Chapter 3: Studies on hydrogen plasma and dust charging in low-pressure filament discharge

Chapter 3

Studies on hydrogen plasma and dust charging in low-pressure filament discharge

Abstract

The hydrogen plasma parameters and dust charging are studied at different working pressure in a multi-dipole dusty plasma device. A cylindrical Langmuir probe is used to evaluate the plasma parameters and electron energy probability function (EEPF) for different working pressure. At very low pressure ($6 \times 10^{-3}$ mbar), a bi-Maxwellian EEPF is observed whereas at $2 \times 10^{-3}$ mbar, a single Maxwellian EEPF is observed at the lower energy range (below 10 eV) of the EEPF plot. Some dip structures are observed at high energy range ($\epsilon > 10$ eV) in the EEPF plot of hydrogen plasma. Different inelastic collisions between electron and hydrogen molecules are responsible for those dips. The charge carried by the tungsten dust grain is calculated by using capacitance model. Current carried by micron sized dust grains are measured with the combination of Faraday cup and a sensitive electrometer. From these observations, a strong influence of working pressure on plasma parameters, EEPF and dust charging is observed. It is also observed that the presence of charged grains affects the shape of the EEPF by redistributing the high and low-energy electron populations.
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Introduction

In this chapter, the hydrogen plasma parameters and dust charging are studied at different working pressures in a multi-dipole dusty plasma device. Special emphasis is given on the effect on electron energy probability function (EEP) due to different working pressures and the presence of dust grains.

3.1 Background

Due to the remarkable impact on different research and technology fields, hydrogen plasma becomes one of the emerging research fields in plasma physics. A better understanding of physical and chemical plasma processes [1-3] is very important for improvement of plasma technologies. All these issues are directly connected to the electron energy distribution function (EEDF). It is a measure of the number of electrons within a specific energy range, plasma uniformity [4] and provides information about the different internal parameters. Knowledge of the EEDF or EEP is important for observing the different plasma parameters as well as for optimizing the plasma processes used for various applications [5, 6]. The shape of the EEDF significantly affects the effectiveness of ion beam sources, especially in tandem plasma sources used for the production of negative hydrogen ions [7].

For a cylindrical Langmuir probe, the EEDF \( F(E) \) is obtained using the Druyvesteyn procedure [8], by the second derivative of \( I-V \) characteristic measured by the
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probe which is proportional to the electron energy probability function (EEPF), which is denoted by $f(\varepsilon)$. The EEPF is related to the EEDF as $F(\varepsilon) = \varepsilon^{1/2} \times f(\varepsilon)$ and hence [9, 10]

$$f(\varepsilon) = \frac{2(2m)^{3/2}}{e A_p} \varepsilon^{12} \left( \frac{d^3 I_c}{dV_B^2} \right)^2$$

...............(3.1)

where $\varepsilon$ is the electron energy in eV, $e$ and $m$ are the electron charge and mass, respectively, $V_B$ is the probe voltage (referenced to the plasma potential), $A_p$ is the probe area and $I_c$ is the current collected by the probe.

The behaviors of the particles (dust) formations in the processing plasma and fusion machine become a very interesting object for the present day scientific community. The presence of the particles strongly influences the discharge structure and the plasma parameters [11]. One of the specific features of dust containing plasma is that the density of plasma electrons decreases due to the charging of dust grain in plasma by capturing the low energy plasma electrons on the surface of the dust grain, which in turn increases the energy of the electrons [12]. It is not well understood about the increase in electron energy in presence of dust particles in plasma than that of the pristine plasma [13].

A number of theoretical and experimental investigations have been carried out for understanding the charging of dust grains in various plasma environments [14-17]. In low temperature laboratory plasma, dust particles are mainly charged by the collection of the plasma electrons and ions flowing onto their surfaces. The ions and electrons are typically approximated using orbit-limited charging currents [18], where it is assumed that the ions and the electrons obey a Maxwellian distribution.
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At the equilibrium charging state, the charge $q_C$ on a dust grain related to its surface or floating potential $\phi_p$ (relative to the plasma potential) is given by [16, 19 and 20]

$$q_C = eN_C = 4\pi e_0 r_d^2 \phi_p$$ ................................ (3.2)

Where $r_d$ is the radius of the spherical grain, $N_C$ is the number charges accumulated on each dust grain and $\phi_p$ is the dust surface (or floating) potential. The dust grain surface acquires a floating potential ($\phi_p$) at which the electron and ion currents become equal in magnitude, i.e. $I_e + I_i = 0$. Substituting the electron ($I_e$) and ion ($I_i$) current, the floating potential of dust grain can be estimated numerically from the relation:

$$-en_e m_e \frac{8k_B T_e}{n_e m_e} e^{e\phi_p / k_B T_e} + en_i m_i \frac{8k_B T_i}{n_i m_e} \left(1 - \frac{e\phi_p}{k_B T_i}\right) = 0$$

$$\Rightarrow \left(1 - \frac{e\phi_p}{k_B T_i}\right) = \frac{n_e}{n_i} \left(\frac{T_e}{T_i}\right) \frac{m_i}{m_e} \exp\left(\frac{e\phi_p}{k_B T_e}\right)$$ ................................ (3.3)

Where $e$, $\phi_p$, $k_B$, $r_d$, $n_e$, $n_i$, $T_e$, $T_i$, $m_e$, $m_i$ are the electronic charge, dust grain surface potential, Boltzmann’s constant, radius of dust grain, electron (ion) density, electron (ion) temperature, mass of electron (ion) respectively.

The study on electron energy distribution function in filamentary (arc discharge) hydrogen plasma is very rare compared to that of inert gas [21]. In the present study, the effect of working pressure on different plasma parameters like electron density, electron temperature, electron energy probability function (EEPF) and on dust charging are described in filamentary hydrogen plasma. The effect on EEPF in presence of dust particles is also examined for different working pressures.
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The current carried by the dust grain is measured experimentally and the results are compared with the dust charge, calculated using capacitance model (i.e. by using eq. 3.2 & 3.3). A sensitive electrometer (Keithley Instruments, 6514), attached to the Faraday cup is used to measure the dust current carried by a single dust [22, 23] whose resolution is of the order of $10^{-15}$ A.

3.2 Apparatus and experimental setup

The experiment has been performed in a multi-dipole dusty plasma device which is shown in Fig 3.1. The lower chamber is the plasma chamber that is placed horizontally and vertical upper chamber facilitates the holding of dust dropper. The plasma discharge chamber was made out of a cylindrical stainless steel chamber of 100 cm in length and 30 cm in diameter.

The dust unit consists of a cylindrical stainless steel chamber of height 72 cm and 15 cm in diameter with a dust dropper, which is fitted inside the dust chamber. A diffusion pump (1000 lit/s) backed by a rotary pump (600 lit/min) is used to evacuate the chambers to a base pressure of $2 \times 10^{-6}$ mbar. A full line cusped magnetic field confinement system is used to improve the plasma confinement. A steady state low pressure, direct current hydrogen plasma is produced by hot cathode filament discharge technique. Two numbers of thoriated tungsten filaments (total length 150 mm & diameter 0.25 mm) are used on both the end of the magnetic cage. Hydrogen plasma is produced by striking a discharge between incandescent tungsten filaments and grounded magnetic cage, which serves as the
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anode. Ionizing electrons emitted from hot tungsten filaments are accelerated by applying 80-volt discharge voltage.

Fig 3.1: Schematic diagram of experimental device

The schematic of the dust dropper, used to drop the tungsten dust particles (having size ~ 2.5μm) from the top of the dust unit is shown in Fig 3.2. The dust dropper consists of a dust container having SS mesh as the bottom plane and a stepper motor to vibrate the dust

Fig 3.2: Schematic of dust dropper
Chapter 3: Studies on hydrogen plasma and dust charging in low-pressure filament discharge container. The vibration frequency can be controlled by changing the input voltage to the stepper motor.

The setup is also equipped with plasma parameter measurement system and dust current measurement system. Plasma parameters are measured by a single cylindrical Langmuir probe. It is a Hiden Analytical Limited’s ESPION advanced Langmuir probe system, consists of a tungsten wire of 0.15 mm in diameter and a length of 10 mm. The probe voltage is swept from –80 volt to +80 volt and the plasma parameters are calculated in each 0.25 volt division.

The measurements were performed axially at 4 cm away from the centre of the magnetic cage (at magnetic field free region) with the help of Hiden Analytical make (ESPION) single Langmuir probe system. By subtracting the ion contribution of the probe current, the shape of the electron current for probe potentials lower than the plasma potential is used to reconstruct the EEPF. In this voltage regime, the probe effectively acts as a retarding probe for the surrounding electrons, and the current response with respect to this retarding potential provides a relationship between electron energy and probe current [24].

Dust current is measured with the combination of Faraday cup and electrometer (see Fig 3.3). The entrance pinhole of the FC is 2 mm in diameter. A sensitive electrometer (Keithley Instruments, 6514) attached to the Faraday cup through a tri-axial cable, is used to measure the dust current carried by the charged dust particles, when it falls on the Cu plate after passing through the pin hole of the FC.
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Fig 3.3: Image and schematic of Faraday cup

The dust density is measured using laser scattering technique [25] which is of the order of \( \sim 10^6 \text{ c.m.}^{-3} \). The dust charging time [26, 27] inside the plasma chamber in the present set up is \( \sim \) few microseconds considering the plasma density and the electron temperature; whereas the time taken by a dust particle to cross the plasma volume under gravity is \( \sim 0.03 \) sec. So, the dust grains have enough time to reach the equilibrium charge state within the plasma well.

3.3 Result and discussion

3.3.1 Effect of working pressure on plasma parameters

Fig 3.4 and 3.5 show the plasma density and electron temperature profile at different discharge currents and working pressure for constant discharge voltage of 80 volt. The plasma parameters are calculated from the \( I-V \) characteristics of the Langmuir probe. As the working pressure increases, the plasma density increases gradually up to \( 4 \times 10^{-4} \) mbar and correspondingly electron temperature decreases which are due to the increase in
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electron–neutral collisions. Beyond $4 \times 10^{-4}$ mbar (up to $2 \times 10^{-3}$ mbar), the electron density and electron temperature get saturated.

Fig 3.4: Variation of plasma density at different working pressure

Fig 3.5: Variation of electron temperature at different working pressure
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The increase in working pressure enhances the electron density, ion density and neutral hydrogen species (atoms and molecules) in plasma volume as a result of which the different electron-ion and ion-neutral recombination reactions increase. Increase in electron density and reduction of electron temperature increases the electron diffusion. Due to combination of all the above effects, the plasma density gets saturated beyond 4 x 10^-4 mbar.

3.3.2 Effect of working pressure on EEPF

Different researchers observed that the shape of EEDF or EEPF for molecular gases (like N\textsubscript{2}, O\textsubscript{2}) is completely different and much more complicated than atomic gases. The EEPF for N\textsubscript{2} and O\textsubscript{2} plasma show nearly Maxwellian distribution at low pressures (between 10 and 30 mTorr) while the EEDF of the argon plasma is non-Maxwellian in this range by using a cylindrical Langmuir probe [28-31]. Some researchers observed some distinctive features of EEDF in N\textsubscript{2} and O\textsubscript{2} plasma, which consist of dips/peaks in the energy range of inelastic collisions [9, 32].

In the present work, the EEPF is presented in a semi-logarithmic scale, which is more informative and convenient [33]. The logarithmic plot a Maxwellian EEPF is a straight line [36] and a Druyvesteyn distribution is a parabola [34].

During the probe voltage scan, the change in the work-function of probe surface due to a change in probe surface temperature and surface contamination can distort the probe characteristics [33, 35]. Surface temperature can change due to changes in probe heating caused by electron current collection. This effect is more pronounced in high-density and chemically active plasmas.
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Godyak et al [6] suggest that when the probe scanning time \( T \) is very less than the probe thermal equilibrium time \( \tau \) (usually around 1 sec), then probe temperature and probe work-function remain constant. For such condition, the \( I-V \) characteristics of the probe is unaffected by the probe work-function. Fast probe scanning times, in the range of milliseconds or less, avoid the convolution effect caused by a change in the probe temperature [33, 35]. In the present experiment, a Langmuir probe system (Hidden analytical Ltd make) is used to evaluate the electron energy probability function (EEPF) [9]. The probe scan time of the Langmuir probe system is less than the probe thermal equilibrium time \( \tau \). Before each scan, automatically the probe is cleaned by applying a high positive voltage. So, the errors which are often occurred in the EEDF or EEPF measurements are considered to be very small in the present measurement.

![Graphs showing the EEPF at different working pressures](image)

**Fig 3.6:** Semi-log plot of EEPF at different working pressure
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Fig 3.6 shows the EEPFs of hydrogen plasma, in a semi-logarithmic scale, as a function of the working pressure which is normalized with the maximum value. It is seen that at low pressure (at $6 \times 10^{-4}$ mbar), a bi-Maxwellian EEPF is observed in the lower energy range (below 10 eV) with a larger high energy tail and some dips/peaks structure at the high energy range ($e > 10$ eV). The two-temperature EEPF structure at low pressure in the lower energy range (below 10 eV) is due to the presence of high energetic primary electrons that are emitted from tungsten filaments.

As the working pressure increases, the bulk temperature and the tail temperature seem to approach each other due to more collisions. At $2 \times 10^{-3}$ mbar, it is seen that the bulk temperature and the tail temperature become equal and the electron energy distribution function become single Maxwellian distribution in the lower energy range (below 10 eV). The population of high-energy electrons in the tail of the EEPF is depleted at higher pressure due to their frequent inelastic collisions with neutral hydrogen atoms. The electron–neutral frequency ($v_{en}$) increases with increase in the working pressure, which contributes to the disappearance of the bi-Maxwellian structure in the EEPF [30].

The frequency of $e-e$ collisions, $v_{ee}$ is proportional to $N_e^{-3/2}$. Godyak et al. suggested that for $N(<e>/e)^{-3/2}$ larger than approximately $10^{10}$ (cmV$^{1/2}$)$^{-3}$, the EEPF becomes Maxwellian [36]. It is seen from the Fig 3.7 that below working pressure $4 \times 10^{-4}$ mbar, the value of $N(<e>/e)^{-3/2}$ is very low compared to $10^{10}$ (cmV$^{1/2}$)$^{-3}$. Therefore, a distinct bi-maxwellian EEPF is observed below $4 \times 10^{-4}$ mbar.
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Fig 3.7: The values of $N \langle <e>/e \rangle^{-3/2}$ at different working pressure

From Fig 3.6, it is seen that the peak of the low energy electron group gradually increases with increasing working pressure whereas the high-energy electron group decreases with increasing working pressure. At lower pressure ($6 \times 10^{-5}$ mbar), some distinct peaks at the high-energy tail is observed. But at higher pressure ($2 \times 10^{-3}$ mbar), the peaks are comparatively less evident. As the working pressure increases, the primaries are degraded due to the frequent inelastic collision with neutral gas atoms [37]. The primaries are lost via gas collisions to become thermal electrons and the bulk of the primary energy is then deposited in the gas, which increases the efficiency of ionisation and resulting in a large increase in electron density.

Some dip structure is observed at high energy range ($e > 10$ eV) in the EEPF of hydrogen plasma. Such kind of dip structure is observed by Toader [9] in $N_2$ and $O_2$ plasma due to different inelastic collisions between electrons and molecular species.
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Different researchers explained that, there are five categories of correlation reactions in hydrogen plasma which are excitation, de-excitation, ionization, attachment and elastic collision reactions [21]. In low temperature hydrogen plasma, the degree of dissociation is very low. Also the collisional cross section of neutral hydrogen atom is smaller than the hydrogen molecule. As a result, the electron-hydrogen molecule collisions play dominated role than the electron-hydrogen atom collisions in hydrogen plasma. The inelastic collisions in such plasma can be divided into four categories. These are excitation, de-excitation, ionization and attachment reactions. The elementary processes of electron impact collisions with molecular hydrogen are given in TABLE 3.1 [38].

TABLE 3.1: Elementary processes of electron impact collisions with molecular hydrogen

<table>
<thead>
<tr>
<th>Elementary process</th>
<th>Threshold energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ( e + H_2(\Sigma_g^+) \rightarrow e + H_2^*(\nu) + e )</td>
<td>( \varepsilon_i = 15.4 )</td>
</tr>
<tr>
<td>2. ( e + H_2(\Sigma_g^+) \rightarrow e + H_2^*(\Sigma_g^+ \Sigma_u^-) + e \rightarrow e + H^+ + H(1s) + e )</td>
<td>( \varepsilon_i^{(\Sigma_g^+ \Sigma_u^-)} = 18; \varepsilon_i^{(\Sigma_g^+ \Sigma_u^-)} = 26 )</td>
</tr>
<tr>
<td>3. ( e + H_2(\nu = 0) \rightarrow e + H_2^*(\nu = 1,2,3) )</td>
<td>( \varepsilon_i^{(\nu = 1)} = 0.5; \varepsilon_i^{(\nu = 2)} = 1; \varepsilon_i^{(\nu = 3)} = 1.5 )</td>
</tr>
<tr>
<td>4. ( e + H_2(\Sigma_g^+) \rightarrow e + H_2^*(B\Sigma_u^+ 2p\sigma) )</td>
<td>( \varepsilon_i^{(B\Sigma_u^+ 2p\sigma)} = 11.37 )</td>
</tr>
<tr>
<td>5. ( e + H_2(\Sigma_g^+) \rightarrow e + H_2^*(C\Pi_u^- 2p\pi) )</td>
<td>( \varepsilon_{exc}^{(C\Pi_u^- 2p\pi)} = 11.7 )</td>
</tr>
<tr>
<td>6. ( e + H_2(\Sigma_g^+) \rightarrow e + H_2^*(E,F\Sigma_g^+) )</td>
<td>( \varepsilon_{exc}^{(E,F\Sigma_g^+)} = 12.2 )</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Reaction</th>
<th>Energy Dissipation</th>
<th>( e_{\text{diss}}^{(h)} )</th>
<th>( e_{\text{diss}}^{(b)} )</th>
<th>( e_{\text{diss}}^{(c)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. ( e + H_2(X^1\Sigma_g^+) \rightarrow e + H_2^*(b^3\Sigma_u^+, a^3\Sigma_g^+, c^3\Pi_u) \rightarrow e + H(1s) + H(1s) )</td>
<td>( e_{\text{diss}}^{(h)} = 8.5 )</td>
<td>( e_{\text{diss}}^{(b)} = 11.7 )</td>
<td>( e_{\text{diss}}^{(c)} = 11.7 )</td>
<td></td>
</tr>
<tr>
<td>8. ( e + H_2(X^1\Sigma_g^+) \rightarrow e + H_2^*[i\sigma_{s_g}, nl\lambda^h</td>
<td>\Lambda] \rightarrow e + H(1s) + H^*(2s) )</td>
<td>( e_{\text{diss}}^{(h)} = 14.9 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. ( e + H_2(X^1\Sigma_g^+) \rightarrow e + H_2^*[i\sigma_{u_g}, nl\lambda</td>
<td>\Omega^h_2\Pi_u] \rightarrow e + H^<em>(2p) + H^</em>(2s) )</td>
<td>( e_{\text{diss}}^{(h)} = 23 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. ( e + H_2(X^1\Sigma_g^+) \rightarrow e + H_2^<em>[2p\sigma_{u_g}, n = 3] \rightarrow e + H(1s) + H^</em>(n = 3) )</td>
<td>( e_{\text{diss}}^{(h)} = 19 )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The inelastic collisions of electrons with hydrogen molecules and the presence of different hydrogen species like \( \text{H}^+, \text{H}_2^+, \text{H}_3^+, \text{H} \) etc plays a significant role on the shape of the EEPF. In the present experiment, two distinct dips at the high energy range in the EEPF are observed in all working pressures (Fig 3.6). The dip structures between 10-15 eV may be responsible for the reaction 4 - 8 and the dip structure between 20 - 25 eV may be due to the reaction 2, 9 and 10.

### 3.3.3 Effect of working pressure on dust charging

The normalized dust charge at different working pressure is shown in Fig 3.8. The charge accumulated on micron sized tungsten dust is calculated using the equation 3.2. To calculate the dust charge using capacitance model (equation 3.2), the dust surface potential is estimated numerically using the equation 3.3. From the Fig 3.8, it is seen that the magnitude of the dust charge follows the same trend with electron temperature (Fig 3.5). It is seen that the magnitude of the dust charge gradually decreases up to the working pressure...
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4 x 10^{-4} \text{ mbar}. Beyond 4 x 10^{-4} \text{ mbar}, the dust charge gets saturated. It indicates that the dust charge strongly depends on the electron temperature rather than plasma density.

Fig 3.8: Dust charge at different discharge conditions

For better confirmation about the effect of working pressure on dust charging, the charge in terms of current carried by the dust grain is measured experimentally with the help of a Faraday cup and electrometer. The dust particles are negatively charged by the electrons and decharging process [41-43] of dust particles can occur either through ion flux or secondary electron emission due to the impact of electrons, ions, UV-photons, fast atoms or by the effects like thermionic emission or field emission. Since tungsten dust is used in the present work, so the secondary electron emission from the dust grain is not possible [44] for the present experimental conditions. Photoemission becomes important when the dust is exposed to UV radiation. Photoelectric charging of dust can be the dominant
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charging mechanism for dust in many astrophysical situations [45]. These effects are insignificant in the present experiment.

In the present experiment, steady-state continuous plasma is created inside a magnetic cage in multi-cusp configuration. Plasma density inside the magnetic cage is almost uniform due to having large field free region, basic characteristics of multi-cusp configuration. As the plasma is confined by the cups magnetic field and the Faraday cup (FC) is placed just below the magnetic cage i.e. outside the plasma, so the plasma density in the region between the magnetic cage and FC is insignificant. Thus, the discharging processes are considered as negligible in the present experimental conditions.

The current carried by the dust grain is presented in normalized scale (Fig 3.9) to show relative effects for different cases and also to minimize the error due to the minor fluctuations of the dust charge in the plasma volume as well as outside the plasma column.

![Normalized dust current vs. Working pressure](image)

**Fig 3.9: Dust current at different discharge conditions**
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From the Fig 3.9, it is seen that the dust current follows the trend with the dust charge. It is found that the current carried by the dust grains decreases abruptly upto the working pressure $4 \times 10^{-4}$ mbar. Beyond $4 \times 10^{-4}$ mbar, the dust current gets saturated. It is seen that there is a good agreement between charge accumulated on dust grains calculated from the capacitance model and the experimentally observed dust current data.

3.3.4 Effect of dust on EEPF

Fig 3.10 shows that the EEPF with and without dust grains in plasma for discharge current = 100 mA. To study the effect on EEPF due to the presence of dust, the EEPF is considered up to the first dip of the high energy range.

It is seen from the Fig 3.10 that the bulk electron peak of the EEPF slightly decreases and the high-energy tail becomes slightly larger in presence of dust grains than the pristine plasma. Some researchers observed that the distribution of the high and low-energy electron population changes with the dust number density [13, 39]. Different researchers observe similar behavior in EEPF study in presence of dust grains in plasma [11, 13 and 40]. This can be attributed to the collection of plasma electrons by the dust grains on their surface, leading to a higher loss of bulk electrons in the complex plasma compared to pristine plasma. Because of collection (due to inelastic electron-dust collisions) of electrons by the dust, the overall electron loss increases and the system then self-organizes to maintain a balance between the production and loss of electrons by increasing the number of high-energy electrons. This increase of the tail electrons in the EEPF can be associated with a rise of the electric field ($E_p$) sustaining the plasma. As a result, the fraction of high-energy electron in the EEPF tail enhances comparatively.
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Fig 3.10: Semi-log plot of EEPF without/with dust at different working pressure

3.4 Conclusion

From the observations, it is found that as the working pressure increases, the plasma density increases gradually up to $4 \times 10^{-4}$ mbar and correspondingly electron temperature decreases. Beyond $4 \times 10^{-4}$ mbar (up to $2 \times 10^{-3}$ mbar), the electron density and electron temperature gets saturated. The EEPF of hydrogen plasma is presented in a semi-logarithmic scale. It is seen that at very low pressure (below $4 \times 10^{-4}$ mbar), a bi-Maxwellian EEPF is observed in the lower energy range (below 10 eV) with a larger high energy tail and some dips/peaks structure appear at the high energy range ($e > 10$ eV). When the working pressure increases, the bulk temperature and the tail temperature seem to approach each other and at $2 \times 10^{-3}$ mbar, a single Maxwellian distribution is observed in the lower energy range (below 10 eV). The dip structures between 10 - 15 eV and between
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20 - 25 eV may be due to the different inelastic collisions of electrons with hydrogen molecules and different hydrogen ion species.

The dust charging profile is demonstrated for different working pressures. It is found that the dust charge strongly depends on the electron temperature. The effect of plasma density on dust charging is not significant in low pressure plasma. For dust accelerator which is generally used to investigate the hypervelocity dust impacts onto various materials, higher dust charging is preferable. It is observed that low working pressure is preferable for higher dust charging.

The presence of dust grains in plasma changes the shape of the EEPF. From the observations, it is seen that the number of high-energy electrons increases with respect to the number of the mid-energy range electrons in presence of dust grains. It indicates that the addition of dust grains to plasma can efficiently thermalize the plasma.

3.5 References


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