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Investigation on the electron energy distribution in the equatorial plane of the plasma confined by a dipole magnet

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The dipolar magnetic field confines the plasma in a unique pattern, giving rise to a wealth of physical phenomena such as particle transport, fluctuations, excitation of waves, and instabilities resulting from its collective particle motion. These phenomena have been studied over a wide range of observations - from the large-scale confinement in planetary magnetospheres such as those of Earth and Jupiter to laboratory experiments worldwide. However, there are hardly any experiments that carried out detailed spatial measurements of fundamental plasma parameters such as plasma density (N_e), electron temperature (T_e), and electron energy distribution function (EEDF). Although EEDF has been studied in various plasma confinements like tokamak plasma [1], inductively coupled plasma [2], rf plasma [3], multi cusp confined plasma [4], the nature of the EEDF in a dipole plasma is yet to be explored, whether it belongs to one of the standard distributions such as Maxwellian, Druyvesteyn, or F4 distributions [5], or is of a different nature. It should be borne in mind that the dipole magnetic field goes as $1/r^3$, and therefore the plasma is relatively unmagnetized as one moves outward from the central magnet. More importantly, the EEDF at different spatial locations in the dipole plasma needs to be explored, which will help in the understanding of the particle energies and rates of processes such as ionization, recombination, and diffusion.

We have recently carried out a detailed spatial (radial and polar) profiling of N_e and T_e in a compact laboratory dipole plasma created using a single permanent magnet [6], including investigation of diffusion induced transport. Using these profiles, it was reported that the dipole plasma follows primarily classical diffusion $(1/B^2)$ in the majority of available space.[7, 8] However, in the case of magnetized plasma, the diffusion coefficient (D) may have a scaling regime between the Bohm type diffusion $(1/B)$ and classical diffusion $(1/B^2)$, or maybe independent of B.[9,10] In the case of classical diffusion, the particles diffuse out of the plasma exhibiting random walk phenomenon, by a distance equal to one Debye length (λ_d) after executing one gyro-orbit. In such a situation, the particle encounters different particles on each orbit, and after the collision, they transfer energy and momentum to each other.[11] The energies of such particles are expected to be thermalized and follow the Maxwellian distribution. The possibility of classical diffusion was supported by our observations that $\omega_p > \omega_c$ and $r_{ce} > \lambda_d$ where ω_p is the plasma frequency, ω_c is the cyclotron frequency, r_{ce} is the electron gyroradius and λ_d is the Debye length [7].

To investigate the above, we report experimental measurements of the EEDF in the equatorial plane $(\theta = 90°)$ of the magnetized argon plasma confined in a stainless-steel spherical vacuum chamber of radius 25 cm, using a cylindrical NdFeB permanent dipole magnet of diameter 2.3 cm and height 4.1 cm. [7] A retarding field energy analyzer (RFEA) is used to obtain the EEDF at various radial distances (r). The experiments reveal that the plasma is Maxwellian until ~ r = 13 cm, and beyond this radial distance, the EEDF is close to a Druyvesteyn like distribution. The extent of the energy value (E_{max}) at which the experimental and standard EEDFs (Maxwellian, Druyvesteyn, F4 distributions [5]) overlap, is found to be high for the region of high plasma density (r = 4 to 8 cm) and high normalized local emissivity (until r = 9 cm). [12] The values of N_e, T_e, average energy ($\langle E \rangle$), calculated from the EEDFs will be presented, along with important process rates at different spatial locations in the dipole plasma.

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