Institut für Plasmaphysik

KERNFORSCHUNGSANLAGE JÜLICH

des Landes Nordrhein-Westfalen - e. V.

ASSOZIATION EURATOM - KFA

Breakdown of an electrodeless ring discharge and the development of the electron density and temperature in a spindle cusp

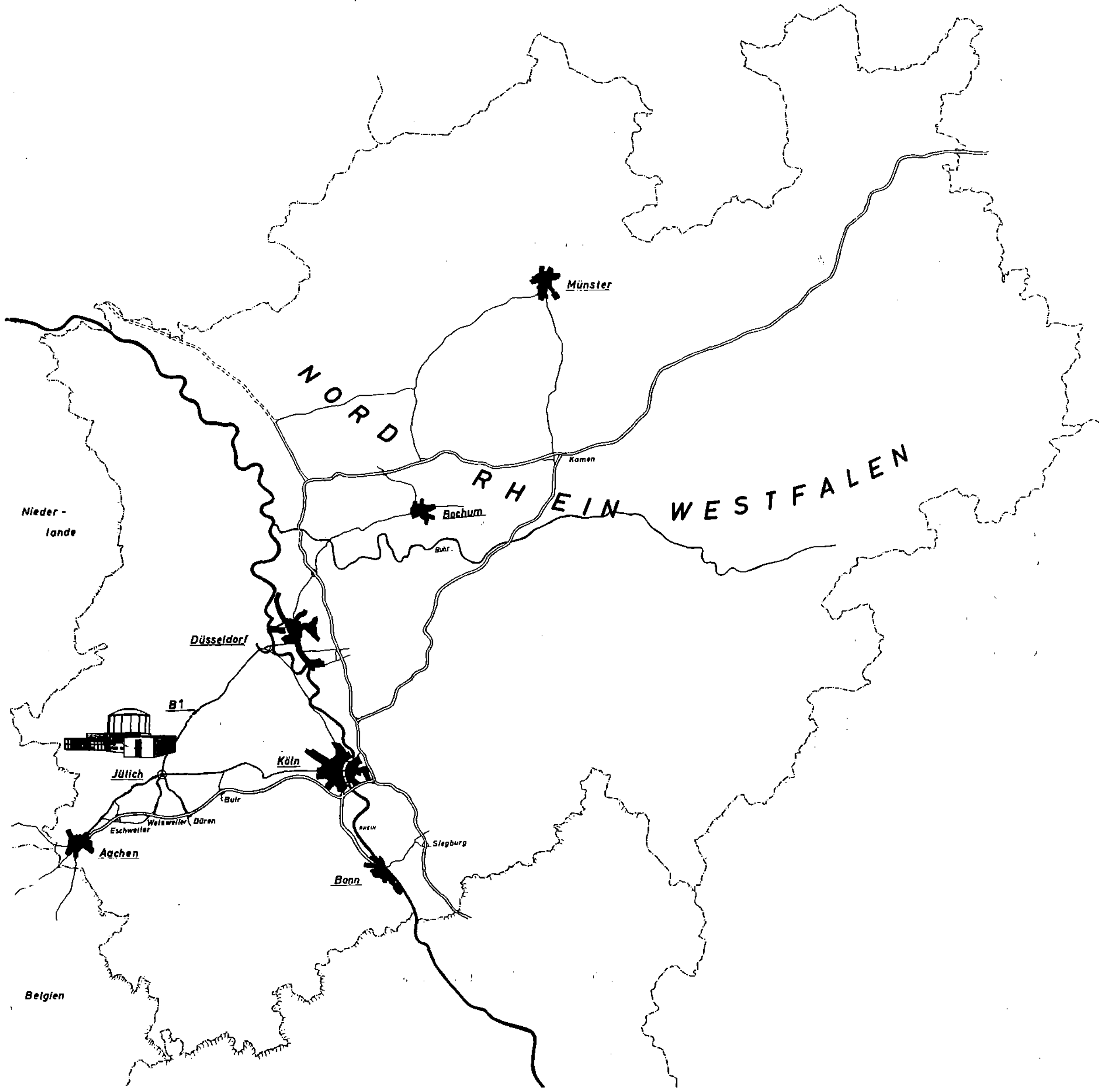
by

H. J. Belitz and E. Kugler

Jül - 352 - PP

Januar 1966

Als Manuskript gedruckt



Berichte der Kernforschungsanlage Jülich – Nr. 352

Institut für Plasmaphysik Jül – 352 – PP

Dok.: Electrodeless Ring Discharge - Breakdown
Spindle Cusp - Electron Temperature
Spindle Cusp - Electron Density

DK: 621.385 : 621.039.624

Zu beziehen durch: ZENTRALBIBLIOTHEK der Kernforschungsanlage Jülich, Jülich, Bundesrepublik Deutschland

Breakdown of an electrodeless ring discharge and the development of the electron density and temperature in a spindle cusp

by

H. J. Belitz and E. Kugler

BREAKDOWN OF AN ELECTRODELESS RING DISCHARGE AND THE DEVELOPMENT OF THE ELECTRON DENSITY AND TEMPERATURE IN A SPINDLE CUSP

H.J. Belitz and E. Kugler

INSTITUT FÜR PLASMAPHYSIK

der Kernforschungsanlage Jülich des Landes Nordrhein-Westfalen

Assoziation EURATOM-KFA

ABSTRACT

The magnetic field, electron temperature and density of a hydrogen plasma, generated by discharging a o,5 μF, 25kV condenser to a pair of conical coils producing a cusp shaped magnetic field, have been measured space and time resolved.

Electron densities of 10^{16} - 10^{17} cm^{-3} and electron temperatures of 1.5 - 3 eV were obtained from Stark broadening of H_β, from the absolute intensity of the continuum and from the relative intensity of H_β/continuum respectively.

By combining the results with magnetic probe measurements a consistent picture of the plasma can be proposed.

Fast magnetic compression allows one [1] to generate a cusped shaped plasma with convex boundaries (Fig. 1a) which should be magnetohydrodynamically stable. Fig. 1b shows the sequence of commutation of the electrical circuits. At maximum current the electron density is of the order $10^{17} cm^{-3}$; the electron temperature lies in the range 10 to 70 eV.

The important influence of the preheating on the results of the fast magnetic compression made it necessary to investigate this phase separately: H_2-gas was preionized by a rf-transmitter; the ring discharge was produced by switching only one 0,5 μF, 25 kV condenser on the cusp coils. With magnetic probes (1 mm Ø, 1 mm long), giving a good time and space resolution, the magnetic field has been measured in the midplane along a radius r, along the z-axis, on two lines parallel this axis, separated from it by 5 and 1o mm, and under an angle of 45^o.

Fig. 2a shows the field distribution in the midplane. 1.2 μsec after triggering the condenser discharge, a strong trapped magnetic field is present within the plasma (whereas the vacuum field would have been zero). From $r = 0$ to $r = 4$ cm the direction of this trapped field remains unaltered at later times; i.e. it is independent of the coil field polarity. In the external region ($r > 4$ cm) the plasma field has the same polarity as the vacuum field. Fig. 2b shows the trapped field boundaries at different times.

These measurements have been checked and completed [1] using another preheating system (0.38 kJoule); they lead to the following conclusions:

1.) Since rot $\vec{B} \neq 0$ in the surroundings of the trapped field boundary, azimuthal electrical currents exist within the plasma even when the external current is zero.

2.) At given time the trapped field may change its sign twice, three times, or more; that means that azimuthal currents may coexist in different plasma regions ("onion" structure).

3.) For the experiment described here, magnetic field is trapped in the plasma at the 3rd half cycle, in other cases it may be trapped at the beginning of the second half cycle.

4.) By varying the geometry of the cusp coils, it was shown that the trapped magnetic field boundaries could be closed upon themselves not only in the midplane but also on the z-axis.

The electron density and the electron temperature were determined from Stark broadening of the H_β -line and from the relative intensities of the H_β -line and the 5300 Å-continuum-radiation respectively [2] , [3] , [4] . Slits in the coils (Fig. 2b) allowed these measurements to be carried out side on at various distances z from the midplane.

In order to obtain the H_β -profile, about 7 to 1o discharges were necessary. Each gave the time resolved intensity at a fixed wavelength (Fig. 3a). At the times of interest the signal-to-noise ratio was sufficiently high. The H_β -profiles (Fig. 3b) show the good experimental reproducibility.

Fig. 4, 5 and 6 show the electron density, corresponding to initial gas pressure of 0.1, 0.2, 0.5 Torr, at various distances from the midplane and at various times. This density is at first very small everywhere (0.1 ... 0.5 $\cdot 10^{16}$ cm^{-3}). In the centre it suddenly increases to a maximum which is greater than one would expect if locally all the H_2 -gas were totally ionized. At later times the density decreases, its final value being lower than that corresponding to the total ionization of the H_2 -gas. The high electron density region is localized in a small volume surrounding the centre. This was shown by measurements in the midplane at various distances from the z-axis and confirmed by smear camera pictures.

Independently of the initial gas pressure in the domain investigated, the maximum electron density in the midplane was found to be about $5 \cdot 10^{16}$ cm^{-3}. Beyond z = 25 mm the density is about 0.5 to $1 \cdot 10^{16}$ cm^{-3}. The high density region seems however to be smaller at higher initial gas pressures then at lower pressures.

The electron density has been determined independently by measuring the absolute intensity of the continuum radiation at 5000 Å, 5500 Å, and 6000 Å [5] . The values are somewhat higher (about 1.5) than those obtained from the Stark broadening of the H_β -line. The time dependence and the variation of n_e along the z-axis agree with the results described above.

Fig. 3c gives the oscillograms of the intensities of the H_β - and the 5300 Å-continuum-radiation. The variations of the intensity ratio corresponds to relatively small temperature differences only. During a short time interval the temperature reaches a maximum of about 2 to 2.5 eV; at other times the temperature is about 1 to 1.5 eV.

The electron density in the centre of the cusp coils reaches a maximum at 1.8, 2.1, and 2.7 μsec, when the initial gas pressure is 0.1, 0.2, and 0.5 Torr respectively. The electron temperature, determined by the intensity ratio of H_β/5300 Å-continuum, reaches its maximum at the same times (within the experimental error of better than 0.1 μsec). No correspondence to the phase of the coil current appears: the two maxima, at 0.1 Torr initial pressure, occur when the external current is zero (or nearly zero). At 0.2 and 0.5 Torr, they occur when the current has extreme values.

To get a rough check of the electron temperature the CIII spectral line was looked for. Its appearance leads to an estimated electron temperature of at least 4 to 6 eV; this is much higher than the value obtained from the H_β/continuum ratio. However, the reason for this disagreement seems to be clear: the CIII line appears first at 1.2 μsec, when the plasma traps the magnetic field, i.e., when strong azimuthal currents circulate in the plasma. The electrical resistivity can be calculated from $\sigma = \Delta \vec{B} / \mu \dot{\vec{B}}$ and from the skin depth, and gives, using Spitzer formula, a local temperature of about 8 to 10 eV in a region near the boundary of the trapped field. It can be assumed therefore that the CIII line is emitted mainly from this region and that the temperature is not distributed uniformly within the plasma.

It was the purpose of this work to study the preheating phase in order to make fast magnetic compression in the cusp compression experiment more effective. From this point of view the following results are important:

1.) At the end of the second half period a magnetic field is trapped by the plasma, and at the same time the CIII spectral line appears. These effects are independent of the initial gas pressure.

2.) The configuration of the trapped field is practically independent of the external field during a time of about one period; during that time the boundary of the trapped field domain does not move by more than a few millimeters.

3.) The maximum electron density is higher than the corresponding value of the fully ionized H_2-gas, while about 0.5 μsec later the density is much smaller. At 0.5 Torr the electron density decreases more rapidly than at 0.1 Torr.

4.) Only one maximum of the electron density is observed in the center of the coils, and during a short time interval. By the H_β/continuum ratio, the highest temperatures are observed simultaneously. The instant at which these maximum values appear, increases with increasing initial gas pressure. No correlation with the phase of the external magnetic field has been observed.

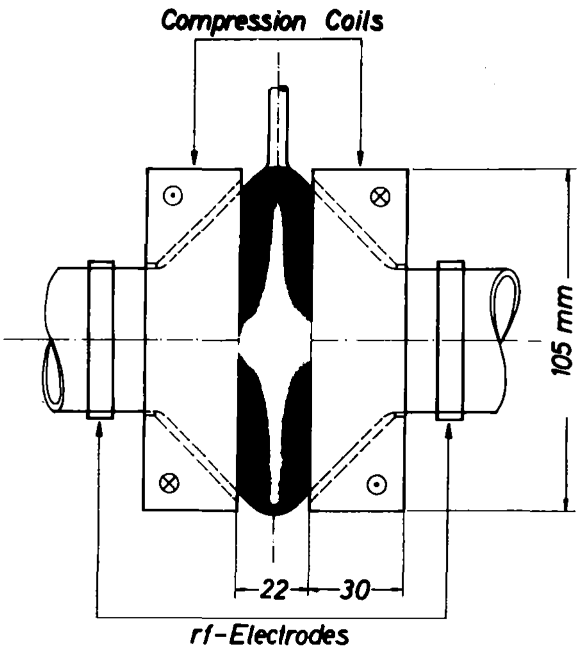
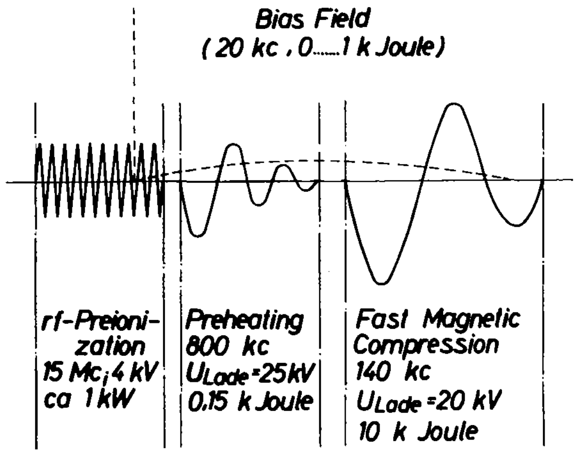


Image converter picture of the plasma compressed by cusp-coils

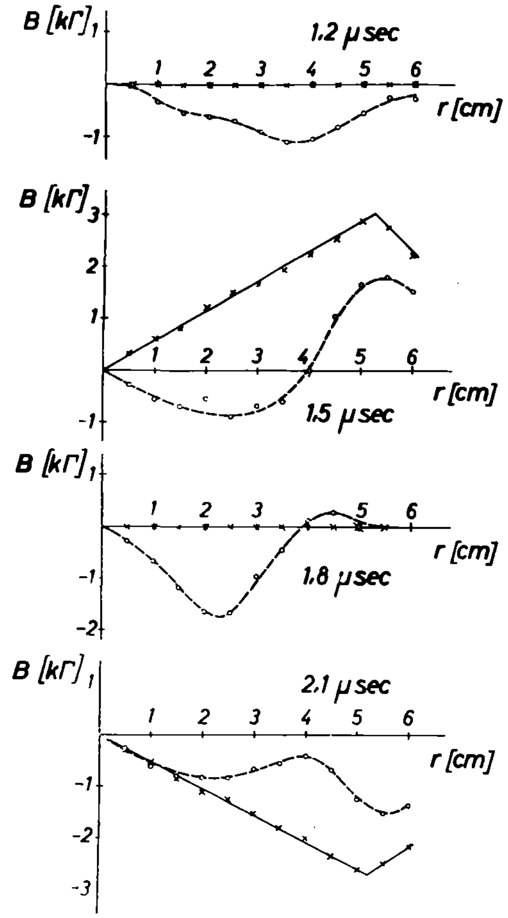
(a)



The various phases of the compression experiment

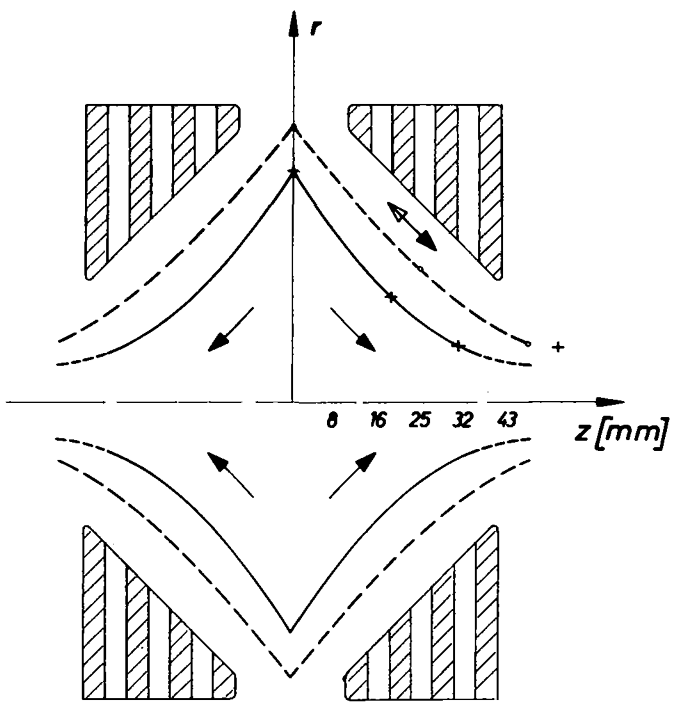
(b)

Fig. 1



Magnetic field in the middle plane between the cusp-coils
× in vacuum ; ○ in plasma
p_{H_2} = 0.2 Torr

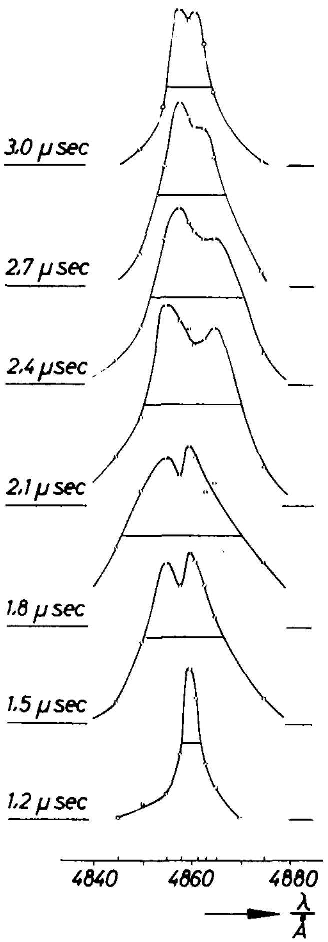
(a)



Shape of the trapped magnetic field
(— 1.2 < t < 2.1 μsec ; - - - t > 2.4 μsec)
Arrangement of the slits for the optical measurements

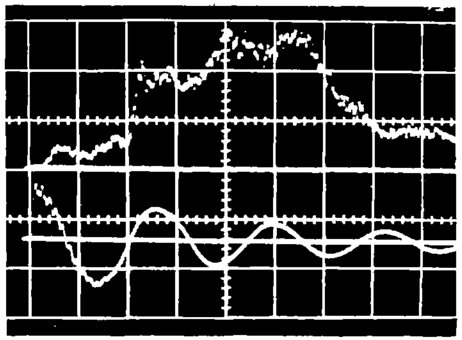
(b)

Fig. 2



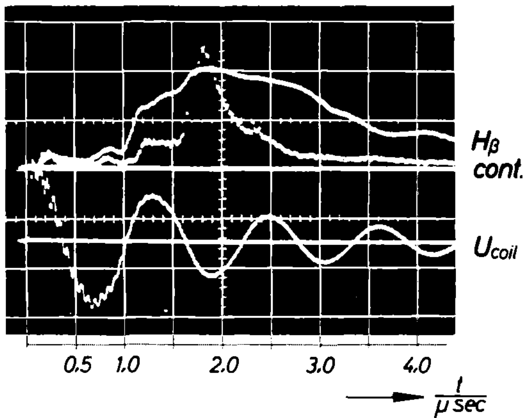
H_β profiles at various times

(b)



Intensity of the H_β-radiation

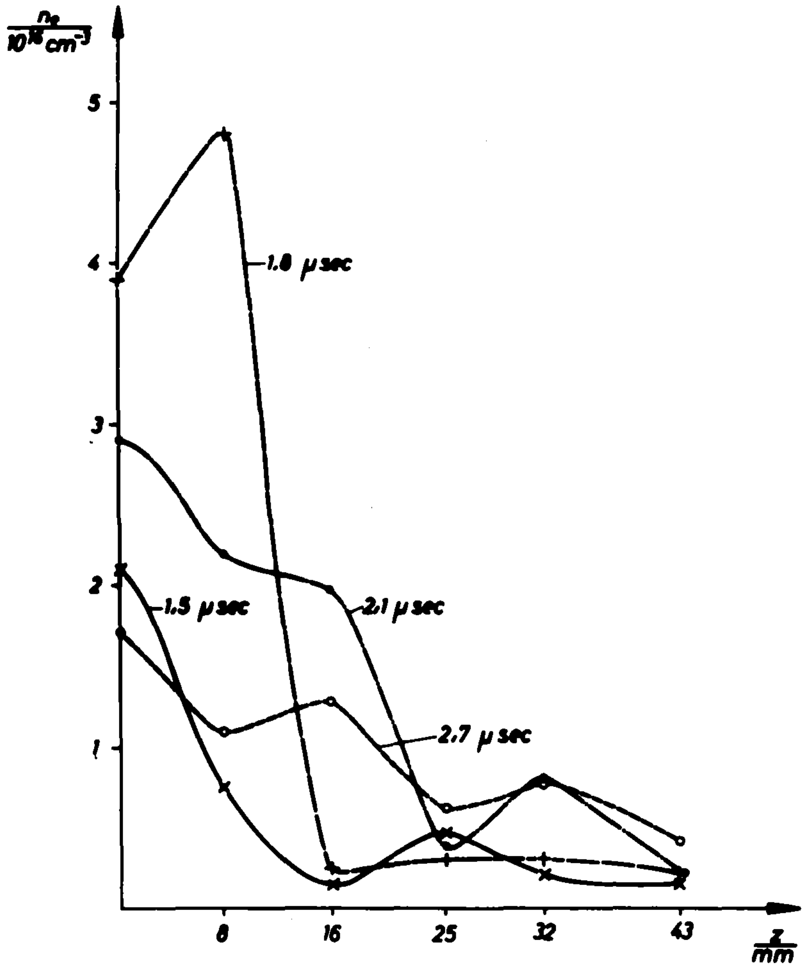
(a)



Intensities of the H_β- and the 5300 Å continuum-radiation

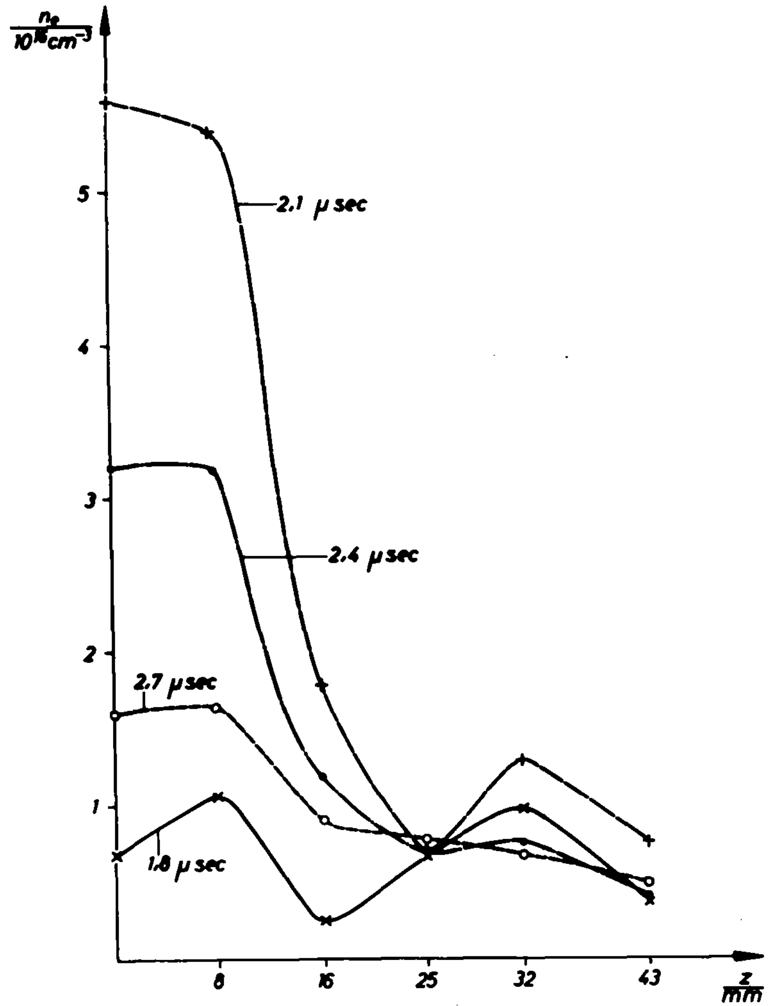
(c)

Fig. 3



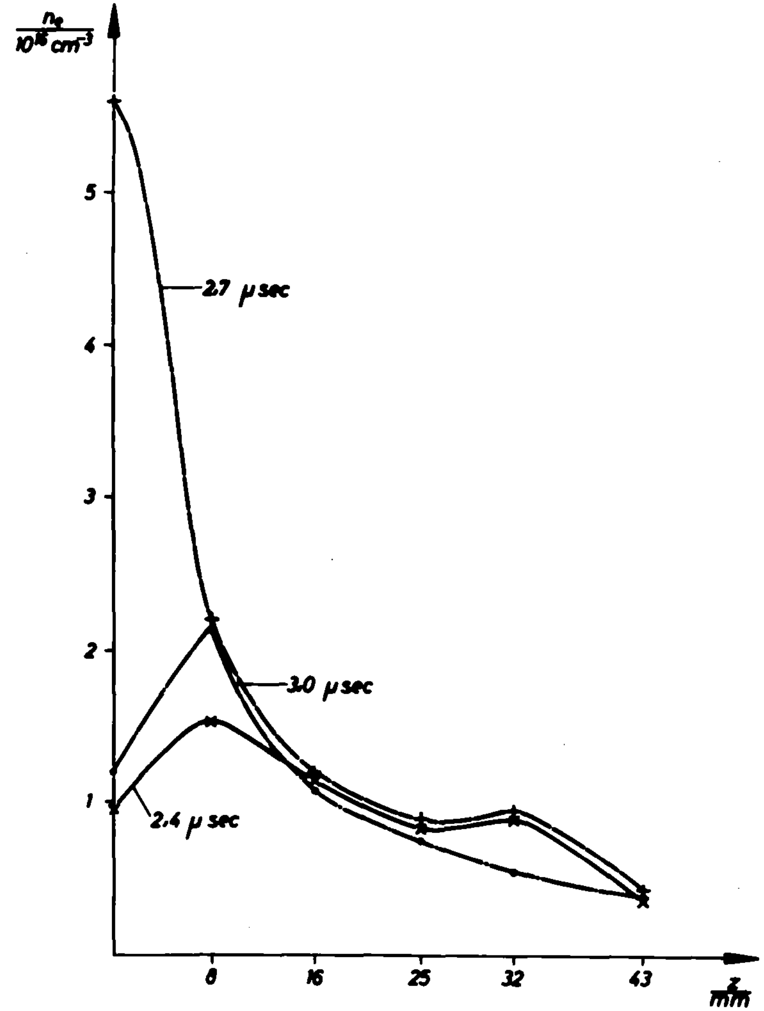
The variation of the electron-density along the z-axis at various times $p_{H_2} = 0.1$ Torr

Fig. 4



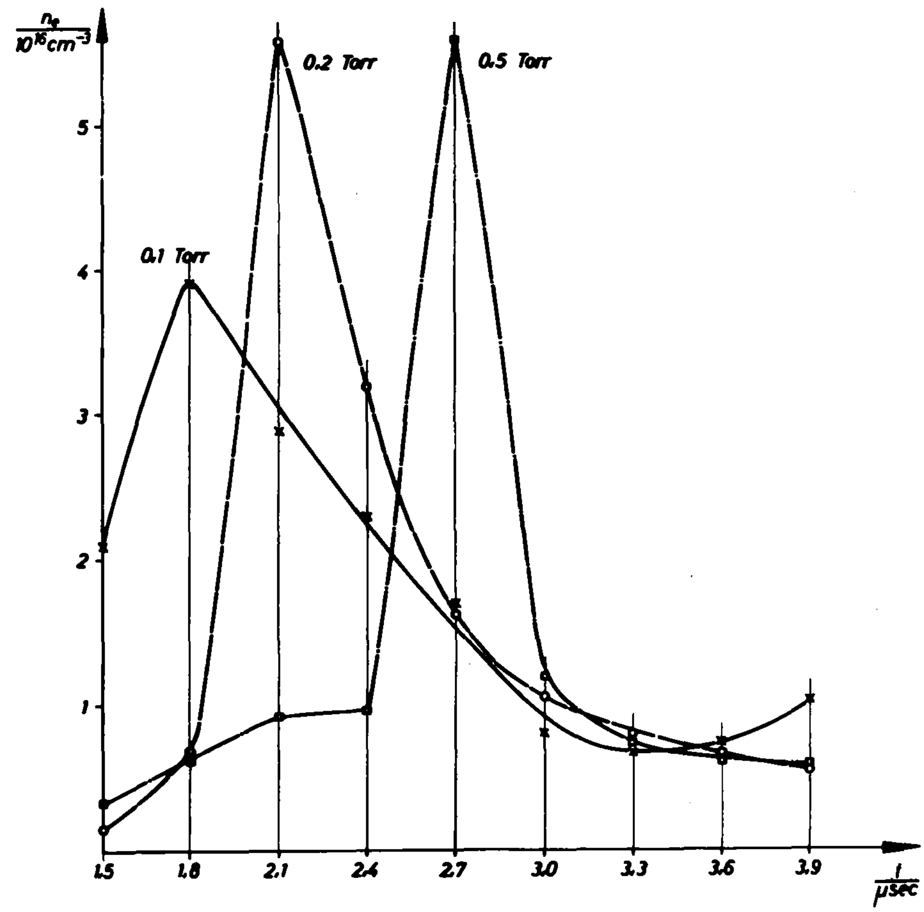
The variation of the electron-density along the z-axis at various times
$p_{H_2} = 0.2$ Torr

Fig. 5



The variation of the electron-density along the z-axis at various times
$p_{H_2} = 0.5$ Torr

Fig. 6



Time dependence of the electron-density in the centre of the cusp-coils at various initial gas pressures

Fig. 7

R E F E R E N C E S

[1] H.J. Belitz, E. Kugler

Magnetische Sondenmessungen während der Vorheizphase eines Spindle-Cusp-Experimentes.

Jül - 281 - PP

[2] P. Bogen. Z. Physik, 149 (1957), 62.

[3] H.R. Griem et al., Phys. Rev., 116 (1959) 4.

[4] H.R. Griem. Plasma Spectroscopy. (McGraw-Hill Book Comp.) 1964.

[5] P. Bogen, J. Schlüter

Comptes Rendus de la VIe Conférence Internationale sur les Phénomèmes dans les Gas.

Paris 1963, pp 561 - 565.