

OBTAINING GLOW DISCHARGE PLASMA ELECTRON DENSITY FROM SIMPLE I-V CHARACTERISTICS

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(Accepted for publication: June 9, 2013)

Abstract

In this work all necessary mathematical formulation needed to calculate the approximate value of the glow discharge plasma electron density is carried out. The formulation is converted to a matlab computer code that can directly give the density. The inputs to the program are the gas pressure, breakdown potential, discharge voltage and current values, and the anode cross section area.

Introduction

Plasma electron density is considered as one of the most important parameters in glow discharge physics research. Its importance is related to the fact that plasma electron density represents a direct measure of the degree of the gas ionization. The latter has a direct effect in controlling the rates of surface treatments effects used in a wide range of plasma applications such as plasma etching, cleaning, and deposition. [Raizer P. Y. 1991, Lieberman M. A. & Lichtenberg A. J. 1994, Marcus R. K. & Broekaert J. A. C. 2003, Boyd T. J. M. & Sanderson J. J. 2003, Pelletier J. & Anders A. 2005, Belkind A. & Gershman S. 2008.]

The standard methods customary used in plasma physics to measure plasma electron density involve the use of Langmuir single and double probes, microwave plasma diagnostic techniques, and optical spectroscopic techniques. Although these methods have been extensively developed over a years to give results to a high degree of accuracy, their use in many situations may become difficult due to geometrical or financial considerations. In such cases, it would be useful to have a more simple method of electron density measurements.

In this work, we suggest a method that uses information generally available in any glow discharge experiment to estimate the electron density. These information's are limited to the operating plasma voltage V , the discharge current I at the specified voltage V , the anode cross section area A and the type of gas. The ultimate purpose is to convert the calculations to a matlab computer code that calculates the approximate value of the plasma electron density once the above information's are provided.

Theoretical Considerations

The starting point of the calculation is based on the fact that the plasma electron density n_e is related to the plasma conductivity σ , and the electron-neutrals collision rate ν_m , the electronic charge e and mass m through the relation [Lisovskiy A. & Yakovin S. D. 2000]

$$\sigma = \frac{e^2 n_e}{\nu_m m} \quad (1)$$

or

$$n_e = \frac{\sigma m \nu_m}{e^2} \quad (2)$$

The collision rate in units of collisions per second per unit volume is simply the product of electron collision cross section with neutral atoms δ , the average electron velocity $\langle v \rangle$, and the number of neutrals per unit volume of the gas N .

$$\nu_m = \delta N \langle v \rangle \quad (3)$$

The mean free path for electrons λ can be written in terms of pressure P , temperature T , collision cross section δ and Boltzman's constant k_B as

$$\lambda = \frac{k_B T}{\sqrt{2} \delta P} \quad (4)$$

The number of neutral gas molecules per unit volume N is given by

$$N = \frac{P}{k_B T} \quad (5)$$

To a first approximation, the mean velocity of electrons $\langle v \rangle$ can be calculated if we assume that the electrons are accelerated each time over one mean free path. If we assume that

the applied voltage between the electrodes separated by a distance L is V , then

$$\frac{1}{2}mv^2 = eV \frac{\lambda}{L} \quad (6)$$

Or

$$\langle v \rangle = \frac{1}{\sqrt{2}} \left(\frac{eV\lambda}{mL} \right)^{\frac{1}{2}} \quad (7)$$

Substituting for N and $\langle v \rangle$ and λ into equation (2) and substituting for the conductivity σ in terms of the measured current I , voltage V and the discharge tube dimensions as

$$\sigma = \frac{LI}{AV} \quad (8)$$

We get

$$n_e = \frac{I}{Ae^{3/2}} \left[\frac{mL\delta}{2\sqrt{2}k_B TV} \right]^{1/2} \quad (9)$$

The Software

The above calculations are converted to a MATLAB computer code called *plasma_density*. The input arguments to the program are the gas pressure P in Pascal, the discharge voltage V in volts, the discharge current I in amperes, the gas temperature T in Kelvin, the discharge tube length L in meters, the electrode cross section area in meters square, and the gas type 'gas'. The software can be freely obtained from the author. Thus and in order to obtain the plasma density of a particular discharge under the following conditions for example,

Discharge gas is Argon = 'Ar'

Pressure = 2 Pascal

Discharge voltage = 500 Volt

Discharge Current = 1 mille ampères = 0.001 amperes

Temperature = 27 °C = 300 °K

Tube length = 10 cm = 0.1 m

Electrode Area = 0.0001 m²,

The following command is to be entered on the matlab work space

$n=plasma_density(2,500,0.001,300,0.1,0.0001,'Ar')$

The program will directly output the plasma density under those conditions. The software can handle ten different gas discharge types commonly used in plasma physics works. The gases are hydrogen, helium, argon, neon, nitrogen, oxygen, carbon dioxide, sulfur hexafluoride, mercury and air. These gases should be entered as string variables with the following input arguments respectively:

'H2', 'He', 'Ar', 'Ne', 'N2', 'O2', 'CO2', 'SF6', 'Hg', and 'Air'

Although most of the calculations performed by the software are direct implementations of equations (2 to 9), the calculations cannot be performed without the direct knowledge of the electron energy dependence of the ionization cross section for each of these gases. In order to obtain such essential data, a compilation of published results from references [Pelletier J.& Anders A., Tawara H.& et al.1990, Itilkawa Y.& et al. 1999, Christophorou L. G.& Olthoff J. K. J . 2000, Itilkawa Y. J. 2002, Itilkawa Y. J. 2006] related to these cross sections is carried out. Due to the fact that most of these published results are in graphical form, special matlab software capable of extracting numerical data from graphical presentations have been written for this purpose. The software operation is based on image processing technique and calibrating pixel numbers to real variables x-y coordinates. For each of the above mentioned gases, twenty cross section data points for electron energies below 100 eV are extracted. These data points are re-plotted as black circles in figures (1 to 10). In order to obtain the continues cross sections energy dependence in each case, the data are fitted to the empirical equation of the form

$$\delta(E) = a_1 \left[1 - e^{(E-a_2)/a_3} \right] \quad (10)$$

Where a_1 , a_2 , and a_3 are free fitting parameters depending on the gas type.

The results of all fits are shown as solid lines in figures (1 to 10).

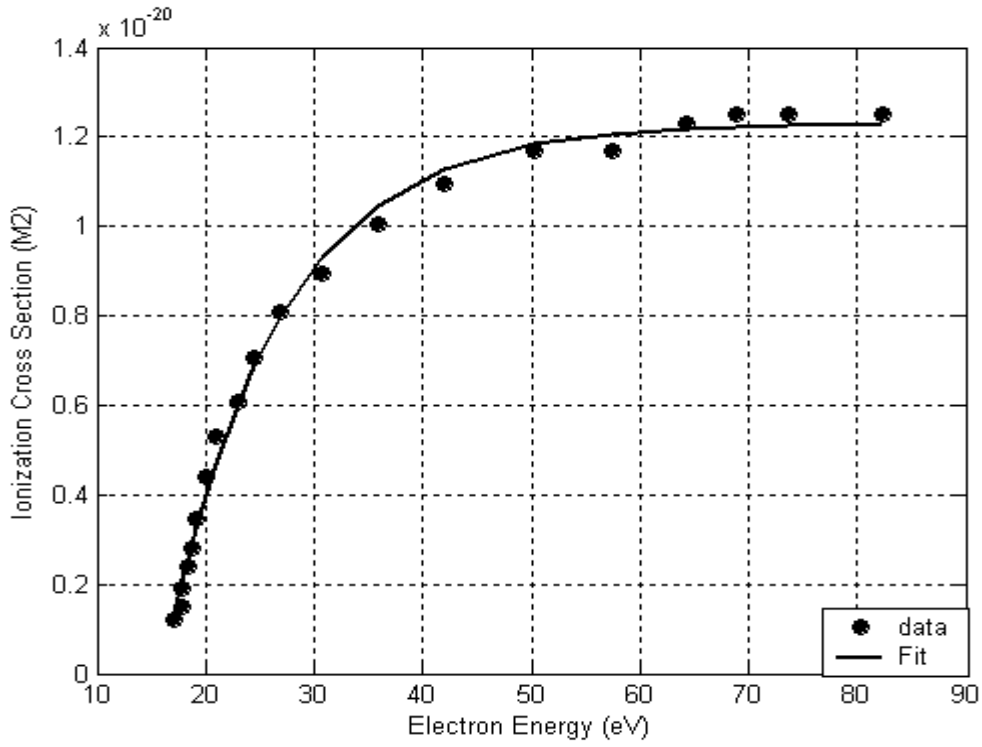


Figure (1) Electron ionization cross section for Hydrogen Data from ref. [Tawara H. & et al.1990, Franz G.2009]

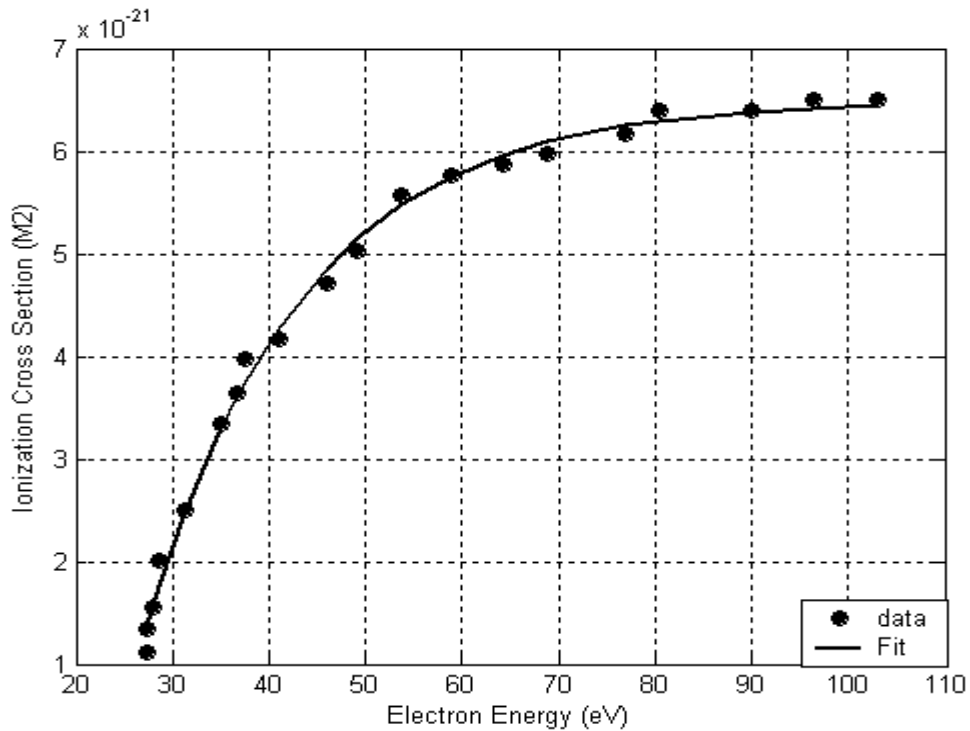


Figure (2) Electron ionization cross section for Helium Data from ref. [Tawara H.& et al 1990]

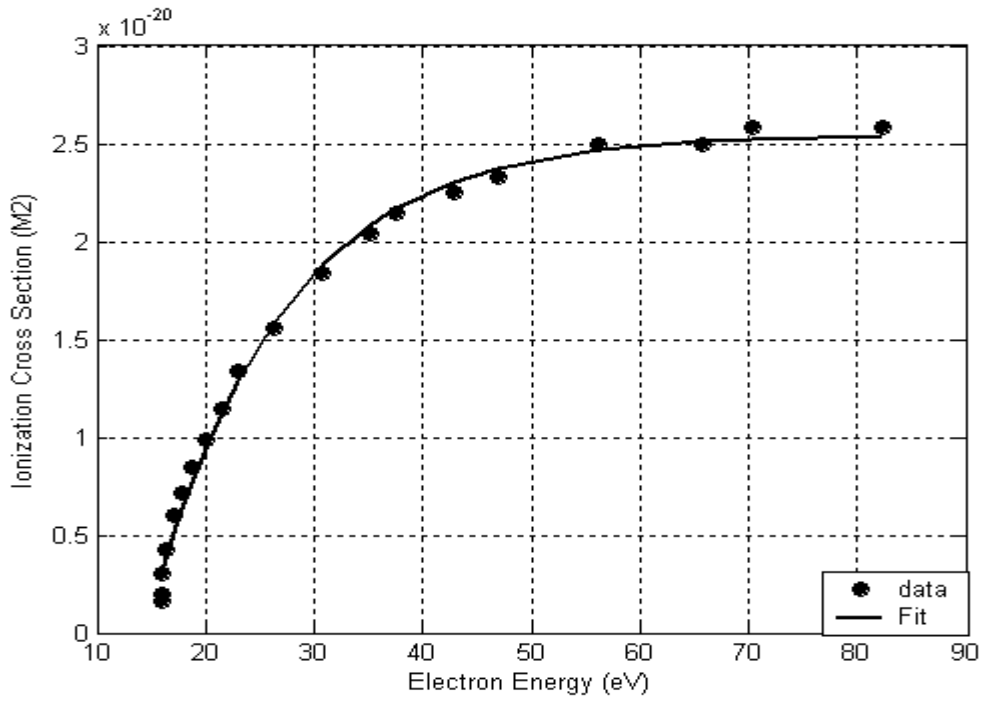


Figure (3) Electron ionization cross section for Argon Data from ref. [Tawara H. & et al 1990]

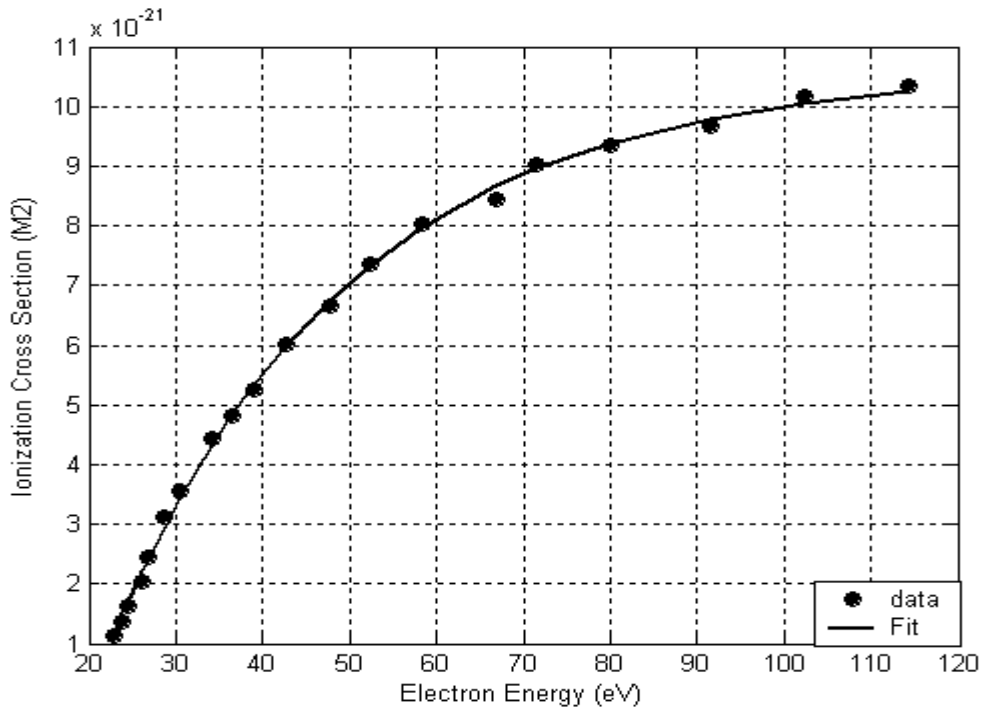


Figure (4) Electron ionization cross section for Neon Data from ref. [Tawara H. & et al 1990]

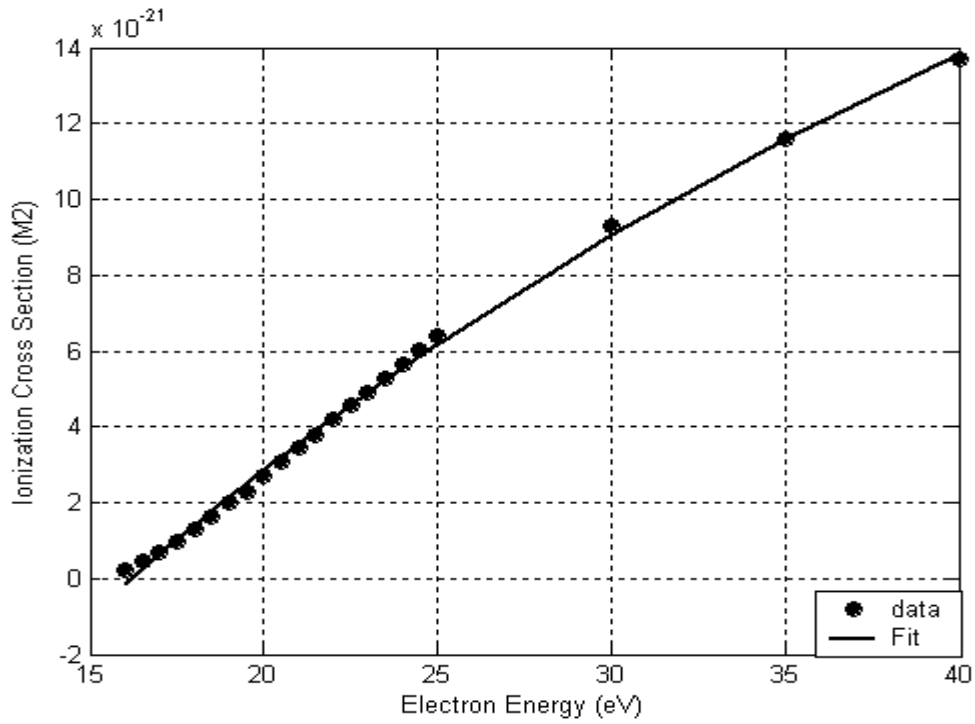


Figure (5) Electron ionization cross section for Nitrogen Data from ref. [Itilkawa Y. J.2006]

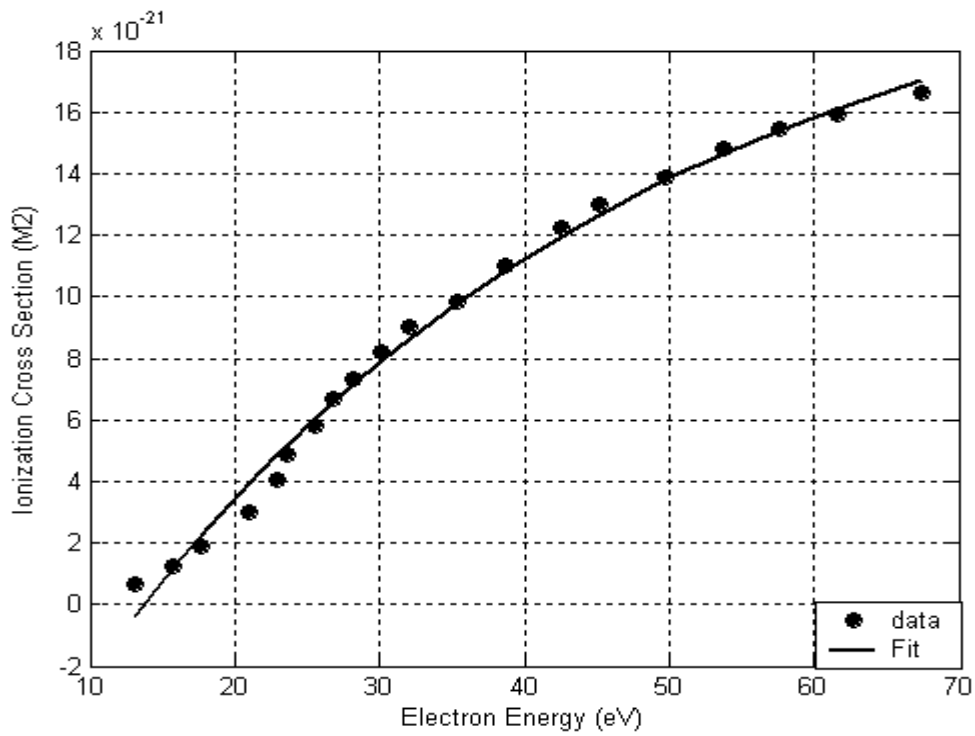


Figure (6) Electron ionization cross section for Oxygen. Data from ref. [Tawara H.1990]

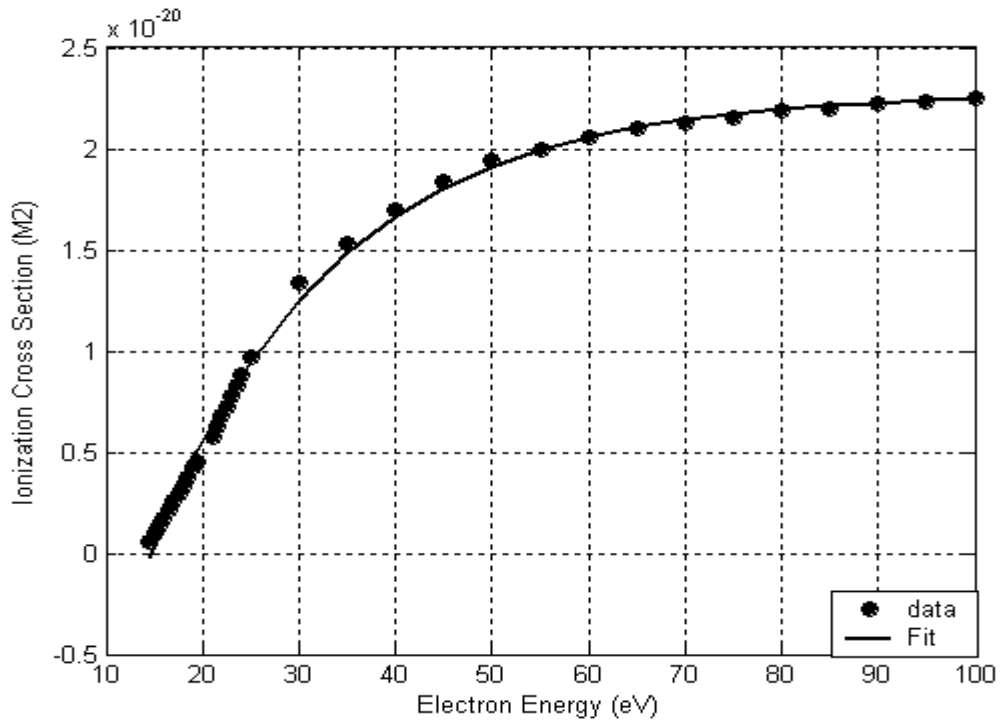


Figure (7) Electron ionization cross section for CO₂. Data from ref. [Christiphorou L. G.& Olthoff J. K.2000]

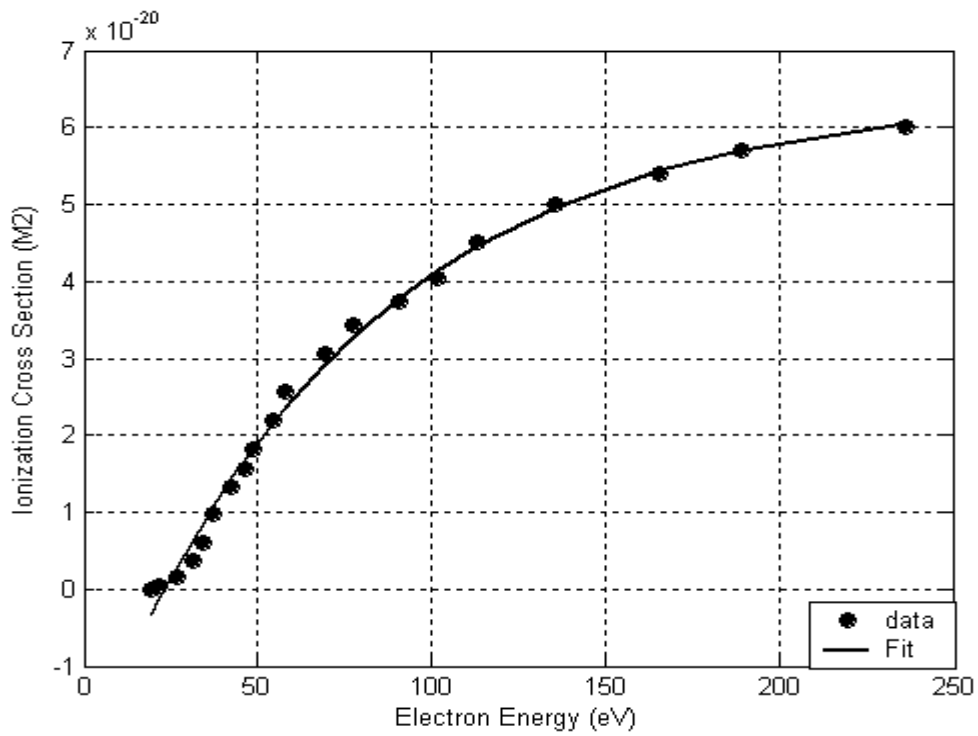


Figure (8) Electron ionization cross section for SF₆ Data from ref. [Christiphorou L. G.& Olthoff J. K. 2000]

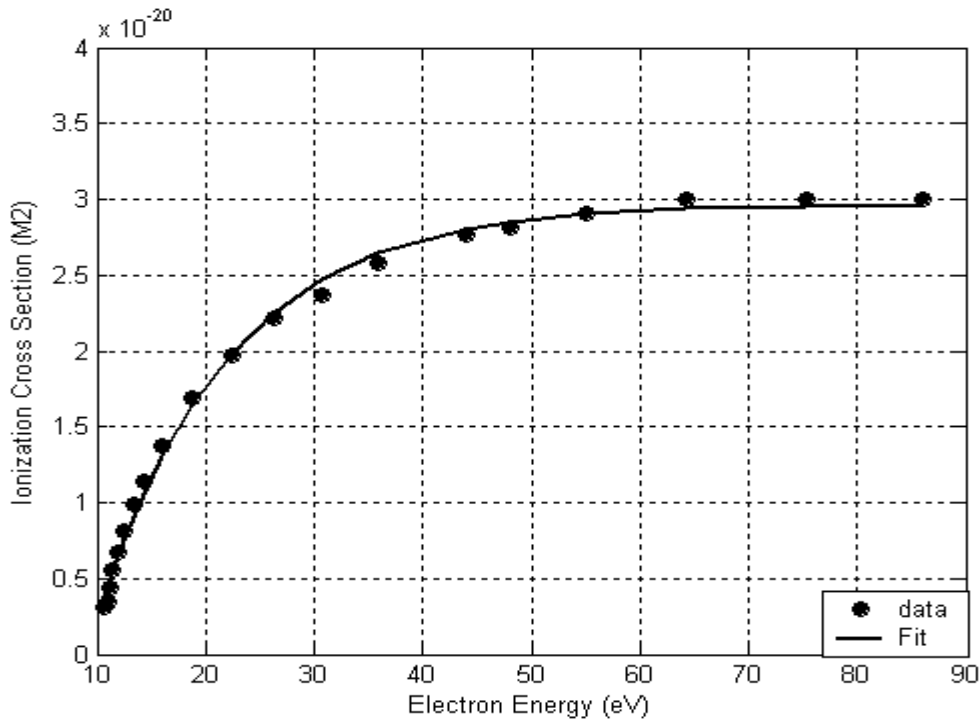


Figure (9) Electron ionization cross section for Hg Data from ref. [Tawara H.& et al 1990]

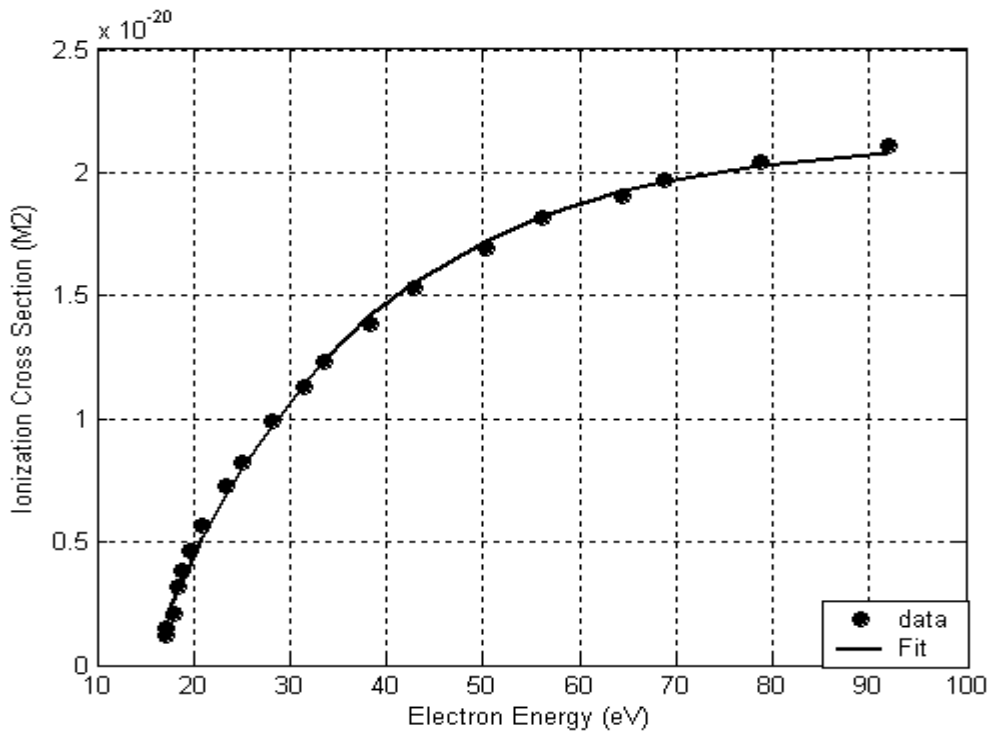


Figure (10) Electron ionization cross section for Air Data from ref. [Franz G.2009]

The set of three parameters for each type of gas is obtained and stored in the software data base. The program substitutes the electron energy into equation (10) using the appropriate parameters for the particular gas under consideration to calculate the cross section at the

electron energy acquired at the end of one mean free path. The software uses calculated ionization cross section to calculate the plasma electron number density, mean free path, and collision frequency. The software also uses the ionization potentials of the gases under

consideration to set the threshold limit for the energy an electron must acquire before being able to cause any ionization. It is worth mentioning that in cases when the electron energy is less than the ionization threshold, the program output a message "NO PLASMA" If the ionization conditions are satisfied, the program will output the estimated plasma electron density in units of /m³ under the specified conditions entered to the input.

Results and Discussion

In order to check for the above formulation self consistency, the software is run for all the gases that can be handled by the program. The plasma electron densities as calculated by the software assuming a fixed applied voltage of 500 volts across 1 -10 cm length, 1 cm² cross section area, which is assumed to produce a discharge current of 0.1 A at variable pressure values ranging between 0-600 Pa. This correspond to $pd = (\text{pressure}) \times (\text{tube length})$ values of 0 – 4.5 Torr.cm. The plasma electron density for each gas is plotted against pd in figure (11). The units of Torr.cm are used instead of Pascal for the purpose of making further comparisons easier.

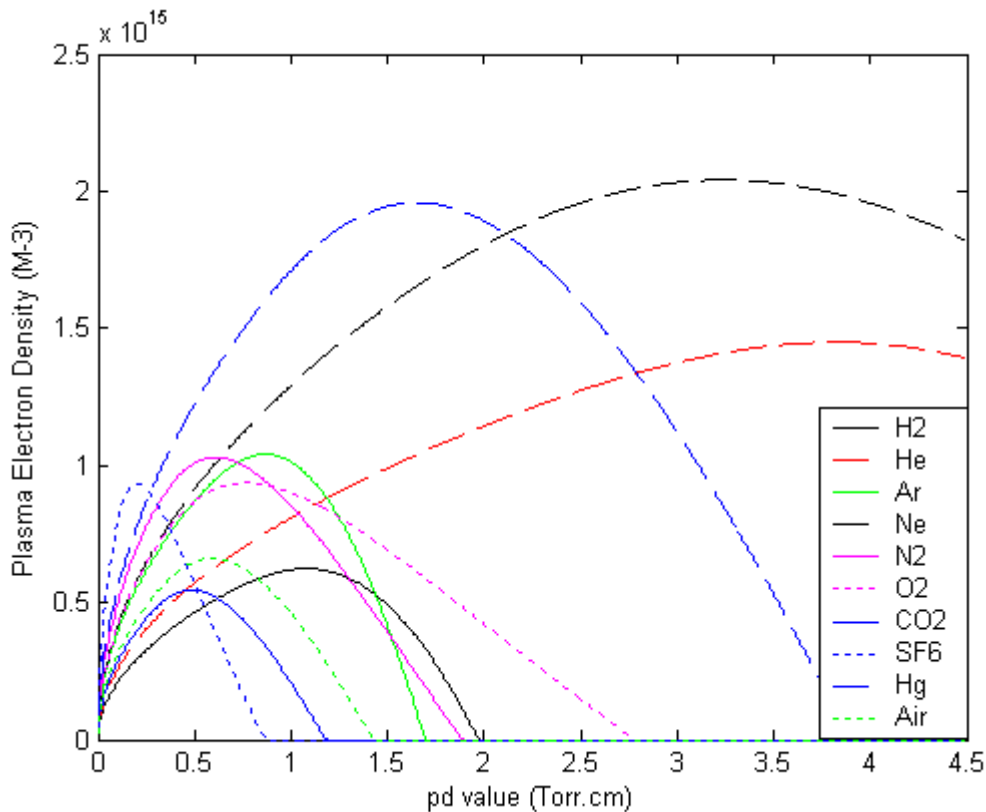


Figure (11) Simulate Plasma electron densities for different gases as a function of pd .

One interesting feature related to the results in figure (11) is that the plasma density tends to start increasing with increasing (pd) values reaching a certain maximum value after which it begins to fall. The (pd) value associated with maximum density is related to the gas type. This behavior can be understood in terms of being a reflection of the Paschen curve effect. The maximum point corresponds to the minimum Paschen point. At this point, a minimum voltage is required to create the discharge. The rest of the applied voltage (500 V) in this case will act

to create more electrons through collision resulting in higher density. To demonstrate this effect further, the values of the maximum density point for each gas in figure (11) are compared with published data on Paschen minimum voltage point for the same gas [<http://home.earthlink.net/~jimlux/hv/paschen.htm>, <http://www.newagepublishers.com/samplechapter/000357.pdf>].

The two sets of data are presented in table(1).

Table (1) Comparisons between published and calculated minimum Paschen voltage V_s for different gases

Gas	Published V_s min (V)	Reference	Calculated V_s min (V)
H ₂	1.15	http://home.earthlink.net/~jimlux/hv/paschen.htm	1.08
	1.05	http://www.newagepublishers.com/samplechapter/000357.pdf	
He	4.0	http://home.earthlink.net/~jimlux/hv/paschen.htm	3.82
	4.0	http://www.newagepublishers.com/samplechapter/000357.pdf	
Ar	0.9	http://home.earthlink.net/~jimlux/hv/paschen.htm	0.87
Ne	4.0	http://www.newagepublishers.com/samplechapter/000357.pdf	3.23
N ₂	0.67	http://home.earthlink.net/~jimlux/hv/paschen.htm	0.61
	0.65	http://www.newagepublishers.com/samplechapter/000357.pdf	
O ₂	0.7	http://home.earthlink.net/~jimlux/hv/paschen.htm	0.76
	0.7	http://www.newagepublishers.com/samplechapter/000357.pdf	
CO ₂	0.51	http://home.earthlink.net/~jimlux/hv/paschen.htm	0.49
	0.57	http://www.newagepublishers.com/samplechapter/000357.pdf	
SF ₆	0.26	http://www.newagepublishers.com/samplechapter/000357.pdf	0.20
Hg	----		1.65
Air	0.567	http://home.earthlink.net/~jimlux/hv/paschen.htm	0.59
	0.55	http://www.newagepublishers.com/samplechapter/000357.pdf	

Conclusion

It is clear from table (1) that the results for minimum Paschen breakdown voltage for different gases V_s obtained from the above modeling compare reasonably well with published data. The relatively small differences between published and calculated results are to be considered acceptable if one considers the fact that only first ionizations of gases are considered.

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<http://www.newagepublishers.com/samplechapter/000357.pdf>
- <http://home.earthlink.net/~jimlux/hv/paschen.htm>

حساب الكثافة الالكترونية لبلازما التفريغ التوهجي من الخصائص البسيطة للتيار والفولتية

الملخص

تم في هذا البحث حساب جميع الصيغ الرياضية اللازمة لحساب القيمة التقريبية للكثافة الالكترونية لبلازما التفريغ التوهجي وتم ادخال جميع هذه الصيغ في برنامج حاسوبي بلغة (MATLAB) كتب خصيصا لحساب قيمة الكثافة الالكترونية مباشرة . مدخلات البرنامج هي ضغط الغاز, جهد الانهيار, قيم تيار وفولتية التفريغ و مساحة مقطع القطب الموجب .

ب دهست فه ئينان خالى كرنا گردارا پلازمايى يا چريا نهلكترونا ژ ساخله تين I-V يين ساده

كورتى

دقى فه كولينيى دا ههمى هاو كيشين ماتماتيكي نهويت بيدقى بو هژمارتنا نهجاميت نيزيك ييت چريا نهلكترونى د پلازما فالاكرا گردار هاتنه ب كارئينان .
نهؤ هاو كيشه هاتنه گهورين بو زمانى ماتلابى يى كومپوتهرى, كوئيكسه نهجاميت چريا نهلكترونى هاتنه هژمارتن .
فاكتهرى پهستانا گازى, كهفتنا جياوازيه پهستانا كارهبى, قولتيا فاله كهر, تهزوو و رووبهرى نهودى هاتنه دان بو پروگرامى بو هژمارتنا نهجاما .