Absolute Measurement of Radiation Losses from a Theta Pinch Plasma in the Wavelength Region from 10 to 200 Ångstroms [+)]

by

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Abstract: A calibration procedure of a grazing-incidence spectrograph is described to allow for measurement of the radiation losses from a theta pinch plasma. The losses turn out to be small compared to both the electron energy content and to heat conduction losses.

1. Introduction There is lots of experimental evidence for the limitation of the electron temperature in linear theta pinches by energy losses /1/. One of the possible loss mechanisms are radiation losses by impurities within the plasma. According to the plasma temperature most of the radiation is emitted in the grazing-incidence region from about 10 to 200 Å. Because of the little knowledge of ionization and excitation cross sections, especially for more complicated ions, predictions on radiation losses from such a plasma are only possible within one order of magnitude accuracy. In order to get more accurate information the radiation from the plasma has to be measured.

Measurements therefore were performed on a linear theta pinch device (Isar II) having a stored energy of 200 kJ, a maximum magnetic field of 52 kG, and a 2.75 µsec quarter period. Coil length and diameter measured 100 cm and 10 cm. Typical plasma parameters were: $n_e = 1\text{-}4\cdot 10^{16}\,cm^{-3}$, T_e= 200-300 eV, T_i = 0.5-3keV.

2. Calibration procedure of the Spectrograph The spectral resolution was obtained by use of a grazing-incidence spectrograph with either photographic plates or scintillator/multiplier combinations as detectors. For relative calibration of the instrument advantage was taken from ratios of lines from hydrogen-like ions such as CVI, NVII, OVIII being emitted from the plasma. Within either the Balmer series (76-182 Å) and the Lyman series (15-34 Å) line ratios were calculated by assuming corona equilibrium. The relative sensitivity of the apparatus was gained in these two wavelength intervals from the measured photographic densities. The intervals were then connected by branching ratios. For that the first Balmer line and the second Lyman line were suited since both start from the same level n = 3. A difficulty was the fact that the sublevels of level n = 3 showed deviations from statistical population which the branching ratios had to be corrected for. The correction was enabled by measurement of the intensity ratios of the fine structure components of the Balmer line. The relative calibration of the instrument, thus gained, could be well confirmed (within 20 % accuracy) by checking with known intensity ratios of lithium-like ion lines emitted by the plasma. The branching ratios 2S-3P/3S-3P of these ions finally allowed to hang the grazing-incidence spectrograph absolutely on a monochromator absolutely calibrated for the 3S-3P OVI line at 3811 Å. Usually the lines used were optically thin, with few exceptions, which could be corrected by extrapolating their optical thickness by seeding impurities of known amount.

3. The Results of Radiation Loss Measurements. Using the calibrated instrument the time integrated total energy losses were measured for different added impurities at filling pressures of 40 mtorr deuterium. Normalized to 1 % seeded impurity concentration the following radiated energies were obtained: carbon 27.7 J (CVI:24.9 CV:2.8), nitrogen 14.1 Joule (NV:0.95 NVI:5.1 NVII:8.0), oxygen 21.1 J (OVI:4.4 OVII:14.1 OVIII:2.6). No distinct dependence on the kind of the seeded impurity became evident. The distribution of the radiated energy on the different ionization stages of the atoms however showed characteristic features. The lighter the atom, the higher is the ionization stage by which most of the energy is radiated. Comparing these total energy losses, for example at 40 mtorr filling pressure, with the energy content of the electrons ($n_e=4\cdot 10^{16}\,cm^{-3}$, T_e=200eV) they turn out to amount to 6 % only. Thus radiation cooling does not affect the electron temperature as long as the impurity concentration does not exceed 5 %.

Values for radiation losses from discharges without seeded impurities for different filling pressures and cases with bias field included are summarized in table 1. For 40 mtorr filling pressure and zero bias field the natural contamination is 0.085 % oxygen, 0.095 % carbon, and 0.0025 % nitrogen. For other pressures it is of the same order of magnitude and in any case smaller than 0.5 %. Only for low filling pressures and with bias field the more intense wall contact at the beginning of the discharge leads to unreproducible contamination and therefore often to larger energy losses. The contribution of free-free and free-bound continuum radiation to the losses is way below that of the line radiation.

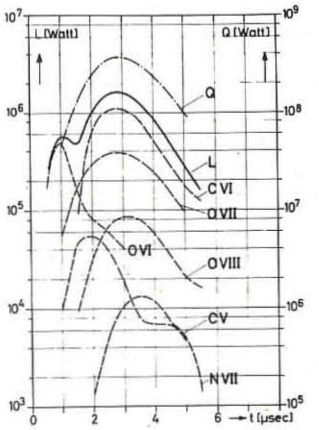

Figure 1 Radiation losses L and thermal conduction losses Q (p_o= 40 mtorr, B_o= OG, no impurity added)

In fig. 1 the time dependence of the radiated power is displayed as determined photoelectrically. Absolute calibration stems from comparison of the time integrated power of a line with its photographic density on the plate. Losses by the thermal conduction estimated according to a model proposed by Green et al. /1/ are included in fig. 1. They exceed the radiation losses by a factor of 100 throughout the discharge. Except for impurity concentrations larger than 5 % the power radiated can exceed thermal conduction, predominantly by the ion OVI. These results agree essentially with measurements of Bodin et al. /2/.

References:

/1/ T.S. Green et al., Culham-Report CLM-P 124 (1966)
/2/ H.A.B. Bodin et al., Culham-Report CLM-P 198 (1969)

P_o mtorr	B_o G	oxygen	nitrogen	carbon
		Energy in Joule		
11	0	1,3	-	0.14
	500	19.0	0.017	0.035
17	0	5.0	0.012	1.3
	500	55	0.025	0.15
40	0	1.8	0.046	2.4
	500	14	0.025	0.73
80	0	1.0	0.056	2.3
	500	28	0.097	0.64

Table 1 Radiation losses under different initial conditions. No impurity added.

+) This work was performed as part of the joint research program between the Institut für Plasmaphysik, Garching and Euratom.