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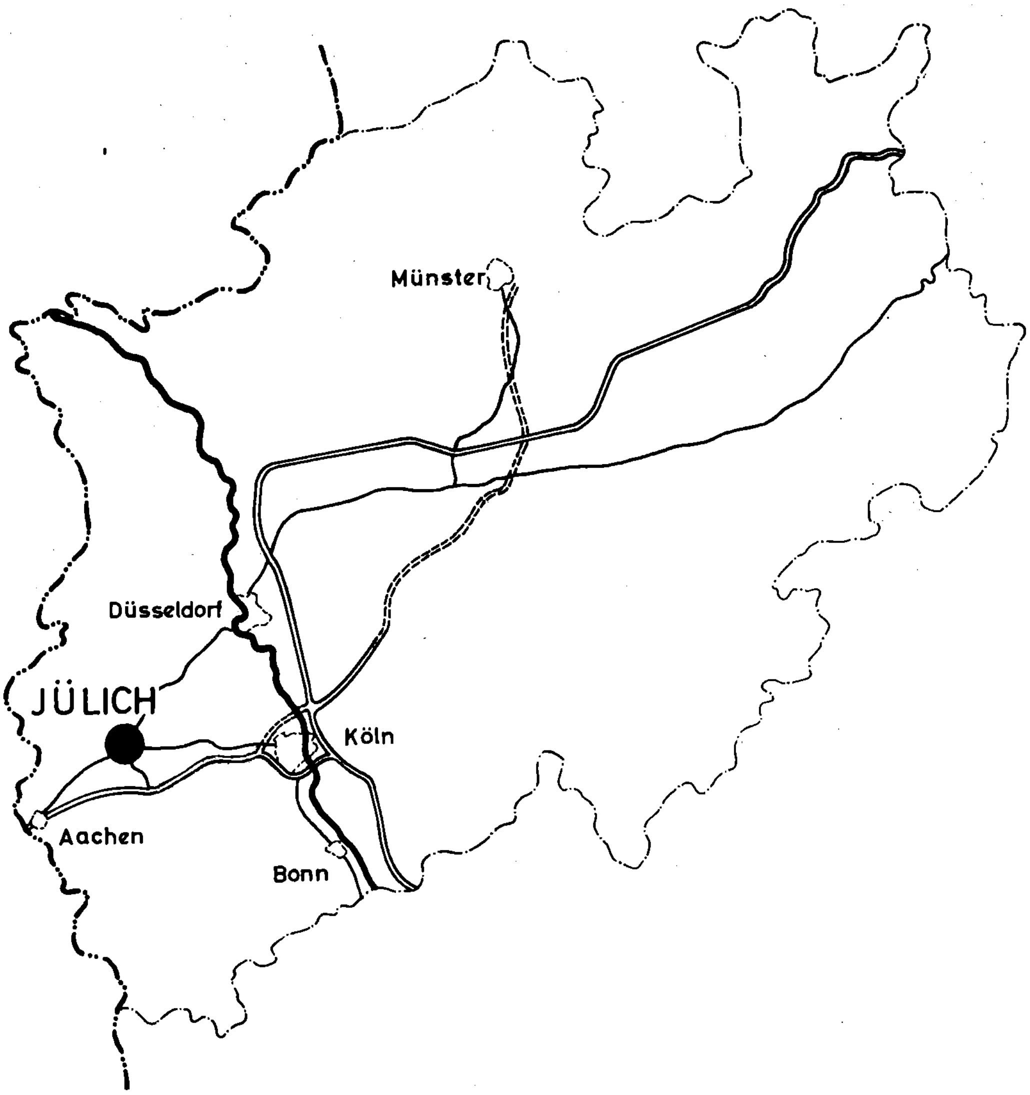

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Investigations on a Pulsed Electrodeless Ring Discharge with Magnetic Bias Fields of Different Amplitudes

by

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Deutschland

Abstract: The formation of a plasma in an electrodeless ring discharge with a steady magnetic bias field of different amplitudes was investigated. Internal and external magnetic fields and the intensities of suitable spectral lines were measured. The temporal behaviour of the discharge was observed with a streak camera. It was possible to measure the electron temperature and to estimate the electron density in interesting time intervals.

The results show that the obtained electron temperatures essentially depend on the initial magnetic field. This is caused by different amounts of trapped field in the first current halfcycle, which give high magnetic field gradients in the second current halfcycle. End losses are also strongly influenced by the presence of a steady magnetic field.

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1. Introduction

One method to produce a high density, high temperature plasma makes use of the rapid compression of a preheated deuterium gas by axial magnetic fields. These magnetic fields are usually generated by the discharge of a low inductance condenser bank through a cylindrical, single turn coil. During the last year at this laboratory experiments were performed with the object of preheating the gas by a pulsed electrodeless ring discharge which is generated by the same coil. It could be shown[1,2] that with a simple experimental arrangement electron temperatures of about 2 eV and almost complete ionization in a pressure range from 50 μ - 500 μ could be obtained. A special advantage of this type of discharge is that the impurity level of the plasma proved to be very low.

Further investigations on this electrodeless ring discharge were made with an additional steady magnetic bias field. Some preliminary results of this work, concerning the formation and subsequent decay of the plasma due to end losses and recombination, are communicated in this paper.

2. Diagnostic Methods

For the formation and the decay of the plasma, electron temperature and electron density are of main interest. An estimate of these quantities can be obtained by observation of the intensities of suitable spectral lines and by smear camera pictures of the discharge. Magnetic probe measurements can give additional information on the heating mechanism and on the homogeneity of the plasma.

Above 2 eV the electron temperature can be determined by measuring the relative intensities of the C II (4267 A) and C III (2297 A) lines. The calibration of the optical system and of the photomultipliers, and the elimination of the transition probabilities was performed by the Fowler-Milne nethod, as described in 1).

For this method a rough estimate of the electron density is necessary. Assuming complete ionization this estimate can be obtained by measuring the compression ratio of the plasma by means of smear camera pictures.

Below 2 eV a simple estimate of the electron temperature can be made at the intensity maximum of $H_ß$, assuming that the plasma at this time is not being compressed. At this temperature recombination begins to be important.

3. Experimental Arrangement

The gas is contained in a quartztube of 600 mm length and 40 mm diameter, which is surrounded by a single turn, cylindrical coil. This coil is connected to two separate banks, one of which generates the steady magnetic field, the other one the alternating magnetic field. A diagram of the electrical circuit is shown in fig.1.

The current generator for the steady magnetic field is an artificial delay line which is terminated by its impedance, thus producing a nearly rectangular current pulse. The duration of the pulse is about 100 μ s, the rise time 4 μ s and the maximum amplitude of the current 36 000 A, the maximum B-field correspondingly being 3 000 Gauss. By the discharge of C_1 an oscillating magnetic field with a maximum amplitude of 5 000 Gauss, an oscillation frequency of about 900 kcs per sec and a damping constant of 2.6 μ s is generated. The maximum voltage at the coil is about 5 kV.

The experiment is operated in the following way. The gas is first preionized by a 500 watt, 10 Mc/s RF generator, then F_2 is fired and after a delay of 25 μ s the condenser C_1 is switched on the coil. The discharge then starts when the magnetic field has reached its full amplitude.

Magnetic field measurements are made with a steel shielded probe of 1 mm total diameter. The probe is inserted radially into the discharge tube and can be moved continuously along a diameter of the tube for the measurement of the magnetic field distribution.

The optical arrangement is shown in fig.2.

The plasma radiation passes through a slit perpendicular to the axis of the compression coil and is focussed by a system of mirrors on the entrance slits of two Bausch and Lomb monochromators, each of which has a photomultiplier attached to its exit slit. Time integrated spectra were obtained with a quartz spectrograph simultaneously end on and side on.

End on smear camera pictures were taken from the discharge with a Beckmann 339 streak camera.

4. Results

The following measurements have been made mainly with steady magnetic fields of 1 200 and 2 400 gauss at an initial pressure of 230 μ D_2 and H_2. In order to get favorable conditions for the breakdown of the gas during the first halfcycle of the alternating field, the two banks were charged up with opposite polarity.

Some characteristic features of this type of discharge can be understood from fig.3, which shows a typical set of measurements at an initial pressure of 230 $/u$ H_2 with a steady magnetic field of 1 200 gauss. The gas breaks down shortly after the voltage at the coil has reached its maximum, and a hollow plasma cylinder is formed near the walls. However, due to the low conductivity at this early stage of the discharge, the external magnetic field penetrates through the plasma. At the start of the second current halfcycle this field stays trapped.

Shortly after the second maximum of the external magnetic field, the magnetic field on the axis changes its direction very rapidly. At this time there must be high magnetic field gradients in the plasma, indicating strong currents. Simultaneously the C III line appears, showing that at this time the plasma is fully ionized at least in the zone of highest temperature. The dissipation of the trapped reverse field energy is accompanied by a compression of the plasma. In the subsequent half cycles the distribution of the magnetic field is strongly inhomogeneous, as magnetic probe signals show. These complicated phenomena due to field diffusion and dynamic effects will not be considered.

In contrast to this, rather clear conditions are met in the time interval from 0.9 - 1.4 μs. Magnetic probe signals show that the magnetic field distribution has a simple structure and streak camera photographs allow a good identification of the radiating zone. Therefore at this time it is possible to measure the electron temperature and to make an estimate of the particle density with a simple experimental technique.

Fig.4 shows photomultiplier traces of the C II and C III lines, and the temporal development of the electron temperature derived from their relative intensities. At the indicated high temperature the plasma should be almost fully ionized and with this assumption one obtains from the initial density and the compression rate an estimate of the actual electron density.

In the same way the electron temperature was measured for other interesting experimental conditions. The results are:

	1 200 Gauss	2 400 Gauss
D_2	32 500 ^oK	27 500 ^oK
H_2	29 000 ^oK	25 500 ^oK

Both, spectroscopic and magnetic field measurements indicate that with the experimental conditions mentioned plasma and magnetic field are uniformly distributed across the diameter of the discharge tube after about 9 μ s. As pointed out before, with this assumption a maximum of H_β intensity should be expected. Fig.5 shows the intensity of H_β as a function of time in hydrogen and deuterium with an initial magnetic field of 1 200 gauss and without initial magnetic field.

In all cases the maximum appears after about 11 μ s, indicating a temperature of about 13 000°K at this time.

Another important conclusion, concerning the reliability of magnetic probe measurements, can be drawn from the measurements discussed here. The optical observations have been made in a plane about 2 mm away from the axis of the magnetic probe. As the oscillograms show (figs.3 and 4) no systematic error caused by the probe, can be observed. This means that at the temperatures obtained and during the time interval used for the observations the magnetic field probes show no effect on the general behaviour and the impurity degree of the plasma.

5. Discussion of the Results

As these measurements demonstrate, the electron temperature in an electrodeless ring discharge strongly depends on the magnitude of the initial magnetic field. It has already been shown in another report$^{1)}$ that in the case of zero initial magnetic field complete ionization occurs not before 1.5 μs and the maximum electron temperature is only 22 000°K. The observed dependance of the electron temperature on the value of the initial magnetic field clearly shows a maximum.

However, one can also consider how the electron temperature depends on the amount of trapped fields at the start of second current half cycle. One observes, that the electron temperature increases monotonously with increasing trapped magnetic field.

In the same way the different electron temperatures in hydrogen and deuterium with the same initial magnetic field can be explained, in deuterium the amount of trapped field being considerably larger than in hydrogen.

The value of the magnetic field, trapped during the first current half cycle, is controlled by ionization growth and sheath formation at the start of the discharge.

The measured temperature rise of the plasma during the second half cycle can be attributed to the observed dissipation of the trapped reverse field energy.

The decay of the plasma likewise depends on the amplitude of the steady magnetic field and on the atomic weight of the gas. From the intensity of H_β one concludes that the electron density in deuterium after 11 μs is about 30% larger than in hydrogen. This factor 1.3 can be easily explained by the different escape velocities due to different atomic weights.

The comparison of the H_β intensities in discharges with and without magnetic field furthermore shows that the electron density in the case with magnetic field after 11 μs is smaller than without a magnetic field. This is attributed to different end losses, partly due to higher plasma temperature, partly to different magnetic field configurations during the discharge.

The object of the experiments with the electrodeless ring discharge was the production of a plasma with a superimposed magnetic field in the configuration described, for magnetic compression experiments. Thereby certain qualities such as complete ionization, high purity and sufficiently large conductivity are required for the plasma. It could be shown that these requirements can be fulfilled for various values of the initial magnetic field. However, when the plasma is homogeneously distributed to some degree, particle densities depend strongly on the atomic weight of the gas and on the amplitude of the magnetic bias field. To fix the initial conditions for a magnetic compression experiment, the initial particle density therefore must be measured separately.

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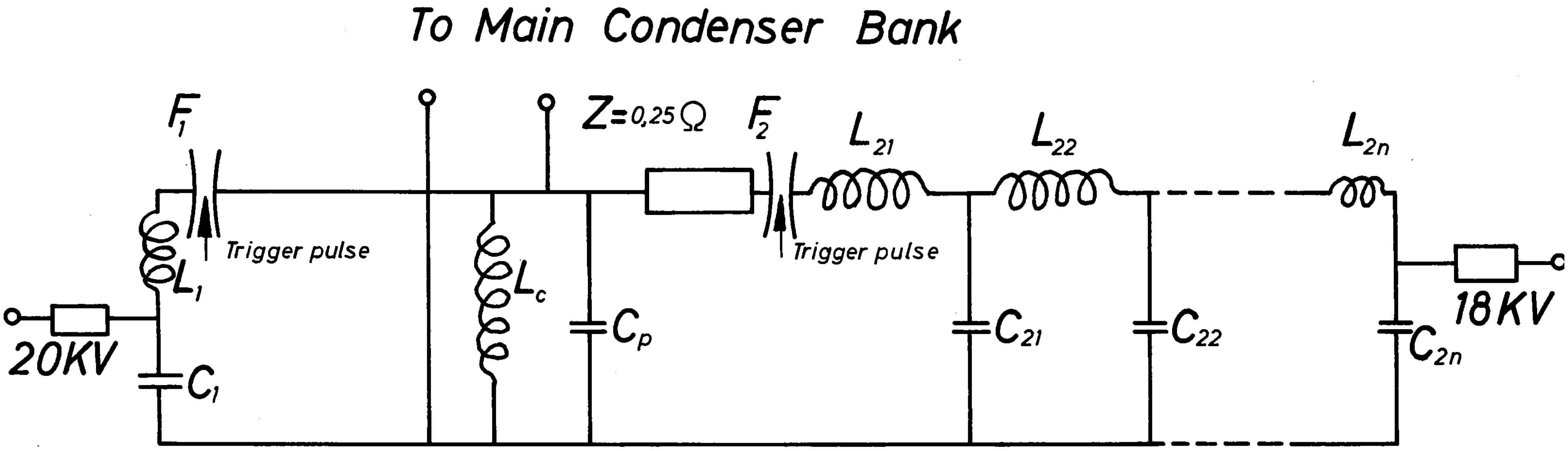


C_p = Capacitance of Collector-plate

C_1 = Capacitance of Preheat-condenser

$\left.\begin{matrix} C_{21}---C_{2n} \\ L_{21}---L_{2n} \end{matrix}\right\}$ = Jnductances and Capacitances of Artificial Delay Line

L_c = Jnductance of Discharge Coil

Electrical Circuit Diagram

Fig.1

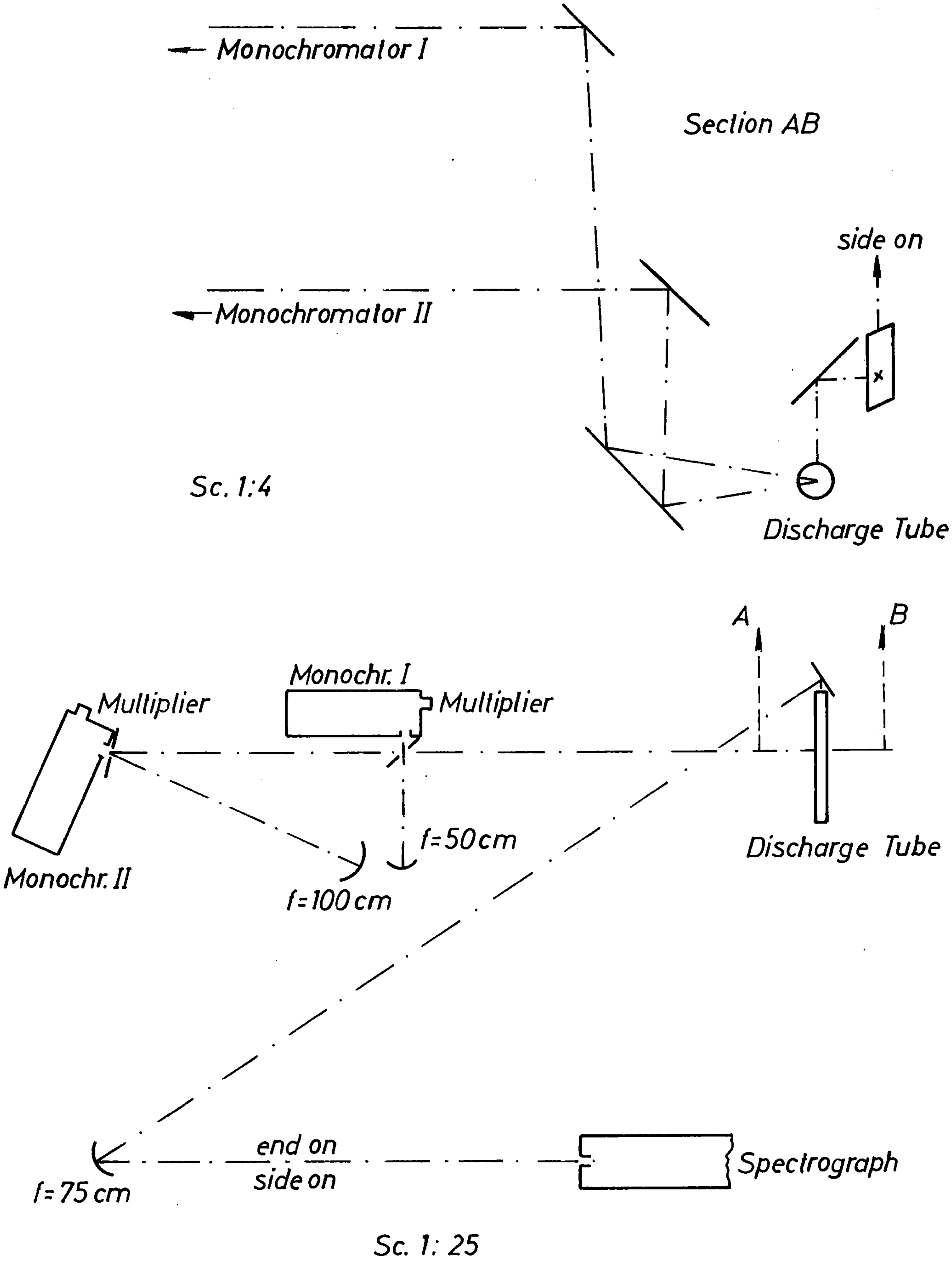


Fig: 2 Optical arrangement

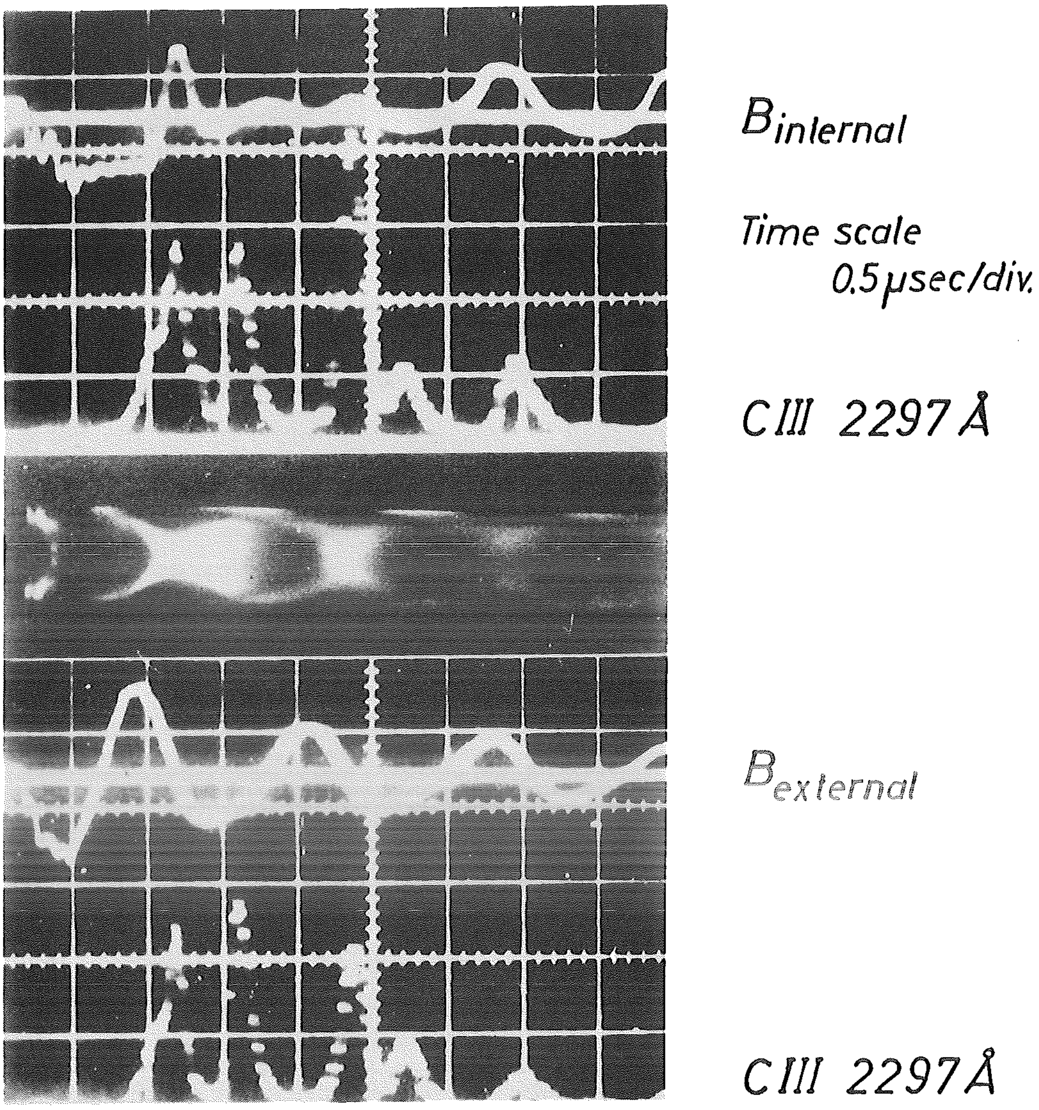
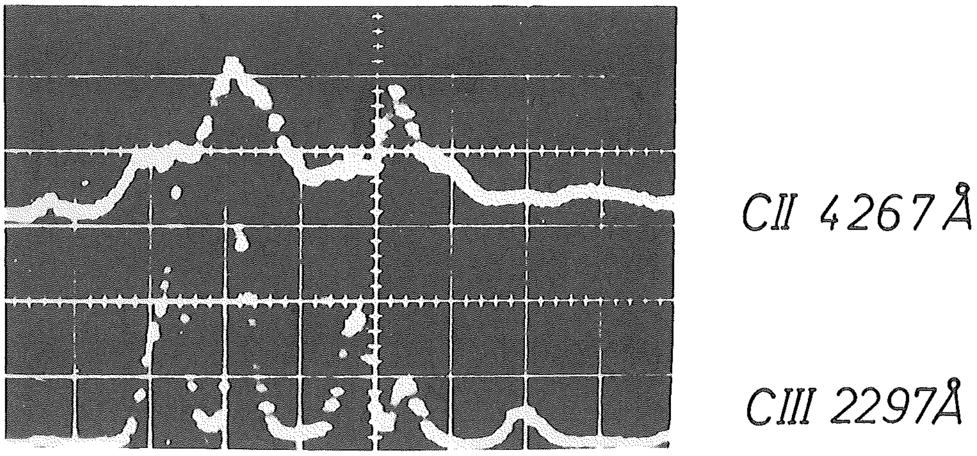


Fig. 3 $B_{internal}$, $B_{external}$ CIII spectral line as a function of time together with a streak photo of the discharge at an initial pressure of 230 μ H_2 and with an initial magnetic field of 1200 gauss.



Time scale: 0,5 μsec/div.

Fig. 4 a

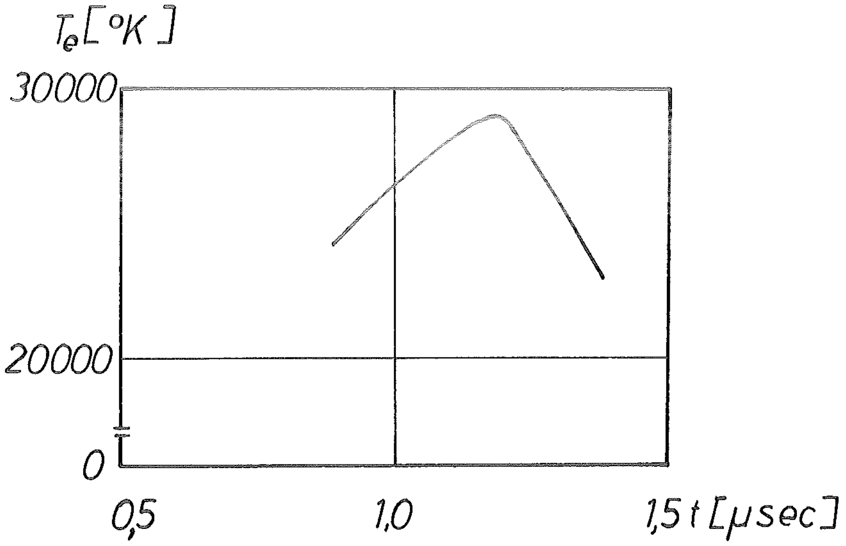


Fig. 4 b

Fig. 4a CII and CIII spectral lines as a function of time at a pressure of 230 μ H_2+1/760 CH_4 and an initial magnetic field of 1200 gauss.

4b T_e as a function of time

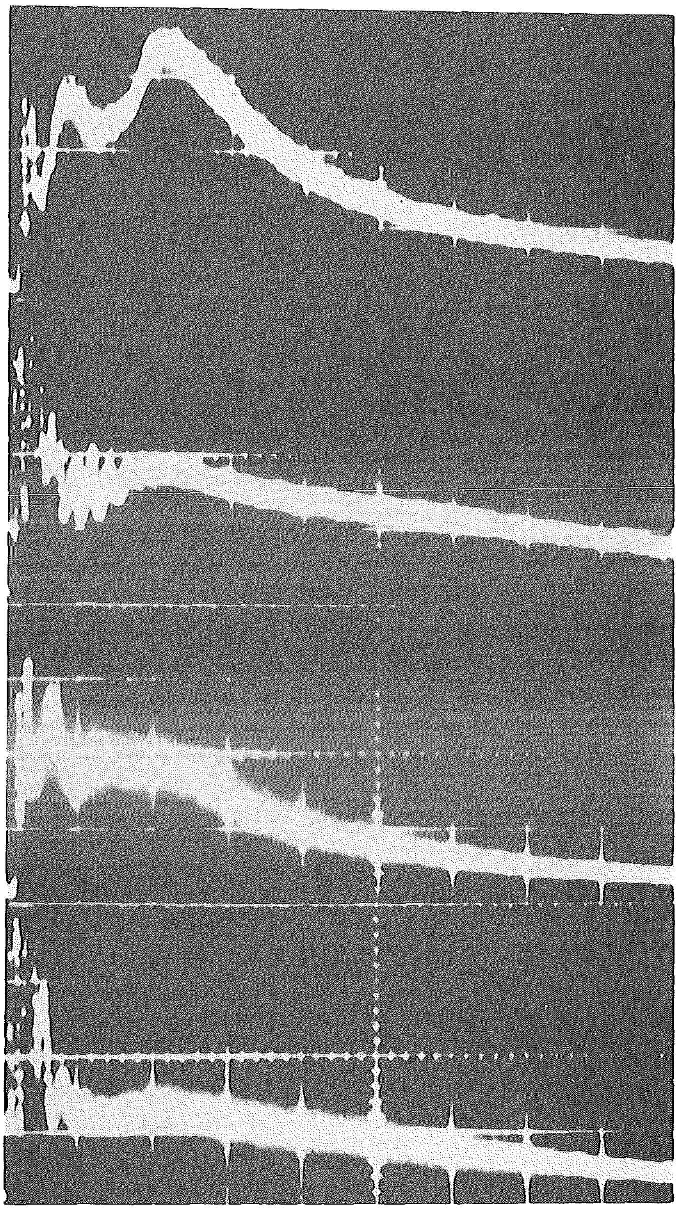


Fig. 5 D_β and H_β with an initial field of $B_{z_0} = 0$ and $B_{z_0} = 1200$ gauss at 230μ.