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Absolute Density Distribution  
of the Atomic Beam of a Q-Device

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Die nachstehende Arbeit wurde im Rahmen des Vertrages zwischen dem Institut für Plasmaphysik GmbH und der Europäischen Atomgemeinschaft über die Zusammenarbeit auf dem Gebiete der Plasmaphysik durchgeführt.

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Spectroscopic Measurements of  
Absolute Density Distribution  
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March 1968 ( in English)

Abstract

The absolute density distribution of a finely collimated atomic beam of barium is measured by resonance fluorescence scattering of light.

## Introduction

To determine the particle losses (end plate recombination and diffusion perpendicular to the magnetic field) in a Q-device, a knowledge of the absolute density (or flux) distribution of the atomic beam "illuminating" the hot end plates becomes necessary for the following reasons:

- 1) According to the "equilibrium" theory [1] end plate recombination should be the dominant loss process at strong magnetic fields. The particle balance equations yield a relation between the atomic flux  $j_0$  [ $\text{cm}^{-2}\text{sec}^{-1}$ ] and the plasma density  $n$  [ $\text{cm}^{-3}$ ].

In a cesium plasma, the plasma density  $n$  is usually measured by Langmuir probe and microwave techniques. Additionally, in a barium plasma, the plasma density can be measured by resonance fluorescence scattering of light by barium ions.

However, in all the experiments performed up till now to verify the equilibrium theory,  $j_0$  was determined indirectly, just by measuring the total number of "fresh" ions being injected into the plasma per second,  $\Phi$  [ $\text{sec}^{-1}$ ] [2, 3, 4, 5].

This was done by

$$j_0 = \frac{\Phi}{\pi r_{\text{eff}}^2} \left( \frac{La}{1 + La} \right) \quad (1)$$

where  $La$  is the Langmuir function and  $r_{\text{eff}}^2 = 2 \int \frac{n(r)rdr}{n_{\text{peak}}}$

- 2) If the recombination at the hot end plates is known, the diffusion perpendicular to the magnetic field can be determined by measuring the e-folding length of the radial density profiles as a function of  $B$  as shown in reference [6]. However, in this experiment a direct knowledge of the atomic beam pro-



files was lacking.

Since the experiments show particle losses much larger than predicted by the equilibrium theory and the nature of these losses is not yet understood, a direct measurement of the absolute density distribution of the atomic beam of barium "illuminating" the end plate seems desirable. This can be performed by resonance fluorescence scattering method as described in this report.

## 2. Experimental set-up

In order to measure the absolute density distribution of the atomic beam, the barium oven (in normal operation mounted near the hot end plate) was moved below the mid-plane of the Q-device BARBARA (fig. 1) and adjusted in such a way that the measuring plane "b" (identical with the mid-plane of the device) (fig. 2) corresponds to the surface of the end plate in normal operating conditions, the peak of the neutral density striking the centre of the end plate.

The barium oven is shown in fig. 2. The barium vapor coming from a hole of 2.5 mm in diameter and making an angle of  $45^\circ$  with the vertical axis. Two foils, the lower having a hole 1.5 mm in diameter and the upper having a hole 1.0 mm in diameter, collimated the beam as shown in the same figure. The distance between the plane "b" and the uppermost hole of the oven collimator system being 3 cm.

It is thus possible to map spectroscopically the density distribution of the atoms striking the hot end plate.

By changing the plane of measurement in vertical direction, the solid angle of the neutral beam was checked by measuring the width of the profiles at different distances from the oven (planes "a" and "c" in fig. 2). The neutral peak density as a function of oven temperature, whose reproducibility has been checked over a long period.

### 3. Spectroscopy

The application of the resonance fluorescence scattering method to determine the density in a singly ionized barium plasma of a Q-device using 4554 Å and 4934 Å lines has been described in detail in references [7, 8, 9].

In the case of barium atom,  $6^1S_0 \rightarrow 6^1P_1$  transition, the  $[\lambda = 5535.5 \text{ Å}, f_{\text{obs}} = 1.4 \text{ [10]}]$ , see fig. 3, can be easily excited by the light of a carbon arc. The scattered light is detected perpendicular to the incident light by a monochromator-photomultiplier system which is calibrated by a tungsten ribbon lamp. For some of the measurements, instead of the monochromator, an interference filter of 5 Å half-width is used.

Since no accurate measurements of the branching ratio between  $6^1P_1 \rightarrow 6^1S_0$  ( $\lambda = 5535.5 \text{ Å}$ ) and  $6^1P_1 \rightarrow 5^1D_3$  ( $\lambda = 15000.4 \text{ Å}$ ) transitions are available, the determination of densities from the scattered light intensities is rather difficult. On the other hand, it can be inferred from the references [10] and [11] that the transition  $6^1P_1 \rightarrow 5^1D_3$  can be neglected.

The density profiles of the atomic beam are measured by moving the detecting system along the image of the atomic beam on the entrance slit, keeping the solid angle of the scattered light constant during a particular run. The volume out of which the scattered light was detected is about  $3.5 \times 10^{-3} \text{ cm}^3$ .

### 4. Results

Figure 4 shows the measured spectrum of the light scattered by the barium atoms. Except the 5535.5 Å line, no other line is observed between 3900 Å and 7000 Å.

Figure 5 shows the neutral peak density as a function of oven temperature, whose reproducibility has been checked over a long period.



Fig. 6 is a graph of atomic density profiles at different oven temperature at the plane "b" (see also fig. 2). It is seen that the half-width is about 6 mm and the total width is about 16 mm, both being independent of the oven temperature T.

Figure 7 represents normalized atomic density profiles at the planes "a", "b", and "c" (see also fig. 2). As expected, the half-width increases with the increasing distance between the plane of measurement and the oven-collimator system. From these profiles the solid angle is found to be about  $10^{-2}$  sr.

Figure captions

- Fig. 1 Q-device "BARBARA" with experimental set-up
- Fig. 2 Oven-collimator system with measuring planes "a", "b" and "c"
- Fig. 3 The low-lying energy levels of Ba'. Wavelengths in Ångströms
- Fig. 4 Spectrum of the light scattered by barium atoms
- Fig. 5 The atomic peak density as a function of oven temperature T
- Fig. 6 The atomic density profiles at different oven temperatures
- Fig. 7 The normalized atomic density profiles at different measuring planes "a", "b", and "c"

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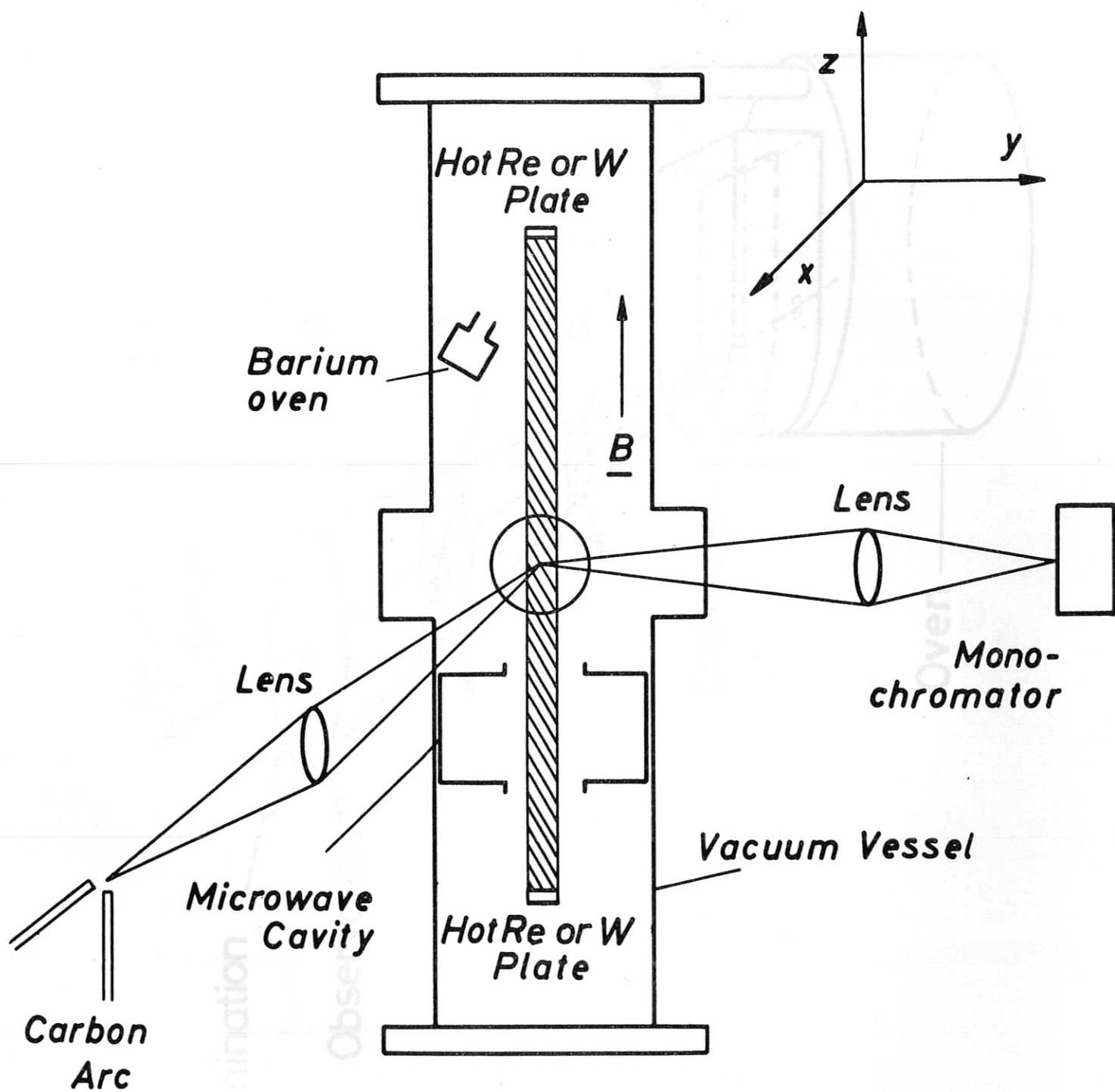


Fig. 1



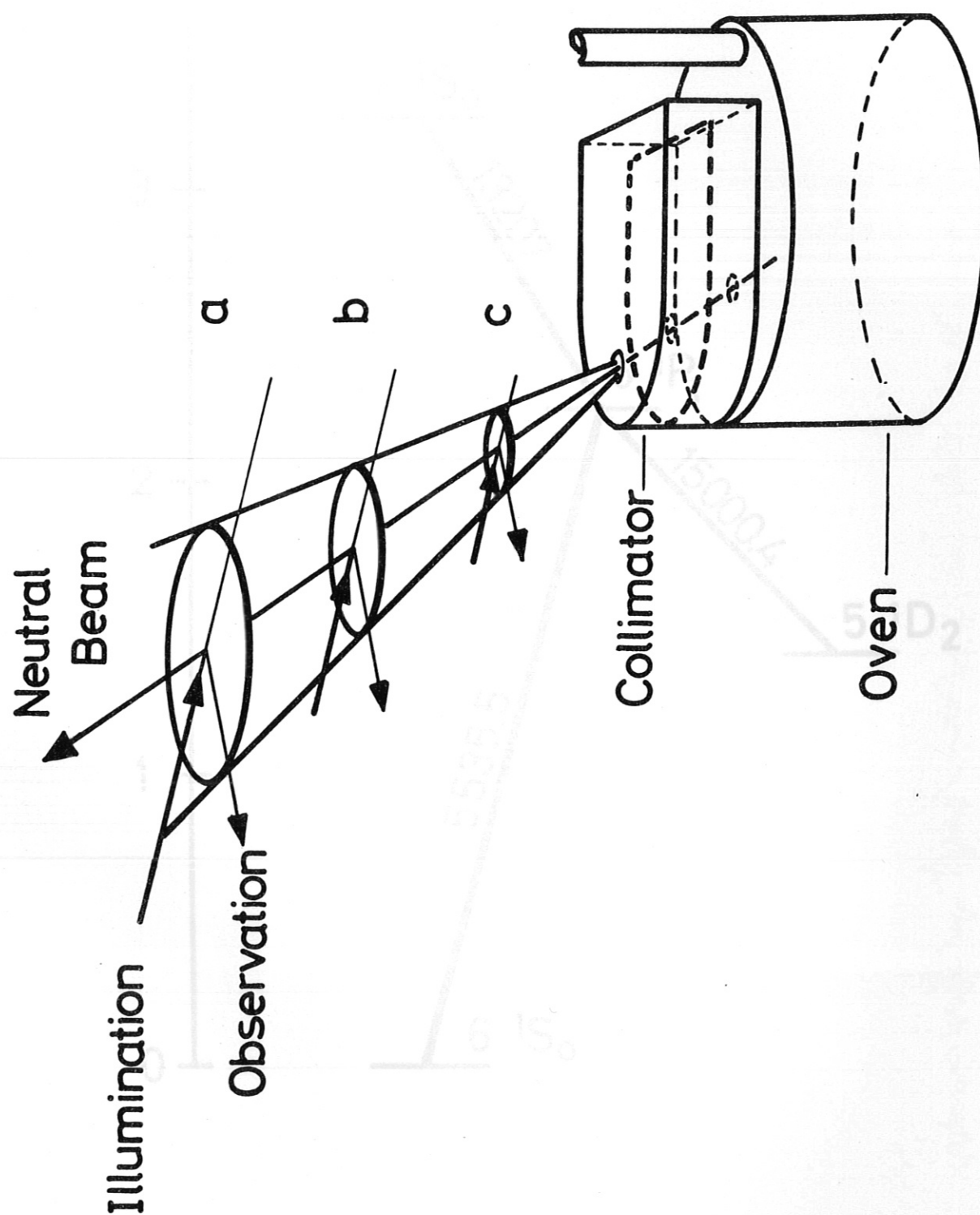


Fig. 2

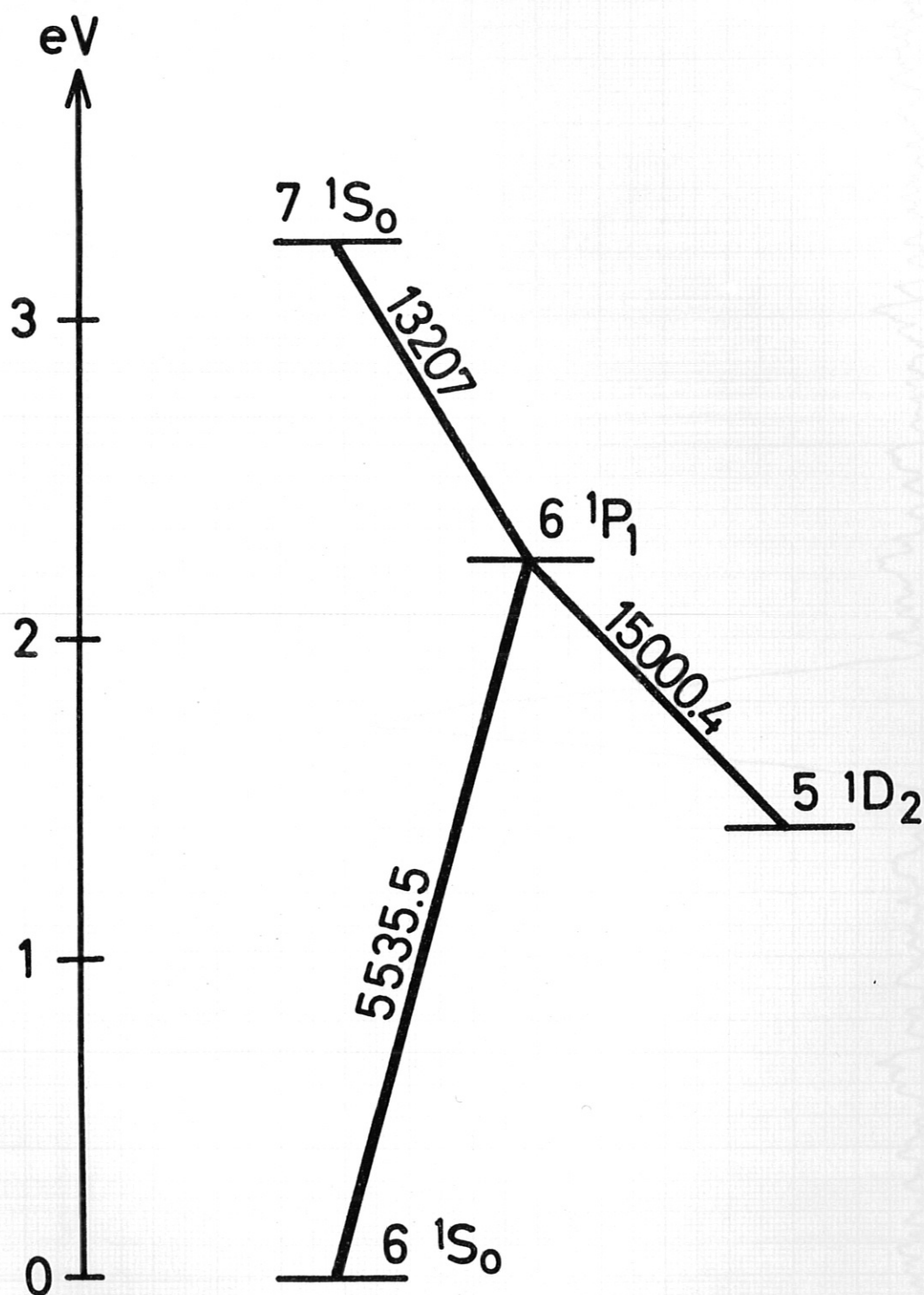


Fig.3



15.2.68

Oven 650°C

$P \approx 8 \cdot 10^{-6}$  Torr

Ba line 5535.5 Å

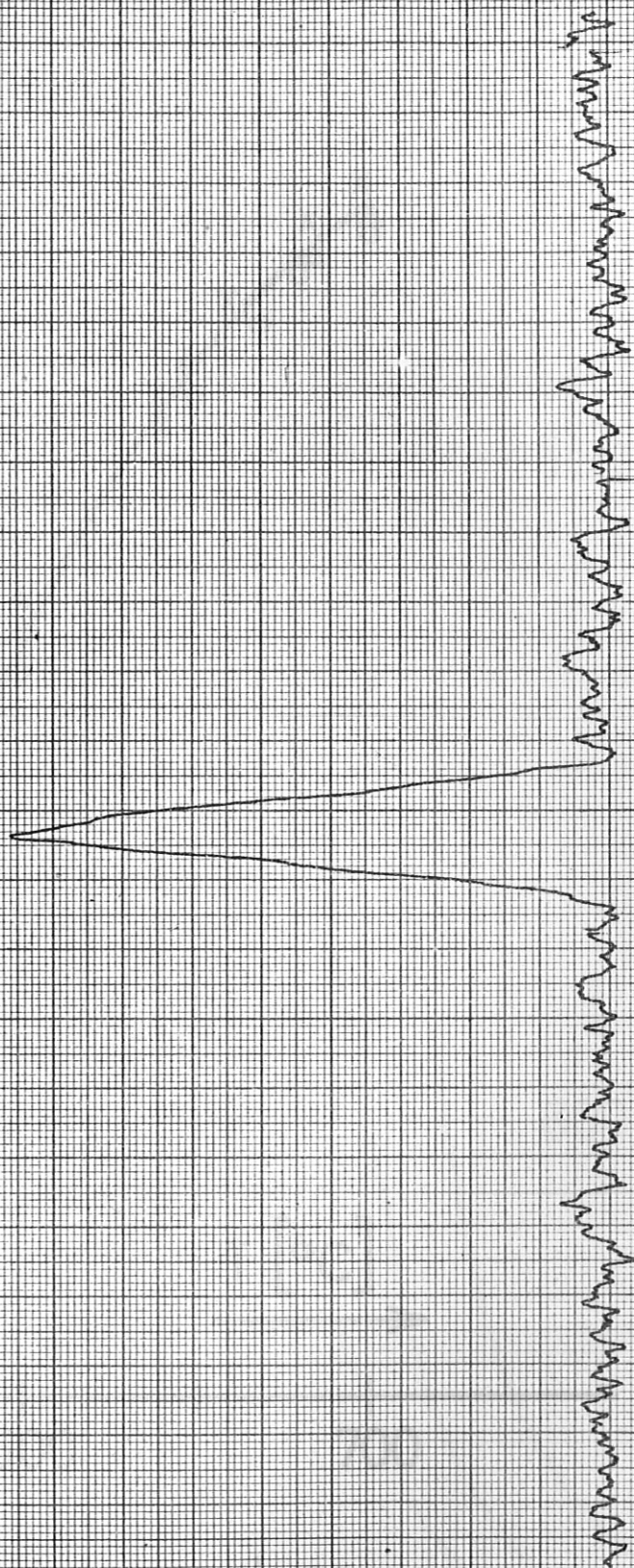


Fig.4

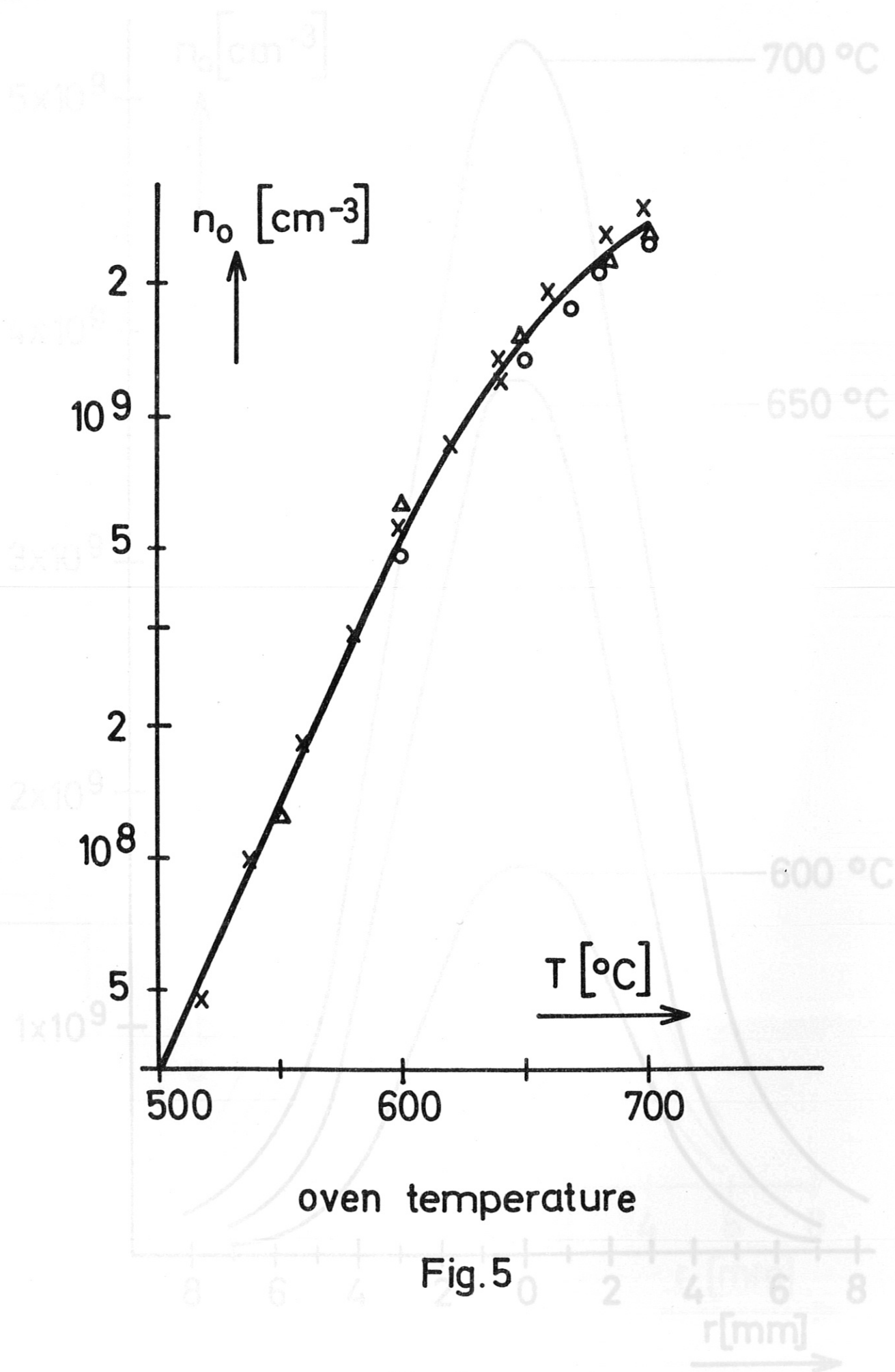


Fig.5

Fig.6

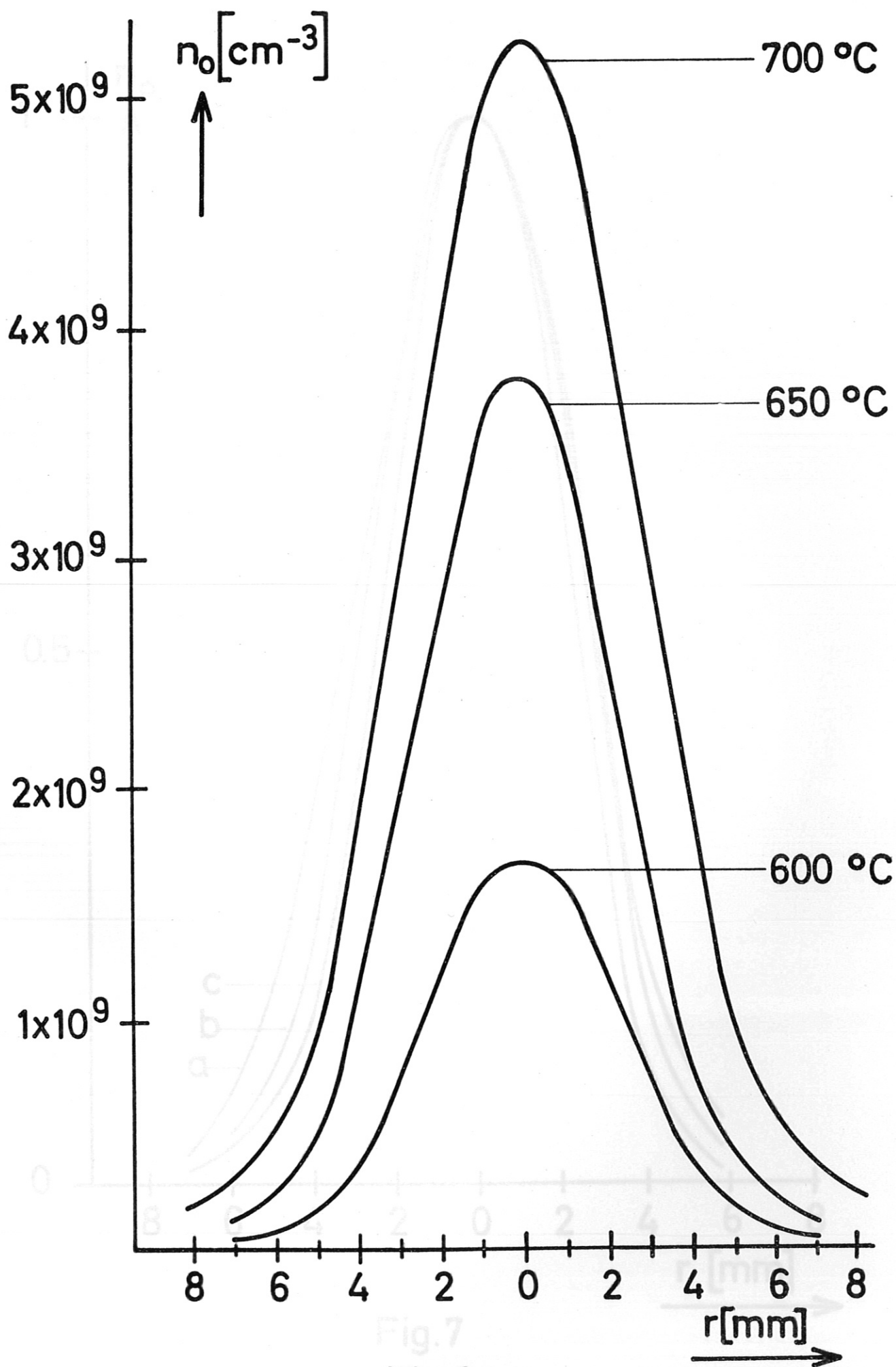


Fig.6

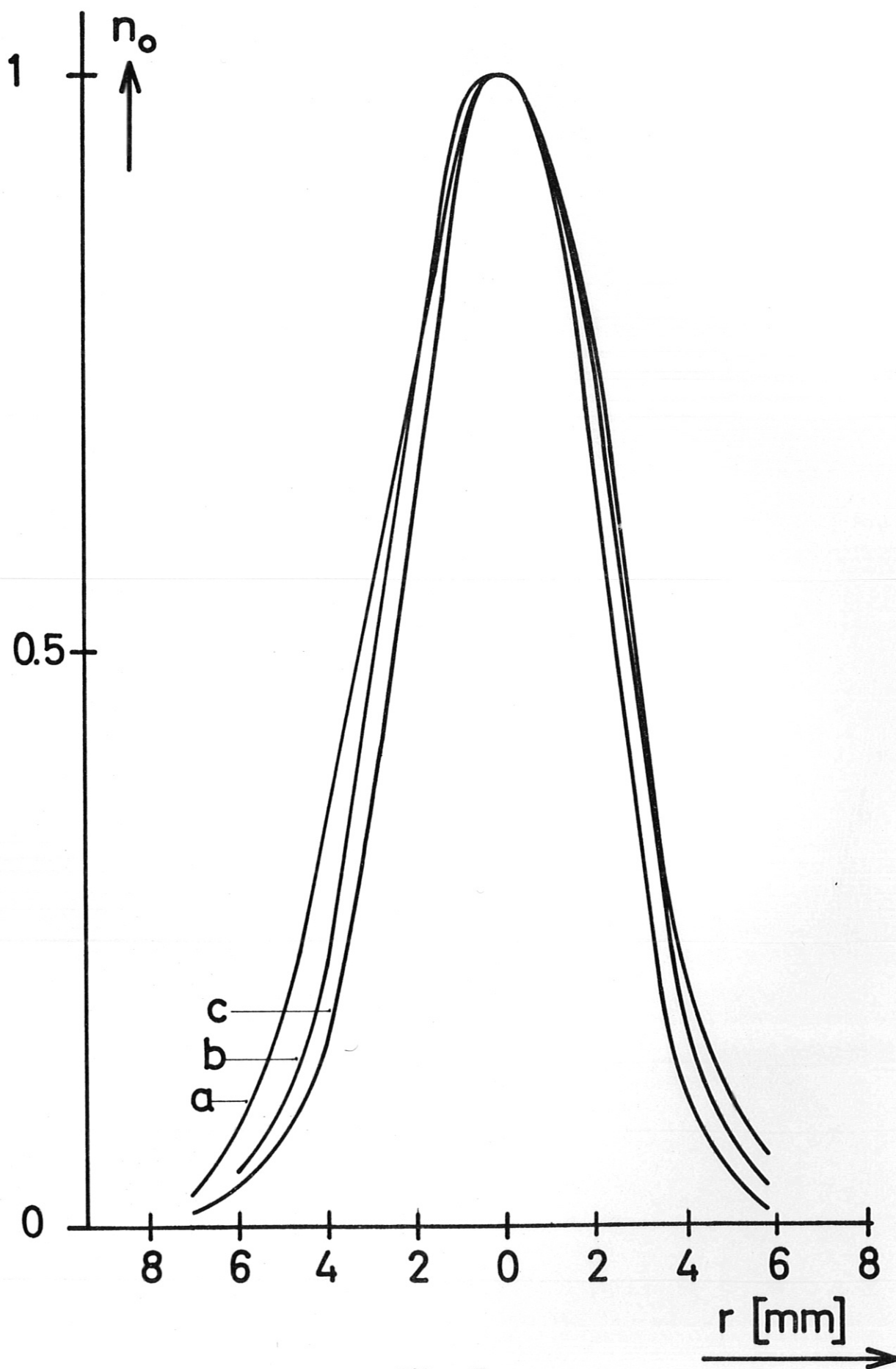


Fig.7