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Studying the Effect of Air Pressure on Plasma Parameters in a Capillary Tube Using a Floating Twin probe

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Abstract

The DC glow discharge in the capillary tubes acquired considerable attention in many applications due to its important electrical characteristics. In the present study, an electrical discharge system was designed consisting of a capillary tube and two electrodes. The cathode was made with a hollow shape from nickel material to obtain a high density. The anode electrode was tungsten material. The distance between the electrodes was chosen as 13 cm. The Langmuir double probe was used as a diagnostic technique to measure the plasma parameters at different ranges of gas pressure. The I-V characteristics of the double probe were measured at pressures 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7 tor. All measurements were conducted at a constant power of 0.6 watt. Electron temperature and ion saturation current were extracted from the I-V characteristics curves. The electron density, debye length, and plasma frequency were calculated. It was observed that the electron temperature decreases with increasing working gas pressure. The effects of pressure on electron density and ion saturation gave a clear similarity to the change in them with pressure. The results were in reasonable agreement with previous research.

دراسة تأثير ضغط الهواء على معلمات البلازما في أنبوب شعري باستخدام مجس مزدوج عائم

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ملخص البحث:

اكتسب التفريغ التوهجي المستمر في الأنابيب الشعرية اهتمامًا كبيرًا في العديد من التطبيقات نظرًا لخصائصه الكهربائية المهمة. في العمل الحالي ، تم تصميم نظام تفريغ كهربائي يتكون من أنبوب شعري وقطبين. تم صنع شكل الكاثود بشكل أجوف من مادة النيكل للحصول على كثافة تيار عالية. وأن القطب الموجب هو مادة التنكستن. تم اختيار المسافة بين الأقطاب الكهربائية ١٣ سم. تم استخدام مجس لانكمور المزدوج كأسلوب تشخيصي لقياس معلمات البلازما في نطاقات مختلفة من ضغط الغاز. تم قياس خصائص I-V للمجس المزدوج عند ضغوط ٠,٢ و ٠,٣ و ٠,٤ و ٠,٥ و ٠,٦ و ٠,٧ تور. يتم إجراء جميع القياسات بقدرة ثابتة تبلغ ٠,٦ واط. تم استخراج درجة حرارة الإلكترون وتيار تشبع الأيونات من منحنيات خصائص I-V. بينما تم حساب كثافة الإلكترون وطول ديباي وتردد البلازما. لوحظ أن درجة حرارة الإلكترون تنخفض مع زيادة ضغط غاز العمل. أعطت تأثيرات الضغط على كثافة الإلكترون وتيار تشبع الأيونات تشابهًا واضحًا مع التغير في الضغط. كانت النتائج في اتفاق معقول مع البحث السابق.

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Introduction

There are many types of electrical discharge, the most important and widespread is continuous discharge plasma DC glow discharge [1]. In addition to the continuous discharge, the types of electrical discharge are represented by the alternating discharge and the radio discharge, which is similar in its regions to the direct current discharge [2, 3]. In which the plasma is divided into several regions distinguished by voltage and electric field as well as current density and regions of the distribution of negative and positive charge density [4]. Also, this type of plasma has entered into many industrial applications and has become one of the important tools, especially deposition sputtering [5,6]. The result of important calculations of the parameters of the plasma itself, for example, the electron temperature [7] and the plasma density are the same as the electron temperature, and these variables are closely related to other variables such as pressure, discharge voltage and other parameters [8-11]. The correlation of these variables indicates that they are very important in continuous electrical discharge applications and in other types and discharges.

Researchers have dealt with these measurements for the conditions of discharge in the case of low pressure as well as changing the distance between the electrodes. Lisovskiy, et.al [12] studied the electrical breakdown in the long tube in a continuous electrical discharge at low pressure were interested in studying the electrical breakdown and the effect of secondary electrons, calculating the ionization coefficients and the effect of the reduced field [13,14].The breakdown was studied using different gases, In addition to the secondary emissions using helium gas with several cathode electrodes of different materials, they also concluded that the breakdown voltage at the lower limit of helium is a lower value than that of argon [15]. Usually, the single and double probe technique is used to measure plasma parameters by measuring the current and voltage of the probe at the same instant. [16,17]. Kanzo and Takayoshi [8] give solutions and methods by which it is possible to overcome practical problems through the use of the measurement system using floating probes. The effect of high voltage applied across the two electrodes on the electron temperature and electron density was found by the use of a double probe[5, 18-21]. Debye length and plasma frequency were calculated [19]. Plasma parameters are calculated as a result of stabilizing the discharge current or the power to the continuous electric discharge [٢2]. Plasma parameters are calculated as a result of stabilizing the discharge current or the power to the continuous electric discharge [23]. Kiselev et. al [24] used the long tube as well as the movable anode design in the long tube, the relationship between current and voltage was the basis for finding the voltage gradient longitudinally in the positive column using the computer programs to calculate the electron temperature. Plasma applications Capillary discharge tube is useful as it is used to waveguide. The most common use of electrostatic discharge in capillary tubes is the emission of light X-rays [25], as well as the use of capillary tube in plasma discharge to improve the plasma jet [26].

In the present work ,the aim is to develop a capillary tube electric discharge system to study the effect of the pressure on plasma parameters as electron temperature, plasma density, through the use of Langmuir double probe technology.

Experimental apparatus

The electrical discharge system as it consists of three parts: the first represents the left part of the system. Those parts are a copper coil in the form of a spiral wire whose ends are connected only to one end of it is connected to a high voltage tungsten rod and the other is connected to a solid steel cylinder completely perforated, penetrated by a wire whose surface has been isolated by small diameter capillary tube to prevent the connection between the inner surface of the cylinder hole and thus a connection occurs between the cylinder piece and the parts that provide transitional movement of the anode with the help of magnets, as well as with the anode itself. The diameter of the cylinder is equal to (2 cm) and its length is (2.5 cm). The anode is a wire of diameter (1 mm) of tungsten material of length (10 cm) connected to the other side of the cylindrical piece through a small conductive piece.

The length of the electric discharge changes and shortens with the increase and decrease of the distance between the electrodes of the electric discharge, in other words, the length of the positive pole changes. The separation distances between the cathode and the anode 13 cm. The inter-electrode distance between the cathode and the anode is measured using a metric ruler installed near the discharge system as shown in Figure (1). So that the anode has flexibility through this structure associated with it so that the proximity of the anode to the cathode will be inside the important part of the glass tube which is the capillary tube whose length 12 cm and diameter 3.1 mm.

The two identical probes were placed on one side of the capillary tube and immersed in plasma and at a distance from the capillary tube and a distance from the cathode equal to 8 cm, the two probes whose diameter 0.35 mm and their net length inside the capillary tube 1.9 mm and the distance between them is equal to 1 cm. The location of the probes was chosen so that it is located within the positive column region for the continuous capillary glow discharge tube.

From the right side is a glass tube containing a hollow cathode with a length (2.8 cm) and a cavity diameter equal to 0.77 cm and the outer diameter is equal 0.78 cm of the nickel material. The negative polarity of the high-voltage device is connected to it, which is connected to it through a resistance of 10 $k\Omega$ through which the plasma current is measured. The system is evacuated of air via the vacuum pump type Forevac, ultimate vacuum 10^{-2} torr via the high-pressure valve of the T-Junction shown in figure (2). The range of pressures at which the

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measurements were made is in the range of 0.2 to 0.7 torr with six pressures for air as a working gas. The pressure was measured using a Pirani Edwards.

The gas discharge process is accomplished by a high voltage source that supplies voltages from 0 to 6000 volts and current 100 mA Leybold- Heraeus operation from 110-2240 volt Ac. The current of the electric discharge was measured by a voltmeter type across the resistance of10 $k\Omega$, while the higher voltages were measured by a voltmeter from 0 to 6 kV Leybold- Heraeus. As shown in figure 2.

The current of the probe was measured through digital multimeter UNI-T model UT136B that can detect the current of the probe to 0.1 µA micro-ampere and digital voltmeter, the voltage source of the probe circuit type Leybold- Heraeus 52235 can supply a voltage from 0 to 300 volts and current 50 mA. Figure (2) shown photograph of the capillary continuous electrical discharge system, the double probe system, and the measuring devices.

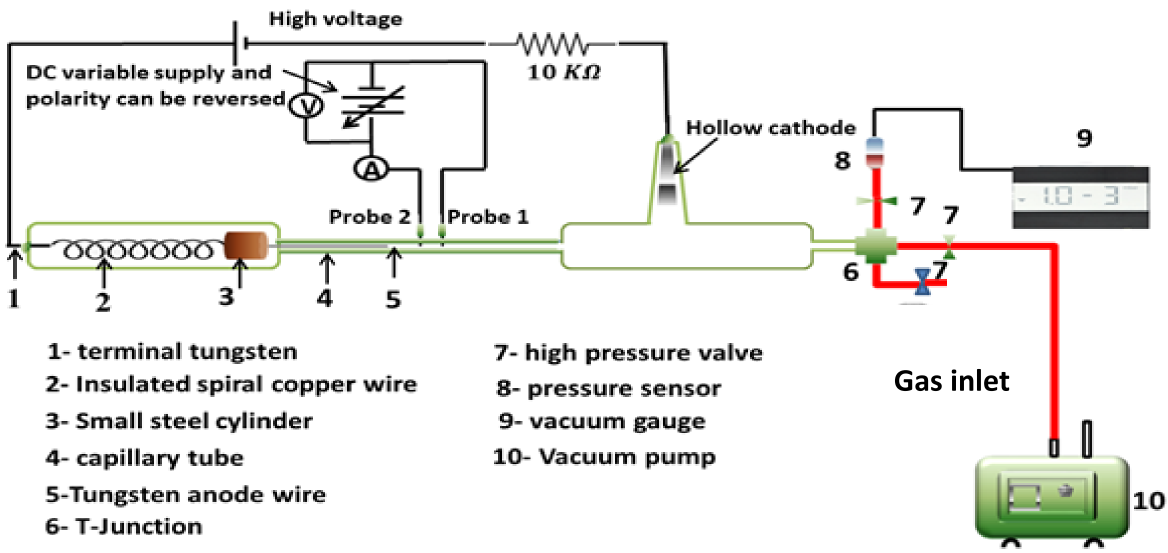

Fig. (1) shows a schematic diagram of a continuous capillary electric discharge system and double probe diagnostics

Fig. (2) A photograph of the capillary continuous electrical discharge system, the double probe system, and the measuring devices.

Results and Discussion

In a capillary glow discharge, the investigation of plasma parameters is the desired goal. The technique of using the Langmuir double probe is adopted as the diagnostic system here. Figure (3) shows the I-V characteristics curves of the double probe at different pressures with constant power at 0.6 watt and the distance between the electrodes is 13 cm.

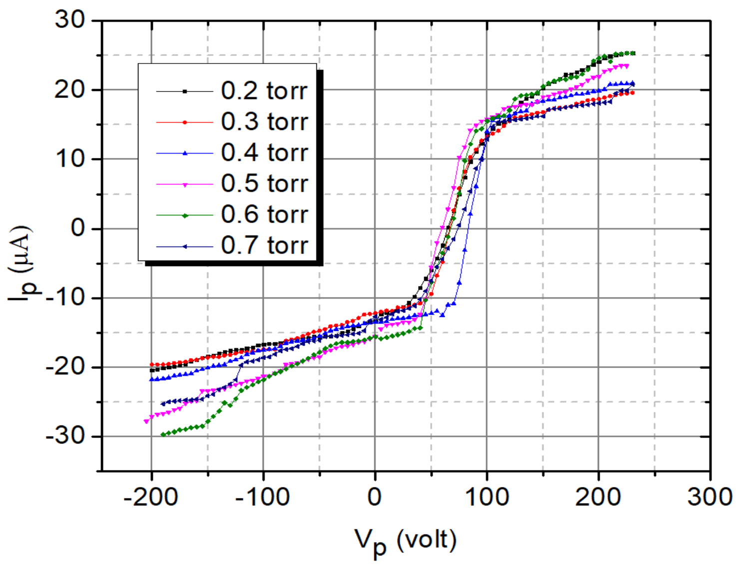

Fig. (3) Double probe I-V characteristics at different air pressure and the inter-electrode distance is 13 cm at constant power 0.6 watt.

From analyzing the relationship between probe current I_p and voltage probe V_p it can be noted, as is well known, that the current and voltage curves took the same methodically and at all pressures and assuming that the plasma has a Maxwellian distribution [20]. The electron temperature was calculated by finding the slope of the linear part of the characteristics curves where each curve gives a special slope that differs from the slope of the other curve [22]. From the relationship in figure (٤) between the electron temperature and pressure at a distance of 13 cm and a fixed power, there is a clear decrease with the increase in pressure due to the increase in the number of collisions made by electrons in the plasma[5]. Usually the pressure leads to an increase in the number of neutral atoms of the gas, and thus the number of collisions increases with the increase in pressure, or it may due to collisions with the wall containing the plasma as it is a capillary tube and the capillary tubes are narrow tubes so that the plasma in them is confined in a narrow and directed space as well.

Plasma parameters are numerous, and one of the other most important parameters is the plasma density, which is calculated by determining the ion saturation current, and from the calculated values of the electron temperature, it is calculated through the following formula [2٧].

$$I_{sat} = 0.6An_e\sqrt{\frac{KT_e}{m_i}} \quad ………. (1)$$

. Where m_i, n_e, and T_e are representing the ion mass, electron density, and electron temperature respectively, K is the Boltzmann constant's [28]. Figure(5) illustrate electron density versus pressure. This change gives a clear indication, which is the increase in the electron density with the increase in pressure and reaching a certain peak, which is the pressure 0.5 torr. With the increase in pressure, the number of neutral atoms increases accordingly. The electrons have a great opportunity to ionize those atoms. The density increases in two cases, either increasing pressure or stabilizing power and vice versa. In our case, changing the pressure leads to an increase in the ionization process and thus an increase in electrons, and we do not forget the electrons that come and are generated as a result of the collision of the ion with the cathode and the production of secondary electrons. The available mechanisms are ionization, diffusion, and the process of recombination to form a neutral atom. It is clear that with an increase in pressure produce a decrease in the plasma density, this means that there is a loss of electrons as a result of the less. It is worth mentioning, theoretically and from dealing with long tubes, it is necessary to reach a state of balance or equality between the ionization process and the impact of the electron and diffusion to the wall containing the plasma[12]. A close relationship between the electron density and the ion saturation current increases and decreases with increasing gas pressure. Figure (6) shows the change of ionic saturation current with pressure.

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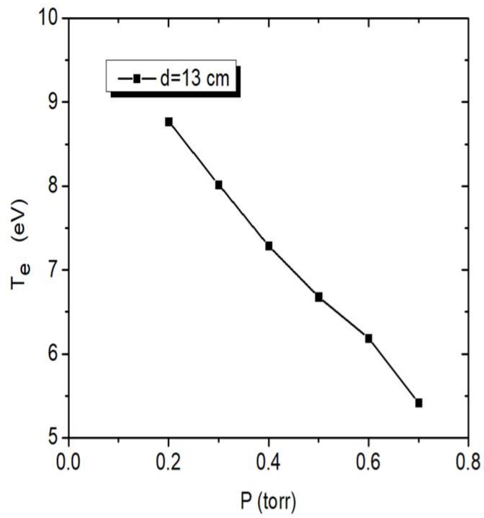

Fig.(4) Changing electron temperature with a change in pressure at constant power and a separation distance between the electrodes 13 cm

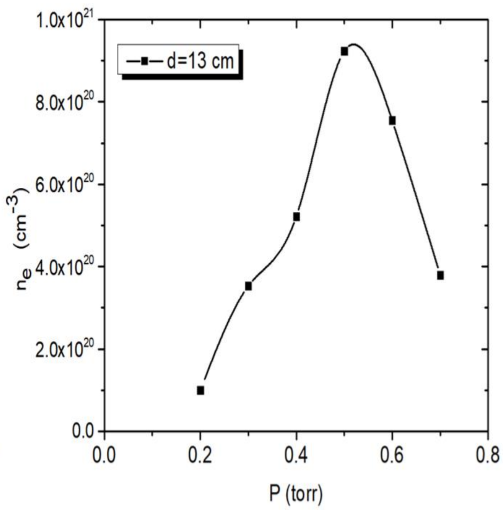

Fig.(5) Changing the electron density with a change in pressure at constant power and a separation distance between the electrodes 13 cm.

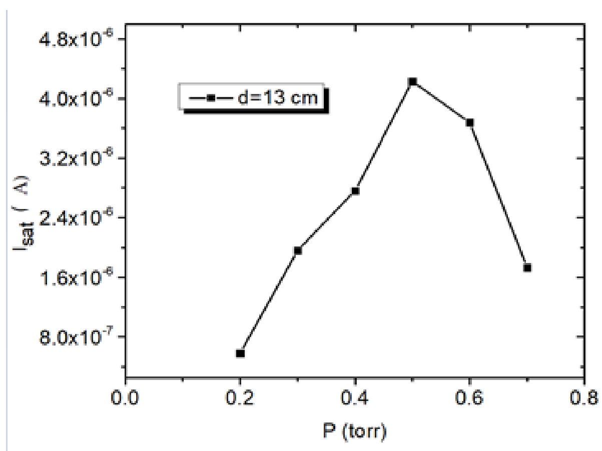

Fig. (6) the change of ionic saturation current with pressure.

Debye length is the distance over which the electric field is neutralized due to the separation of positive and negative charges from each other. It is in itself one of the properties and parameters of the plasma, and the definition of the plasma itself is closely related to the Debye length, which is much less than the dimensions of the boundary surrounding the plasma and is given [16].

$$\lambda_D = \sqrt{\frac{\varepsilon_0 K T_e}{n_e e^2}} \qquad \text{........ (2)}$$

Where m_e , e, and ε_0 represent the electron mass, charge of the electron, and vacuum permittivity respectively, The plasma frequency is also given by the following formula, which is related to the electron density [2٨].

$$f_p = \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} \;\ldots\ldots\; (3)$$

Figure (7) gives the change of Debye length with pressure, as with the increase in the number of electrons and other words the increase in the electron density, the Debye length decreases with the increase in pressure this change in density with pressure gives a change in Debye length. Figure (8) shows the frequency of the plasma against the pressure. The plasma frequency also increases in two cases, the first with increased power with constant pressure, and the second with an increase in pressure in the case of constant power with the increase of pressure and due to the state of attraction and is considered as a restoring force that arises between the negatively charged electron and the positive ion, the electron vibrates back and forth. The plasma frequency is related to the plasma density. As the pressure increases and the electron density increases, the plasma frequency begins to increase, and as the density decreases, the plasma frequency will inevitably decrease [5].

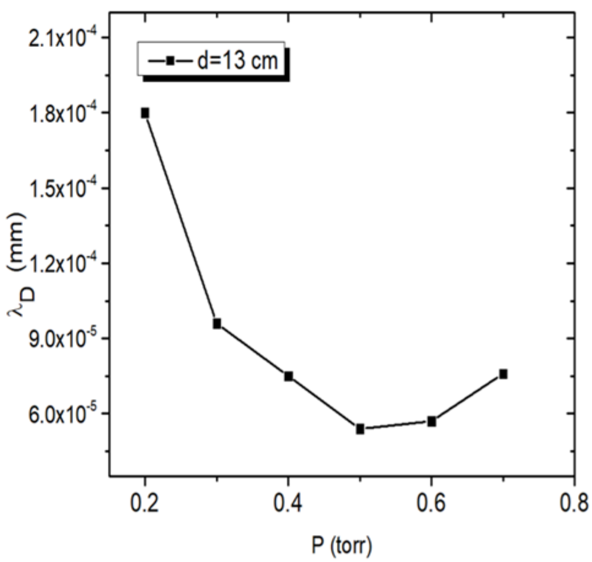

Fig.(7) Changing Debye length with a change in pressure at constant power and a separation distance between the electrodes 13 cm

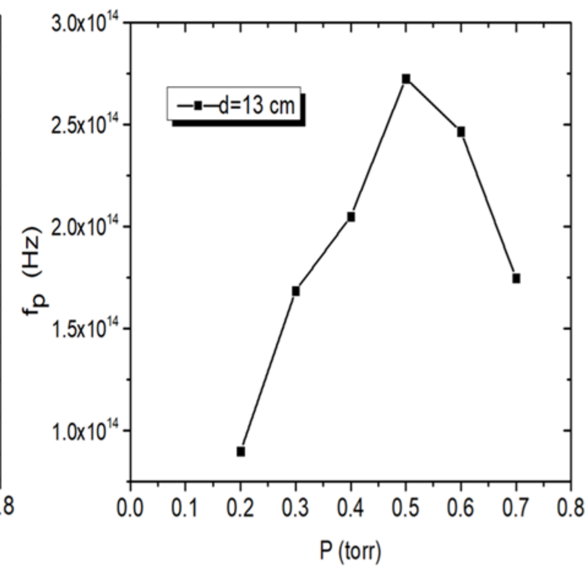

Fig.(8) Changing the plasma frequency with a change in pressure at constant power and a separation distance between the electrodes 13 cm.

From the capillary electrical glow discharge and by using the diagnostic technique of the Langmuir double probe to calculate some parameters of the plasma, some important conclusions have been formulated:

- Electron temperature and ion saturation current were inferred from the I-V characteristics Langmuir double probe at a fixed power of 0.6 watt.
- The I-V characteristics curves are systematic.
- Due to the collision of electrons with the neutral atoms of the gas, the electron temperature decreases with increasing working pressure.

- Debye length decreases with the increase in pressure.
- A close relationship between the electron density and the ion saturation current increases and decreases with increasing gas pressure.
- The plasma frequency begins to increase, and as the plasma density decreases, the plasma frequency will inevitably decrease.
- Reasonable results are consistent with the research [5].

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References

[1]- A. Von Engel ,"Ionized Gas", 2nd Ed Oxford University press, Oxford, 1955.

[2]-, N. S. J. Braithwaite, "Introduction to gas discharges," *Plasma sources science and technology*, *9*(4), 517, 2000.

[3]- H. Conrads, &, M. Schmidt," Plasma generation and plasma sources,". *Plasma Sources Science and Technology*, *9*(4), 441, 2000.

[4]- A. M. Howatson,"An introduction to gas discharges": Pergamon international library of science, technology, engineering and social studies: Elsevier," 2013.

[5]- A. K. Shrestha, R. Shrestha, H. B. Baniya, Tyata, R. B. Tyata, D. P. Subedi, & C. S. Wong, ," Influence of discharge voltage and pressure on the plasma parameters in a low pressure DC glow discharge,".*International Journal of Recent Research and Review*, Vol. VII, Issue 2, June 2014.

[6]- S. A. Hassan, A. A. Anber, E. A. Abdullah, J. F. Odah, N. J. Jubier, &, A. A. Abd Alwahab, "Electrical Properties and Optimum Conditions of A Home-Made Magnetron Plasma Sputtering System," *Iraqi Journal of Science*, 4353-4363, 2021.

[7]- R. Hippler, H. Kersten, M. Schmidt, & K. H. Schoenbach, "Low temperature plasmas," *Eds R Hippler et al, Berlin: Wiley, 787,* 2008.

[8]- K. Yamamoto, & T. Okuda, On the floating probe method for the measurement of ionized gas," *Journal of the Physical Society of Japan*, *11*(1), 57-68, 1956.

[9]- K. Shirai, T. Iizuka, & S. I. Gonda,"Electric probe measurements in an ECR plasma CVD apparatus," *Japanese Journal of Applied Physics*, *28*(5R), 897, 1989 .

[10]- L. Ledernez, F. Olcaytug, & G. Urban, "Independent influence of the inter-electrode distance in Paschen curves," In *20th ESCAMPIG* , 2010 .

[11]- Fu, Y., Yang, S., Zou, X., Luo, H., & Wang, X.," Intersection of Paschen's curves for argon," *Physics of Plasmas, 23*(9), 093509 , 2016 .

[12]- V. A. Lisovskiy, V. A. Koval & Yegorenkov, V. D. Yegorenkov, ” Dc breakdown of low pressure gas in long tubes,” *Physics Letters A*, *375*(19), 1986-1989, 2011.

[13]- D. Mariotti, J. A. McLaughlin & P. Maguire, “Experimental study of breakdown voltage and effective secondary electron emission coefficient for a micro-plasma device,” *Plasma Sources Science and Technology*, *13*(2), 207, 2004 .

[14]- G. Auday, P. Guillot, J. Galy & H. Brunet, “Experimental study of the effective secondary emission coefficient for rare gases and copper electrodes,” *Journal of applied physics*, *83*(11), 5917-5921, 1998.

[15]- M. A. Hassouba, F. F. Elakshar & A. A. W. Garamoon,” Measurements of the breakdown potentials for different cathode materials in the townsend discharge,” *FIZIKA A-ZAGREB-*, *11*(1/4), 81-90, 2002.

[16]- J.D. Swift and M.J.R. Schwar, Electrical Probes for Plasma Diagnosticsî (Elsevier, New York, 1969). [17]- E. V. Shun’ko ,“Langmuir probe in theory and practice,” Boca Raton, Florida, 2009.

[18]- E. O. Johnson & L. Malter,”A floating double probe method for measurements in gas discharges,” *Physical Review*, *80*(1), 58, 1950.

[19]- T. Dote,” A new method for determination of plasma electron temperature in the floating double probe,” *Japanese Journal of Applied Physics*, *7*(8), 964, 1968.

[20]- S. A. Ghasemi, A. Mazandarani & S. Shahshenas, “Double Langmuir probe measurement of plasma parameters in a dc glow discharge,” *Iranian Journal of Physics Research*, *18*(3), 494-494, 2018.

[21]- S. Bhattarai, “Interpretation of Double Langmuir Probe IV Characteristics at Different Ionospheric Plasma Temperatures,” *AJEAS*, *10*(4), 882-889, 2017.

[22]- V. I. Demidov, M. E. Koepke, I. P. Kurlyandskaya & M. A. Malkov,” Basic factors for acquiring, correcting, and interpreting probe current-voltage characteristic in moderate-collisional plasma for determining electron energy distribution,” *Physics of Plasmas*, *27*(2), 020501, 2020.

[23]- M. A. Ahmed, Q. T. Algwari and Younus M. H. “ Plasma properties of a low-pressure hollow cathode DC discharge,” *Iraqi Journal of Science*, accepted No:PH/5492, 20/12/2021.

[24]- A. S. Kiselev, D. K. Kostrin, A. A. Lisenkov & E. A. Smirnov (2017)” Determination of the plasma parameters of a glow discharge in long tubes,” In *Journal of Physics: Conference Series* (Vol. 789, No. 1, p. 012027). IOP Publishing.

[25]- J. J. Rocca, M. C. Marconi, & F. G. Tomasel,” Study of the soft X-ray emission from carbon ions in a capillary discharge,” *IEEE journal of quantum electronics*, *29*(1), 182-191, 1993.

[26]- T. Neger & H. Jäger, “A capillary discharge for determination of plasmadiagnostically relevant atomic quantities,” *Zeitschrift für Naturforschung A*, *41*(9), 1094-1100, 1986 .

[2٧]- R. L. Merlino, “Understanding Langmuir probe current-voltage characteristics,” *American Journal of Physics*, 75(12), 1078-1085, 2007.

[2٨]- Yu P. Raizer," Gas Discharge Physics," Springer-Verlag, 1991.