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Effect of Applied Voltage on Spectroscopic Characterization of Neon Plasma

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Abstract

In this work, the glow spectrum from a neon strip lamp, used in homes and all private places, was diagnosed using optical emission spectroscopy (OES), to measure plasma parameters from spectral data (electrons density, electrons temperature, plasma frequency, Debye length). The intensity of the emission spectrum increases with increasing the applied voltage (100-220V). A spectral diagnosis was made of the cold plasma generated by the neon glow system where the glow spectrum produced was prepared for the diagnosis at variable alternating voltages that begin to rise gradually. The diagnosis was made at atmospheric pressure and room temperature of 27℃. The results showed a gradual increase in the intensity of the neon spectrum generated by the system with the amount of gradual increase in the applied voltage. Between (250-850) nm, the behavior of neon spectral lines varied between high and low spectral intensity peaks.

Keywords: Neon Plasma, Emission Spectroscopy, Plasma Parameters, Applied Voltage, Spectral Intensity.

تأثير زيادة الجهد المطبق على توهج بلازما النيون ومعلماتها المشخصة بواسطة مطياف الانبعاث البصري

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الخلاصة

في هذا العمل، تم تشخيص الطيف المتوهج الصادر من جهاز أعمدة النيون والتي تستخدم في البيوت وجميع الأماكن الخاصة باستخدام التحليل الطيفي للانبعاثات الضوئية (O.E.S) ، والذي تم توظيفه لقياس معلمات البلازما من البيانات الطيفية (كثافة الإلكترون ، درجة حرارة الإلكترون ، تردد البلازما ، وطول ديباي). من ناحية أخرى فإن تأثير زيادة الجهد المطبق على شدة الطيف يتضح تدريجياً من (100–220) فولت. تم إجراء التشخيص الطيفي للبلازما الباردة الناتجة عن نظام التوهج لجهاز النيون، حيث تم إعداد النظام للتشخيص بفولتية متناوبة متغيرة تبدأ في الارتفاع تدريجياً. تم التشخيص عند الضغط الجوي ودرجة حرارة الغرفة 25 سْ ، وأظهرت النتائج زيادة تدريجية في شدة طيف النيون الناتج عن النظام مع مقدار الزيادة

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التدريجية في الجهد المطبق. حيث تراوح سلوك الخطوط الطيفية للنيون بين القمم العالية والقمم المنخفضة للشدة الطيفية بين (250−850) نانومتر.

1. Introduction

A wide variety of industries use plasma technology. High-temperature atmospheric pressure plasma has been used in several fields, including arc welding and garbage disposal [1]. Low-temperature atmospheric pressure plasma has garnered much interest as of late due to its ability to lessen heat damage to the target material and its high reactivity while keeping gas and ion temperatures low. As a result, low-temperature atmospheric pressure plasma has been studied for use in various processes, including decontamination, combustion aid, surface modification, and even medical uses [2– 4].

As long as the atom's number of protons and electrons is constant, the resulting electrical charge is zero. Ions, or atoms missing an electron, are still present and are responsible for maintaining the plasma's overall neutrality [5]. In contrast to gas, plasma conducts electricity through free charges [6]. In reality, applying a voltage across a gas creates and maintains plasma. Accelerated by the voltage, free electrons smash with neutral atoms, converting some of them to ions, thus sustaining the plasma [7,8].

It is necessary to correctly diagnose plasma obtained from all their generation sources, no matter how different they are, to utilize the plasma in the correct way. Analytical atomic spectroscopy relies heavily on low-electron-density plasmas as a light source for optical emission spectroscopy (OES) and sample atomization in atomic absorption [12–14]. It also has uses in plasma processing and other technologies. Since there is a growing demand for plasma diagnostics, it is essential that existing methods be refined and that new methods be developed [2]. In particular, the OES techniques are attractive because of the lack of perturbative effects, making them suitable for use with standard laboratory equipment seen in spectroscopy. The corona equilibrium model is used to explain the characteristics of low-electron-density plasmas, which are typically outside of local thermal equilibrium (LTE) [15]. Electron density and temperature are crucial factors for plasma characterization due to the electrons’crucial role in plasmas. Further, some OES diagnostic methods are only usable with an understanding of electron density distribution. The probe diagnostic method uses optical emission spectroscopy as a supplemental approach [14,16].

Optical emission spectroscopy is a powerful tool, for it is a quick and simple measurement method and requires little setup. In OES, the light emitted by the plasma is passively recorded. When plasma particles collide with electrons, they are stimulated to higher electronic states. A photon is created when an excited particle relaxes to a lower energy state [17]. The wavelength of the spectral line is proportional to the energy of the photon produced, which is equal to the difference between the excited and lower energy states as the following equation [18]:

$$\lambda = \frac{hc}{E_p - E_k} \qquad (1)$$

Where: h is Planck’s constant, c is the speed of light, E_p and E_k is the upper and lower energy state, respectively.

Neon strip lamps are in everyday use these days. The glow from it is the light output of billions of individual neon atoms [2]. When held in a plasma state, neon emits this kind of light. When atoms and electrons collide, they don't always become ions. Rather, the atoms absorb some of the collision's energy and quickly re-emit it as invisible ultraviolet rays and

visible light unique to each atom type. Neon is what gives the neon lamp its signature orange-red glow; other gases, such as argon, would produce a different hue of light [9–11].
This article aims to study the optical spectra resulting from the glow of the neon lamp with the increase of the applied voltage and to calculate the plasma parameters through the data.

2. Experimental Procedures

The glow from the neon lamp under study, of 40 cm long installed in a tight electrical base, represents cold plasma, a spectral diagnosis was performed with an optical diagnostic spectrometer (S3000-UV-NIR). Its optical spectrum sensor was placed 2 cm away from the neon lamp at an angle of 45̊ to capture the spectrum emanating from the plasma glow of the neon lamp, as illustrated in Figure 1. The neon lamp was directly connected to a voltage supply of a voltage range (0-300) volts coupled with an alternating voltage regulator, which was used to control the voltage passing through the lamp. The spectral diagnosis was performed in the middle area of the lamp as well as at its upper and lower to compare the intensity of the spectra resulting from the glow with the continuous increase of the applied voltage. The experiment was conducted at room temperature with the lights turned off to ensure accuracy in recording the spectral data given by the neon lamp. Spectrum data were evaluated and compared to the information from the National Institute of Standards and Technology (NIST). The plasma parameters were calculated, and their characteristics were discussed.

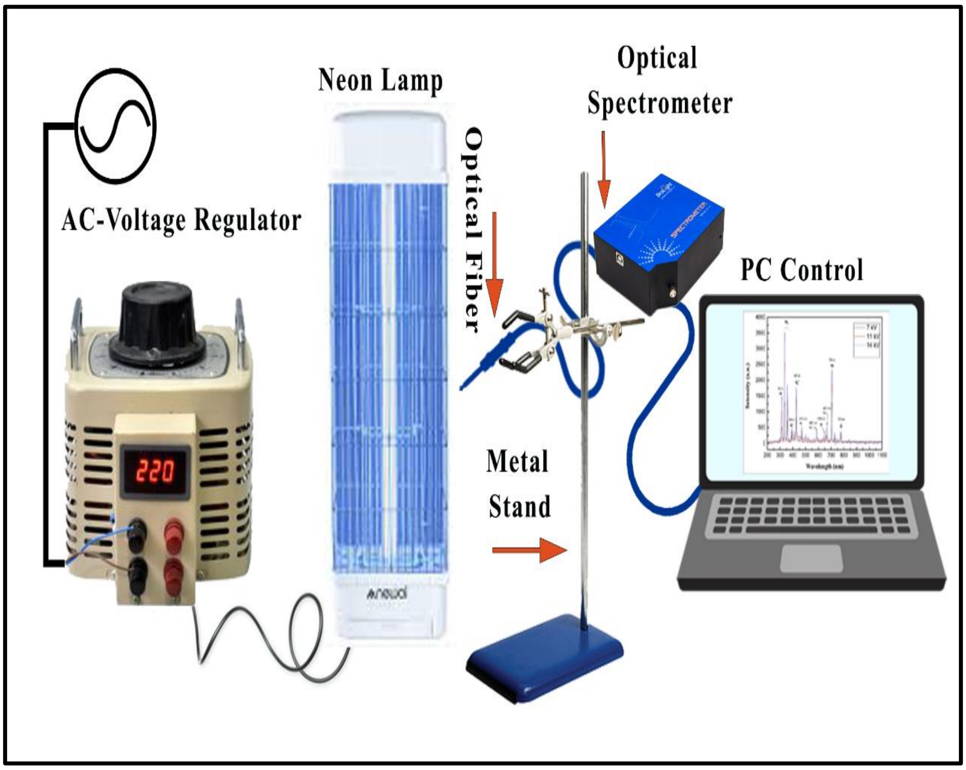

Figure 1: Diagram of Spectroscopic Analysis of the Neon Plasma Lamp System.

3. Results and Discussion

Figure 2 represents the optical emission spectra, obtained with the diagnostic OES device, for the glow produced by the neon plasma system at the top and bottom of the neon lamp candle for different values of an alternating voltage in the range (100-220) volts, applied to the system. The resulting optical emission spectra at the top and bottom of the neon lamp candle were similar. Similarly, optical emission spectra were obtained for the glow produced by the neon plasma system in the middle area of the neon lamp candle, as shown in Figure 3. Differences in the emission spectra were noted.

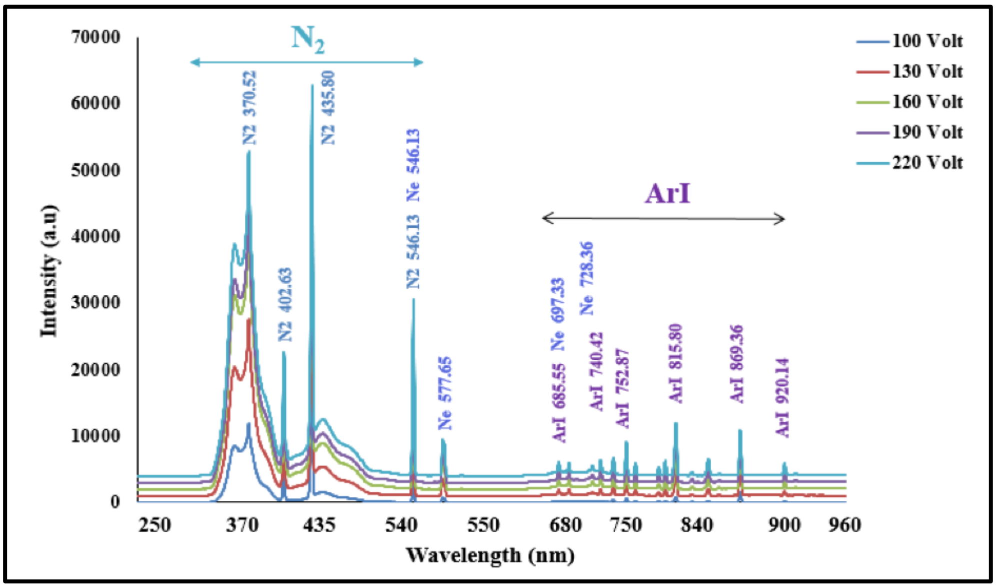

Figure 2: Optical emission spectra of the neon plasma lamp system at the top and bottom of the neon lamp candle.

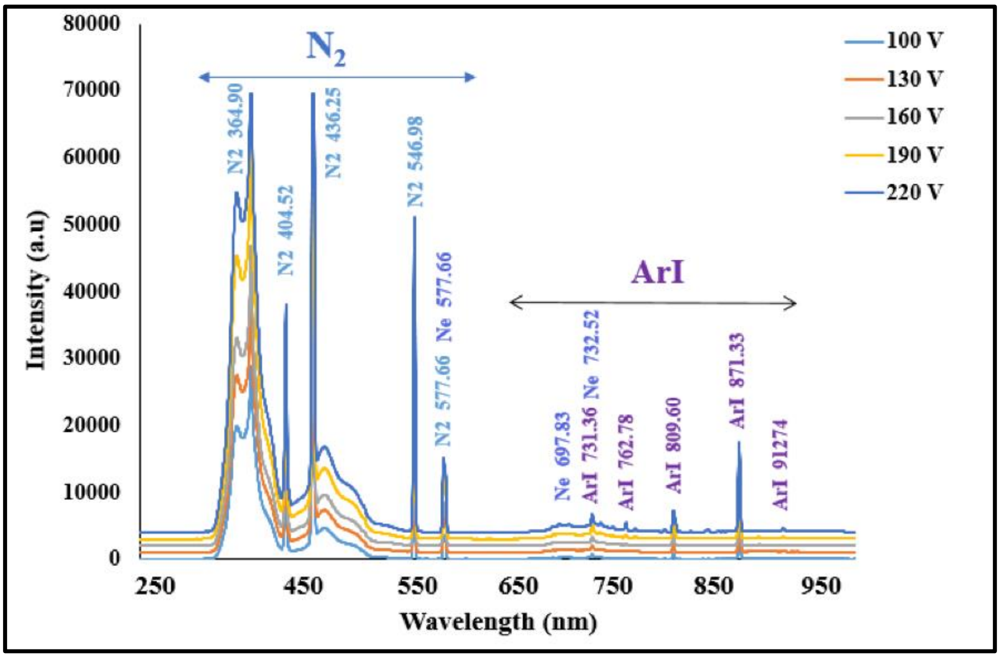

Figure 3: Optical emission spectra of the neon plasma lamp system at the middle area of the neon lamp candle.

The optical emission spectra showed several peaks for nitrogen, argon, and neon, most of which agree with the Higher Institute (NIST) data. The highest peak was for argon gas at the wavelength of 815.50 nm and 871.33 nm, while the highest peak was for nitrogen gas at 435.80 nm. The figures also show peaks of neon gas located between (540-750) nm. All the peaks of these gases increase in intensity with the gradual increase in the applied voltage; this indicates an increase in the collisions and interactions of the neon gas molecules inside the neon lamp candle. Therefore, when a suitable voltage is applied to the neon gas in the candle, ions and free electrons are produced that are accelerated by the electric field applied between the two electrodes, thus gaining additional kinetic energy that enables them to excite other neutral atoms through collisions. The movement of electrons is more important than the movement of ions in the process of irritation by collisions because of their smaller mass and because the rate of the kinetic energy of electrons is much greater than the rate of the kinetic energy of ions in the case of low gas pressures. The transfer of energy in the collisions between ions and atoms is very large due to the mass of ions and atoms being somewhat close. As for the electrons, they effectively transfer energy between them through collisions that take place away from the cathode area. Electrons take more energy from the electric field than ions because of their smaller mass and greater drift speed. Therefore, the spectrum intensity at a voltage of 100 volts is low compared to the highest spectrum intensity at a voltage of 220 volts.

The electron temperature (T_e) in eV for LTE is calculated using the equation below [21]:

$$ln[\frac{\lambda_{ji} I_{ji}}{hcA_{ji} g_j}] = -\frac{1}{kT}(E_j) + ln\, ln\, \left|\frac{N}{U(T)}\right| \quad (2)$$

Where: g denotes the statistical weight, λ denotes the wavelength, E_j is the excited state energy in eV, I_{ji} denotes the intensity of spectrum, A_{ji} denotes the transition probability, N denotes the density of the state's population, and k denotes the Boltzmann constant. So, using Eq.2 the electron temperature (T_e) can be calculated from the slope of the linear fitting of the resulting plotted curve of ln (λ_{ji} I_{ji})/(hcA_{ji} g_j) versus (E_j), as shown in Figure 4.

A Gaussian profile is typically produced by instrumental broadening, natural broadening, and Doppler broadening. In contrast, Stark broadening can lead to a Lorentzian profile if the electron impact widening is taken into account. When ignoring the ion dynamics during the radiative process, the electron density (n_e) can be calculated by the formula below, using the (FWHM) for every voltage, as illustrated in Figure 5 [21]:

$$n_e = \left[\frac{\Delta\lambda}{2\omega_s}\right] N_r \ (cm^{-3}) \quad (3)$$

Where: $\Delta\lambda$ is the full width at half maximum (FWHM) nm of the spectral line as showed in Figure 5, and ω_s is the Stark broadening parameter that can be found in the standard tables, and N_r is the reference electron density.

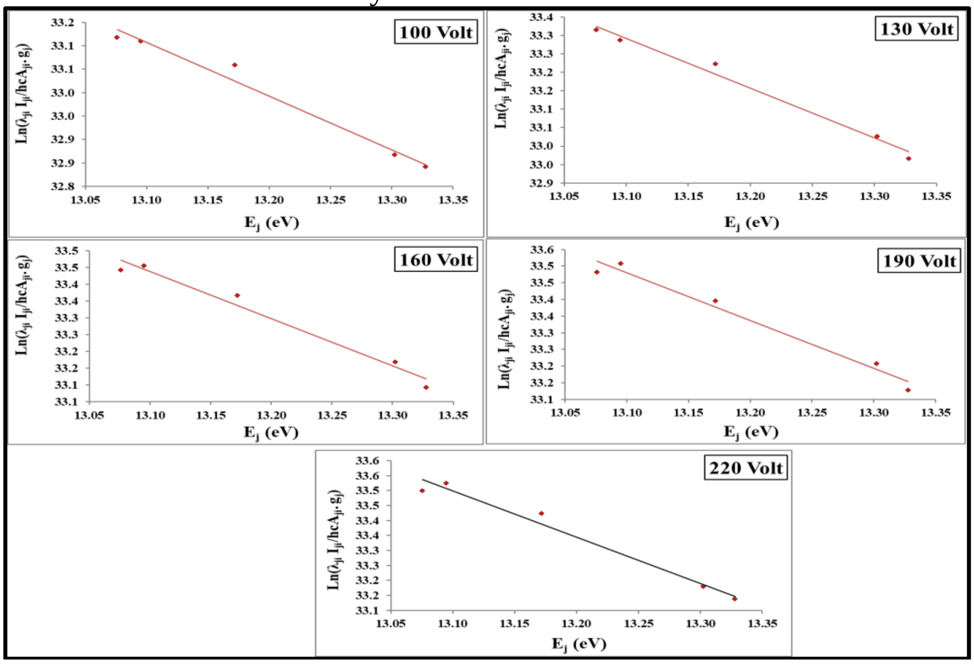

Figure 4: Boltzmann Plots for various values of voltage (100-220) Volt.

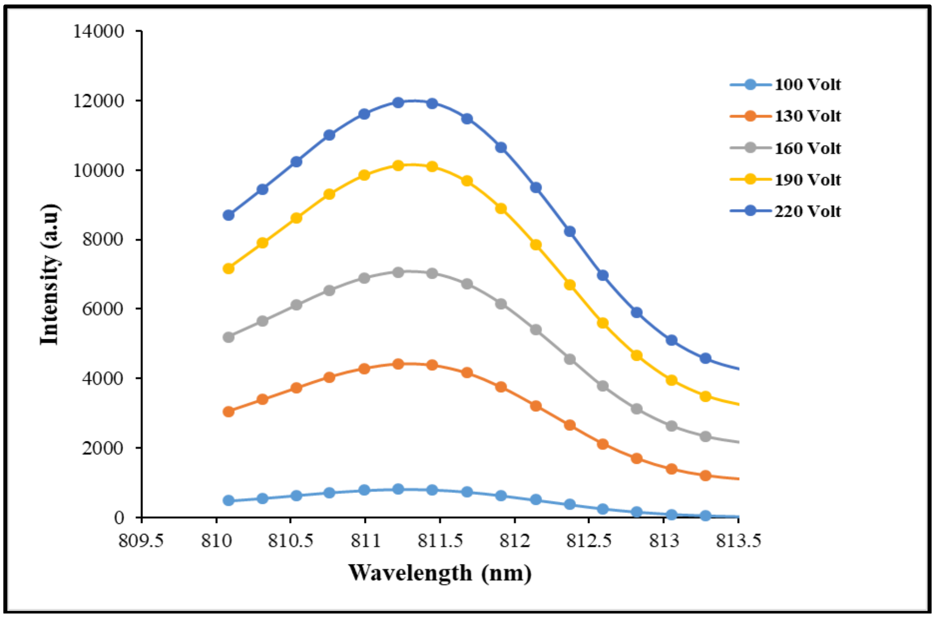

Figure 5: Full Width at Half Maximum(FWHM) as a function of wavelength and voltage (100-220) Volt.

Figure 6 shows the agreement of the changes due to the increase in the alternating voltage applied (or used in this system to generate the neon plasma) of the electron temperature (T_e) with that of the electron number density (n_e). The results indicated a clear increase in electron temperature from (0.4136 to 0.7165) eV and electron number density from (8.3144×10^{17} cm^{-3} to 12.5364×10^{17} cm^{-3}) with the raising of the applied voltage from 100V to 220V. The values of the plasma parameters are listed in Table 1. All electron temperature and density steadily increase with increasing the applied voltage, indicating an increase in collisions and interactions of neon gas molecules inside the neon lamp. As a result, when a suitable voltage for the neon gas is applied to the neon lamp candle via the voltage regulator, ions and free electrons are produced, which are accelerated by the electric field applied between the two electrodes, obtaining additional kinetic energy that allows them to excite other neutral atoms through collisions. In the process of irritation by collisions, the movement of electrons is more essential than the movement of ions due to their smaller mass and because the rate of the kinetic energy of electrons is much greater than the rate of the kinetic energy of ions at low gas pressures [22]. Therefore, neon plasma's electron temperature and density at 100 volts are smaller than at 220 volts. The frequency of plasma (f_p) is determined from the following equation [12]:

$$f_p = 8.98\sqrt{n_e}\ (Hz) \tag{4}$$

The frequency of a plasma wave is a fundamental property that is totally and entirely determined by its electron density. Plasma has a high frequency due to the low mass of its constituent, electrons. Debye shielding (λ_D) is a charged particle response that decreases the impact of electricity on local fields, giving the plasma its quasi-neutrality. Debye shielding, abbreviated λ_D indicates a measure of the distance at which the effect of the electric field of an individual charged particle is felt by other charged particles inside the plasma. and is calculated using Equation 5 [12]:

$$\lambda_D = \sqrt{\frac{\varepsilon_o k T_e}{n_e e^2}} = 743 \times \sqrt{\frac{T_e}{n_e}} \quad (cm) \tag{5}$$

Electrons are accelerated from the cathode to the anode, colliding with gas molecules in the space between the electrodes; some of these electrons are absorbed by the neutral particles, while others are lost in the collisions (electron-neutral particles), and as the applied field accelerates the newly liberated and colliding electrons, a secondary ionization process occurs; thus the plasma frequency increased from (9.513 to 10.432)x10^{12} Hz and Debye length from (0.52 to 0.642)x10^{-6} cm, respectively, as the applied voltage increased from 100 to 220 volts. This indicates that the measured plasma parameters are directly related to all applied voltage values.

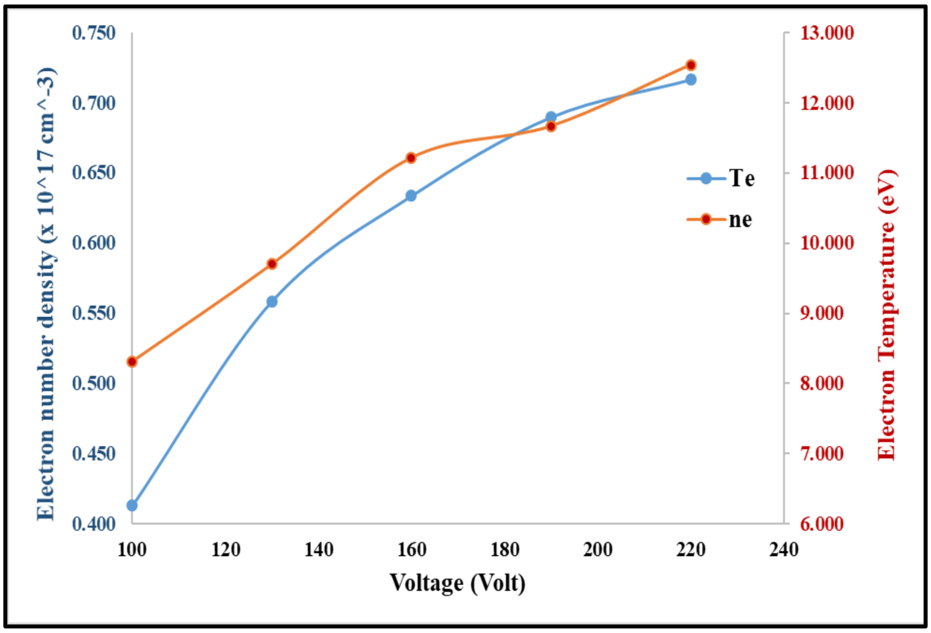

Figure 6: The Effect of Applied Voltage (100-220) Volt on the Temperature and Density of Electrons.

4. Conclusions

The results demonstrated that at varied voltages (100-220 volts), spectral analysis of the glow produced by the neon plasma system at the middle, top and bottom of the neon lamp candle yielded nitrogen, neon (Ne), and argon (Ar) gas peaks of varying intensities. The effect of increasing the voltage was apparent in measuring the plasma parameters when making the diagnosis, as the electron temperature increased from (0.413-0.716) eV and the electron density from (8.314-12-536) x10^{17}cm^{-3} of the plasma. In addition, the behavior was similar to the plasma frequency and Debye length, as the results showed an apparent increase in these parameters with the gradual rise in voltage. When the voltage is increased more (30 volts upwards), a collapse occurs from the ion bombardment of the negative pole, liberating many secondary electrons. The bombardment with electrons, photons, and neutral atoms also contributes to this process; each of them differs from the other in energy as a result of the acceleration of secondary electrons in the field of the negative pole and their collision with the atoms of the remaining neon gas, causing the production of new ions, which rush back towards the negative electrode to produce new secondary electrons. This process continues until we reach a stage in which the discharge process is self-supporting, and the neon gas begins to glow.

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