EXPERIMENTS WITH A 400 KeV VAN DE GRAAFF USED AS A PULSED NEUTRON SOURCE

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I - INTRODUCTION

The study of thermal neutron diffusion by the pulsed neutron source method, permits to obtain directly two parameters (absorption cross-section Σ_a and diffusion length L) whereas a single one (L) is obtained in stationary processes. Besides, the pulsed neutron source method, generally permits the use of reduced dimensions of systems, a very interesting aspect from a practical point of view.

For the development and utilization of the non-stationary techniques on the study of moderators and multipliers media, the Reactor Physics Division of the I.E.A. has an electrostatic accelerator model PN-400 of the High Voltage Engineering Corporation. Since the beginning, the Van de Graaff has been used to measure the parameters of thermal neutrons diffusion in the water.

For its intrinsic importance and because there are more than ten works already published by groups of all the world, this experiment was considered basic for the study and development of the method.

Considering the results of the experiments done in other centers, the precision of the results here presented is beneath expectation.

However, it was possible to accomplish a survey of the problems connected to technique, not only from the experimental view-point, but also in relation to the data analys s.

II - THEORY

If a fast neutrons burst is injected into a moderator, the neutron balance, after thermalization, will be described by the time dependent diffusion equation, on absence of sources, which solution is (A1)

$$n\,(r,t) = \sum_{lmn} K_{lmn}\; S_{lmn}\; e^{-\lambda_{lmn} t} \qquad \text{II.1}$$

where the K_{lmn} S_{lmn} are the thermal spatial distribution for $t = 0$. The form of the S_{lmn} depends exclusively of the moderator geometry, when the boundary conditions are given[1].

For any instant after the establishment of the equilibrium between the neutron gas and the medium

$$\lambda_{lmn} = \bar{v}\,\Sigma_a + DB^2_{lmn} \qquad \text{II.2}$$

where $\bar{v}$ is the mean velocity of the maxwellian distribution of thermal neutrons, D is the thermal diffusion coefficient on the equilibrium, and Σ_a is the thermal macroscopic absorption cross section. B^2_{lmn} the buckling of the medium, is an increasing function of the indexes. It implies that, from a certain value of t[1] the only important contribution to the thermal neutron population will be the one of the fundamental harmonic ($l = 0$, $m = 0$, $n = 0$). Then the temporal behaviour of the neutron population will be described by $\exp\left[-\lambda(B^2)\right]$ II.3

with $\lambda(B^2) = \bar{v}\,\Sigma_a + DB^2$ II.4

where we made: $B^2_{000} = B^2$ and $\lambda_{000} = \lambda$

So, λ is a linear function of B^2 and the straight line parameters are $\bar{v}\,\Sigma_a$ and D. They can be obtained from the decay curves which correspond to two values of B^2, at least.

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(1) $\lambda_{tr} =$ on the extrapolated boundary of the system.

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(1) This instant may be calculated if the coefficients of II.1 are explicitly known.

However, the linear dependence is true only for small values of B^2 (large dimensions of the moderator). When B^2 increases, $\lambda(B^2)$ takes a parabolic form. What happens is that the escape of more energetic neutrons causes a decrease of the effective mean temperature of the neutron population. One can obtain a better description of the process considering a two groups theory of neutrons. With such a theory, $\lambda(B^2)$ will be given by:

$$\lambda(B^2) = \bar{v}\,\Sigma_a + DB^2 - cB^4 \qquad \text{II.5}$$

The term $-cB^4$, presented on II.5 takes this behaviour into account. The coefficient c is called diffusion cooling coefficient.

III - EXPERIMENTAL PROCEDURES

Description of the Apparatus

Fig.1 is a schematic drawing of the experimental set up. The target is isolated from ground. The incidence of an ion burst produces an electric pulse. From the beam preamplifier the pulse goes to the monitor oscilloscope and to unity A-1, which is a discriminator amplifier and furnishes formed pulses to the trigger of the analyser. The burst repetition rate is fixed, and chosen so as to allow the neutron population to decrease completely before the next pulse. Of course this interval should be sufficient for the total sweeping of all the analyser's channels. The signal from the BF_3 counter goes to a scaler which serves as monitor and also furnishes formed pulses for the analyser. The micro amperimeter allows reading of the mean ion current.

On Fig.2 is given the detail of the source-moderator-detector arrangement. On the bottom of the cylinder was placed a cadmium mask, cut according to the function $J_o\left(\frac{2.405\,r}{R}\right)$ (DS 2). With this mask it is expected that all radial harmonics, with exception of the fundamental one, be eliminated. The detector is a BF_3 counter positioned on the cylinder's base and its dimensions are 5 cm diameter and 45 cm length. The water container is an aluminum cylinder placed inside a box whose walls are a boric acid and paraffin mixture, covered with Cd internally and externally. The several bucklings were obtained by varying the water level.

Neutron Source

The accelerated particles were deuterons, striking a Tritium target.

The characteristics of the pulses were:

period	1100 μsec
duration	20 μsec
amplitude	65 μA
rise-time	.6 μsec

Time Analyser

A TMC 256 channels time analyser was used, with a 211 time of flight unit.

The storage time of this unit is 16 μsec, so that it is possible to count more than one neutron per pulse.

The unit 220-A (Data Output Unit) of the analyser (fig.1) is used to preset the number of "bursts".

IV - RESULTS AND ANALYSIS METHODS

Analysis of the Decay Curves

The decay curves were analysed by a least squares method (M1). The minimized expression is:

$$S^2 = \frac{1}{n - k} \left[Y_i - Y(t_i) \right]^2 . w_i$$

where:

n = number of experimental points

K = number of parameters

Y_i = points on the calculated curve

$Y(t_i)$ = experimental values

$W_i = 1/\sigma^2_Y$

σ_{Y_i} = standard deviation in $Y(t_i) = \sqrt{Y(t_i)}$

The points on the time axis were considered free of errors and the counts at each channel was computed as it occurred in the initial instant. All decay curves were obtained with channels of 4 μ sec width. The analyses were carried out considering only the channels with a delay greater than 80 μsec.

The fact of some channels being closed (due to the storage time) after receiving an event leads to a correction of counting losses which in some cases (good statistics) is significant. This correction is made normalizing the obtained countings in each channel, referring them to the number of bursts. A correction was also made for the time resolution of the BF_3-Pre-Amplifier-Scaler set.

The channels were grouped two by two or three by three for the least squares fittings.

The decay curves were adjusted for one or two exponentials plus a constant term.

<u>Straight line adjustment of $\lambda(B^2) = \bar{v}\Sigma_a + DB^2$</u>

In this case, the minimized expression was:

$$S^2 = \frac{1}{n-k} \sum (W_B V_B^2 + W_\lambda V_\lambda^2)$$

where W_B and W_λ are respectively the weights on the coordinates B^2 and λ and are equal to the inverse of the square of the errors. V_B, V_λ are the deviation of the experimental values in relation to the calculated curve.

The errors on the cylinder radius and on the water volumes were evaluated for the B^2 error calculation. Afterwards a more careful analysis showed that, probably, the volume errors were overestimated on 30%, but the correction would not imply necessarily a better adjustment of the data.

For both adjustments, programs were made in Fortran language for the IBM 1620 Computer of the "Centro de Cálculo Numérico da Escola Politecnica da Universidade de São Paulo."

The decay curves analyses program was a modification of Moscatti's program (M 1). The introduced modifications aimed at adapting the program to our experimental conditions.

<u>Results</u>

On Fig.3 we have λ_{00} (decay of the fundamental harmonic) versus the buckling. It was tried to adjust the experimental values to a curve $a + bx + cx^2$, but the data were insufficient to characterize the parabola. Table 1 is a summary of the experimental values that were obtained.

Due to the use of the mask cut according to the function $J_o\left(\frac{2.405r}{R}\right)$ we could only expect in our setup the presence of axial harmonics ($m = o$, $n = 1, 2, 3...$) besides the fundamental component. Fig.4 shows the secondary components of the decay curves in function of B^2_{01}. The straight line was traced with $\bar{v}\ \Sigma_a$ and D given in fig.3 and may be considered as a theoretical prevision for the λ_{01} values.

The complete disagreement of the experimental points with this curve indicates that, probably, the experimental points of fig.4 represent the decay due to the scattering on the laboratory walls, floor and ceiling.

V - CONCLUSIONS

Comparing our results with the ones found in the literature (see table 1 in (LB 1) and also (RSW 1)), we can see that the errors in $\bar{v}\ \Sigma_a$ and D of our experiments are very high. We may point out some of the causes that contributed for this. The deviation of the experimental points in relation to the calculated curve reach 4%. In the experiment of (LB 1) for example, there is a maximum deviation of 1%. Besides this, we considered only B^2 values between .08 cm^{-2} and .201 cm^{-2} while in the experiments already published, larger intervals were explored. Of course it would be interesting to maintain the density of experimental points, if we increase the B^2 values interval. For a quality evaluation of our results, a comparison with (LB 1) experiments was made, as follows:

We selected from that work λ_{00} values between the B^2_{00} values region enclosed by our experiment.

An analysis of these values by the least squares method gave errors in the straight line parameters comparable to the ones obtained by us.

In relation to the λ_{00} values, we believe that the deviations could be decreased, if we improved the statistics of countings, which was never better than 10^5 countings on the first channel. Health Physics reasons were an important factor on this limitation[1].

It would also be desirable that each computed value of λ_{00}, be the result of some measurements instead of just one, because we may have statistical fluctuation on this parameter.

There are works in which the experiments are made with more than one channel width so as to take into account possible errors which can be introduced by the equipment. Our work also does not have this refinement. We limit ourselves to calibrate the time scale and the width of our analyser's channels.

If we are really detecting the laboratory's decay, as we were lead to believe by the data of fig.4, it is reasonable to expect also that this variable background would be present at least as contaminations on the curves which were adjusted for only one exponential; but we cannot evaluate how much this background influenced our results.

On the other hand, we are not sure to have isolated the decay of the laboratory on the curves where two exponentials are present (the harmonic λ_{01} may be present as contamination). In conclusion, we may point out that the elimination of this background is an important factor to improve the quality of our results[1].

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(1) We hope that this situation will be completely changed, with the removal of the V.G. to the shed, which has very thin walls.

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(1) Actually, with the removal of the Van de Graaff to an outside shed, these restrictions of Health Physics will be eliminated. The daily operation time and the acceleration potential improvement of the counting statistics.

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TABLE 1

Summary of the Results

$B^2_{od}(cm^{-2})$		$\lambda_{oo}(sec^{-1})$		$\lambda_{o1}(sec^{-1})$	
.0780	± .0014	7652	± 123	16700	± 809
.0877	.0017	8003	109	19521	1278
.1021	.0021	8036	134	17482	1043
.1054	.0022	8340	115	18019	1148
.1171	.0026	8593	191	17919	1996
.1254	.0029	9235	50	27730	2298
.1431	.0036	9286	287	17117	3238
.1608	.0042	10288	94	22317	5260
.1807	.0055	11145	23	- -	- -
.2010	.0057	11580	19	- -	- -

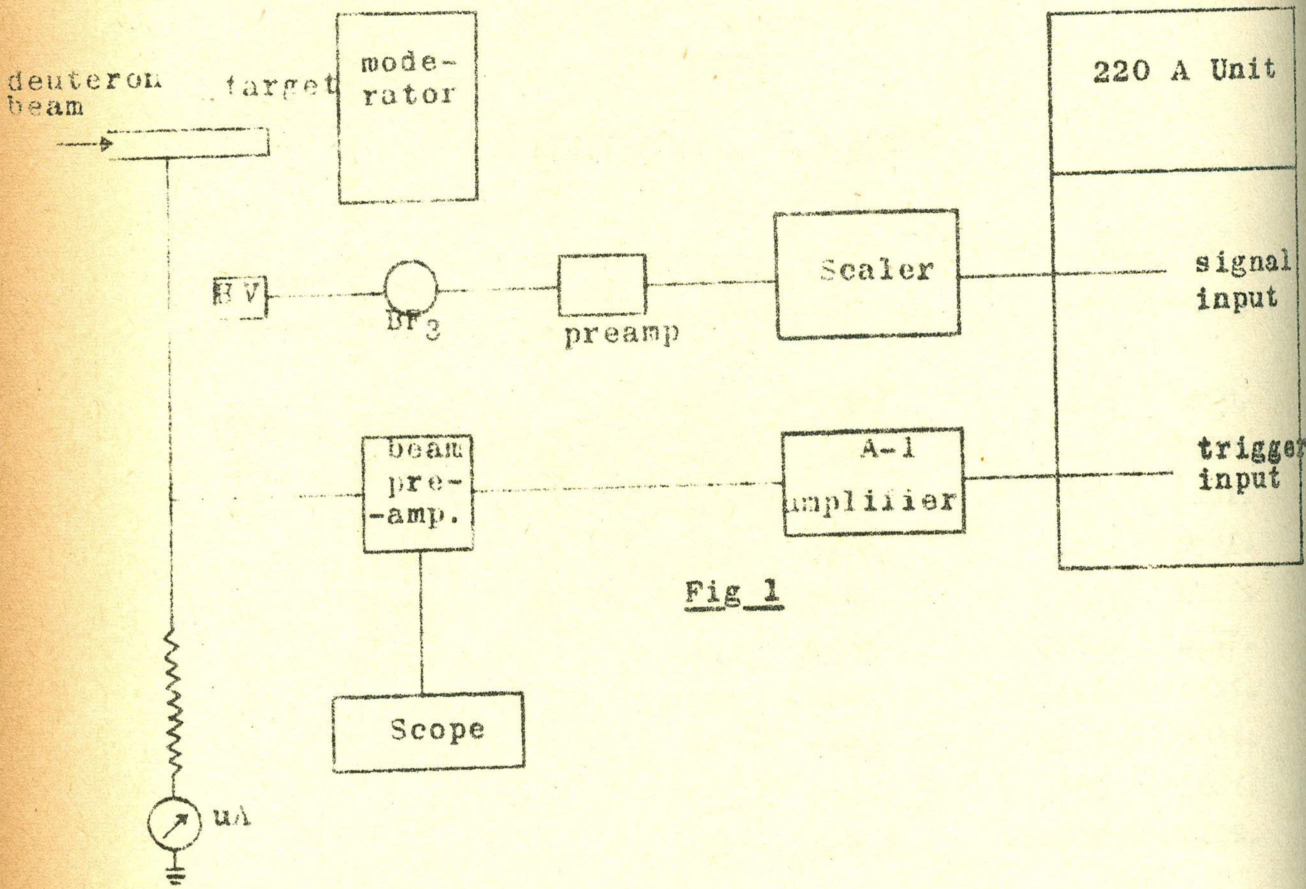

deuteron beam
target
mode-rator
220 A Unit
H V
BF_3
preamp
Scaler
signal input
beam pre--amp.
A-1 amplifier
trigger input
Scope
uA

Fig 1

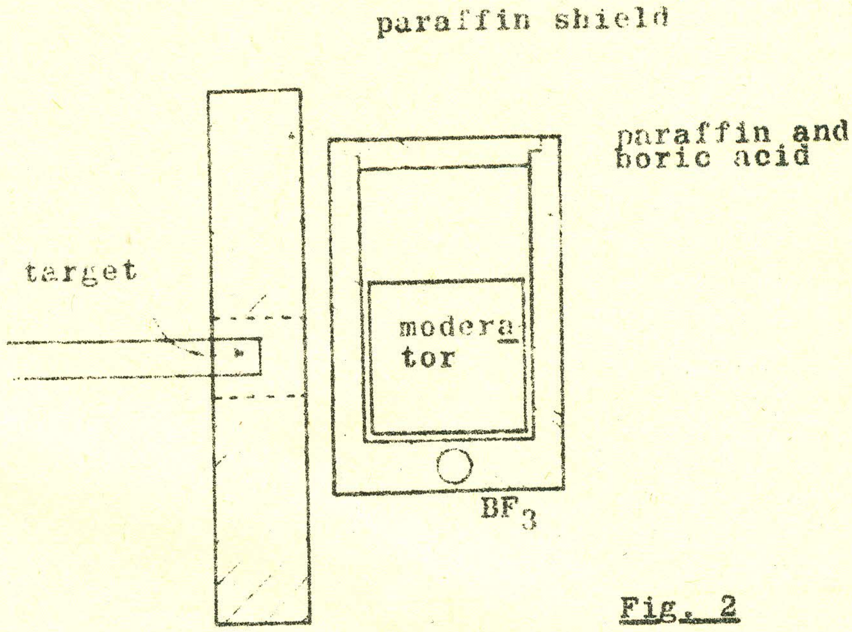
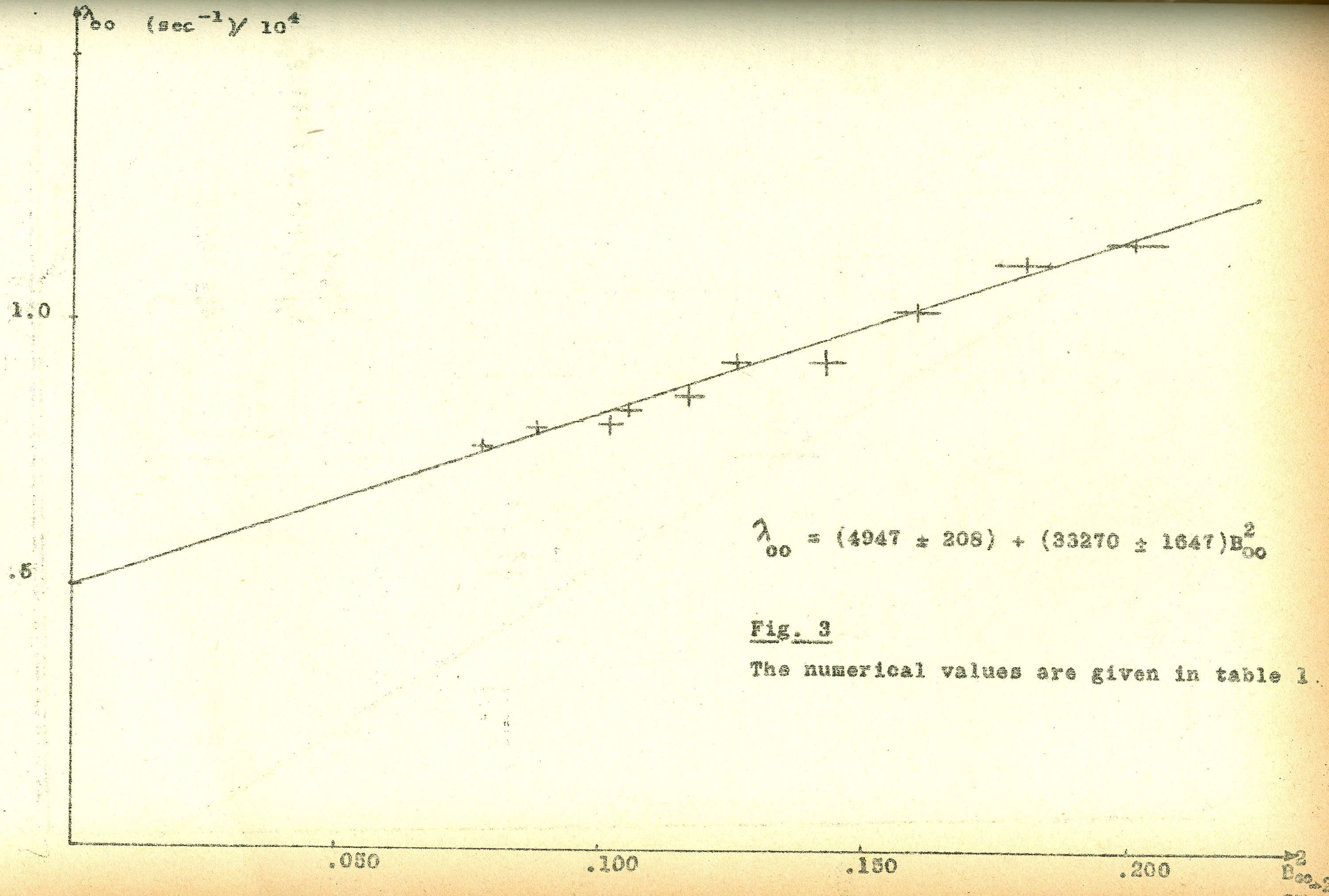

paraffin shield
paraffin and boric acid
target
modera tor
BF_3

Fig. 2



$$\lambda_{oo} = (4947 \pm 208) + (33270 \pm 1647)B_{oo}^2$$

Fig. 3

The numerical values are given in table 1.

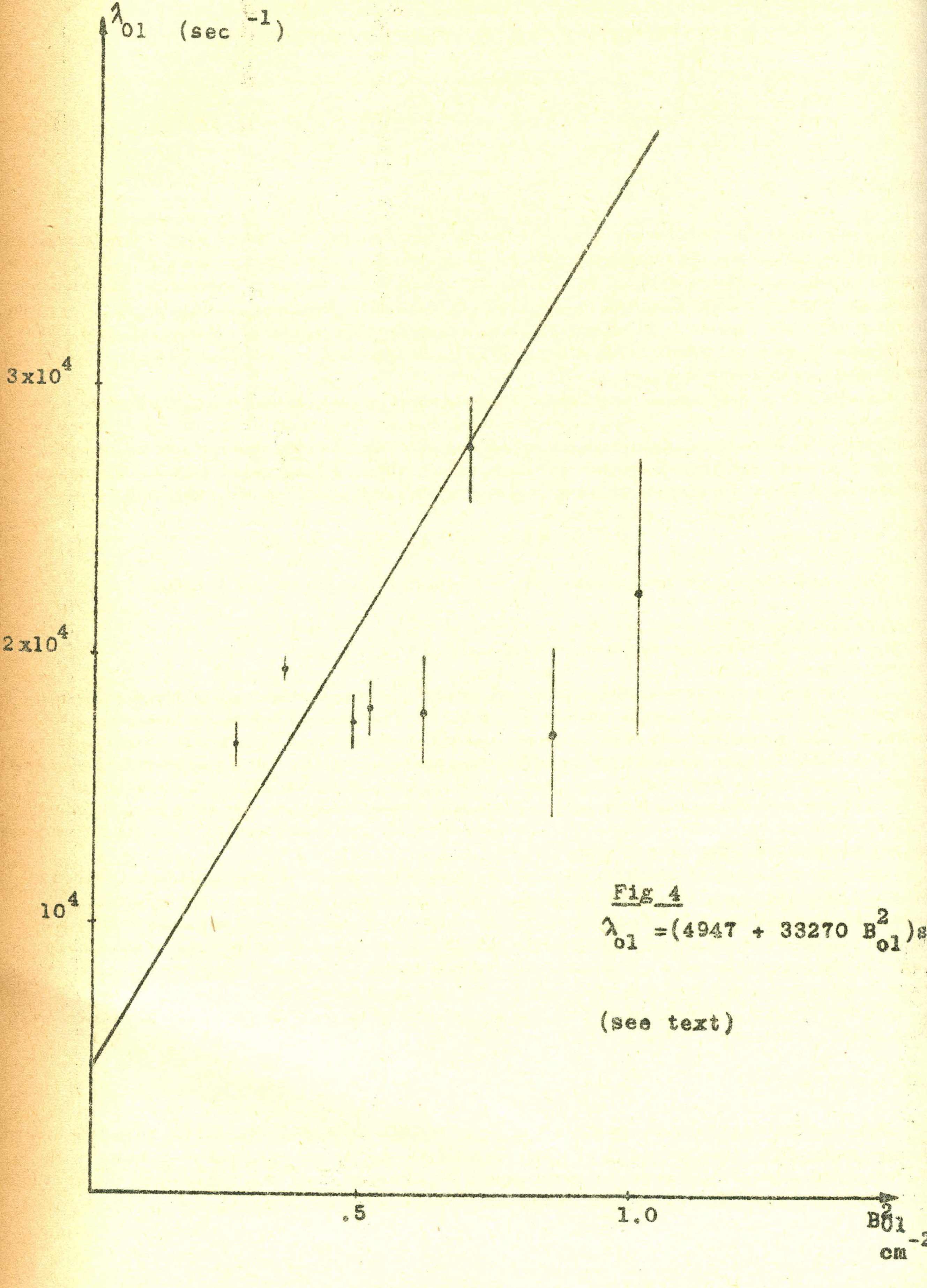


Fig 4

$\lambda_{01} = (4947 + 33270\ B^2_{01})\,\text{sec}^{-1}$

(see text)