Electromagnetic Field Effect on Particles Diffusion in Gases

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Abstract

In this job, 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 EXB, 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. These results had be tabulated and graphically plotted, which an agreement with appeared experimentally and theoretically literature.

Keyword: Electromagnetic field, particles, diffusion, electric field, transports equation.

1. Introduction

In crossed fields E×B can afford valuable information about the energy dependence of the momentum transfer cross section or from energy distribution [Allen, 2005, A. N. Tkachev, 2006]. The electron swarms moves in crossed electric and magnetic fields have been investigated for many years, the first experiments by Townsend and Tizard (1913) being used as a method of measuring electron drift velocities more recently detailed examinations of the motions of electron swarms under these conditions (e.g. Huxley 1960) 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 fields, 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 J.S. Townsend [Allen, 2005- Boris, 2001].

2. Equation Derivation:

The general Bailey formula is used to measure the current ratio Re, which is, [Aldo, 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:

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

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

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

In case of absent the magnetic field yield:

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

Substitute eq. (5) into eq. (1) yield:

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

Where:

$$\frac{D}{\mu} = \frac{KT_g}{e} \qquad (7)$$

Where Tg is gas temperature and e represent electron charge:

$$\frac{\mu}{D} = \frac{e}{KT_g} \qquad (8)$$

Substitute eq. (8) into eq. (6) yield:

$$\mathrm{Re} = \psi\left(\frac{eE}{KT_g d}\right)e^{-\eta d} \qquad (9)$$

By equating equation (9) with equation (4) yield:

$$\psi\left(\frac{\mu_{11} E}{D_T d}\right)e^{-\eta d} = \psi\left(\frac{eE}{KT_g d}\right)e^{-\eta d} \qquad (10)$$

By simplified the eq. (10) after eliminate which is like from two sides yield:

$$\frac{\mu_{11}}{D_T} = \frac{e}{KT_g}$$

We can obtain for the case of the magnetic field to the value:

$$\frac{D_T}{\mu_{11}} = \frac{KT_g}{e} \qquad (11)$$

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

$$K_1 = \frac{e}{KT_g}\frac{D}{\mu} \qquad (12)$$

$$\frac{KT_g}{e} = \frac{D}{K_1 \mu} \qquad (13)$$

Substitute eq. (13) into eq. (11) yield:

$$\frac{D_T}{\mu_{11}} = \frac{1}{K_1}\frac{D}{\mu} \qquad (14)$$

By simplified eq. (14) yields:

$$\frac{D_T}{D_{11}} = \frac{1}{K_1} \qquad (15)$$

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

$$D_{11} = \frac{1}{3}(\frac{\upsilon^2}{v_m}) \qquad (16)$$

Therefore, the transverse diffusion coefficient (D_T) as:

$$D_T = \frac{1}{3}(\frac{v_m \upsilon^2}{v_m^2 + \omega_b^2}) \qquad (17)$$

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

By division eq. (16) on eq. (17) yield:

$$\frac{D_{11}}{D_T} = \frac{\frac{1}{3}\left(\frac{\overline{v^2}}{v_m}\right)}{\frac{1}{3}\left(\overline{\frac{v_m\, v^2}{v_m^2 + \omega_b^2}}\right)}$$

$$= \frac{\overline{v^2}}{v_m} \, \frac{\overline{v_m^2 + \omega_b^2}}{\overline{v_m\, v^2}} = \frac{v_m^2 + \omega_b^2}{v_m^2}$$

$$= 1 + \frac{\omega_b^2}{v_m^2} = 1 + (\frac{\omega_b}{v_m})^2 \qquad (18)$$

We can define the cyclotron frequency ω_b as:

$$\omega_b = \frac{eB}{m} \qquad (19)$$

Where, e is a represents the electron charge, m is an electron mass. Substitute eq. (19) into eq. (18) yields:

$$\frac{D_{11}}{D_T} = 1 + \left(\frac{\frac{eB}{m}}{v_m}\right)^2 \qquad (20)$$

$$\frac{D_{11}}{D_T} = 1 + \left(\frac{eB}{m v_m}\right)^2 \qquad (21)$$

Where:

$$\mu = \frac{e}{m v_m} \qquad (22)$$

Where, μ is a represent of the mobility. Substitute eq. (22) into eq. (21) we obtain:

$$\frac{D_{11}}{D_T} = 1 + (\mu B)^2 \qquad (23)$$

Simplified eq. (23) yields:

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

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

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

$$\mu = \frac{1}{B}\left(\frac{D_{11}}{D_T} - 1\right)^{\frac{1}{2}} \qquad (24)$$

Substitute eq. (24) into eq. (5) yields:

$$W = \mu E = \frac{E}{B}\left(\frac{D_{11}}{D_T} - 1\right)^{\frac{1}{2}} \qquad (25)$$

From eq. (15) we can obtain the value of K_1, like this:

$$K_1 = \frac{D_{11}}{D_T} \qquad (26)$$

Substitute eq. (26) into eq. (25) yields:

$$W = \frac{E}{B}(K_1 - 1)^{\frac{1}{2}} \qquad (27)$$

$$B = \frac{E}{W}(K_1 - 1)^{\frac{1}{2}} \qquad (28)$$

By squaring the two sides of eq. (28) yields:

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

By arrange eq. (29) yields:

$$\frac{B}{E} = \frac{1}{W}(K_1 - 1)^{\frac{1}{2}} \qquad (30)$$

Multiplying the two sides of eq. (28) by the factor 1/P, where P represents the gas pressure, yields:

$$\frac{B}{P} = \frac{E(K_1 - 1)^{\frac{1}{2}}}{pW} \qquad (31)$$

Where the equation no (31), represents the magnetic field in term of pressure. From the mathematical relation [9], we can find:

$$N = 3.54 \times 10^{16} \times \frac{273.15P}{T} \qquad (32)$$

$$NT = 3.54 \times 10^{16} \times 273.15P$$

$$P = \frac{NT}{3.54 \times 10^{16} \times 273.15} \qquad (33)$$

Substitute eq. (33) into eq. (31) yield:

$$\frac{B}{\frac{NT}{3.54 \times 10^{16} \times 273.15}} = \frac{E(K_1 - 1)^{\frac{1}{2}}}{\frac{NTW}{966.951 \times 10^{16}}}$$

$$\frac{B}{N} = \frac{\frac{TE(K_1 - 1)^{\frac{1}{2}}}{966.951 \times 10^{16}}}{\frac{NTW}{966.951 \times 10^{16}}}$$

$$\frac{B}{N} = \frac{TE(K_1 - 1)^{\frac{1}{2}}}{966.951 \times 10^{16}} \times \frac{966.951 \times 10^{16}}{NTW}$$

$$\frac{B}{N} = \frac{E(K_1 - 1)^{\frac{1}{2}}}{NW} \qquad (34)$$

From the ratio of the electric field to the gas number density, E/N [Charles,2001], we can find the following relation. Substitute eq. (32) to the above ratio, which is:

$$\frac{E}{N} = \frac{E}{3.54 \times 10^{16} \times \frac{273.15\,P}{T}}$$

$$= \frac{E}{966.951 \times 10^{16}\,\frac{P}{T}}$$

Simplified the equation yield:

$$\frac{E}{P}=\frac{E}{N}\times 966.951\times 10^{16}\,\frac{1}{T} \qquad (35)$$

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 .

3. The calculations:

From through derivation of magnetic field equation, we can calculation:
1 – Find the Townsend's energy factor K_1, equation No. (12).
2 – The magnetic field B, equation no (28).
3 – Ratio of magnetic field to the electric field B/E, equation no. (30).
4 – Ratio of magnetic field to the gas pressure B/P, equation no. (31).
5 – Ratio of the magnetic field to the gas total number density B/N, equation no. (34).
6 – Ratio of the electric field to the gas pressure E/P, equation no. (35).

To calculate the above equations, we constructed the "computer program" which is the list of program below. This program receives data such as: (electric field E, drift velocity W, characteristic energy D/μ) as table (1) from the Nomad program which it's solve the numerically transport equation [Rockwood, 1980, Farhan, 2005].

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

4. 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 eq. (12) and E/P_{300} eq. (35) as show in table (2) . In table (3) we calculate the parameter B from eq. (28),in table (4) we calculate the parameter B/E eq. (30) and in the table (5) we calculate the parameters B/P_{300} eq. (31) and B/N eq. (34) 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 $0.5\times10^{-20} < E/N < 5\times10^{-20}$ V m^2; $1.61\times10^{-4} < E/P_{300} < 16.1\times10^{-4}$ V m^{-1} Torr^{-1} are shown in figures (1-24).

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,1964].

Figs. (4-5) 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].

Figs.(6-7) are showing 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 .

Fig.(8) represents 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.

Figs.(9-10) are showing 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.

Figs.(11-12) are representation 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.

Figs.(13-14) are showing 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 .

Figs.(15-16) are showing 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.

Fig.(17) shows 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 .

Fig.(18) shows 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 .

Fig.(19) represents 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.

Fig.(20) represents 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 .

Fig.(21) shows 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 .

Fig.(22) shows 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 .

Fig.(23) shows 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 .

Fig.(24) represents 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 .

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Table (1)

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)

E/N (V m^2) ×10^{-20}	E/P_{300} (V m^{-1} Torr^{-1}) × 10^{-4}	D/μ (eV)	K_1 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)

E/N (V m^2) × 10^{-20}	E/P_{300} (V m^{-1} Torr^{-1}) × 10^{-4}	E(V/m) × 10^2	W (m/S) × 10^3	K_1 (eV	B[15] (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)

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)

B/N (G m^3)$\times10^{-23}$	B/P_{300} (G $Torr^{-1}$)$\times10^{-7}$	K_1 (eV)	W (m/S)$\times10^3$	E (V/m)$\times10^2$	E/P_{300} (V m^{-1} $Torr^{-1}$)$\times10^{-4}$	E/N (V m^2)$\times10^{-20}$
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

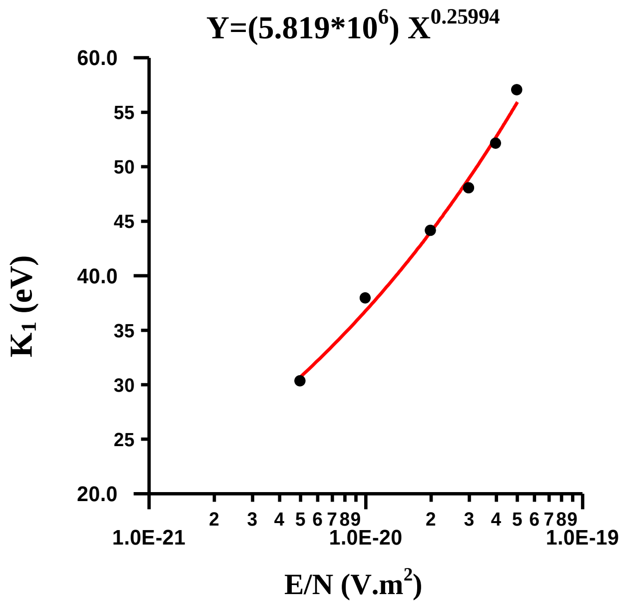

Fig (1): The Townsend's energy factor as a function of the ratio of the applied electric field to the total number density in a pure nitrogen gas.

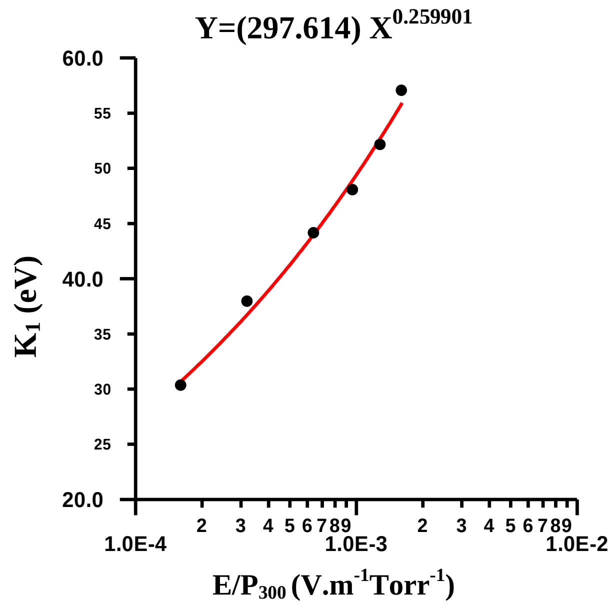

Fig (2): The Townsend's energy factor as a function of the ratio of the applied electric field to the gas pressure in pure nitrogen.

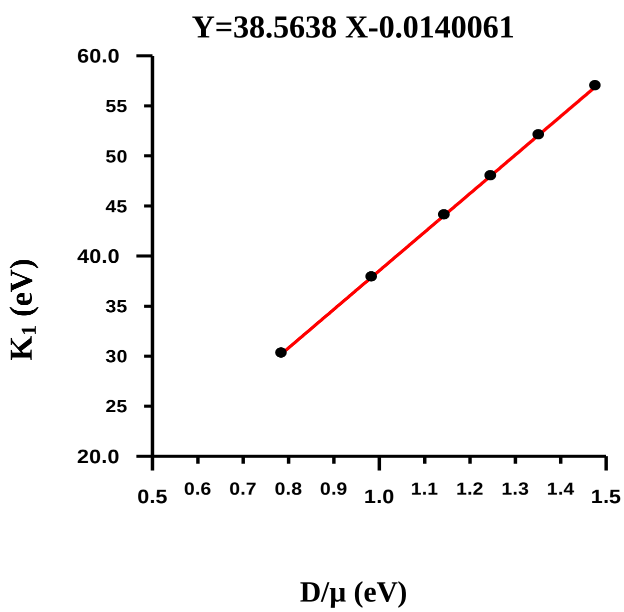

Fig (3): The Townsend's energy factor as a function of the ratio diffusion coefficient to the mobility in a pure nitrogen gas.

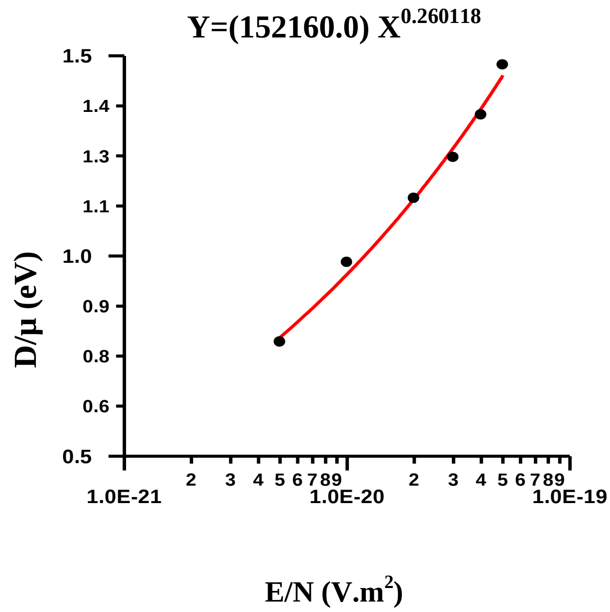

Fig (4): The characteristic energy as a function of the ratio applied electric field to the gas total number density in a pure nitrogen gas.

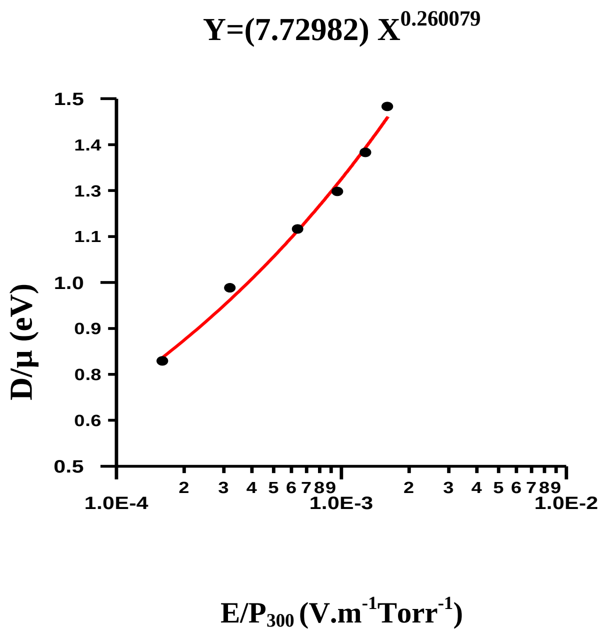

Fig (5): The characteristic energy as a function of the ratio applied electric field to the gas pressure in a pure nitrogen.

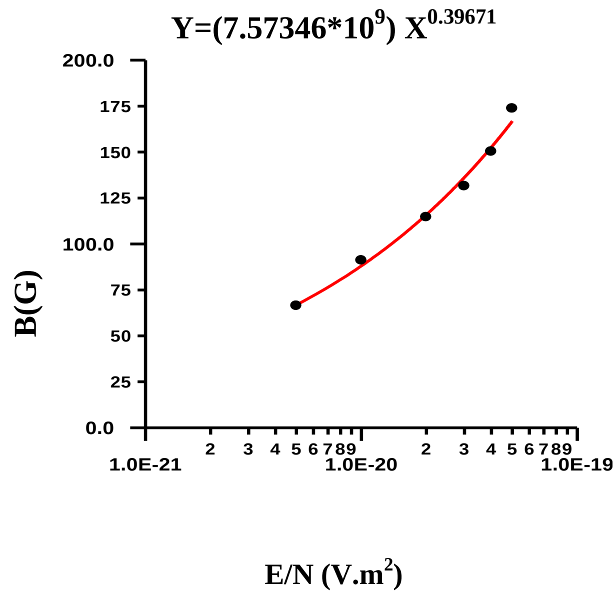

Fig (6): The magnetic field as a function of the ratio applied electric field to the total number density in pure nitrogen.

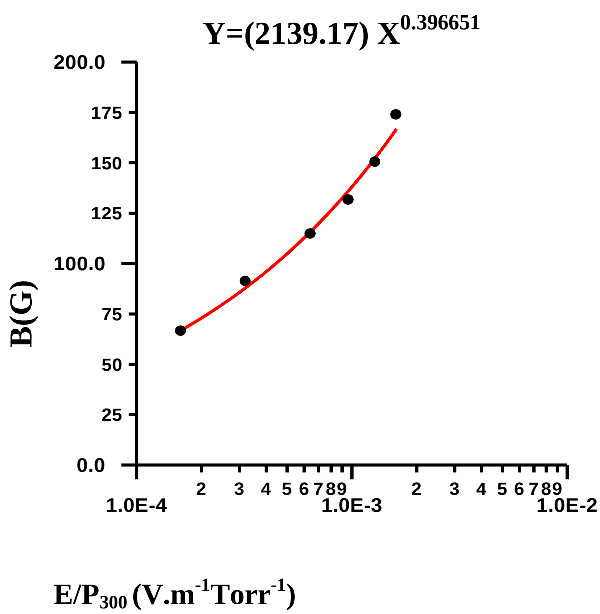

Fig (7): The magnetic field as a function of the ratio applied electric field to the gas pressure in a pure nitrogen gas.

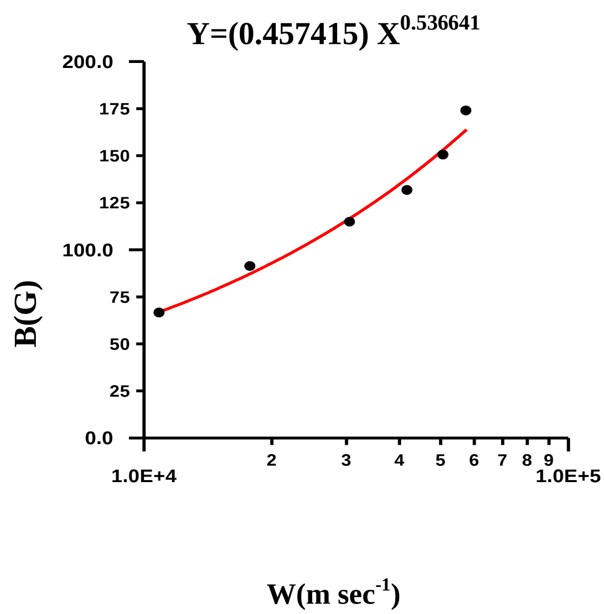

Fig (8): The magnetic field as a function of the drift velocity in pure nitrogen gas.

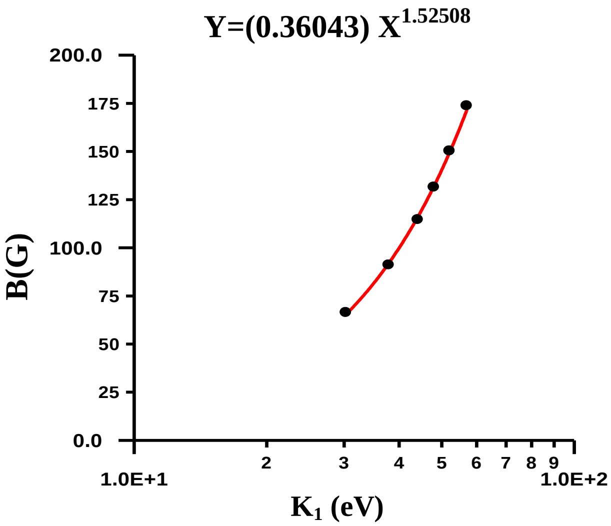

Fig (9): The magnetic field as a function of the Townsend's energy factor in a pure nitrogen gas.

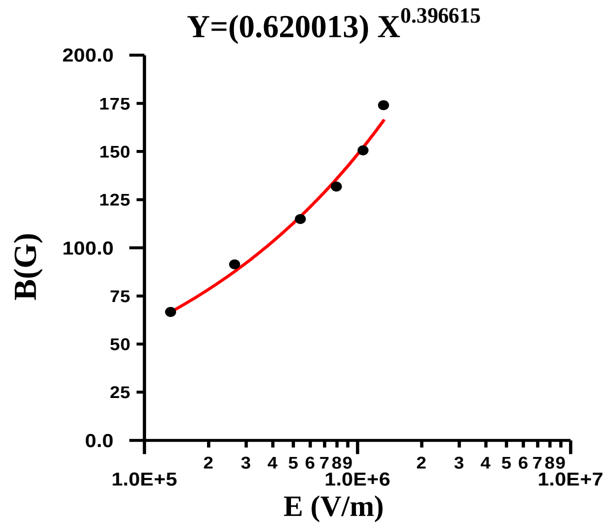

Fig (10): The magnetic field as a function of the applied electric field in a pure nitrogen gas.

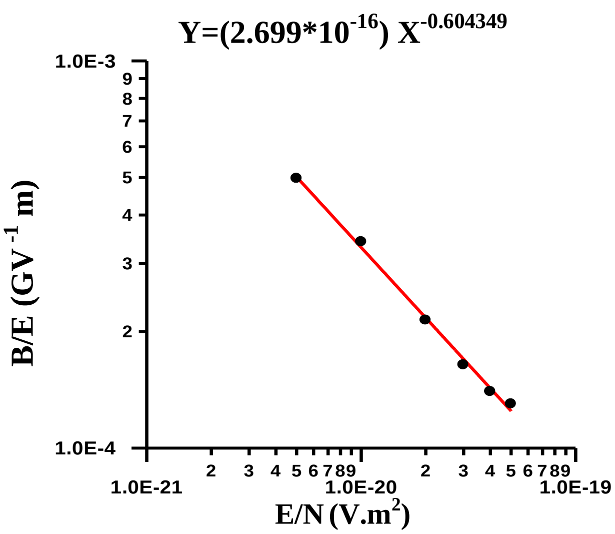

Fig (11): The ratio of magnetic field to electric field as a function of the ratio applied electric field to gas total number density in a pure nitrogen gas.

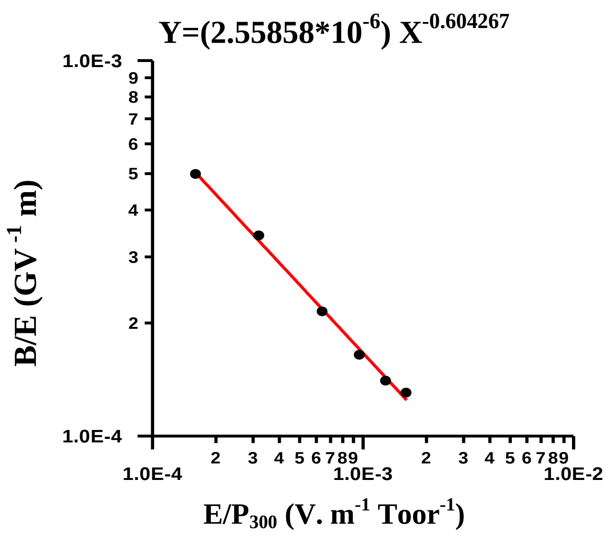

Fig (12): The ratio of magnetic field to electric field as a function of the ratio applied electric field to gas pressure in a pure nitrogen gas.

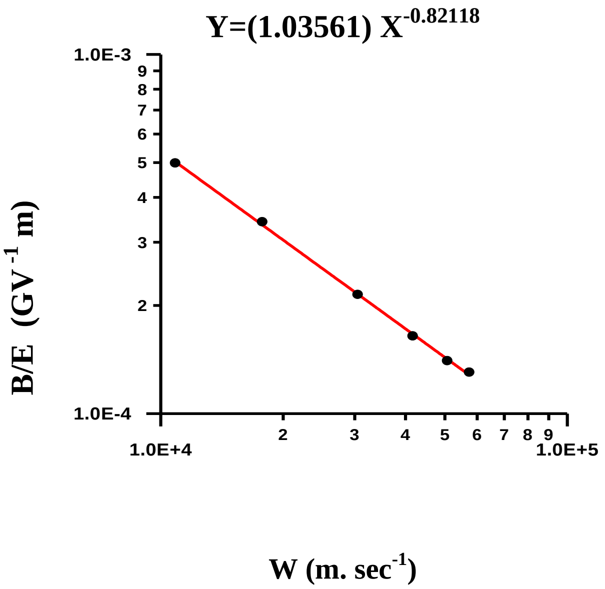

Fig (13): The ratio of magnetic field to electric field as a function of the drift velocity (W) in a pure nitrogen gas.

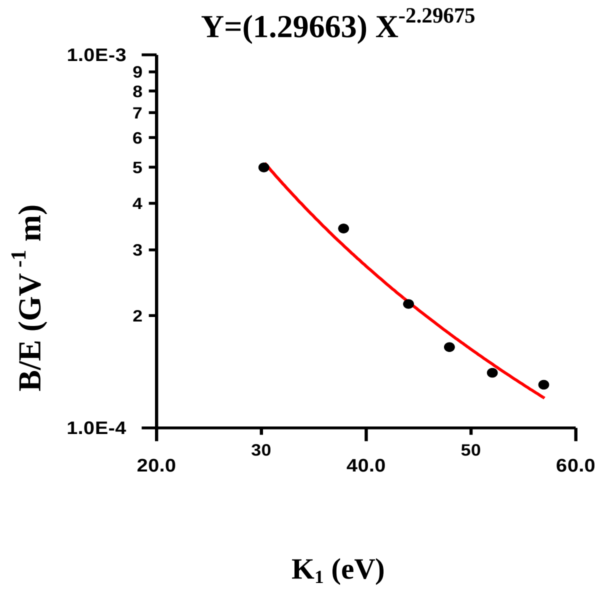

Fig (14): The ratio of magnetic field to electric field as a function of the Townsend's energy factor (K_1) in a pure nitrogen gas.

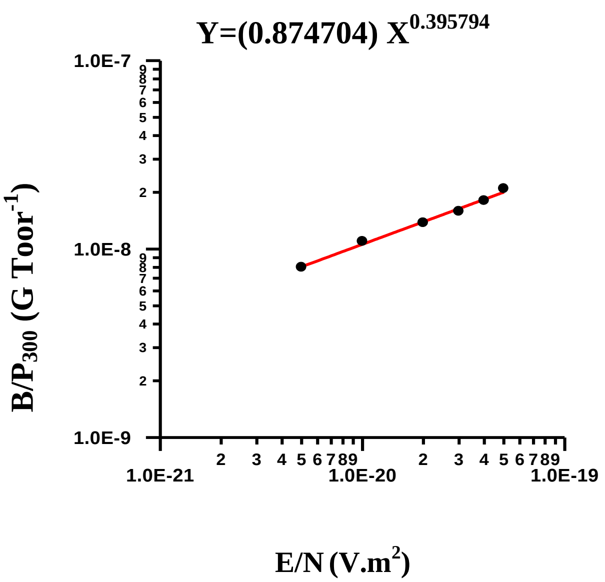

Fig (15): The ratio of magnetic field to the gas pressure as a function of the ratio applied electric field to gas total number density in a pure nitrogen gas.

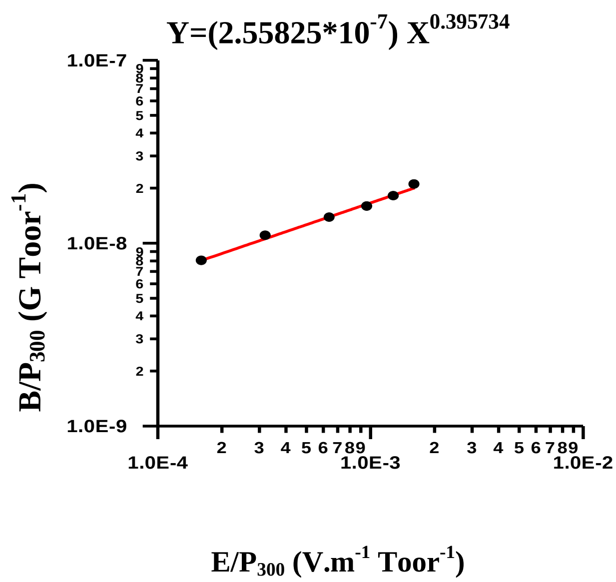

Fig (16): The ratio of magnetic field to gas pressure as a function of the ratio applied electric field to gas pressure in a pure nitrogen gas.

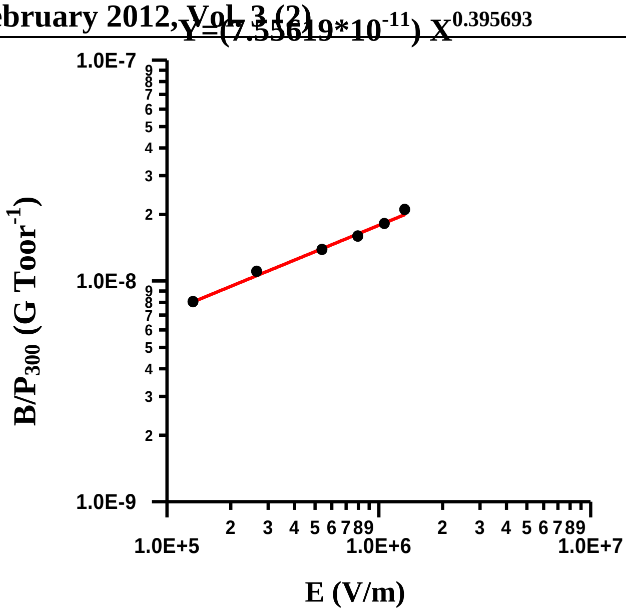

Fig (17): The ratio of the magnetic field to gas pressure as a function of the applied electric field in a pure nitrogen gas.

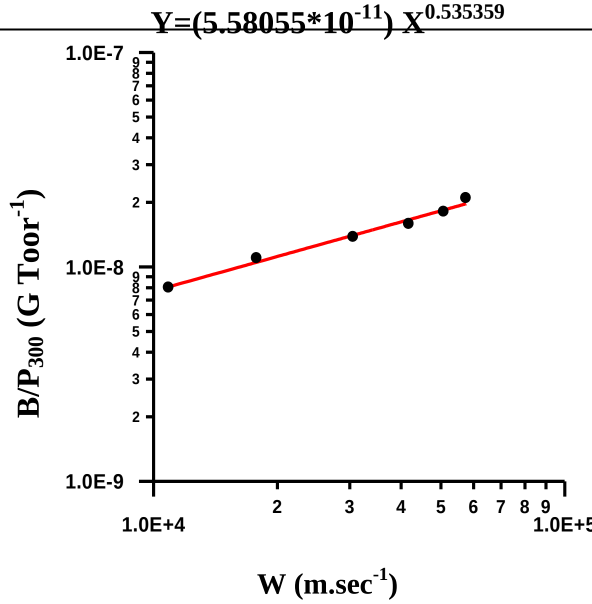

Fig (18): The ratio of magnetic field to the gas pressure as a function of the drift velocity in a pure nitrogen gas.

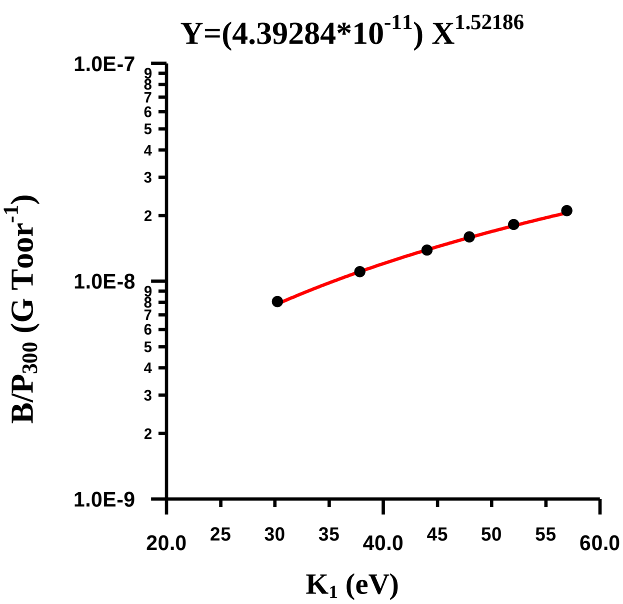

Fig (19): The ratio of magnetic field to the gas pressure as a function of the Townsend's energy factor in a pure nitrogen gas.

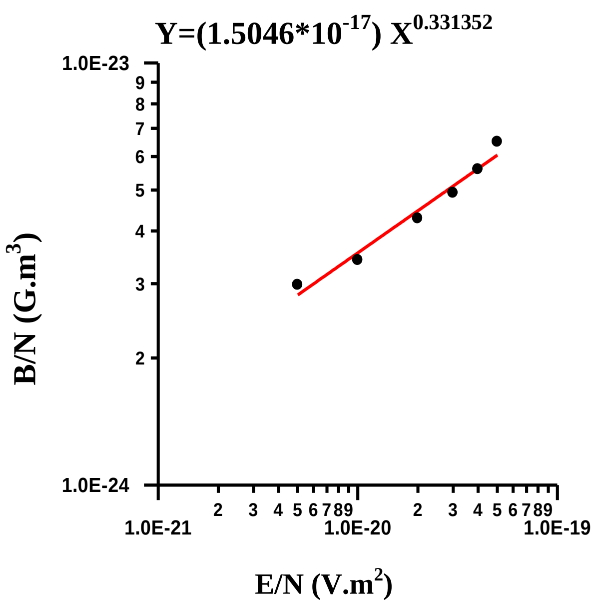

Fig (20): The ratio of the magnetic field to the gas total number density as a function of the applied electric field to the gas total number density ratio in a pure nitrogen gas.

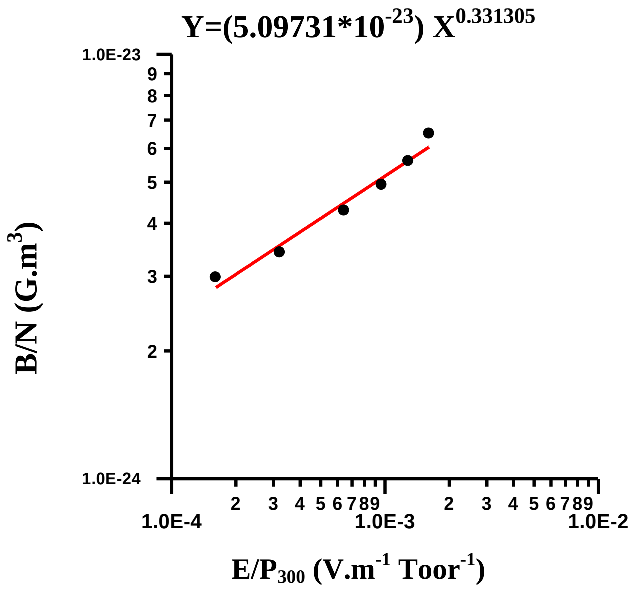

Fig (21): The ratio of the magnetic field to the gas total number density as a function of the ratio of the applied electric field to the gas pressure in a pure nitrogen gas.

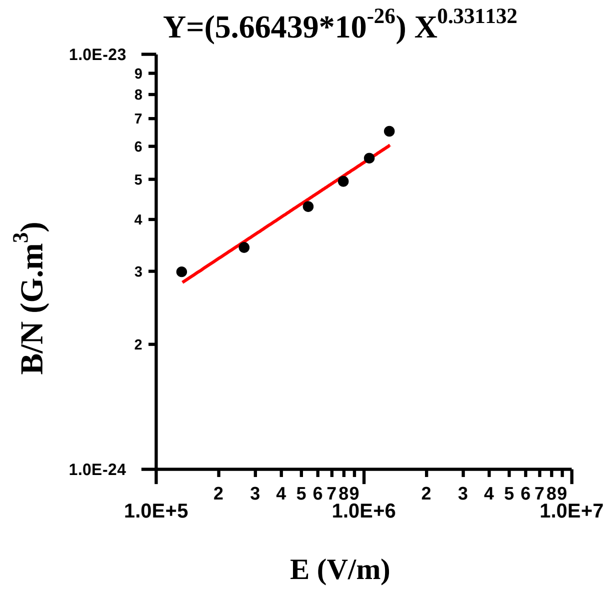

Fig (22): The ratio of magnetic field to the gas total number density as function of the applied electric field in a pure nitrogen gas.

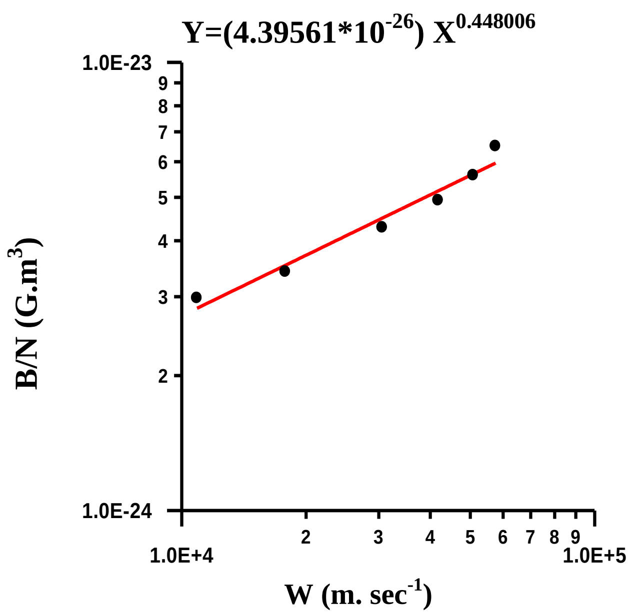

Fig (23): The ratio of magnetic field to the gas total number density as a function of the drift velocity in a pure nitrogen gas.

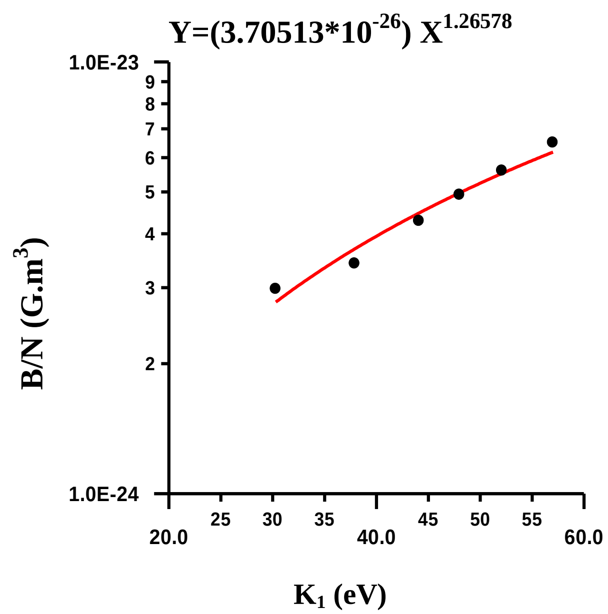

Fig (24): The ratio of the magnetic field to the gas total number density as a function of the Townsend's energy factor K_1 in a pure nitrogen gas.