Principle of the Innsbruck Q-machine and investigations therein

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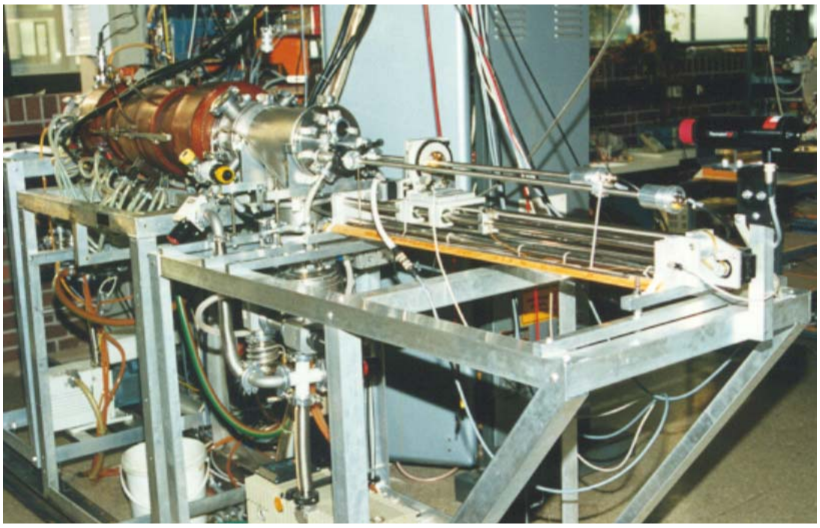
Introduction

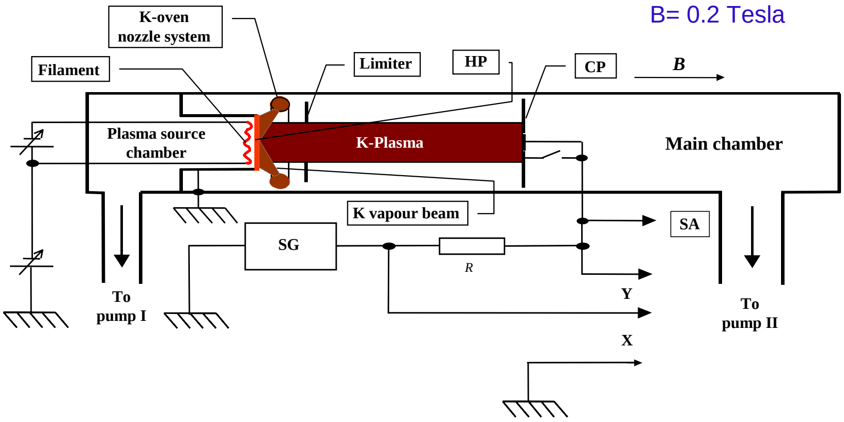
- In 1960, two independent groups, in America, developed sources to confine alkali plasmas magnetically, which was named Q-machines.
- The letter Q, means "quiescent" was chosen with the hope that a thermally produced plasma would be quiescent, or free from low-frequency instabilities.
- This expectation was not fully met, but allowed the study and discovery of basic low-frequency plasma wave modes.

Innsbruck Q-Machine



Schematic of the Innsbruck Q-Machine

$n = 10^6$-10^9 cm^{-3}
T= 0.2 eV
B= 0.2 Tesla



HP = hot plate, CP = cold plate, SG = signal generator, SA = spectrum analyzer

Creation of Plasma in Q-Machine

Ions are created in Q-Machine by contact ionization.

The hot plate is heated above 2000 Kelvin by electron bombardment from a filament. When chamber is evacuated down to 10^{-6} mbar, atoms from the oven strike the hot plate. The relation between the work function of the hot plate and the ionization energy of the atom forces the atom to surrender an electron to the hot plate, creating a source of ions.

Electrons are created by the thermionic emission of the hot plate.

Creation of Plasma in Q-Machine

Once the ions and electrons are liberated, a powerful magnetic field confines them and their motion is limited to a small column running down the length of the chamber. At the end of the chamber, the plasma column either terminates at a cold end plate, recombining the ions and electrons into neutral atoms (the **single-ended Q-machine**), or is reflected off of another hot plate, which serves as a second plasma source. (a **double-ended Q-machine**)

Creation of Plasma in Q-Machine

The ionisation probability P is

$$P = \left\{ 1 + \frac{g_n}{g_i} \exp\left[\frac{e(E_i - W_M)}{k_B T_M} \right] \right\}^{-1}$$

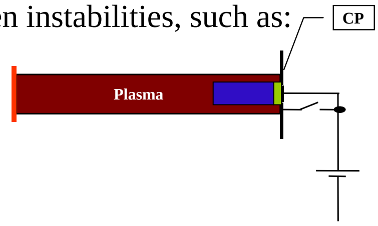
The density of the electrons produced from the hot plate is given by Richardson's law:

$$j_e = A^* T_M^2 \exp\left[-\frac{eW_M}{k_B T_M} \right]$$

A^* is Richardson's constant, $A^* = 4\frac{\pi m_e k_B^2 e}{h^3} = 121 \text{ A cm}^{-2}\text{K}^{-2}$

Important research work performed so far in the Innsbruck Q-machine

- Investigations of electron current-driven instabilities, such as:



- the **p**otential **r**elaxation **i**nstability (PRI), excited by an electron current through the *entire* plasma column towards the cold plate (CP),

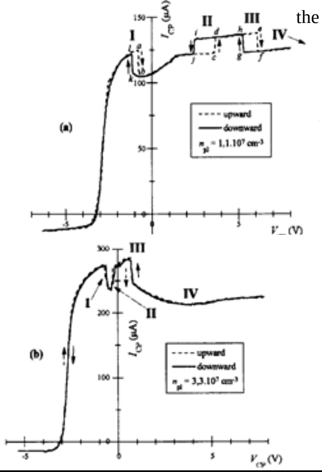
- the **e**lectrostatic **i**on-**c**yclotron **i**nstability (EICI), excited by an electron current through only a small current channel towards a collector. The current channel has to be surrounded by a sufficiently thick annular layer of unperturbed plasma.

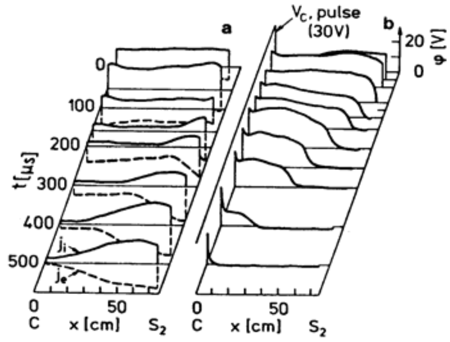
Both instabilities show a strongly nonlinear behaviour, both in the current-voltage characteristic and in their temporal evolution

The Potential Relaxation Instability (PRI)

Examples of the current-voltage characteristic of the system when the current flows through the entire channel towards the cold plate (CP).

Each current jump with hysteresis indicates the onset of the PRI or a strong change of the mode.





Temporal evolution of the ion and electron density profiles (LHS up – ion, down – electron) and of the plasma potential profile (RHS) during one period of the PRI.

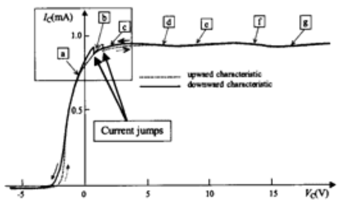
During each period of the PRI a space charge double layer propagates from the HP towards the CP, followed by a wave of fresh plasma.

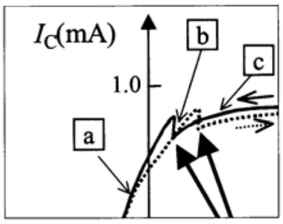
Hysteresis is always a sign of strong nonlinearity and of a kind of memory of the system.

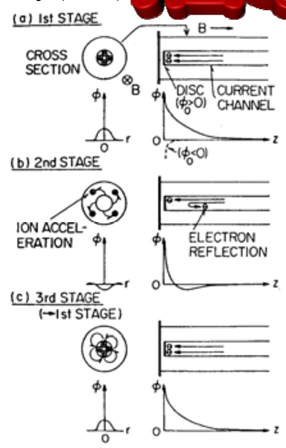
The Electrostatic Ion-Cyclotron Instability (EICI)

Examples of the current-voltage characteristic of the system when the current flows through only a small channel towards the collector.

Also in this case the hysteretic current jump indicates the onset of the EICI and thus of the increased







Schematic of the temporal evolution of ions and of the plasma potential profile inside the current channel during one period of the EICI.

During each period of the EICI a localized space charge structures appears in front of the collector, while the ions perform trochoid trajectories through the surrounding plasma. .

Future plans for the research in the Innsbruck Q-machine

Comprehensive investigations of complex space charge structures, as they have been observed in context with the two current-driven instabilities, in particular

- in front of the CP and the collector,
- in dependence on the pressure and the background gas,
- where the background gas can be e.g. potassium or sodium vapour, inert gases (He, Ar, Xe), or oxygen,
- in which case also optical investigations of the possibly emitted light and of absorption lines will be performed.

- References:

- Motley, Robert. *Q Machines*. Academic Press, London, 1975.
- Class notes of Dr. Roman Schrittwieser

Danke Schön