Salahaddin University- Erbil
زانكۆى سەلاحەددين-هەولێر

Plasma Physics And The Effect Of Gas Density On Electron Mobility And Ionization Coefficient By Using Boltzmann Transport Equation In Xenon Gas

Research project
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By:

Fatima Yaseen Taha

Supervised by:

M.Gullala Yaseen Baker

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بِسْمِ اللهِ الرَّحْمنِ الرَّحِيمِ

قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ

صدق الله العظيم

سورة البقرة الاية32

Supervisor Certificate

This research project has been written under my supervision and has been submitted for the award of the degree of BSc. in (Bittencourt).

Signature

Name: Gullala Yasen Bakr

Date 6 / 4 /2023

I confirm that all requirements have been completed.

Signature:

Name: Dr Rashad Hasan

Head of the Department of Physics

Date 6 / 4 /2023

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Summary

Equation over the density-normalized electric field strength, E/N from 0.01 to 200 Td (1Td=10^{-17} V.cm2). Electron energy distributions have been obtained for electrically excited Xe by numerically solving the Boltzmann equation for conditions typical of electric discharges. The calculated distribution functions were found to be markedly non-Maxwellian, having energy variations which reflect the important electron-molecule energy exchange processes. The swarm parameters such as, Electron mobility and ionization coefficient were analyzed using a set of cross sections for Xenon gas.

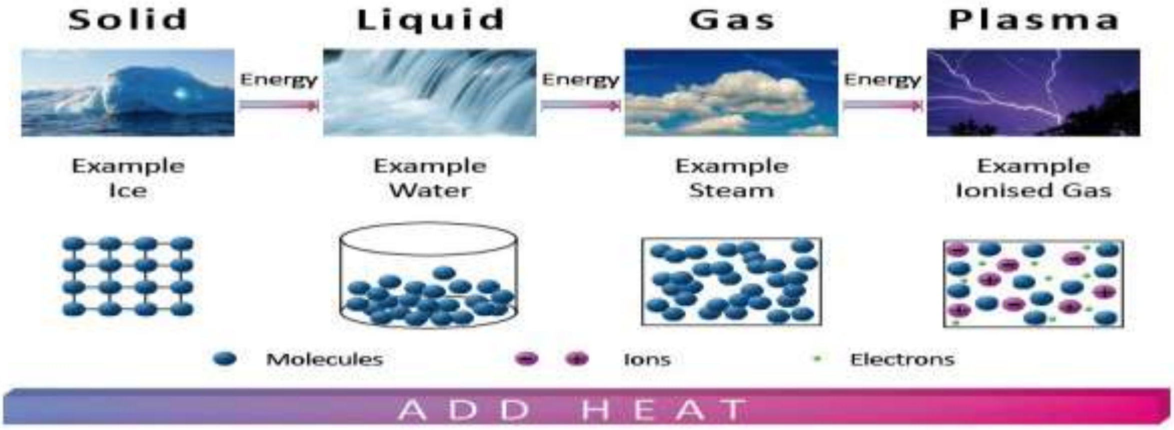
For this porpoise Xenon gas is chosen to carry out these calculations. The preparation of electron energy dependent cross sections for elastic and/or inelastic collisions and all related data are required as input data.

CHAPTER ONE

INTRODUCTION

1.Introduction:

From a scientific point of view, matter in the known universe is often classified in terms of four states: solid, liquid, gaseous, and plasma. The basic distinction among solids, liquids, and gases lies in the difference between the strength of the bonds that hold their constituent particles. Plasma exists in many forms in nature and has a widespread use in science and technology. It is a special kind of ionized gas and general consists of:- positively charged ions ('positive ions'), - electrons, and neutrals (atoms, molecules)(Bittencourt, 2004).



Figure(1-1): The state of mater

1.1 Definition of plasma state

Plasma is an ionized gas, consisting of free electrons, ions and atoms. We understand this with an example that when a solid is heated sufficiently that the thermal motion of the atoms break the crystal lattice structure and liquid is formed. When a liquid is heated enough that atoms vaporize, a gas is formed. When a gas is heated enough that the atoms collide with each other and electrons, ions produced in the process, a plasma is formed, ie, fourth state of matter. The constituents of these states (solid, liquid, gas) are atoms and molecules. The transformation from one state to another is done by supplying energy, e.g. , heat. Further transformation to fourth state (plasma) take place when the gas is further energized by very high temperature or subjected to energetic radiations (F) results to electrons and ions and neutral atoms. Therefore, this fluid consisting of charged particles and neutral atoms or molecules is called Plasma. An ionized gas has unique properties. In plasma, charge separation between ions and electrons gives rise to electric fields and charged particle flows give rise to current and magnetic fields(Bittencourt, 2013).

Plasma plays an essential role in many applications ranging from advanced lighting device and surface treatments for semiconductor applications or surface layer generation. Other applications are controlled fusion research, solar physics, astrophysics, plasma population, ionosphere physics and magnetospheric physics (Smirnov, 2008).

As the temperature of any solid material is raised, its state changes from solid to liquid and then to gas. If we increase the temperature of a gas beyond a certain limit, it enters a regime where the thermal energy of its constituent particle is so great that the electrostatic forces which ordinarily bind electrons to atomic nuclei are overcome. Instead of hot gas composed of electrically neutral atoms, we then have a mixed population of charged and neutral particles. With increasing temperature the number of ionized particles increases and the ionized gas starts behaving differently. After the fraction of ionized particles is sufficiently high the ionized gas starts exhibiting the collective behavior and the state of matter is plasma(Bittencourt, 2013).

1.2 History of plasma physics

Historically ,plasma research was initiated by studies of gas discharges. In 1929 , Tonks and Langmuir observed an electric oscillation in a rarefied gas dis- charge]. They referred to this oscillation as" plasma oscillation ."Since then the word" plasma " has been used to represent a conducting gas. Because it has properties which are quite different from those of ordinary neutral gas, the plasma state is often called the fourth state of matter, distinct from the previously known three states of matter, solid, liquid, and gas(Sturrock, 1994).

The word plasma comes from the Greek and means something molded.It was applied for the first time by Tonks and Langmuir, in 1929, todescribe the inner region, remote from the boundaries, of a glowing ionized gas produced by electric discharge in a tube, the ionized gas asa whole remaining electrically neutral(Bellan, 2007).

1.3 Plasma as the Fourth State of Matter

By heating a solid or liquid substance, the atoms or molecules acquire more thermal kinetic energy until they are able to overcome the binding potential energy. This leads to *phase transitions*, which occur at a constant temperature for a given pressure. The amount of energy required for the phase transition is called the *latent heat*.

If sufficient energy is provided, a molecular gas will gradually dissociate into an atomic gas as a result of collisions between those particles whose thermal kinetic energy exceeds the molecular binding energy.

At sufficiently elevated temperatures an increasing fraction of the atoms will possess enough kinetic energy to overcome, by collisions , the binding energy of the outermost orbital electrons, and an *ionized gas* or *plasma* results. However, this transition from a gas to a plasma is not a phase transition in the thermodynamic sense, since it occurs gradually with increasing temperature(Sturrock, 1994).

1.4 Type of plasma:

1. Cold plasma:

In low pressure gas discharge, the collision rate between electrons and gas molecules is not frequent enough for non-thermal equilibrium to exist between the energy of the electrons and the gas molecules. So the high-energy particles are mostly composed of electrons while the energy of the gas molecules is around room temperature. This type of plasma is called a "cold plasma"(Pankaj and Keener, 2017).

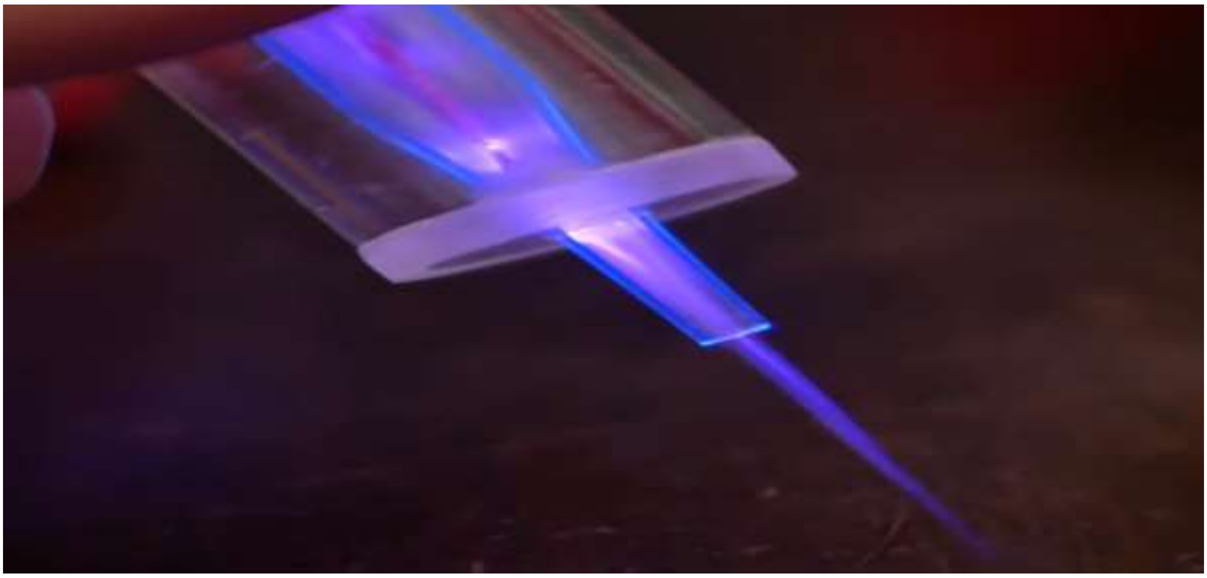


Figure (1-2): cold plasma

2. Hot plasma:

In a high pressure gas discharge the collision between electrons and gas molecules occurs frequently. This causes thermal equilibrium between the electrons and gas molecules. We call this type of plasma a "hot plasma"(Bauche et al., 2015).

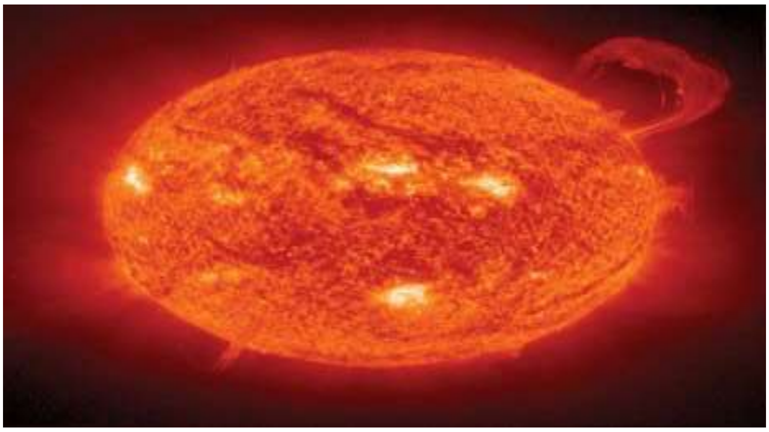


Figure (1-3): hot plasma

CHAPTER TWO

THEORY

2.1.Boltzmann equation.

In order to calculate the average values of the particle physical properties the macroscopic variables of interest), it is necessary to know the distribution function for the system under consideration. The dependence of the distribution function on the independent variables r, v, and is governed by an equation known as the Boltzmann equation. We present in this section a derivation of the collision less Boltzmann equation and the general form it takes when the effects of the particle interactions are taken into account, without explicitly deriving any particular expression for the collision term . The transport Boltzmann equation governing the electron distribution function and inspecting its time derivative." From this equation meres important swarm parameters could be determined that it is as yet

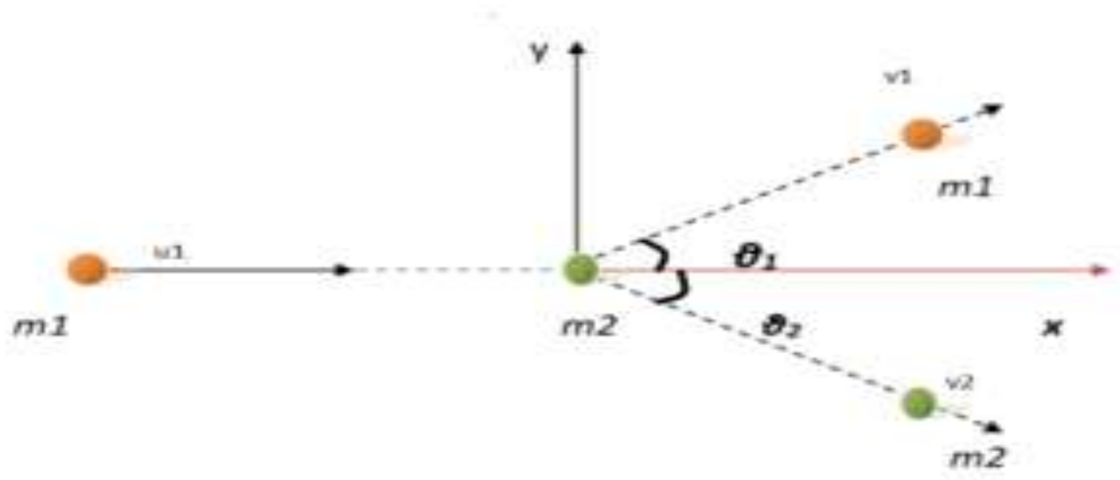
being utilized as a part of numerous contemporary research projects to model transport phenomena. The Boltzmann equation for electron in an ionized gas The transport Boltzmann equation governing the electron distribution fundamental function; this equation can be driven simply by defining a distribution function and in spacing its time derivative . From this equation numerous important swarm parameters could be determined that it is as yet being utilized as a part of numerous contemporary research projects to model transport phenomena. The Boltzmann equation for electrons in an ionized gas is (Jawad, 2017).

$$\left(\left(\frac{\partial}{\partial t}\right) + \mathrm{v}.\nabla \mathrm{r} + \left(\frac{eE}{m}\right).\nabla v\right)\mathrm{f(r,v,t)} = \left(\frac{\partial f}{\partial t}\right)_{collisions} \qquad \ldots.1$$

Or The fundamental equation governing the electron distribution function is the Boltzmann equation. For spatially uniform gas in the presence of the steady electric field (E), the spatially homogeneous Boltzmann equation for electrons is given by electron energy distribution function is important physical parameters used to calculate electron swarm consider an electron gas drifting in uniform dc applied electric field E, in V/cm with a velocity distribution f(v), the general form of the Boltzmann equation describes the evolution of the distribution function in six-dimensional space(Jawad, 2017).

2.2.Collisions

Collisions between charged particles in a plasma differ fundamentally from those between molecules in a neutral gas because of the long range of the Coulomb force . Let us consider now the form of the collision term for some mica names of production and loss of particles in plasmas. The processes leading to production and loss of particles are usually related to inelastic collisions, such as those involving ionization, recombination, or electron attachment . In order to distinguish between the different phases of matter it is useful to understand the concept of 'mean free path". This is defined as the average distance travelled by a given particle (that is, a typical particle whose motion we follow) between collisions with the medium in which it moves. The mean free path is inversely proportional to the density of the medium, that is, for higher density the mean free path becomes smaller. From this we learn that since the density of the solid phase is usually larger than that of the liquid and the liquid density is larger than that of the gas, the mean free path of a particle varies in each phase. In a solid the mean free path is usually smaller than in a liquid and in a liquid it is much smaller than in a gas. In the plasma state of matter, one can find densities similar to those in all the different phases. How can the properties of the plasma and the other phases be distinguished when comparing their mean free paths? This can be done by noting that the mean free path is inversely proportional not only to the density of the medium, but also to the probability that the given particle will collide with other particles in the medium. This probability of collision is described by the term known as cross section (measured as an effective area)(Singh et al., 2021)



Figure(2-1): collisions

2.3.Type of collision

An interaction between free particles (including photons, atoms and nuclei), aggregate of particles or rigid bodies, in which they come near enough to exert a mutual influence, with change of energy, momentum or charge. Actual contact is not necessarily implied.

1. Elastic collision: One in which the total kinetic energy of the system is the same before and after the collision(Smirnov, 2008).

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ …… 2

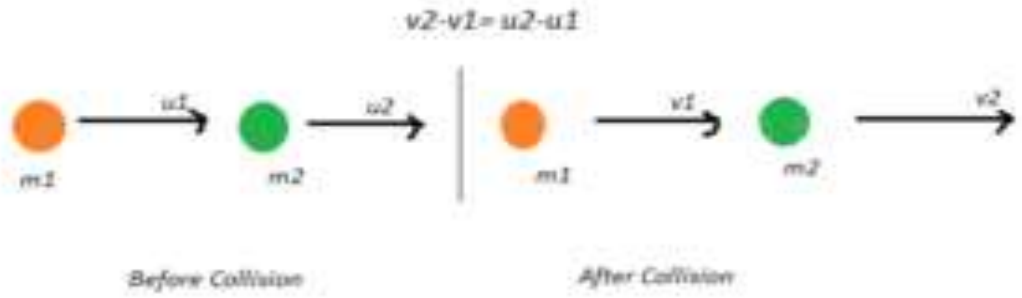
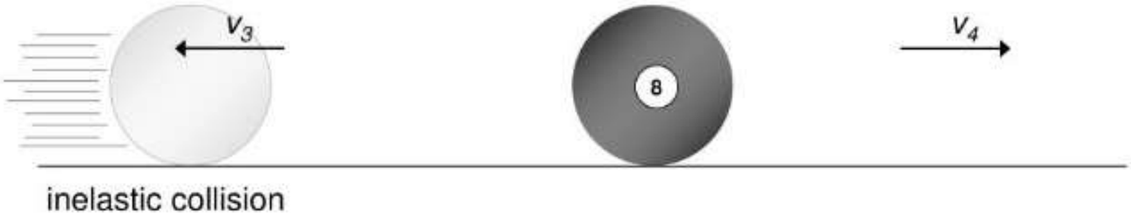


Figure (2-2): Elastic collision

2. Inelastic collision: One in which total kinetic energy after the collision is less. In an inelastic collision the target (atom or molecule) gains internal energy at the expense of the kinetic energy of the impinging electron. The impact results in excitation or ionization of the target, and the amount of energy lost by the electron is determined by the quantum states of the target. If in an inelastic collision the whole or part of the energy lost by the electron is emitted as electromagnetic radiation, the collision is called radiative. Such collisions, involving emission of radiation generally have small cross sections, but they may play an important role in certain phenomena such as radiative electron attachment(von Angel, 1965).



Figure(2-3): inelastic collision

3. Super elastic collision: One in which total kinetic energy after the collision. collisions of this type are important at low electron energies (close to thermal) and in collisions of electrons with meta-stable atoms and molecules. They requires the target atom or molecule to possess energy in excess of that of its lowest energy configuration(von Angel, 1965).

2.4.Electron energy distribution function

Because of its importance for computing reaction rates, the EEDF has a fundamental role in plasma modeling . The EEDF assumes that elastic collisions are dominating; therefore the effect of inelastic collisions (ionization or excitation) on the distribution function is insignificant (Behlman, 2009). To describe the EEDF several functions are mentioned such as Maxwellian, Druyvesteyn, generalized Maxwellian – Druyvesteyn, and solution of Boltzmann equation. There are many computational resources and numerical techniques used to find the transport properties . The latter can be derived from EEDF, thus the choice of EEDF would affect the results of plasma modeling. The (EEDF) software package gives results of the kinetic and transport coefficients of plasma in the mixture of gases by numerically solving the Boltzmann equation of

EEDF in plasma under an electric field with the two-term approximation(Faraj, 2017).

2.5.Distribution function:

The distribution function is f (r,v.t). in general, a function of the position vector r. When this is the case the corresponding plasma is said to be inhomogeneous. In the absence of external forces, however, a plasma initially inhomogeneous reaches, in the course of time, an equilibrium state as a result of the mutual particle interaction. In this homogeneous state the distribution function does not depend on(Faraj, 2017).

2.6. Electron mobility:

the mobility is defined as the proportionally coefficient between the

drift charged particle and electric field . the mobility of electrons is (Othman et al.)

$$.\mu_e = \frac{e}{m\,v_m} = \frac{vd}{E} \qquad \text{....3}$$

2.7. Ionization coefficient:

The primary ionization coefficient (α) and attachment coefficient (η) these coefficients are used in describing the behavior of a swarm of electrons traveling through a gas, the ionization coefficient is (Othman et al.) .

$$\frac{\alpha}{N} = \frac{1}{V_d}\left(\frac{2e)}{m}\right)^{1/2} \sum_K \int_i^{\infty} \frac{N_k}{N} \; Q_i \text{ (u) f (u)u du} \qquad \text{…..4}$$

CHAPTER THREE

Result and discussion

3.1 . Xenon gas

is a chemical element with the symbol Xe and atomic number 54. It is colorless, dense, odorless noble gas found in Earth's atmosphers in the amounts. Although generally unreactive, xenon can undergo a few decal actions such as the formation of xenon hexafluomo platinale, the noble compound to be synthesized. It is well known that the swarm parameters of electrons and the collision cross sections with molecules are related to each other through the medium of the velocity distribution function of the swarm. In particular, the electron transport data are very important for deriving the elastic scattering cross-section for a Ramsauer-Townsends gas, in which this cross-section changes very rapidly with energy when this is low and in the vicinity of the minimum(Fitzpatrick, 2014). Xenon is taken as a simple problem in order to calculate the electron distribution function and transport parameters.

The quantitative behavior of electrons in Xenon is analyzed in the terms of the swarm parameters. In this section we have analyzed the swarm parameters of electrons in Xenon in the region over a range E/N from ($1x10^{-19}$ to $2x10^{-15}$)V.cm^2 at gas temperature of 300K.

The choice of Xenon gas a host medium for electron interactions with the atoms and/or molecules of these gases depends on the availability of their energy dependent cross sections for elastic and inelastic types of such interactions.

For a range of **E**/N values, the steady-state Boltzmann equation is solved to evaluate the corresponding EEDF as shown in figure(3-1). The energy variation of cross-sections has a very significant influence of the electron energy distribution function for typical conditions of electric discharges. At low energies(**E**/N = $1*10^{-19}$ V.cm^2), the normalized distribution appears to be quite close to a straight line with a slop of (-1/KT) and hence quite close to Maxwellion distribution. However, for higher **E**/N value ($1*10^{-15}$) V.cm^2, the distribution which is being non-Maxwellian, having energy variations reflected the dominant electron-molecule energy exchange processes.

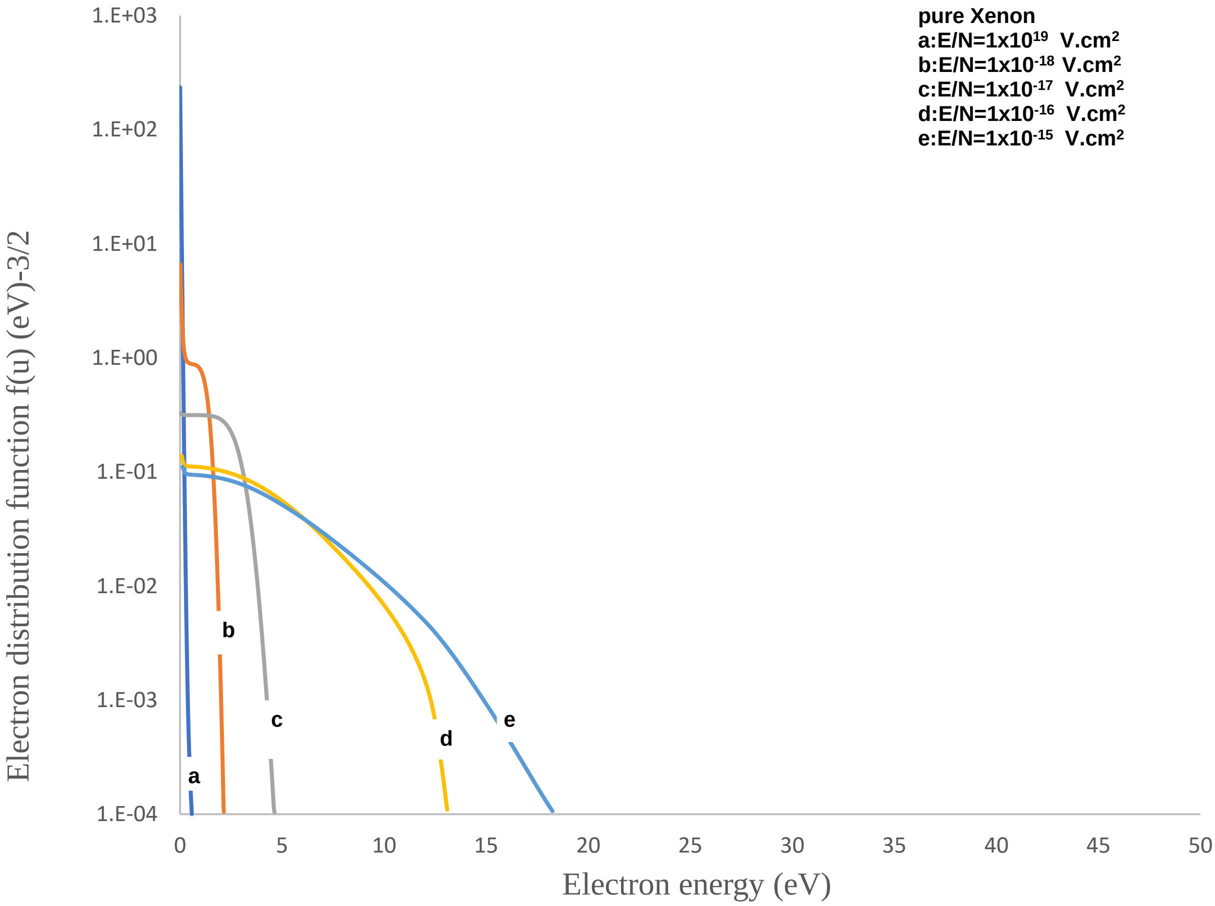
In general case, the electron mobility μ is increase as **E**/N is increase, they will be reach maximum value at **E**/N =$6x10^{-19}$ V.cm^2 for mobility these high μ values at low mean energies results from an overtime at the electron density at low energies (ε<1eV) (as evident in figure (3-2)corresponding to the Ramsaur minimum in Xenon at ε~0.6eV, while figures shows the reverse of that, where the electron mobility decrease as **E**/N increase and this is because of the inelastic collision process which occurs at **E**/N $\geq 6x10^{-17}$ V.cm^2.

The Townsend ionization coefficients α /N has been calculated at the range ($4x10^{-17} \leq$**E**/N$\leq 2x10^{-15}$) V.cm^2 and the results are shown in figure(3-3). The behavior of ionization coefficient being increased with increased of **E**/N. The results at high **E**/N are sensitive to the inelastic collision. This means that the electrons acquire enough energy from the applied electric field to reach the ionization level of Xenon. In this case the number of energetic electrons, which cause the ionization, increase with increase **E**/N according to the ionization cross-sections.

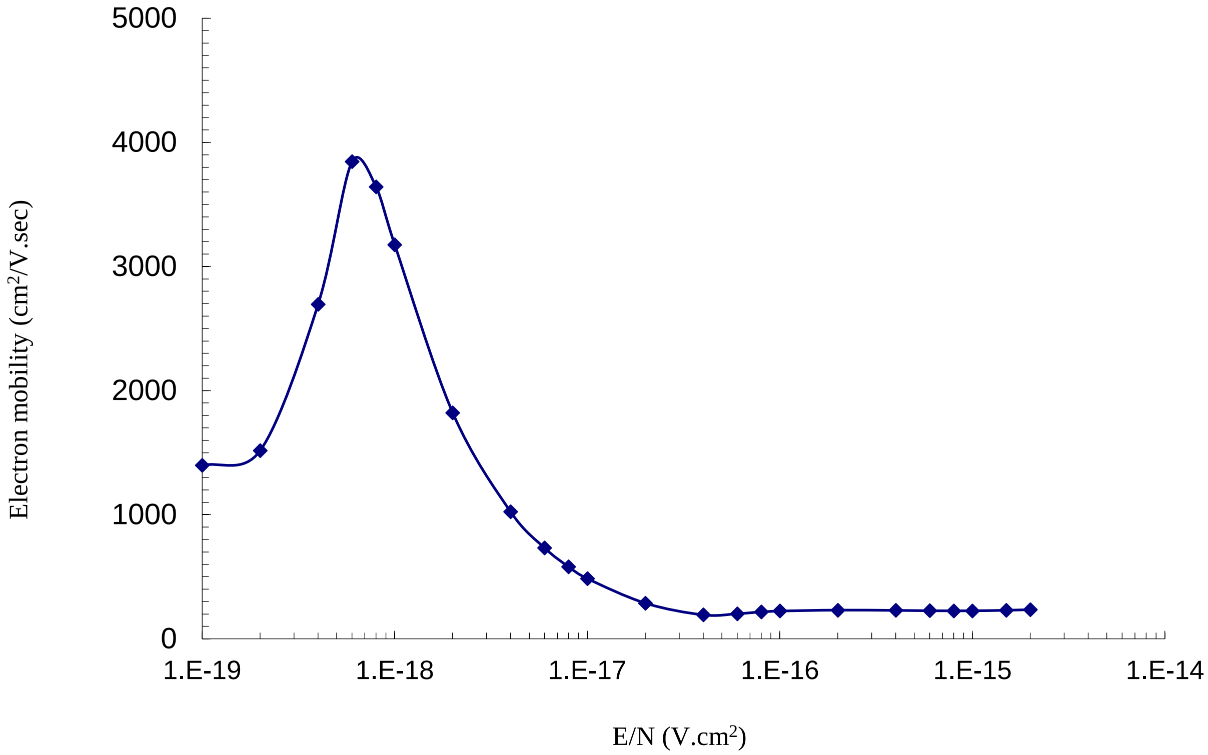
Table(3-1):The calculated transport parameters for pure Xenon at

N=26.8810205x10^{19} molecules / cm^3

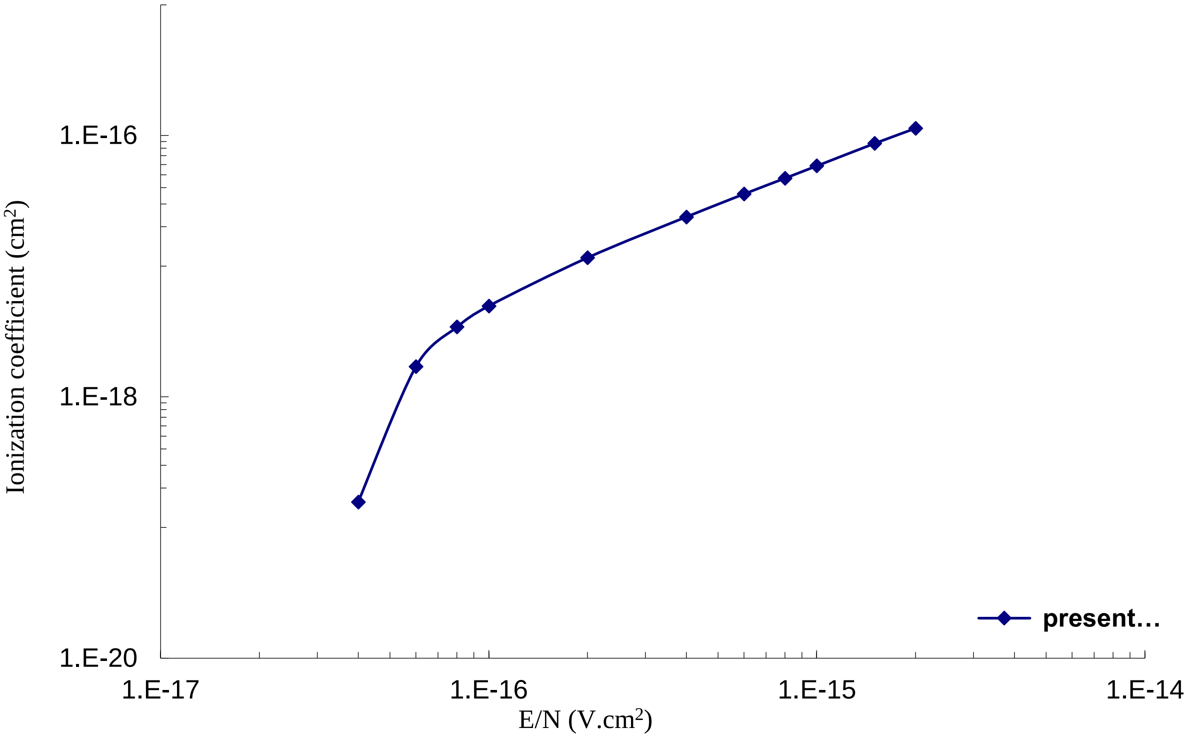
E/N (V.cm^2) x10^{-17}	μ (cm^2/V.sec) x10^2	α/N cm^2 x10^{-17}
0.01	14.647	
0.02	15.728	
0.04	26.860	
0.06	37.572	
0.08	35.644	
0.10	31.312	
0.20	18.107	
0.40	10.215	
0.60	7.323	
0.80	5.800	
1.00	4.858	
2.00	2.859	
4.00	1.791	
6.00	1.512	0.048
8.00	1.548	0.208
10.00	1.617	0.377
20.00	1.731	1.080
40.00	1.345	2.210
60.00	1.031	3.250
80.00	0.781	4.260
100.00	0.599	5.250
150.00	0.341	8.470
200.00	0.206	10.200



Figure(3-1): The electron energy distribution function in pure Xenon gas for several value of E/N.



Figure(3-2): The mobility of electrons as a function of E/N in pure Xenon gas .



Figure(3-3): The ionization coefficient of electrons as a function of E/N in Xenon gas .

CHAPTER FOURE

CONCLUSION

The electron swarm parameters, namely), Electron mobility and ionization coefficient α/N in pure Xenon have been calculated using two term spherical harmonic approximation of the Boltzmann equation analysis at temperature 300 K and pressure 1 atm. The overall E/N is from 0.01 to 200 Td,

The present calculation deal with evaluation of the transport parameters of pure gas. These calculations are based on the practical use and their importance from industrial point of view such as of incandescent lamps, halogen – filled incandescent lamps, discharge phenomena in gases, glass industry plasma displays, gas lasers and so on.

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