Preionization Studies for Toroidal High-Beta-Experiments+)

by

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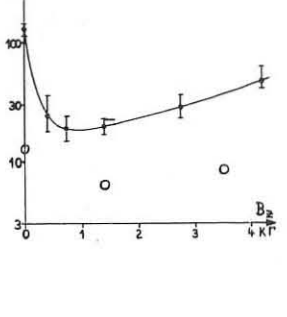
Abstract: Preionization is achieved in toroidal geometry by induced azimuthal currents. Favourable breakdown properties down to filling pressures of 3 mTorr D_2 and suitable preionization plasmas were established by application of a rf- predischarge and superposition of small azimuthal magnetic fields with only 10 kV potential difference around the 2 meter long torus circumference.

In the present studies preionization of deuterium was investigated in toroidal geometry for subsequent high-β experiments. A torus vessel with a major radius R = 30 cm and a smaller radius r = 5 cm was used. It was surrounded by a 1 mm thick copper shell, which was to simulate the current leads in case of a toroidal high-energy experiment. The preionization of the gas was achieved by azimuthal currents which were induced inside the torus by primary currents (I_z-currents) in two current belts. These two belts encircled the circumference of the torus outside the copper shell on the outer and the inner major radius, respectively. Shortening of induced currents in the copper shell was prevented by corresponding insulated slits. The primary I_z-currents in the belts were supplied by a bank of 16 kvolts charging voltage, which corresponds to 10 kvolts potential difference along the 200 cm long belts around the torus. This relatively low value was chosen to reduce the danger of adverse coupling of the preionization circuit to subsequent discharge circuits. The quarter period used was correspondingly relatively long. It had a value of 10 µsec and enabled sufficient breakdown in the same quarter period with delaytimes of up to 7 µsec. In addition to the induced currents azimuthal magnetic fields of up to 5 kGauss could be generated inside the torus by separate meridional windings and the corresponding B_z-bank. Finally, it was possible to investigate the breakdown behaviour of deuterium in the presence of a preceding 8-MHz-rf-predischarge. It was coupled into the torus by 8 pairs of loops around the smaller diameter of the torus vessel, which were equidistantly distributed along its circumference. The average peak to peak voltage of these rf-oscillations was 10 kV.

A) Breakdown properties of the toroidal discharges.
The distribution of the electric fields inside the torus vessel before breakdown corresponds to the equivalent situation in the thetapinch geometry, which was discussed, e.g., by Chodura et al. (1). It results from the superposition of the curl-field due to the increasing I_z-currents and of the electric potential field from the charges on the surface of the electric lead outside the torus vessel, which in the present arrangement is the copper shell rather than the current belts. The azimuthal curl-field contribution, which provides a longer path for the charges inside the torus for further ionization, is established only after the potential field is screened on the inner vessel surface by charge carriers initially formed.
The breakdown characteristics of the discharges investigated, i.e. the relationship between deuterium filling pressure p_o (mTorr) and delay time Δt (µsec) between start of the I_z-currents and actual breakdown, are summarized to a first approximation by the relationship:

$$p_o \cdot \Delta t = \text{const.}$$

In this representation any correction is omitted such as proposed by Malesani and Newton (2). The experimental results are shown in the diagram. The plotted values connected by the solid line refer to the case where no rf-predischarge was applied. They indicate:



(i) The hyperbolic relationship cited gives a suitable representation of the results, which were obtained for filling pressures from 50 mTorr on downwards.
(ii) At complete absence of superimposed magnetic fields breakdown with delay times $\Delta t \leq 7$ µsec could only be achieved for filling pressures $p_o \geq 15$ mTorr.
(iii) Application of small B_z-fields improved the breakdown behaviour considerably: At B_z = 700 Gauss breakdown occured for $p_o \geq 3$ mTorr D_2. This can be understood from an extended presence of accelerated charge carriers inside the torus volume before they are lost for ionization processes by wall contact.
(iv) At higher B_z-fields the breakdown behaviour worsened again. This is attributed to the fact that screening of the electric potential field on the inner vessel surface by charge carriers is increasingly impeded by the higher azimuthal B_z-fields.
Also shown in the diagram are some results where the discharge was preceded by the 8-MHz-rf of 10 µsec duration. A substantial improvement was observed in this situation, e.g. even in the absence of any B_z-field breakdown did now occur for $p_o \geq 5$ mTorr. The duration of the rf-predischarge had only a minor effect on this improvement when longer than 2 µsec. The simple hyperbolic relationship cited, however, is no longer valid: At higher filling pressures breakdown occured together with the start of the I_z-currents, whereas at low p_o-values breakdown rapidly failed. Since only small amounts of impurities were found liberated by the rf-discharge the observed improvement in the breakdown properties is interpreted as an enhanced screening of the potential field by additional charges formed in the rf-oscillations.

B. Properties of the toroidal preionization plasmas.
Without superimposed B_z-fields the plasma was compressed after breakdown to a current channel of about 2 cm diameter which became unstable after 2 µsec. After this moment the impurity level rapidly exceeded values of 1 %. In order to avoid this undesired behaviour of the plasma two measures have been taken:
(i) A crowbar in the primary I_z-current circuit 1 µsec after achieved breakdown provided a limitation of the rapidly increasing plasma current to values between 15 and 20 kAmps.
(ii) As was indicated already, it was tried to reach a stable equilibrium position of the toroidal preionization plasma by superposition of azimuthal magnetic fields.

Probe measurements of the B_z- and B_θ- fields in the plasma gave evidence that even small superimposed fields of B_z = 400 Gauss were sufficient to attain a stable plasma in the torus when the crowbar in the primary I_z-circuit was used. In this case the plasma current flowed fairly homogeneously across about 2/3 of the diameter of the discharge vessel such that the copper walls could support stabilization of the toroidal plasma column. The ionization degree achieved was derived from the $D\beta$(4860) - line profile and was found to be α = 0.7 at 15 µsec after breakdown for p_o = 15 mTorr. The plasma temperature was then estimated to be below 1 eV from the electron density values obtained and from the absolute intensity of the $D\beta$- line. The impurity level from carbon and oxygen contaminations was of the order of 0.1 %. Application of a preceding 8-MHz-rf predischarge did not alter the above findings, except that the impurity level increased to about 0.2 % at 5 µsec rf-duration and 0.8 % at 20 µsec rf-duration.

(1) Chodura,R., Keilhacker,M., Zs.Naturf. 17a, 977 (1962)
(2) Malesani,G., Newton,A.A., Paper on this conference (1970)

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