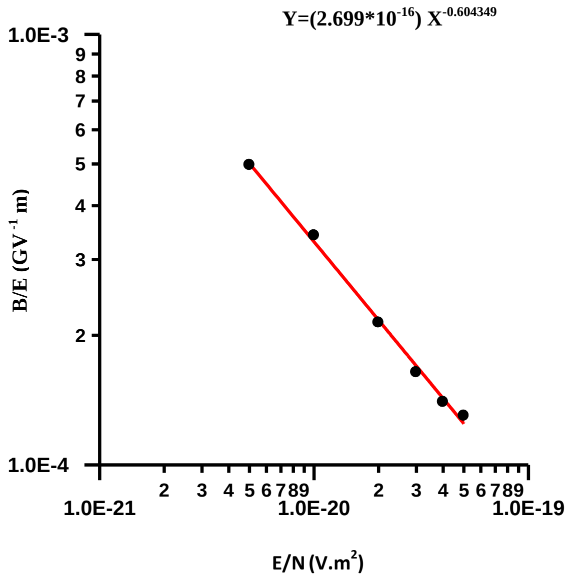


Figure (11): The ratio of magnetic field to electric field as a function of the ratio applied electric field to gas total number

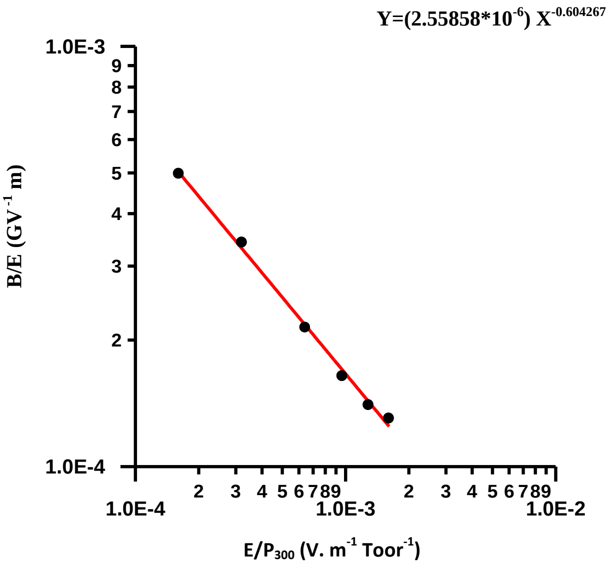


Figure (12): The ratio of magnetic field to electric field as a function of the ratio applied electric field to gas pressure in a pure nitrogen gas.

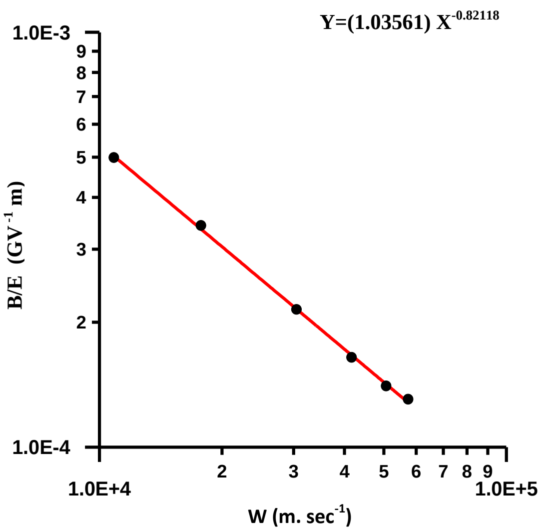


Figure (13): The ratio of magnetic field to electric field as a function of the drift velocity (W) in a pure nitrogen

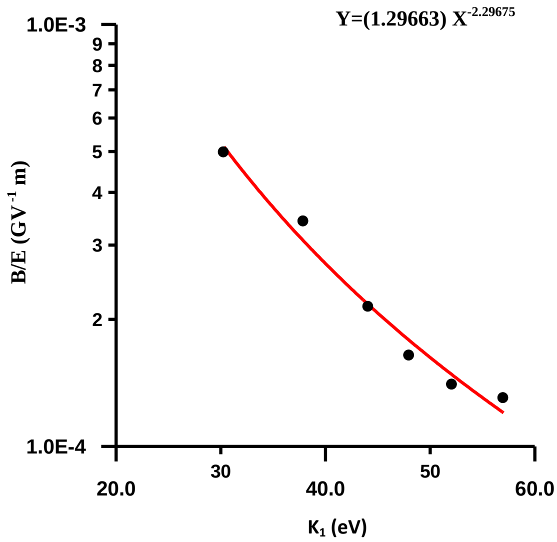


Figure (14): The ratio of magnetic field to electric field as a function of the Townsend's energy factor (K_1) in a pure

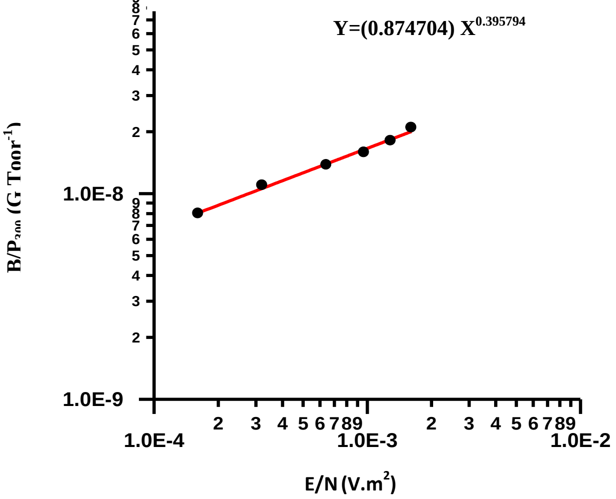


Figure (15): The ratio of magnetic field to the gas pressure as a function of the ratio applied electric field to gas total number density in a pure

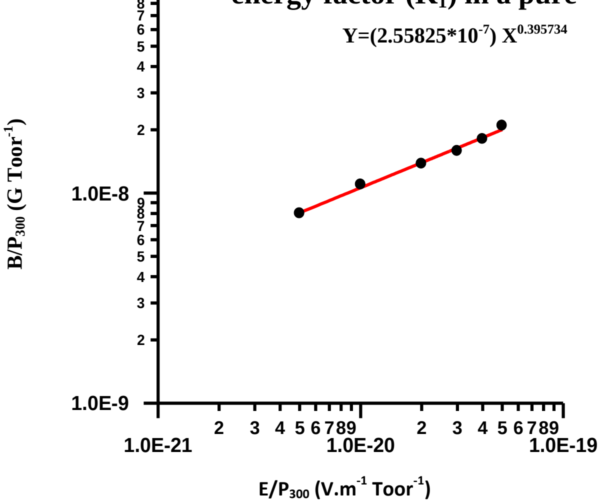


Figure (16): The ratio of magnetic field to gas pressure as a function of the ratio applied electric field to gas pressure in a pure nitrogen gas.

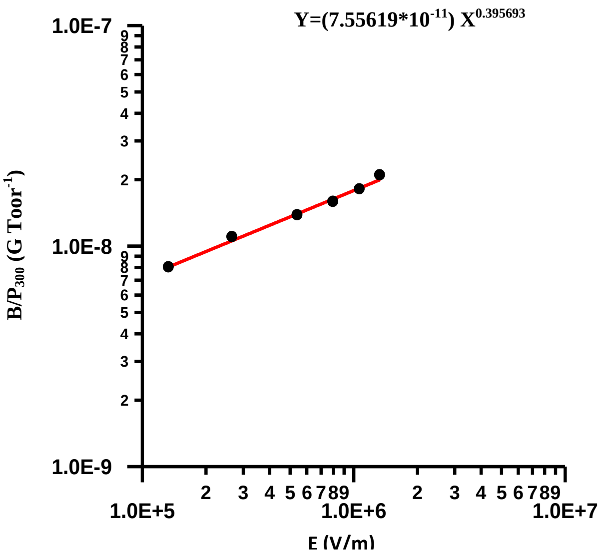


Figure (17): The ratio of the magnetic field to gas pressure as a function of the applied electric field in a pure nitrogen gas.

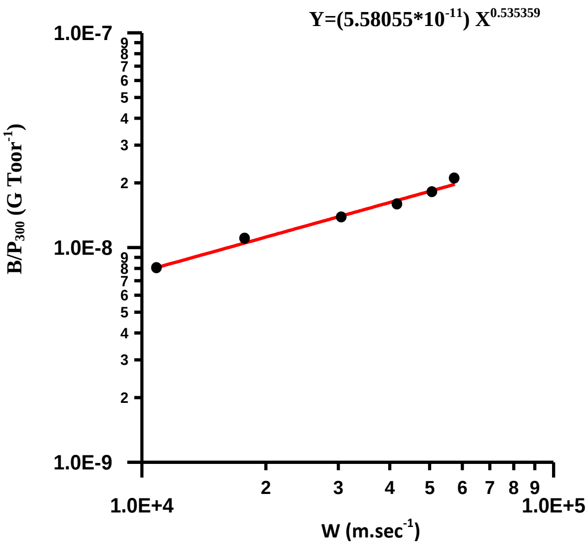


Figure (18): The ratio of magnetic field to the gas pressure as a function of the drift velocity in a pure nitrogen gas.

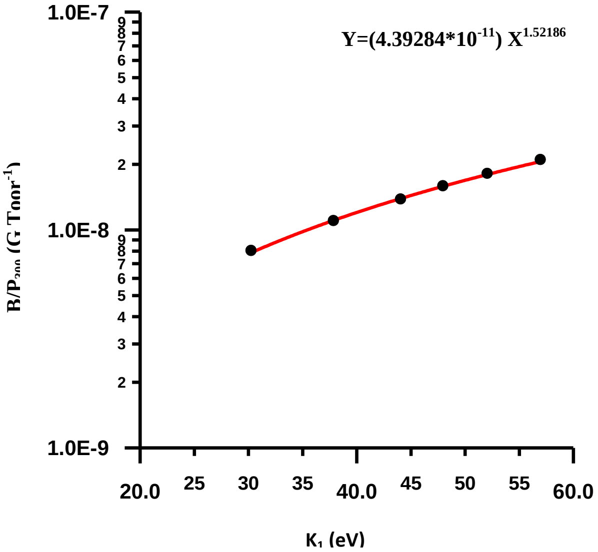


Figure (19): The ratio of magnetic field to the gas pressure as a function of the Townsend's energy factor in a pure nitrogen

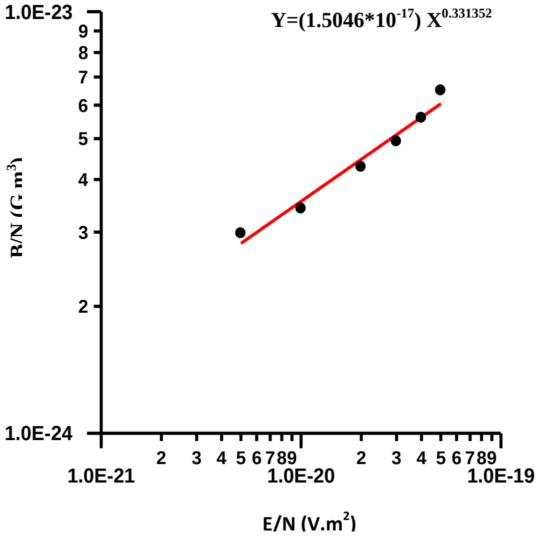


Figure (20): The ratio of the magnetic field to the gas total number density as a function of the applied electric field to the gas total number density ratio in a pure nitrogen gas

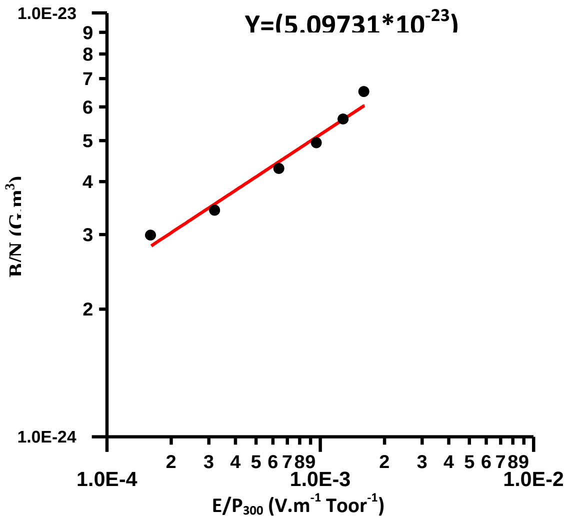


Figure (21): The ratio of the magnetic field to the gas total number density as a function of the ratio of the applied electric field to the gas pressure in a pure nitrogen gas.

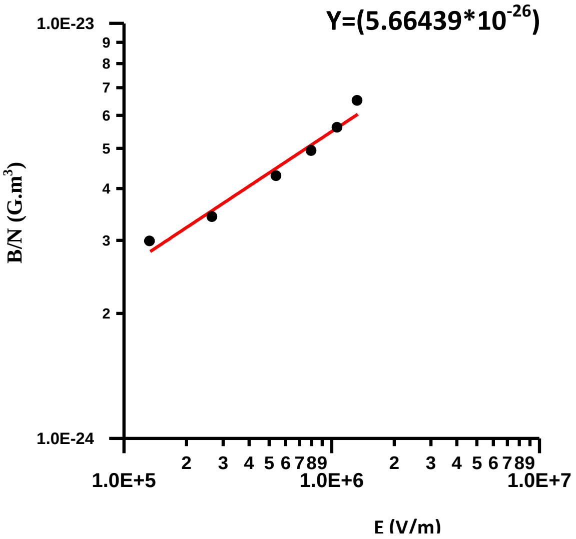


Figure (22): The ratio of magnetic field to the gas total number density as function of the applied electric field in a pure nitrogen gas.

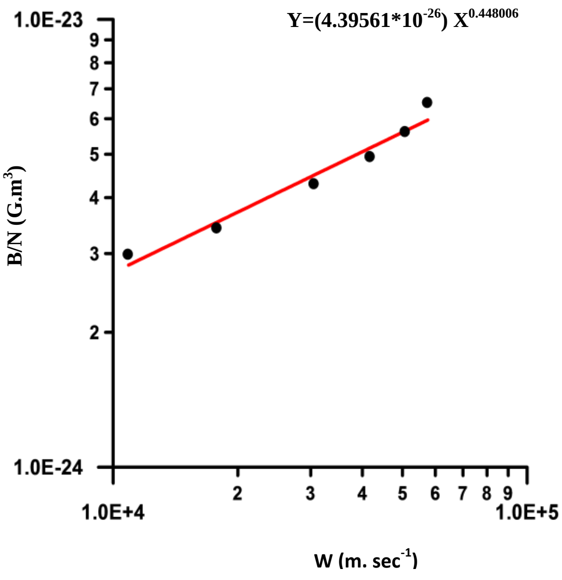


Figure (23): The ratio of magnetic field to the gas total number density as a function of the drift velocity in a pure nitrogen gas.

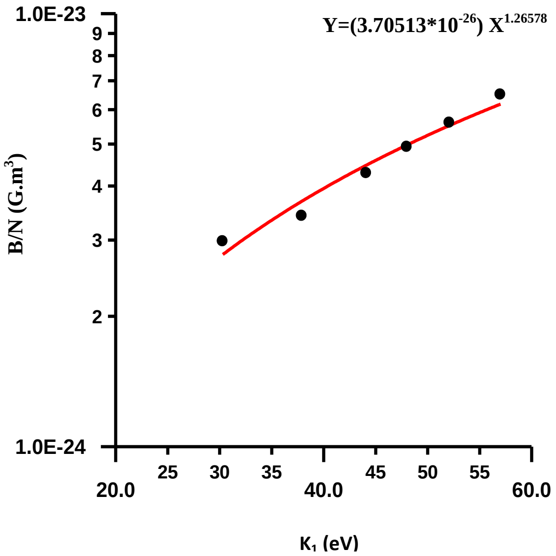


Figure (24): The ratio of the magnetic field to the gas total number density as a function of the Townsend's energy factor K_1 in a

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