Confinement of Photo-Ionized Plasma in the Wendelstein $\ell = 2$ Stellarator (W IIa)

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Abstract: Photoionization of a neutral barium beam provides a steady state point like plasma source for the W IIa stellarator. The resulting confinement properties equal essentially those obtained with contact ionization on a tungsten sphere present in the confinement volume.

The previous experiments (1,2) in our stellarator were carried out using a Barium plasma, generated by contact ionization on a hot tungsten sphere of 3 mm diameter. This sphere, suspended by 2 wires, each 10 μm thick and positioned on the magnetic axis, was heated by laser radiation to 2.300°K. We now wish to report on the confinement of the same type of plasma, but generated by Photo-ionization. Several reasons made it necessary to change the production mechanism to this method:
Up to now, for example, it could not be ruled out completely, that the presence of the hot sphere within the plasma might have damped instabilities by line-tying for example, thus being responsible for the long confinement times observed. Secondly, it was impossible, to decide whether the observed minima in the iota-dependence of the confinement time are a particular stellarator quality or if they are generated by the sphere-suspending wires which could originate convective cells, for instance. In addition to this the presence of the electron emitting sphere inhibits a heating of the plasma due to the very intense thermal coupling between sphere and plasma. For the benefit of better comparison with the former experiments we imposed several conditions on the new plasma source: Barium-plasma should be produced again, d.c.-operation would be desirable, the source region should approach a point source on the axis and the interaction between the ionizing mechanism and the plasma already produced, should be negligible. These requirements rule out any ionization by electron impact, for example, and therefore the application of r.f.-fields. However, crossing a beam of neutral Barium-vapor with an intense light beam provides a plasma source with the desired qualities. When looking for a d.c. light source of sufficient intensity in the relevant spectral range, two possibilities of approach have to be considered. At first, one could excite the metastable levels of a certain percentage of the Barium atoms by running the beam through a gas discharge, before entering the stellarator, or as suggested by E. Hinnov, by resonant charge exchange between neutral Rubidium atoms and Barium ionbeam. In this case the threshold wavelength for ionization is about 3.200 Å (3,4) and it is easy to find an intense light source in this region, a Xenon high pressure arc, for instance. The other possibility is the ionization from ground state. Here the threshold wavelength is 2.380 Å and most of the d.c.-light sources show only poor emission in this spectral range. Therefore one would be inclined to chose the ionization via an enhanced metastable population. But since the generation of this enhanced population, too, turned out to be technically not easy, ionization from ground state was selected as a first attempt.

The light source used was a Maecker-type high power cascade arc (5) running in Argon. (Fig. 1). Typical operating conditions were 1 atm. Argon pressure, 900 Amperes and 110 Volts, resulting in 10 kw/cm arc length.

Fig. 2 gives a schematic drawing of the stellarator W IIa. The important changes are: no probes used anymore, the sphere being removed, and the heating lamp replaced by the cascade arc. Also the measuring circuit for the ion input flux had to be changed slightly. After having removed the sphere the two retractable spoon probes were used as a double probe. If they are aligned with respect to the source volume by virtue of a magnetic field they represent the only essential plasma sink and under those conditions the ion input flux can be deduced from their saturation current. It was checked that the ion collecting spoon did not emit any measurable amount of secondary electrons by photon-bombardement. Unfortunately, it turned out that the saturation of the ion current was not as satisfactory as expected so that there remained a slight uncertainty of about ± 30 % in the magnitude of the ion input flux.

A low base pressure is required, otherwise the ions are cooled down to room temperature due to ion-neutral collisions. This cooling would increase the classical diffusion rate, resulting in a lower peak density, as compared to the earlier measurements. However, the peak density will be reduced anyway because of the increased cross section of the source region. In addition, the Bohm loss rate is decreased due to the lower temperature. The difference between Bohm and classical loss rate is therefore reduced by one or two orders of magnitude. Fig. 3 shows a preliminary plot of the ion density, as obtained with photo-ionized Barium, versus the angle of rotation transform . For an input ion flux of 10^{11} ions/sec. one would expect a density of 10^6 cm^{-3} from Bohm-diffusion, whilst from classical theory one estimates 3.10^7cm^{-3}. This measurement yielded a density of $1,6 \times 10^7$cm^{-3}, one order of magnitude more than the Bohm value and in fair agreement with classical theory. Qualitatively one observes the well known behaviour of the density as a function of iota; i.e., strongly pronounced minima of the confinement time at the rational values of ι. This strongly supports the conclusion, that our previous results with the sphere do indeed reflect general properties of our stellarator and are not caused by the sphere. Furthermore, those plasma loss processes connected with the rational values of ι, are investigated and which reduce the peak density for some orders of magnitude. Because of the short confinement time in this case, probe measurements do induce negligible further losses and thus can be used for obtaining detailed information of the flow pattern.

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Work was performed in association with Euratom.

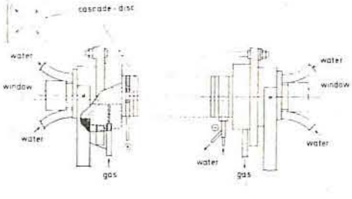

Fig. 1: Cascade arc arc-diameter 10 and 15 mm

"Maecker"-cascade-arc

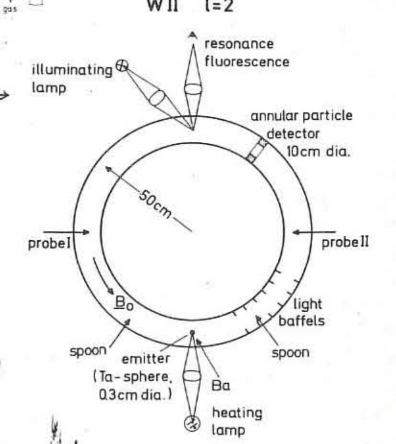

Fig. 2: Schematics of the experimental setup

Fig. 3: Density vs iota Base-pressure $p \approx 8.10^{-6}$ input-flux ca. 10^{11} ions/sec.