Low jitter plasma channel in 3D printed gas filled capillary discharges

Thesis Presentation

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Table of Contents

Table of Contents

What plasma is?

Plasma is defined as an ionized gas of charged and neutral particles, which satisfies the quasi—neutrality condition.

figures/temp_and_states.png

Molecules in the gas dissociate to form a gas of freely moving charged particles — electrons and positive ions.

What plasma is?

So, Plasma is a mixture of electrons, ions, and neutral particles moving in random directions that on the average is electrically neutral ($n_e \simeq n_i$).
In addition, plasmas are electrically conducting due to the presence of these free charge carriers and can attain electrical conductivities larger than metals such as gold and copper.

Plasma characteristics

It is customary to classify a plasma in terms of its electron temperature (measured in eV) and electron densities (in cm^{-3}).

One electron volt is equal to approximately 11 600 K.

Electron densities in the range $10^6\,\mathrm{cm}^{-3}$ to $10^{18}\,\mathrm{cm}^{-3}$

Debye shielding length

Debye length, λ_D, determines the effective interaction between charged particles in a plasma.

$$\lambda_D = \sqrt{\frac{\varepsilon_0 k_B T_e}{n_e e^2}} = \sqrt{\frac{k_B T}{m_e}} \frac{1}{\omega_p}.$$

- Determined by the density and temperature of the plasma.

For a plasma with $T \approx 1\,\mathrm{eV}$ and $N_e \approx 10^{18}\,\mathrm{cm}^{-3}$, $\lambda_D \sim 7\,\mathrm{nm}$.
For any volume with a length scale L satisfying

$$L \gg \lambda_D,$$

overall quasi-neutrality is a good approximation.

Plasma Frequency

This is the typical electrostatic oscillation frequency of electrons in response to a small charge separation.

figures/plasma_oscillation.PNG

$$\omega_p = \sqrt{\frac{N_e e^2}{m_e \varepsilon_0}} \mathrm{rad/\,sec.}$$

For a typical plasma density of $N_e \sim 10^{18}\,\mathrm{cm}^{-3}$, we get $\omega_p = 5.6 \times 10^{13}\,\mathrm{rad/\,sec.}$

The plasma parameter

The plasma parameter Λ is defined as

$$\Lambda = 4\pi N_e \lambda_D^3.$$

It is a measure for the amount of electrons inside a sphere of radius λ_D.
Collective behaviour for plasmas in LWFA environments requires two criteria:

1. overall quasi-neutrality
2. hot plasma, yet underdense[1]— $\Lambda \gg 1$.

[1] Not yet presented.

Collective behaviour — Quantitative description

In an ionized gas there is a significant number of unbound electrons and electrically charged ions.

Although these electrons are unbound, they are *not* free.

When the gas is neutral, two–particle (binary) collisions are predominant.

In plasma, charged particles interact with other charged particles in a *Collective manner*.

A charged particle encounters the electrostatic forces from all the other nearby charged particles[2].

[2] The generated electromagnetic fields are regarded as properties of the plasma.

Collective behaviour — Quantitative description

Indside such a medium, diverse collective phenomena can occur. This allows for electron acceleration in laser–driven plasma wake–fields.

The Spectrum of Hydrogen

An electron making a transition between two energy levels emits a photon.
Hydrogen spectrum is divided into series, determined by the transitions to the final state.

- $n_i = 3 \rightarrow n_f = 2$, 656.3 nm — H_α
- $n_i = 4 \rightarrow n_f = 2$, 656.3 nm — H_β

figures/halphagrotrian.png

Both H_α and H_β are in the visible spectrum, and so are easy to observe.
Other series are Lyman ($n_f = 1$) and Paschen ($n_f = 3$).

The Spectrum of Hydrogen

Spectroscopy study of such emission can give information about the physical conditions in the plasma, such as density and temperature.
Advantage: No probes — no interferance in any way with the plasma.
Disadvantage: Radiation is collected only along the lone of sight in the direction of observation.

The emitted radiation process depends on:

The probability that

1. there is an electron in the upper level of the transition,
2. the electron transition is significant,
3. the emitted photon escapes from the volume of the plasma without being absorbed.

We neglect process (3) and use the approximation of *Optically thin plasma*.
Values of the transition probabily $A_{i \to j}$ for process (2) are tabulated[3].

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[3] See `https://physics.nist.gov/PhysRefData/ASD/lines_form.html` for example.

Optical Depth

Optically thin plasma

text

Local Thermodynamic Equilibrium(LTE)

Electrons are energy providers for many plasma-chemical processes. The rate of such processes depends on the number of electrons having sufficient energy to do the job. This can be described by means of the electron energy distribution function f (e), which is a probability density for an electron to have the energy e. Quite often this distribution function strongly depends upon the electric field and gas composition, and can be very far from equilibrium. Sometimes, however, (even in nonequilibrium plasmas of nonthermal discharges), the f(e) depends mostly on electron temperature Te, and can then be defined by the quasi–equilibrium Maxwell–Boltzmann distribution function:

Line Broadening

A perfectly sharp energy line is impossible, and thus there is a distribution of transitions from states near E_2 to E_1.

Table of Contents

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Some dummy text.