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MODELLING OF THE ENERGY BALANCE IN THE MT-1 TOKAMAK

Hordósy G., Körbel Š., Stöckel J.

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Modelling of the energy balance in the MT-1 tokamak

Hordósy G.[+], Körbel Š.[++], Stöckel J.[++]

Plasma processes in the MT-1 tokamak [1] /a=9 cm, R=40 cm, B_T=1.2 T/ were calculated by two numerical codes.
The first of these TOKATA /2/ solves a simplified system of equations for the energy balance of electron and ion components of the plasma and for plasma current density. Only heat conductivity is taken into account in the energy balance equations as a main channel for the power losses of the both components. The thermal conductivity coefficient for electrons is approximated by the formula /Alcator scaling/

$$\chi_e = 50/n_e \qquad \text{.. /1/}$$

For the ions, the neoclassical expressions are used

$$\chi_i^{PS} = 170 \frac{Z_{eff} \cdot n_i}{B^2 \cdot \sqrt{T_i}} \left(1 - 1.6\, q^2\right) \quad \text{collisional region .../2/}$$

$$\chi_i^{GS} = 38.6 \frac{q_i \cdot T_i^{3/2}}{R \cdot B^2} \quad \text{"plateau" region ... /3/}$$

$$\chi_i^{B} = 115.6 \frac{Z_{eff} \cdot n_i}{B^2 \cdot \sqrt{T_i}} \cdot q^2 \cdot \left(\frac{R}{r}\right)^{3/2} \quad \text{banana regime.../4/}$$

/ units $\chi_i \left[cm^2 ms^{-1}\right]$, $n_i \left[10^{13} cm^{-3}\right]$, $T_i \left[eV\right]$, $B \left[kG\right]$ /

and the following common formula is included the TOKATA code

$$\chi_i = AHI * \left(\chi_i^{PS} + \frac{1}{1/\chi_i^{B} + 1/\chi^{GS}}\right) \qquad \text{.... /5/}$$

where constant AHI allows to increase artificialy the power losses from ion component by thermal conductivity.

+ KFKI Budapest ++ ÚFP ČSAV Prague

The resistivity of the plasma is supposed to be classical /Spitzer/, with possibility of its enhancement by a constant AR

$$\eta = AR * \eta_{class} \qquad \ldots /6/$$

Results of the preliminary calculation for a regime with the current I_p= 20 kA and value of the density at the centre of plasma $n_e(0) = 3.\ 10^{13} cm^{-3}$ /see fig. 1/ have shown, that the coputed central values of T_e and T_i are in reasonable agreement with experimental data for AHI = 3, AR = 1 and Z_{eff}= 3. But the calculated radial profiles are probably too flat, because of neglecting radiation, diffusion and charge-exchange energy losses which play a dominant role at the pherifery of the plasma column.

The second code TOKSAS calculates the detailed energy balance of the ion component so that the energy losses by diffusion P_{dif} and by charge-exchange processes P_{ex} are taken into account, too.

$$\frac{dQ_i}{dt} = P_{ei} - P_{cond} - P_{dif} - P_{ex} \qquad \ldots /7/$$

The neoclassical values of thermal ion conductivity are the same as in TOKATA code, but common formula differs a little

$$\chi_i = \frac{\chi_i^B . (\chi_i^{PS} + \chi_i^{GS})}{\chi_i^{PS} + \chi_i^{GS} + \chi_i^B} \qquad \ldots /8/$$

The radial profile of the neutral atoms /see fig.2/ used for enumerating of the diffusion P_{dif} and charge exchange losses P_{ex} is calculated independently by solving Boltzman transport equation [4], supposing fixed profiles $T_i(r)$, $T_e(r)$, $n_e(r)$

and density of the neutral atoms at the scrape-of-layer $n_a(a)$ as input parameters.

From the main numerical result - the radial profile of ion temperature $T_i(r)$ /see fig. 3/, the radial dependence of all power channels can be enumerated as it is shown on the fig. 4 a, b.

Another two important quantities, suitable for direct comparison of the computed values with the experimental data, are calculated by the code TOKSAS.

One of them the energy spectrum of the fast charge-exchange atoms /see fig. 5/, escaping from the plasma column along the central chord is evaluted by expression

$$\left(\frac{dJ_a}{dE}\right)_{E=E_0} = \frac{1}{4\pi}\int_{-a}^{a} n_a(r).\,n_i(r).\,\varphi_i(r,E_0,T).\,\sigma_{Ex}.\,v(E_0).\,e^{-\tau}\,dr \qquad \dots (9)$$

where φ_i - distribution of plasma ions /supposed to be maxwellian /

σ_{ex} - charge exchange cross-section

τ - factor, describing attenuation of the fast neutral flow by the plasma

Moreover the radial distribution of photons emitted by excited hydrogen atoms can be calculated by subroutine HALPH /see fig. 6/

$$J_{pq} = \frac{1}{4\pi}\cdot n(p).\,A_{pq} = \frac{1}{4\pi}\,p^2.\,r_1(p).\,n_a.\,A_{pq} \qquad \left[\frac{\text{photons}}{\text{cm}^3.\,\text{s}.\,\text{strd}}\right] \dots (10)$$

where p, q - principal quantum numbers for the given spectral line

A_{pq} - transition probability

$r_1(p, n_e, T_e, n_a)$ - coefficient of the proportionality between excited and ground state atoms in the collisional - radiative model [5] approximated for our purposes as

$$r_1(3) = 1{,}13 . 10^{-4} \ln\left(0.78\ 10^{-13} + n_e + 1\right) \qquad H_\alpha \quad \ldots /11/$$

$$r_1(4) = 1{,}8 . 10^{-5} \sqrt{n_e . 10^{-13}} \qquad H_\beta \quad \ldots /12/$$

For direct comparison with optical diagnostic data, the line-integrated intensity of H_α and H_β is calculated

$$I_{pq}(h) = \int_{-\sqrt{a^2-h^2}}^{\sqrt{a^2-h^2}} J(x)\, dx \qquad x = \sqrt{r^2 - h^2} \quad \ldots . /13/$$

$$I_{pq} \left[\frac{\text{photons}}{\text{cm}^2 . \text{s} . \text{strd}}\right]$$

References:

[1] Bürger G., et al.: In proc. of X.Eur. Conf. Contr. Fusion and Plasma Phys., Moscow 1981

[2] Stöckel J., et al.: In proc. of 7. Conf. Czec. Phys., Prague 1981, 03-29

[3] Bernard M. : REPORT EUR-CEA-FC-891, Avril 1977, FONTANAY-AUX-ROSES

[4] Izvoschikov A.B., Petrov M.P.: Fizika plazmy. 2(1976)2, p.212
Zaverjaev V.C., Izvoschikov A.B., et al.: Fizika plazmy 4(1978)6, p.1205

[5] Johnson L.C., Hinnov E. : Princeton University Report MATT 909, August 1972

TOKATA input parameters:

$a = 9$ cm, $R = 40$ cm, $B_T = 1.2$ T, $I_p = 30$ kA, $q(a) = 4.05$

TOKATA output parameters:

$U_z = 2.2$ V, $q(0) = 1.43$, $Q_p = 74$ J, $P_{OH} = 66$ kW

$\tau_E^* = 1.12$ ms, $\beta_p = 0.44$, $p = 770\ J/m^3$

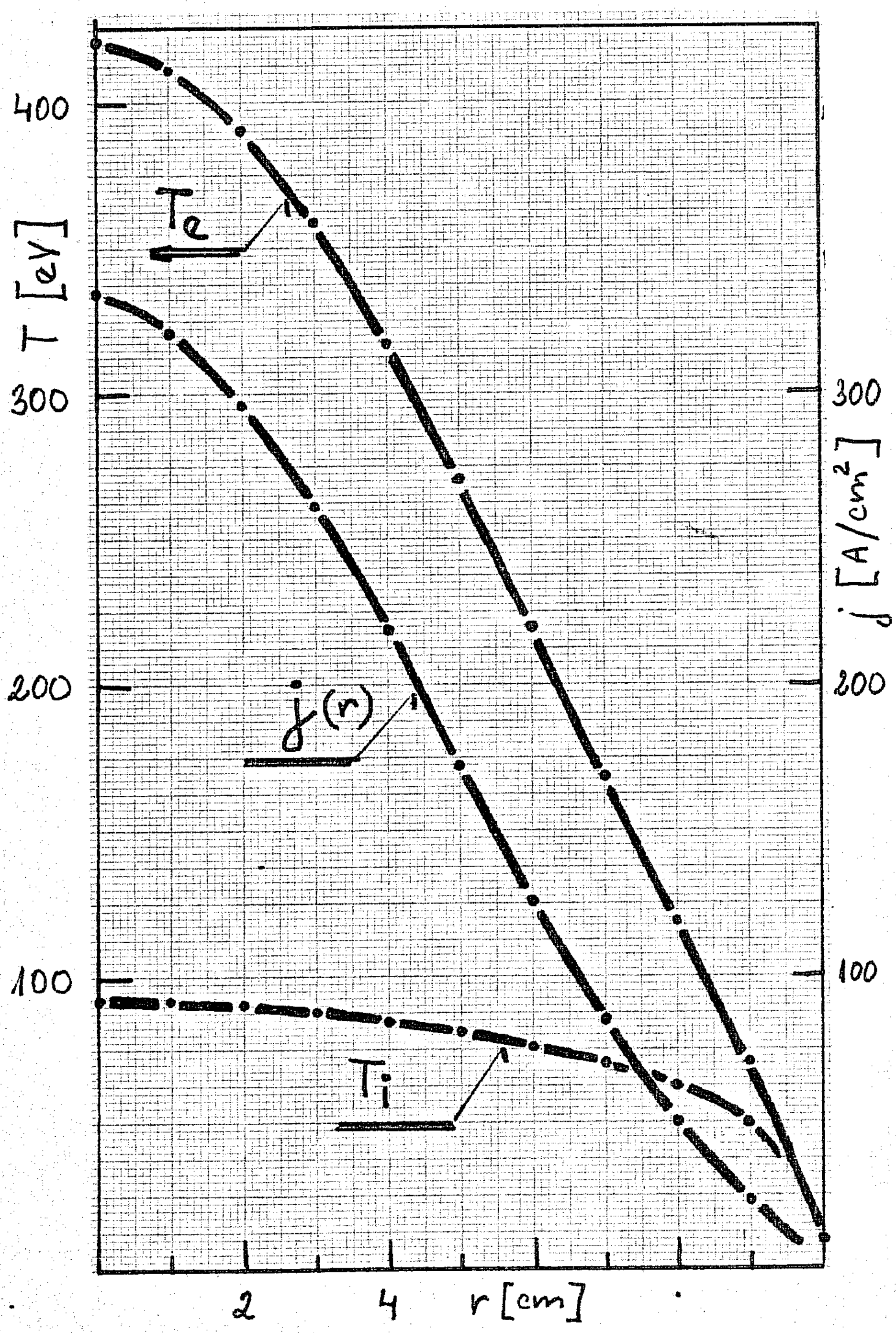

Fig. 1

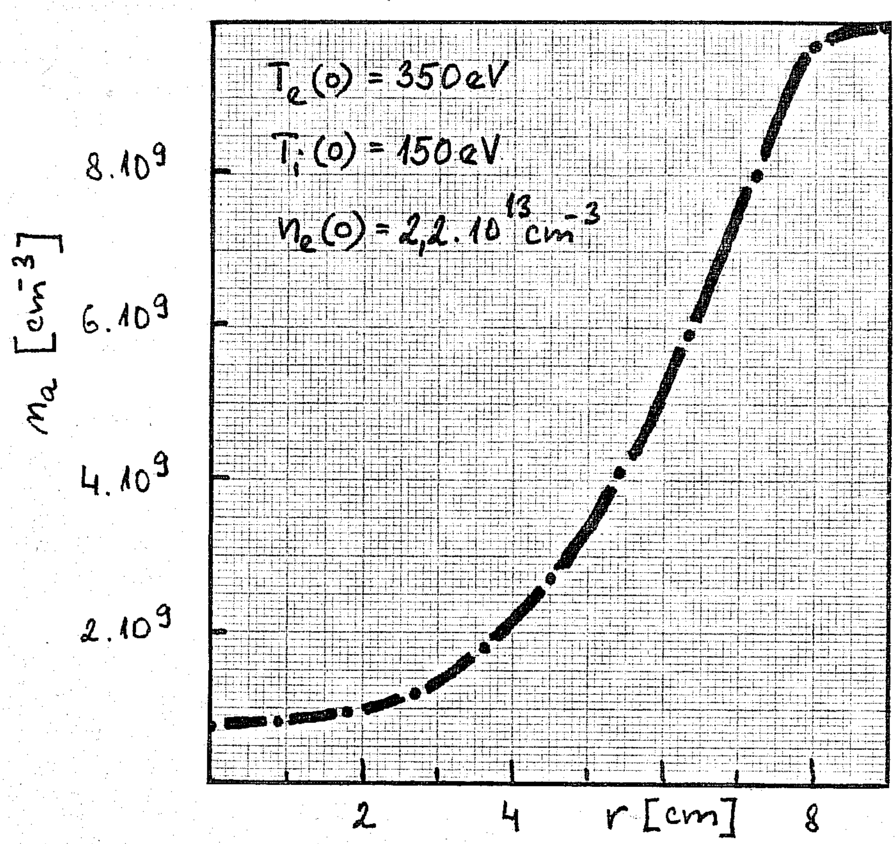

Fig. 2

Radial density profile of hydrogen atoms calculated by the code TOKSAS. The profiles of density and temperature of electrons and ions, the density and temperature at neutrals at the boundary were fixed.

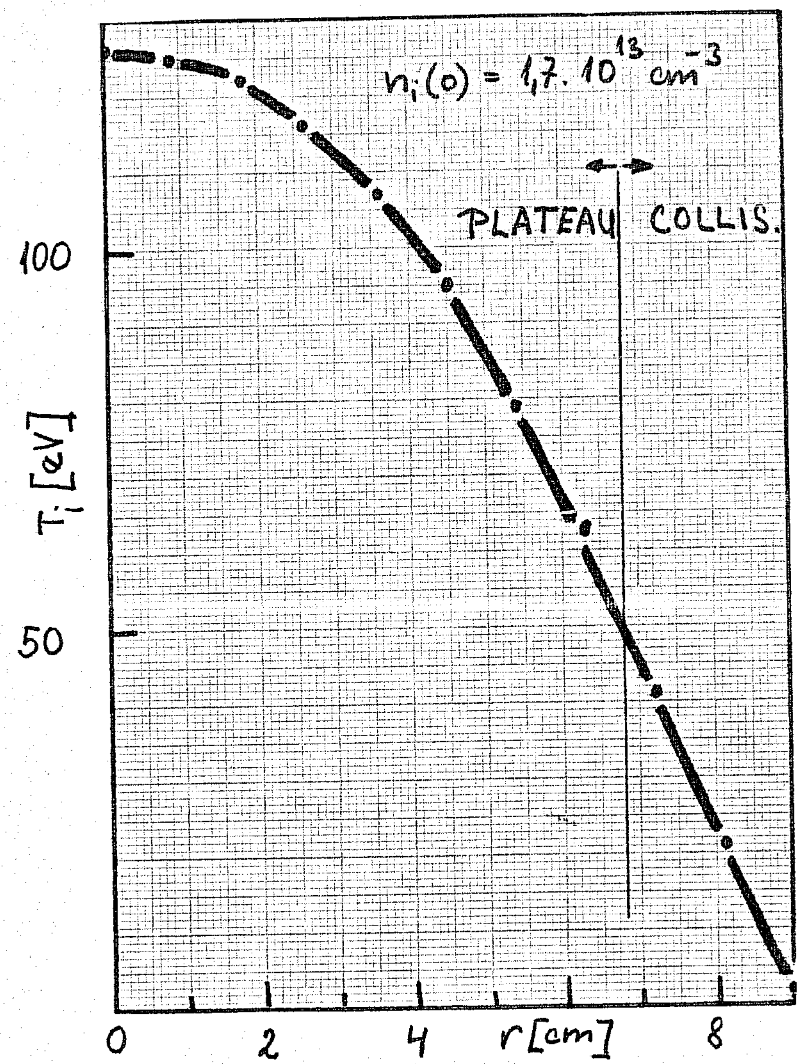

Fig. 3

Radial profile of ion temperature.
Using the density profile of neutrals calculated above and assuming the electron temperatüre profile to be known, the code TOKSAS calculates the ion temperature profile.

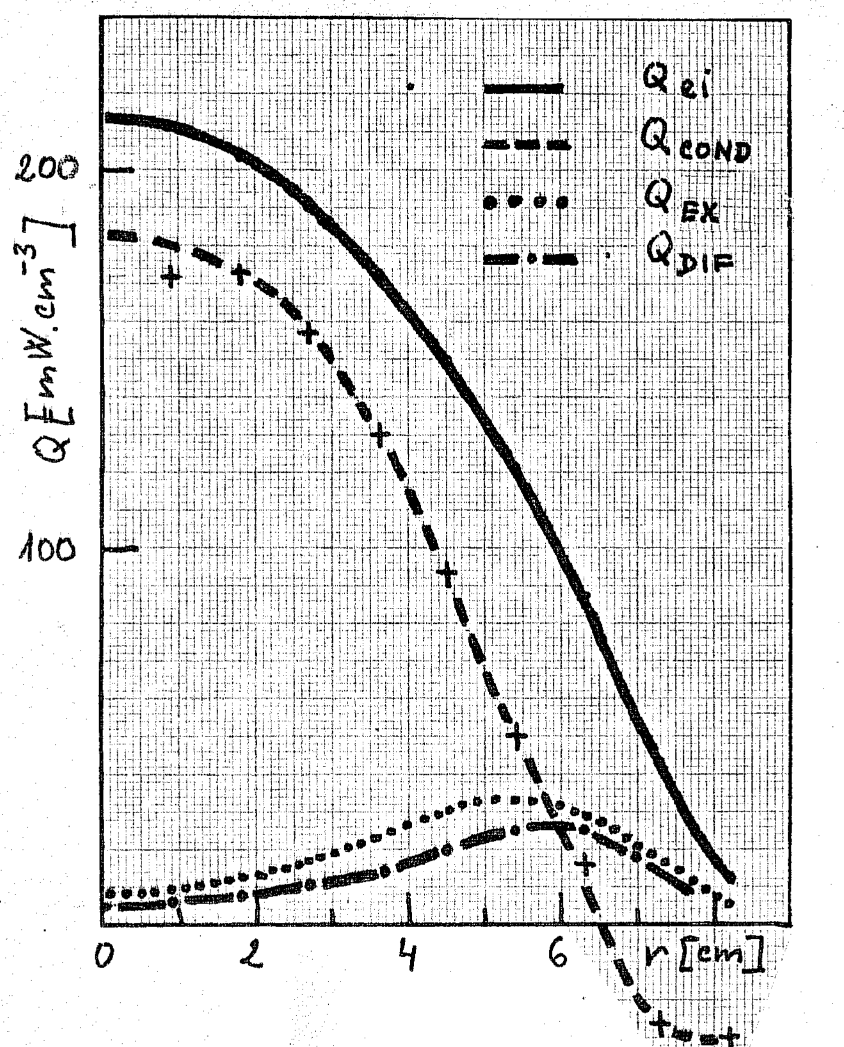

Fig. 4a
Energy gain and different types of energy losses of ions a unit volume

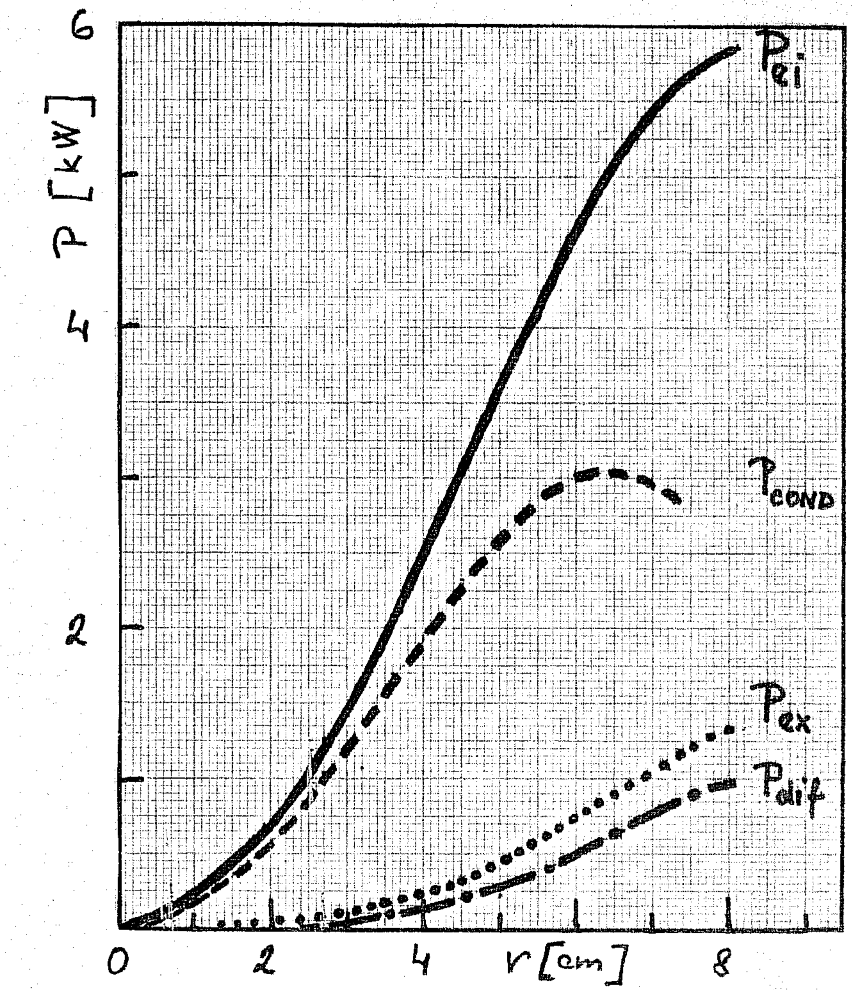

Fig. 4b
Integrated energy gain and losses of ions $P(r) = 2\pi R . \int_0^r 2\pi r' . Q(r') dr'$

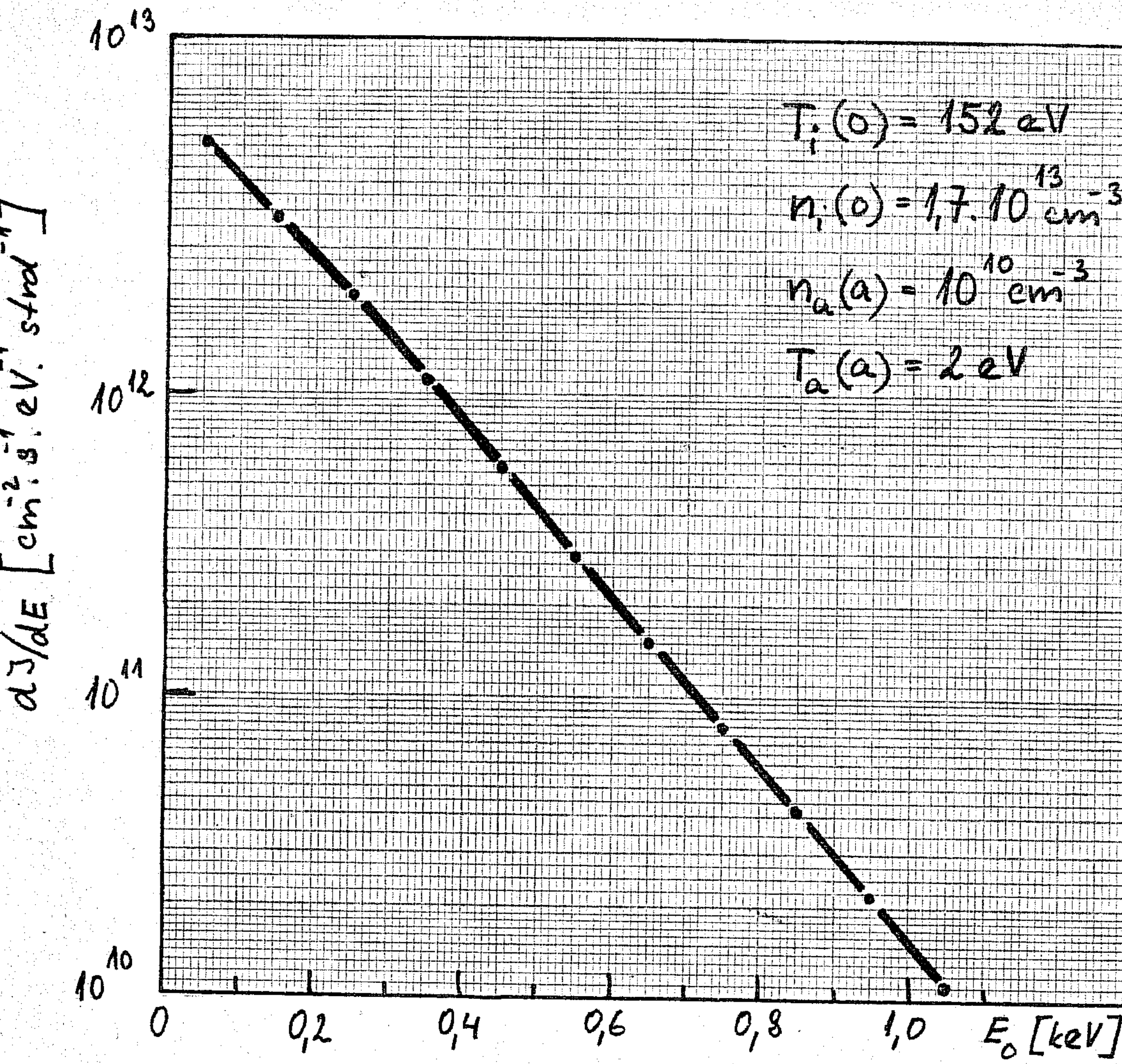

Fig. 5

Energy spectrum of the fast hydrogen atom flow

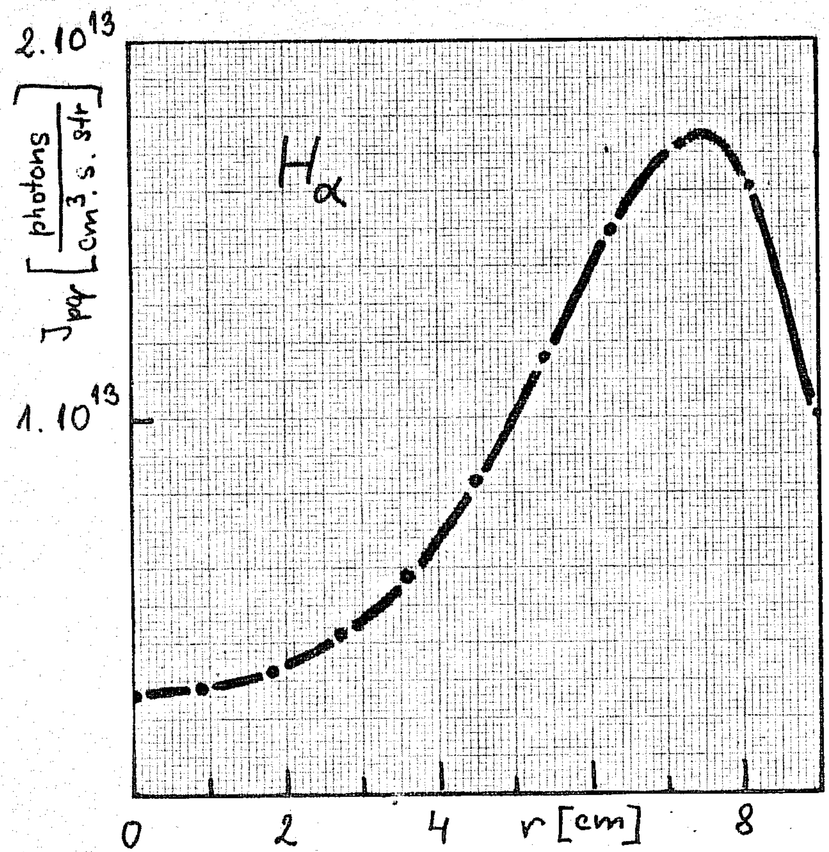

Fig. 6a
Volume intensity of H_α

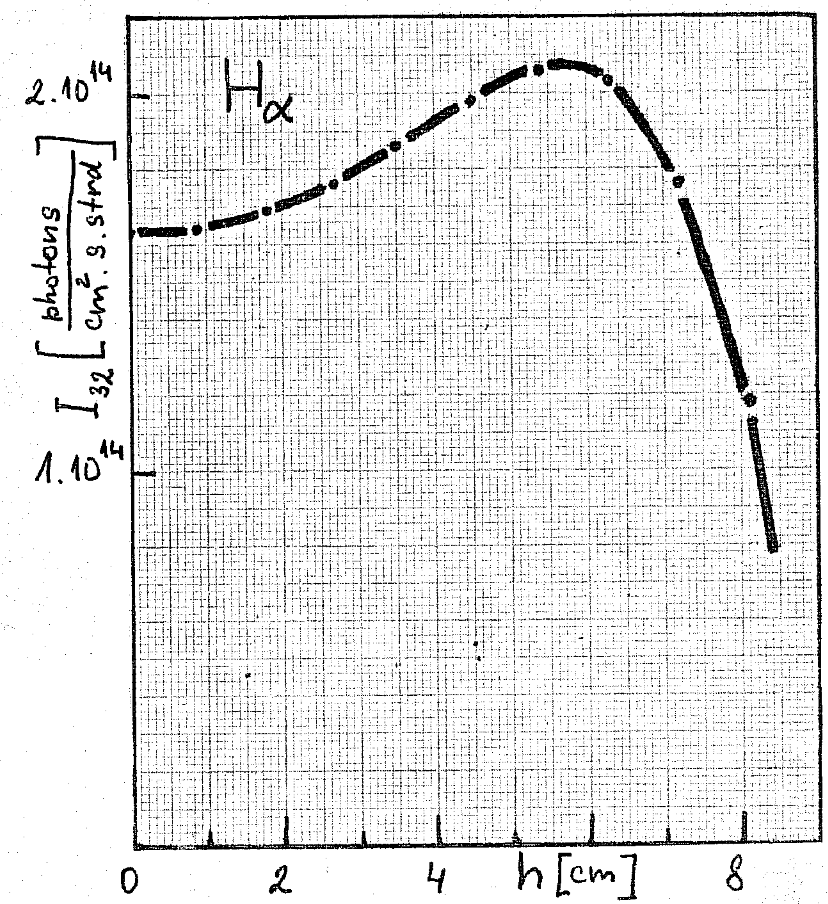

Fig. 6b
Intensity of H_α, line-integrated along different chords.