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Los Alamos Doc Rm. 1/17/51
W.A. Russell, Secy & JRO 1/22/51
Name Title Date

LA - 558 C.3

[redacted]

May 15, 1946

This document contains 15 pages

DIRECTIONAL PROPERTIES OF FISSION NEUTRONS

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ABSTRACT

An experiment has been performed to measure the correlation between direction of neutron and fragment in the fission process. The results are consistent with the isotropic evaporation of neutrons from the moving fragments and with the energy spectrum of fission neutrons.

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DIRECTIONAL PROPERTIES OF FISSION NEUTRONS

The simplest picture of the emission of fission neutrons is that they are evaporated from the moving fission fragment. If this is true, and if the evaporation velocity is comparable with that of the fragments then one would expect the neutrons, when measured in the laboratory system, to be emitted predominantly in the direction of the fragments.

The present experiment was designed to detect and measure the directional correlation of the fission fragments and the emitted neutrons.

Fig. 1 and the photographs show the experimental arrangement. The direction of the fission fragments was determined by the thin collimator which was placed over the U_{235} foil—one mg/cm^2 thick. The collimator consisted of a grid of closely spaced 1/16" holes drilled in 1/8" thick block of aluminum. The holes were drilled over a square area one inch to the side which corresponded to the area of the foil. The fission fragments penetrating the collimator were detected by the ionization chamber formed from the collimator and the ion collection plate 3/8" away. It was possible to rotate the system. The neutron counter consisted of a bundle of ten proportional counters 1-1/2 inches long and 3/8" diameter. The three mil wires along the axis of all counters were connected in parallel to a fast amplifier (Model 500). The inside of each cylinder was coated with paraffin. The sensitive area of the counter was very nearly a square one inch to the side. The front of the neutron counter was 1-7/8" from the center of the U_{235} film. The geometry was such that if the neutrons were emitted exactly in the direction of the fission fragments, then no neutrons would be counted by the proportional counter at angles greater

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than 45° with respect to the direction of the fragments. Argon at 60 cm Hg was used to fill the chamber and was thus the counting gas for both the ionization chamber and the proportional counter. A negative potential of 1000 volts was applied to the collimator and the cylinders so that electrons were collected in each case.

The fission pulses from the ionization collection plate and the neutron pulses from the wire were amplified separately and then led to a coincidence counter. The number of fissions, the number of neutrons, and the number of coincidences were all counted simultaneously when the foil was irradiated by the nearly pure thermal neutron flux of the water boiler. The resolving time of the coincidence system was 0.25μ sec as determined by placing a strong source of fast neutrons of various distances from the proportional counter and counting accidentals.

The first run was made to determine the rate of neutrons per fission in the direction of the fission fragments (0°) to neutrons per fission emitted perpendicular (lab. system) to the fragment direction. The fission counter bias was set as low as possible so that all fragments were registered.

Table I summarizes the results.

The second run was made to try to determine the effect of the energy of the fission fragment counted on the number of neutrons emitted in the direction of the fragment counted (0°) and the opposite direction (π). The energy of the fragment was varied by changing the fission counter bias. A typical bias curve is shown in Fig. 2. The gain of the amplifier was different at the time. The data are summarized in Table II. The statistics are poor as can be seen by the large standard errors given in

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in the last column. There is no effect of the energy of the fragment on neutrons emitted, but there is a slight indication of more neutrons per high energy fragment in the direction of the fragment.

A third run was made to obtain a curve of neutrons per fission at various angles. Table III shows the data and the standard errors listed in the last column show that the data are too rough even to plot. However, anything really unusual might have been noticed even with such rough data.

The experiment was done hurriedly under considerable pressure, and the results should be weighed accordingly

The first run was made under good conditions so let us see what conclusions we can draw from it about the process of neutron emission. Assume the simplified picture that the fission fragments all have the same velocity and that the neutrons are evaporated isotropically with respect to the moving fragment and with a uniform velocity.

The ratio of the number of neutrons emitted in the forward direction to those emitted at 90° can be calculated to be

$$\frac{N\,(\pi/2)}{N\,(0)} = \frac{r\,(r^2 - 1)^{\frac{1}{2}}}{(r + 1)^2} \qquad (1)$$

where $r = v_n/v_f$ and v_n is the speed of the emitted neutron with respect to the fragment and v_f is the speed of the fragments.

Now the proportional counter is sensitive to the energy of the neutrons and the speed of a neutron emitted at 0° is $v_n + v_f$ while that of a neutron emitted at $\pi/2$ is $\sqrt{v_n^2 + v_f^2}$. The energy sensitivity of a

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neutron counter of the same dimensions and gas filling was taken at a different time using a Van de Graaff generator. The curve is shown in Fig. 3 and for our rough purpose the sensitivity can be approximated by $K' \sqrt{E_n}$. If we make this correction to (1) we get

$$\frac{N(\pi/2)}{N(0)} = \frac{r(r-1)}{(r+1)^2} \qquad (2)$$

where $N(\pi/2)/N(0)$ is the ratio of neutrons counted at $\pi/2$ and 0. In Fig. 4 is plotted $N(\pi/2)/N(0)$ as a function of r, and we can read a value of $r = 1.8 \pm .2$ corresponding to the experimental value $N(\pi/2)/N(0) = .18 \pm .3$. If the average energy of a fission fragment is 70 Mev and the average weight is 100, the velocity v_f is the same as that of a neutron of 0.7 Mev, hence the energy of evaporation would be $0.7 \times 1.8^2 \approx 2.2$ Mev. Considering the uncertainty of the sensitivity of the neutron detector, the result is not inconsistent with the data on the fission neutron energy spectrum. Had we assumed that the detector was insensitive to energy the evaporation energy would be about one Mev.

The above description indicates the possibility of the method and it is hoped that the measurements will be repeated more accurately and extended. I had hoped to split the neutron counter and count coincidences between the neutron counters when they were on opposite sides of a piece of uranium exposed to thermal neutrons and when the two counters were on the same side. This would give information about the mechanism of emission of fission neutrons as well as of the quantity $\overline{v^2} - \overline{v}^2$. However, time did not permit this extension of the above experiment.

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TABLE I

Angle	Time min	Recoils / 64	Fissions / 1024	Coinc. / 4	Coinc. / Fiss. x 10^2	Acc. / Fiss. x 10^2	Effect x 10^2
0°	23	472	1941	4.0	2.12	.29	1.83
$\pi/2$	14	273	1093	6.7	0.61	.27	.34
π	5	91	403	8.5	2.11	.26	1.85
$(3/2)\pi$	6	108	573	3.5	.61	.25	.36

Avg. of 0° and π; $N(0) = (1.83 \pm 7\%) \times 3.91 \times 10^{-5}$

Avg. of $\pi/2$ and $(3/2)\pi$; $N(\pi/2) = (0.34 \pm 16\%) \times 3.91 \times 10^{-5}$

$$\frac{N(\pi/2)}{N(0)} = 0.18 \pm .03$$

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TABLE II

Angle	Fission	Time	Recoils/64	Fissions/1024	Coincs./4	Coincs./Fiss.	Acc./Fiss.	Effect
0	0	10	250	796	15	1.88	.35	1.53±.20
0	0	10	240	742	12	1.62	.34	1.28±.24
0	40	10	239	356	7.75	2.18	.34	1.84±.33
0	50	10	238	106	2	1.9	.34	1.6 ±.6
π	0	10	218	682	10.5	1.55	.30	1.55±.24
	40	10	230	318	4.0	1.26	.33	.93±.23
	50	10	239	55	0	0	.35	– ±100%

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TABLE III

Angle	Time	Recoils/64	Fissions/1024	coinc./4	coinc./fiss.	acc./fiss.	effect
0	10	331	729	16.25	2.23	.47	1.76±.28
π/16	12	501	883	14	1.58	.59	.99±.21
π/8	12	417	868	7	.81	.49	.32±.15
3π/16	11	450	780	6	.77	.57	.20±.16
π/4	13	576	910	6.25	.68	.61	.07±.13
3π/8	12	525	824	5	.61	.66	- .05±.13
7π/16	13	595	905	9.75	1.07	.64	.43±.17
π	12	556	831	13	1.56	.65	.91±.22
π	10	487	775	11.75	1.51	.68	.83±.22
(3/2)π	10	439	809	5	.62	.62	.00±.12
2π	12	518	779	12.25	1.58	.60	.98±.23

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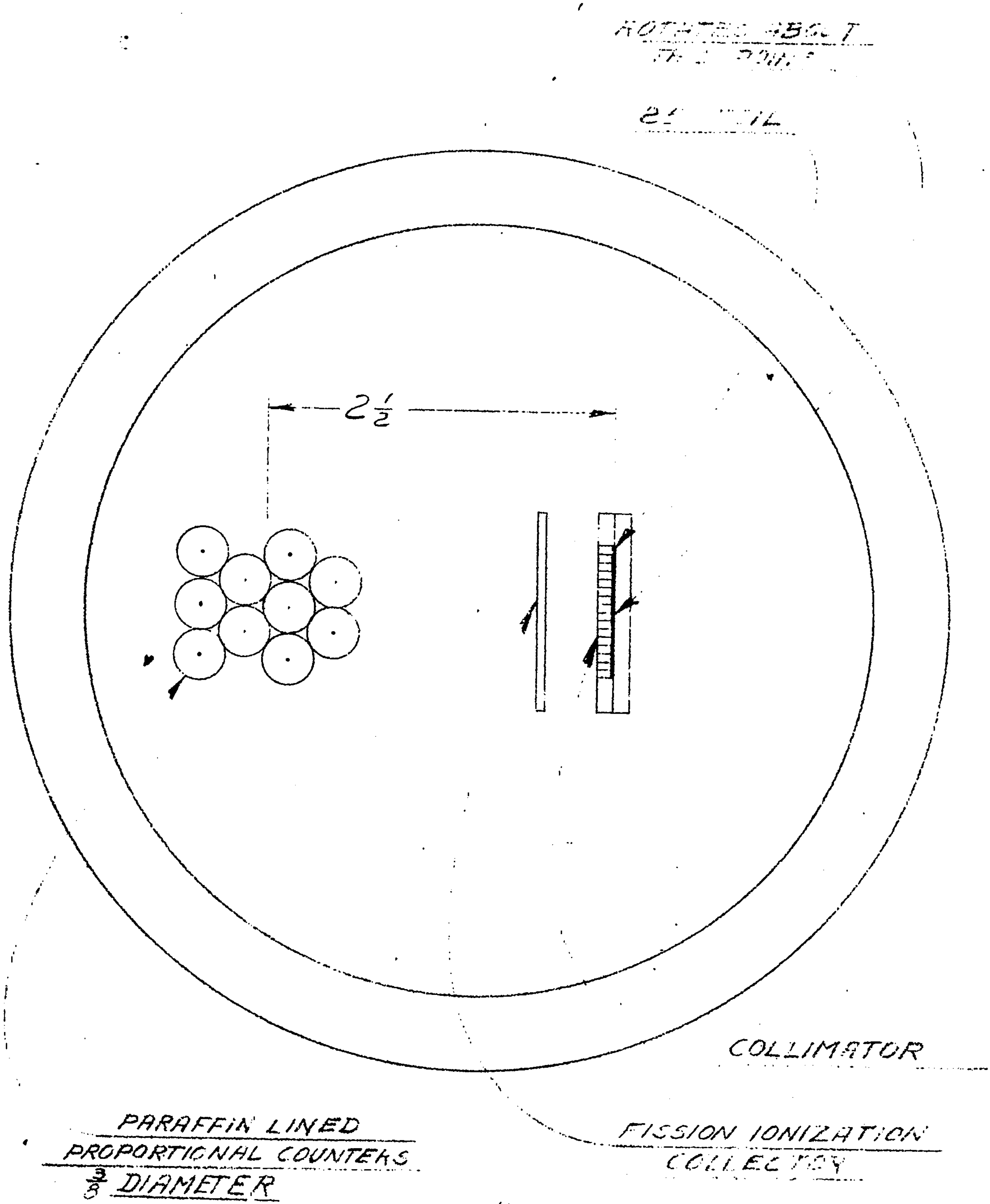

FIG. #1

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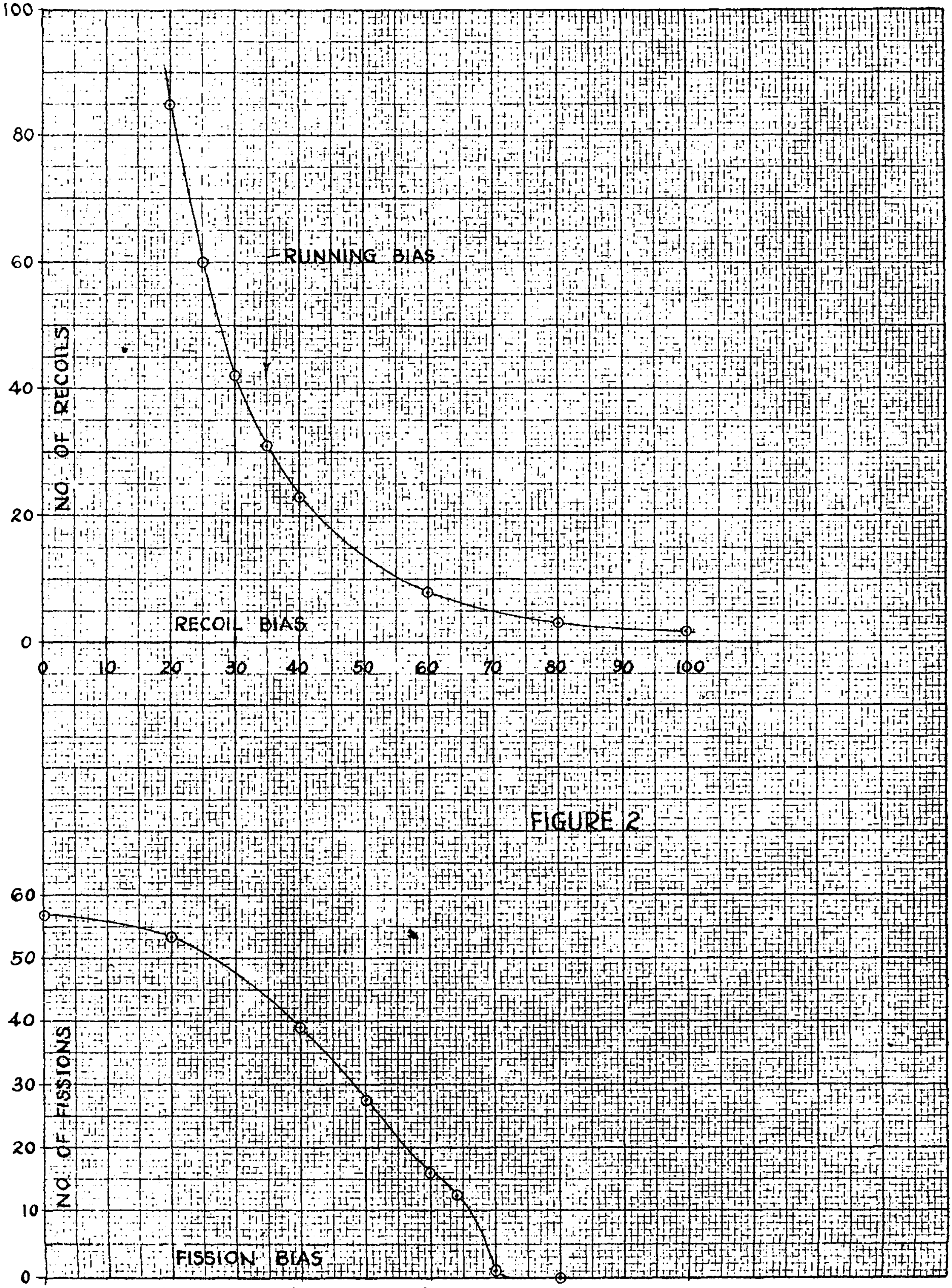

100
80
60
40
20
0
NO. OF RECOILS
RUNNING BIAS
RECOIL BIAS
0
10
20
30
40
50
60
70
80
90
100
60
50
40
30
20
10
0
NO. OF FISSIONS
FISSION BIAS
0
10
20
30
40
50

FIGURE 2

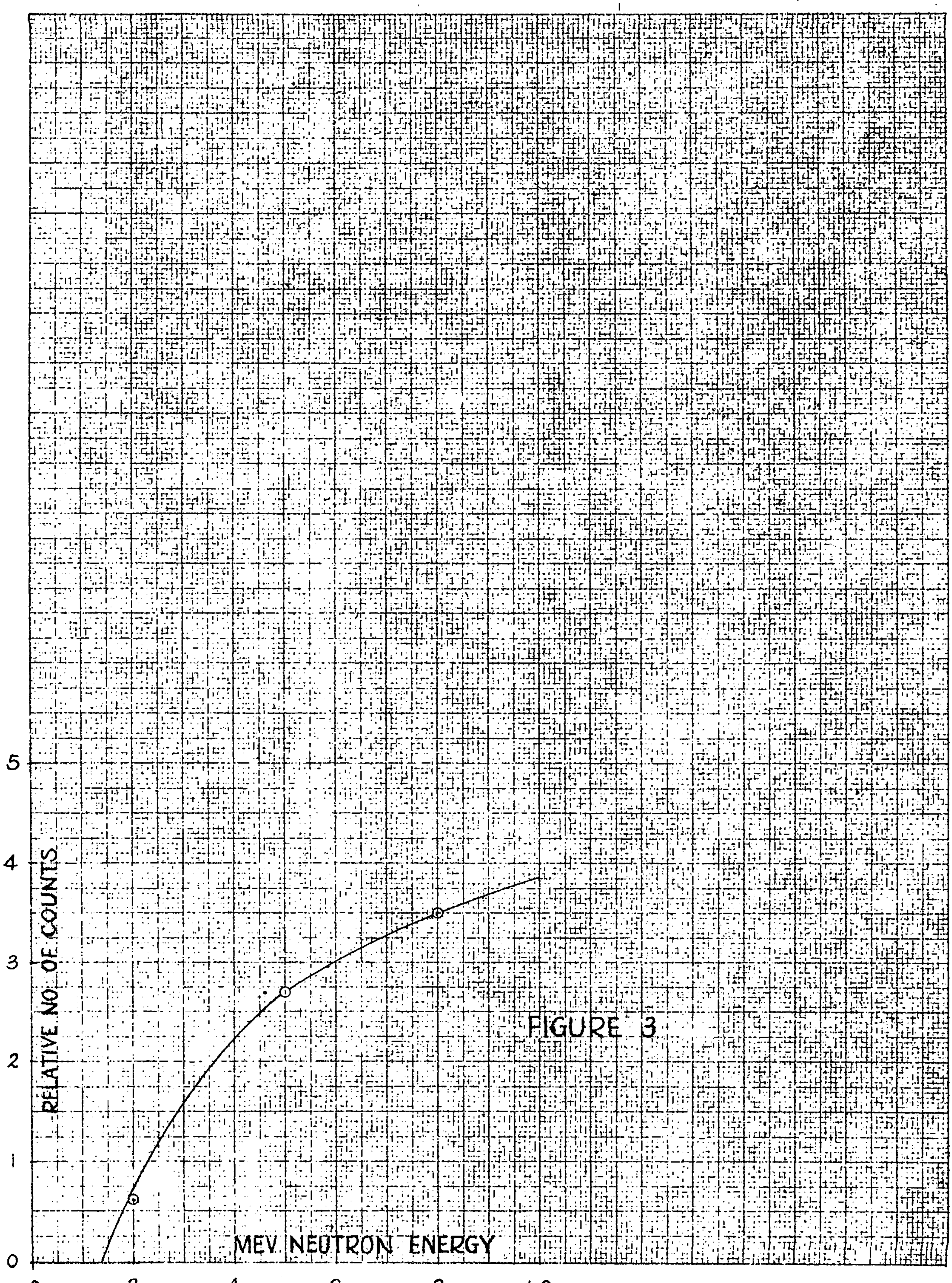


FIGURE 3

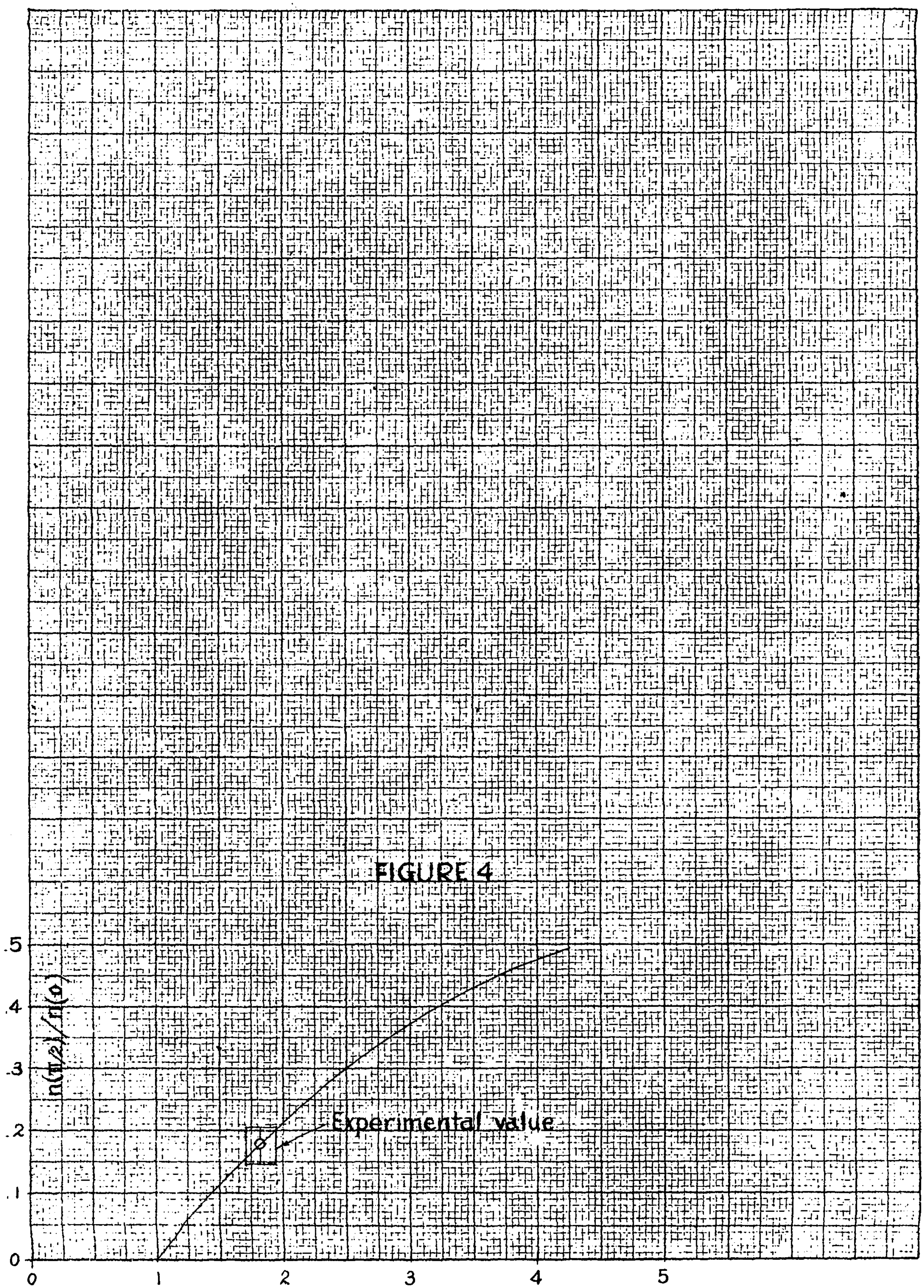
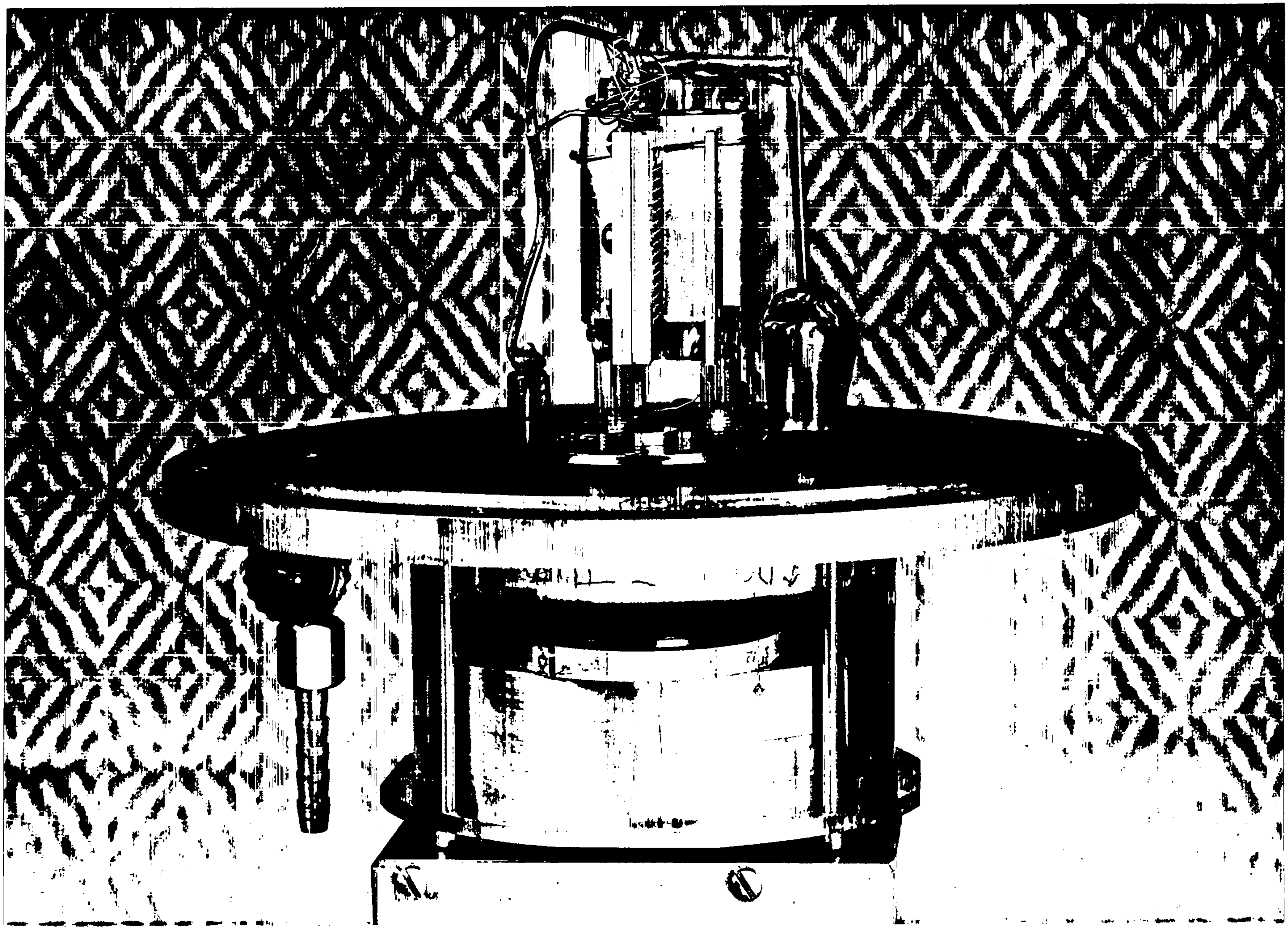


FIGURE 4
n(π/2)/n(0)
.5
.4
.3
.2
.1
0
0
1
2
3
4
5
Experimental value



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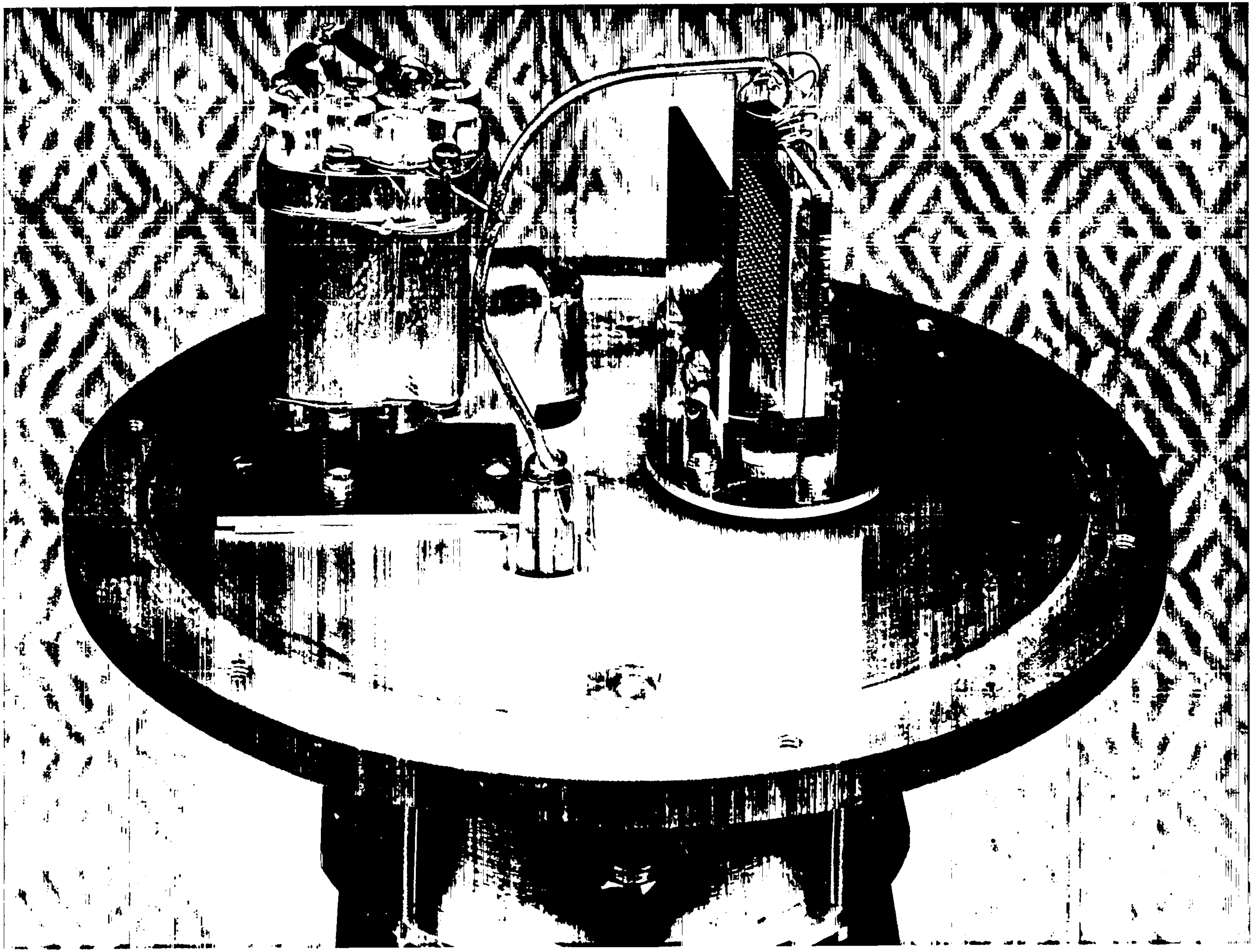

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