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Li^8 SPLINTERS FROM NUCLEAR BOMBARDMENTS

S. Courtenay Wright

October 3, 1949

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Li^8 SPLINTERS FROM NUCLEAR BOMBARDMENTS

S. Courtenay Wright

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Abstract

Li^8 has been produced by 340 Mev proton and 190 Mev deuteron bombardments of C, N, Ne, A, Kr, and Xe. The target element formed the gas of a proportional counter. The 0.88 second beta decay of Li^8 produces Be^{8*} which disintegrates into two alpha particles with a half life of 10^{-21} seconds. Li^8 was detected by observation of these alpha particles and identified by its half life. Deuteron excitation functions for the production of Li^8 are given for C, N, Ne, and A. In the case of 190 Mev deuterons the cross section varies from about 10^{-27} cm^2 for C to 2×10^{-29} cm^2 for Xe. For 340 Mev protons the variation is from about 7×10^{-28} cm^2 for C to 3×10^{-29} cm^2 for Xe. A discussion of the process involved is given.

Li^8 SPLINTERS FROM NUCLEAR BOMBARDMENTS

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Introduction

Since the discovery of Li^8 by Crane, et al.,[1] in 1935, its characteristics have been studied extensively. The ground state of Li^8 is probably a $^3P_2$ according to Feenberg and Wigner.[2] It beta decays with a 0.88 second half life[3] to several excited states of Be^8. The maximum energy of the beta particle is about 13 Mev. According to Wheeler[4] the principal Be^8 level involved is a $^1D_2$ situated 3.3 Mev above the ground state and with a width of 1.8 Mev. The Be^8 nucleus breaks up promptly (10^{-21} seconds) into two alpha particles. The total energy spectrum of the two alpha particles gives a picture of the parent Be^8 level, apart from a small recoil energy from the original beta decay. Recent experiments by Bonner, et al.,[5] and Christy, et al.,[6] tend to confirm Wheeler's views although some of the finer details are still in doubt. An extensive review of these questions can be found in the paper on energy levels in light nuclei by Hornyak and Lauritsen.[7]

Segrè and Wiegand[8] in an unsuccessful search for delayed proton emitters corresponding to the delayed neutron emitter N^{17} observed an alpha particle activity of approximately 1 second half life in 190 Mev deuteron bombardments of several elements. They ascribed this activity to Be^8 formed from Li^8. Their identification of this activity was based on the absence, apart from samarium, of other alpha emitters in elements below lead and the similarity between the observed half life and that of Li^8.

The purpose of this experiment was to study the systematics of Li^8 production in high energy bombardments of various elements. Li^8 has a convenient half life and the alphas from its disintegration* may be easily detected in the presence of other beta activities. These factors make this isotope an amenable fragment to study in high energy nuclear disintegrations.

The average range of the alphas from Li^8 is about 1.3 mg/cm^2 of Al. This combined with the low cross section made the use of solid targets impractical. By the use of gaseous targets the yield in the counter was increased by a factor of 50 as will be described below. These gaseous targets also formed the counter gas. The absolute cross sections for Li^8 production in 340 Mev proton and 190 Mev deuteron bombardments of C, N, Ne, A, Kr, and Xe were determined. The deuteron excitation functions were obtained for all gases mentioned except Kr and Xe in which cases the yield was too small to make the measurement of a complete excitation function feasible.

Very recently Alvarez[9] has reported a 0.5 second activity which he ascribed tentatively to B^8 or C^9. Alpha particles similar to those from Be^8 are involved in this decay and if the B^8 identification is correct, it is likely that the alphas have the same origin as those from the decay of Li^8. In this case some of the alphas observed in the experiment reported here have probably been incorrectly assigned as originating from Li^8. Because of the increased barrier for the expulsion of B^8 over that for Li^8 the error involved should not be important for the heavier elements. For the light elements where it is believed that the Li^8 produced is the residue

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*In the future for brevity, the intermediate Be^8 state will be omitted in references to the decay of Li^8, i.e., Li^8 beta decays to two alpha particles.

of a nucleus which has evaporated the necessary number of protons and neutrons, the error may become more important. However the half life determinations show that in any event the effect of B^8 is small.

Lately the expulsion of heavy charged particles from nuclei has been receiving increasing attention. Experiments dealing with this phenomenon have been carried out in cosmic ray studies using the recently developed electron-sensitive photographic emulsions. The identification of the charge of the fragments has been accomplished by an analysis of the delta rays. Previous to these studies only Li^8 could be positively identified. Its trademark is a "hammer" track - the handle caused by the expelled Li^8, the head by the resultant alphas. An example of such an event is given in Freier, et al.[13] The work of Hodgson and Perkins,[10] Bonetti and Dilworth,[11] Sorensen,[12] and Freier, et al.,[13] indicates that most of the events involve several hundred Mev and their lack of isotropy points toward a knock on process rather than evaporation. It is hoped that the cross sections for Li^8 production found in this experiment will be of use in the clarification of these new found reactions.

Experimental

Once Li^8 has been observed to be produced in deuteron bombardments, the principal problem became one of intensity. The alphas used to detect Li^8 have a most probable energy of 1.5 Mev each. Thus with a thick carbon target in an ionization chamber, a 1 millibarn cross section, and a beam of 3×10^{-5} microamps, only about 3 Li^8 atoms will exist in the counting volume of the chamber under equilibrium conditions. This is too few atoms with which to deal effectively. However, if the target is CH_4 at 1 atmosphere in a proportional counter of effective counting length A cm and the counter axis is along the path of the beam, the number of Li^8 atoms existing under similar conditions will be 7A, an adequate number for this experiment. The gaseous target has the following advantages over the solid target: (1) a factor of four is gained in geometry over a thick target; (2) there is no self absorption; (3) the thickness of the target is limited only by the length of the counter; and (4) possible targets, especially the rare gases, are available in a high state of purity. However, there are certain disadvantages, namely: (1) the number of target elements is limited since each must perform the role of a proportional counter gas; and (2) the characteristics of a proportional counter will vary with each gas used, which is deleterious in this case because the natural spread in energy of the Li^8 alphas will produce a flat bias curve below 1 Mev only under ideal conditions.

The essence of the experiment was the following. A proportional counter filled with the gas under investigation was traversed axially by the cyclotron beam. When Li^8 equilibrium was almost reached the beam was turned off and after a short delay the alphas were counted for nine half lives of Li^8. This process was repeated periodically. The number of Li^8 atoms present at the end of a bombardment will be proportional to $\int I(t)e^{-\lambda t}\,dt$ where I(t) is the current at the time t before the end of the bombardment and λ is the disintegration constant of Li^8. $\int I(t)e^{-\lambda t}\,dt$ will in future be called the effective charge. It is that charge which will, if delivered instantaneously at the end of the bombardment, produce the same quantity of Li^8 as the actual current used in the experiment. The measurement of the effective charge may be performed naturally or numerically as will be described below. The former method of integration was used in the measurement of relative yields, the latter in the determination of absolute cross sections. In practice all yields per unit effective charge were referred to that from carbon using the full energy beam. The absolute cross section was later measured for carbon itself. In this way all the cross sections were placed on an absolute scale.

The experimental arrangement employed was that schematically illustrated in Fig. 1. Proportional counter A had a 2-inch I. D. and an effective counting length of 25 cm. Proportional counter B had a 3-inch I. D. and an effective counting length of 37 cm. The effective counting length was assumed to be the length of the central wire of the counter. Rossi and Staub[14] have shown that this assumption is accurate within a few millimeters. Thus, since the counters used in this experiment were very long, any errors introduced into the absolute cross section measurements from this source were negligible. These two counters were employed for the following reason. While the beam of the cyclotron is relatively constantly over successive periods exceeding several seconds, it varies within approximately a factor of two in successive periods of 0.2 seconds so that relative yields can only be compared if the effective charge integral is integrated over the period of the bombardment. This integration may be performed either numerically if the current is measured on a recording ammeter during each bombardment or naturally, i.e., since the effective charge is a common factor in the yields from both counters A and B in Fig. 1, counter A may be kept under constant conditions in all bombardments and form a relative measure of the effective charge, its purpose being merely to perform the integration. Counter A, which in the future will be called the monitor, was filled with CH_4 and, as may be seen in Fig. 1, was always traversed by the full energy beam.

During bombardments the cyclotron was first switched on for 10 seconds, then switched off and 0.2 seconds later the counters were turned on. After 8 seconds the counters were switched off and following a short delay the cycle was repeated. One complete operation consumed 20 seconds. This cycling process was carried out continuously during bombardments by a motor operated rotary switch as illustrated in the diagram.

Since Li^8 is easily ionized it was probably drawn to the counter wall in most cases before counting began. Nevertheless the fact that two alphas are produced traveling in approximately antiparallel directions will still allow 100 percent counting efficiency. Unfortunately the bias curves will suffer from this effect. The theoretical integral energy spectrum arising from a single alpha particle in the decay of Li^8 is illustrated by the broken curve of Fig. 2. The solid curve in the figure represents a typical bias curve obtained in this experiment. If only one alpha from the decay of each Li^8 atom penetrates the counter gas and all the ions produced along its path lie in the counting volume of the chamber, then the bias curves obtained should agree with the theoretical integral energy spectrum. The dissimilarity of the two curves can probably be accounted for by the following considerations. Firstly, an alpha particle, if directed approximately parallel to the counter wall, will often spend the last part of its range in the chamber wall. This will affect the bias curve by tilting the low energy part away from the horizontal. Secondly, the angle between the paths of the two alphas may differ from 180° by as much as 6° owing to the recoil from the Li^8 beta decay so that in some cases both alphas may lose all or a fraction (as above) of their energy by gas ionization. This mode of decay will fill in the dip of the bias curve near 2 Mev due to the wide range of energies available from it. Thirdly, some alphas produced at the ends of the counter can lose part of their energy in the counting volume of the chamber and part outside of it.

This will produce the same effect as the first consideration. And lastly, if Li^8 becomes a neutral atom during its travel toward the counter wall, it will stop in the gas, causing the ionization from both its alphas to be recorded. This type of disintegration will alter the high energy region of the bias curve.

All counters had small internal sources of polonium to calibrate the pulse heights in Mev except in the cases of krypton and xenon in which the yields were so low that any background at all would have been detrimental to the experiments. The pulse heights for these two elements were calibrated against an external 10 mg Ra-Be source placed one meter from the center of the counter in a direction perpendicular to the axis. The pulse heights to be expected from the Ra-Be source were found by placing the source in the position described with respect to a counter calibrated by polonium alphas.

In order to check the half life of the alphas from each element investigated the monitor was filled with one atmosphere of CH_4 (the most copious Li^8 producer found) and counter B with the gas being studied. One pen of a Brush Recorder was connected to the scale of two output of counter A scaler and the other pen to that of counter B, and the bombardment cycle started. The Brush Recorder is a two-channel recording oscilloscope with a frequency response from D. C. to 100 cycles. Each input signal to the Recorder is passed through an amplifier before it activates the magnetically operated pen unit. Both of the pens record on the same moving tape, the speed of which may be adjusted to 0.5, 2.5, or 12.5 cm per second. The medium speed was used in this experiment. Since the two pens are in symmetric positions and the abundant supply of Li^8 from the monitor always produced pulses on the tape in the first 0.1 second of counting, the monitor pen provided a zero of time on the tape for the half life measurement of the element in question.

In the measurement of excitation functions, mechanical counters were linked to the scale of 256 output from each scaler. Copper absorbers placed between the monitor and counter B reduced the energy of the beam the amount required before it entered counter B. Relative excitation functions were obtained by comparison of the Li^8 counts in counter B with those from counter A, the latter being produced by the full energy deuteron beam. In the 184-inch Berkeley cyclotron the beam after deflection from the tank is passed through a steering magnet which acts as a fine energy spectrometer. It is then collimated and emerges from a vacuum port ready for use. The energy of the deuterons has been measured repeatedly by observing their extrapolated range in some absorber with the aid of a faraday cup. It turns out to be 18.85 ± 0.1 gms/cm^2 of Al. This corresponds to 192 ± 0.4 Mev. This is the value which has been used in these experiments. The extrapolated range is the intersection of the steepest tangent of the transmission-range curve with the range axis. The energy of the deuterons after passing through a given thickness of copper absorber was computed with the aid of tables prepared by Aron, Hoffman, and Williams of the theoretical group at the Radiation Laboratory based on the standard range energy formulae.[15]

The original collimation of the beam is reduced by multiple scattering when several grams of absorber are used. In order to avoid as much as possible errors in the excitation functions from this effect, counter B was built with an I. D. of 3 inches. In all of the experiments the original beam was confined in a circle 1 inch in diameter by the initial collimating system. After the deuteron beam has been reduced in energy to a few Mev, its energy will be inhomogeneous by approximately 5 Mev. This inhomogeneity is caused by straggling and in the case of 340 Mev protons may amount to as much as 40 Mev. Straggling in terms of range as defined by Bethe[15] is the difference between the mean and the extrapolated ranges. It is approximately equal to the standard deviation of the range. In deuteron excitation functions the effects of straggling and multiple scattering are not too important, although they should be considered in dealing with the low energy range of the excitation functions. However the inaccuracies caused by these two effects will make it quite impractical to determine proton excitation functions by this method.

In the reduction of the deuteron energy by absorbers the production of neutrons and protons by stripping[16] must be considered. At the energies involved neutrons should be about as efficient in the production of Li^8 as protons. With enough copper to absorb out all the charged particles in the beam no Li^8 atoms were detected in counter B. This demonstrated that the neutrons from stripping had a negligible effect in this experiment. Since protons formed by stripping will quickly lose their energy in the absorber, it was assumed that they would be even less effective than neutrons.

The absolute cross section for carbon was measured in the following manner. A thin walled ionization chamber of approximately 1 inch thickness, filled with air at atmospheric pressure, was placed before a single proportional counter containing CH_4 in the path of the beam. The chamber output was fed to one input of the Brush Recorder and, after amplification, appeared on the recording tape. The input time constant was made to be 0.1 seconds by placing a 0.01 μf condenser in parallel with the 10 megohm input resistance of the Recorder amplifier. This allowed the beam current to be amplified satisfactorily with the low frequency response amplifier of the Brush Recorder although the pulsed beam from the synchro-cyclotron appears at the deflection port for an interval considerably less than 1 microsecond 60 times per second. The scale of two output on the scaler connected to the lone proportional counter in parallel with the ionization chamber was fed to the remaining pen of the Brush Recorder. During bombardment cycles the Recorder tape was run continuously. The beam current appeared on one pen of the Recorder, the Li^8 counts appeared on the other. The instant the cyclotron beam was turned off was taken as zero on the time scale. A decay curve of the Li^8 counts was extrapolated back to this zero time in order to determine the number of Li^8 atoms existing at the end of the bombardment and to account for the delay between stopping the cyclotron and turning on the counters. The effective charge integral $\int I(t)\, e^{-\lambda t}\, dt$ integrated over the bombardment period was calculated numerically from the Recorder tape. This calculation required knowledge of the amplification factor of the ionization chamber and also that of the Recorder amplifier. The former was measured directly with a faraday cup. The latter was ascertained with a potentiometer and a knowledge of the input resistance of the Recorder. The cross section can then be determined from the Li^8 atoms available at zero time, the gas pressure and effective counting length of the proportional counter, and the effective charge integral. This cross section was found for bombardments of carbon with 190 Mev deuterons and 340 Mev protons. It is recorded in Table I under Carbon. The cross sections for the other elements were then found from these values as mentioned before.

Results

No effect was found from helium outside of the background statistics from a small polonium source within the chamber. In terms of cross sections, the result was $(0.5 \pm 1.0) \times 10^{-29}$ cm^2. This was true with bombardments of 340 Mev protons and 190 Mev deuterons. This showed that any production of Li^8 from the central wire and windows (2 mil stainless steel) could be disregarded. Also no effect was found after the deuteron beam energy had been reduced considerably by copper absorbers placed in front of the chamber. The latter experiment showed that contributions due to the multiply scattered beam hitting the walls of the chamber could be neglected.

The decay curves of the alphas from C, N, Ne, A, Kr, and Xe are given in Fig. 3 to Fig. 8. They are plotted as histograms, the ordinate being the number of counts in a 0.2 second interval. This was the time interval used in reading the Brush Recorder tapes. Since there is no apparent change in half life in deuteron or proton bombardments, a single decay curve of each element is given. The straight lines on the graphs correspond to the ideal decay curve with a half life of 0.88 seconds and the same total number of counts as in the experimental curve. It is seen that the agreement is excellent in all cases save neon where some improvement is to be desired. However, even in this latter case, the agreement with the Li^8 half life is within statistical error. To give an idea of the counting rates in this experiment it may be remarked that the yield with Xe was so low that it required the counts from 150 equilibrium bombardments to produce the decay curve in Fig. 8.

The absolute cross sections for C, N, Ne, A, Kr, and Xe with 340 Mev protons and 190 Mev deuterons are collected in Table I. The difficulties mentioned under Experimental in producing a flat bias curve probably make these values accurate to no more than 30 percent. The values listed are those found with the scalers set to discriminate against alphas of less than 0.7 Mev. Much less discrimination would risk the acceptance of pulses originating from beta disintegrations since the counters were very long (45 cm). The theoretical integral energy spectrum in Fig. 2 makes it seem preferable, in view of the gaseous nature of the target and consequent lack of self absorption, to determine the yield at a fixed low discrimination rather than to extrapolate the curves to zero bias. The cross sections found for Ne, A, Kr, and Xe cannot be due to impurities of gases with a lower mass number. The argon used was 99.7 percent pure. Spectroscopic Ne, Kr, and Xe were used in which the only important impurity was N_2, present in quantities less than 0.05 percent of the total. Ne, Kr, and Xe obtained in liter flasks at atmospheric pressure were transferred to the counters by the use of a Toepler pump after the counters had been evacuated to a few microns pressure with a diffusion pump.

The deuteron excitation functions of C, N, Ne, and A are shown in Fig. 9 to Fig. 12. Statistical counting errors only are marked on the graphs. In the lower energy region some of the deuterons, multiply scattered by the copper absorber, may be lost in the counter wall before traversing the whole counter. This would make the cross section at these low energies appear to be lower than it actually is.

TABLE I

Absolute cross sections for Li^8 production from 340 Mev proton and 190 Mev deuteron bombardments of various elements.

	C	N	Ne	A	Kr	Xe
$(p, Li^8) \times 10^{29} cm^2$	70 ± 20	55 ± 16	20 ± 6	22 ± 7	5.5 ± 2	2.6 ± 0.8
$(d, Li^8) \times 10^{29} cm^2$	105 ± 30	50 ± 15	18 ± 6	16 ± 5	3.0 ± 1	1.8 ± 0.5

Discussion

It is interesting to speculate on what process is involved in the production of Li^8 as described here. The graph of the cross section for Li^8 production with 190 Mev deuterons plotted against A, the mass number of the target element, in Fig. 13 provides some clues. It is seen that there is a sharp discontinuity in slope between the light nuclei (carbon, nitrogen, and neon) and the heavy nuclei (argon, krypton, and xenon). The curve drawn in the figure has no significance other than to emphasize this discontinuity. This indicates that different mechanisms are at work in the two regions. A plausible assumption is that the process for the light group is one in which the compound nucleus boils off the necessary number of neutrons and protons to leave a residue consisting of Li^8. This type of mechanism is obviously not applicable to the heavy group. There is not enough energy available to boil off thirty or more particles. Here it is more likely that Li^8 is expelled from the compound nucleus in a manner similar to evaporation.

In the previous paragraph the formation of the compound nucleus was implicitly assumed. In other words, all the energy of the incident particle was assumed to be distributed among the nucleons of the struck nucleus before any evaporation occurred. It has been pointed out by

Serber[17] that this is not always the case when the mean free path of the incident particle in nuclear matter is of the order of the nuclear dimensions. When such "transparency" conditions are met, as in this experiment, a whole range of excitation energies can be expected of the struck nucleus. If a collision involves only one or two nucleons which promptly remove themselves from the neighborhood of the nucleus, a small excitation energy will result. Other types of collisions, less "local" in character, will provide higher excitation energies. Sometimes the incident particle will be completely absorbed by the nucleus and a maximum excitation will occur. The treatment of the evaporation process which follows is so qualitative that the range of excitation energies of the struck nucleus will be neglected and a compound nucleus with the maximum excitation will always be assumed.

Evaporation is a very difficult problem to treat theoretically in the case of light nuclei. It simplifies considerably if a temperature may be defined for the compound nucleus. Such is the case in heavy nuclei. By employing the principle of detailed balancing, Weisskopf[18] has derived a general formula for the evaporation of particles from a compound nucleus. His argument is the following. Let $W_n(E_A, \epsilon)d\epsilon$ be the probability per second of a nucleus A, excited to E_A Mev above the ground state, emitting a particle n of energy between ϵ and $\epsilon + d\epsilon$ and leaving a residual nucleus B. The inverse process, the capture of the particle with energy ϵ Mev by the nucleus B to form the nucleus A with excitation E_A is equal to $\frac{v\sigma(E_A, \epsilon)}{\Omega}$ where $\sigma(E_A, \epsilon)$ is the capture cross section under the stated conditions, v is the velocity of the particle, and Ω is the volume in which the whole system is enclosed. The principle of detailed balancing relates these two probabilities as follows:

$$W_n\,(E_A, \epsilon) = \frac{v\sigma(E_A, \epsilon)}{\Omega} \cdot \frac{\omega_B\,(E_A - E_o - \epsilon)}{\omega_A(E_A)} \; \frac{4\pi p^2 dp\,\Omega g}{8\pi^3\,\hbar^3\,d\epsilon} \qquad (1)$$

where ω_A, ω_B, $\frac{4\pi p^2 dp\,\Omega g}{8\pi^3\hbar^3 d\epsilon}$ are the densities of states per unit energy of the compound nucleus A, the residual nucleus B, and the free particle respectively. g is the statistical weight and m the mass of the particle. E_o is the binding energy of the particle to nucleus A. The entropy $S_A\,(X)$ of a nucleus A with excitation X Mev is defined as the logarithm of the density of states of that nucleus with excitation X. Employing the usual relation between energy and momentum of a free particle and the entropy as just defined, the formula (1) becomes

$$W_n\,(E_A, \epsilon) = \sigma\,(E_A, \epsilon)\,\frac{g \cdot m \cdot \epsilon}{\pi^2\,\hbar^3}\, e^{S_B\,(E_A - E_o - \epsilon)\,-\,S_A\,(E_A)} \qquad (2)$$

This is Weisskopf's general evaporation formula.

If the expression (2) is integrated over all possible ϵ for a given E_A, the result is the total probability per unit time for emission of the particle, i.e., the width Γ divided by $\hbar$. If the entropy

$$S_A(X) = \left(\frac{A \cdot X}{2.2}\right)^{1/2} \qquad X \text{ in Mev.} \qquad A \text{ the mass number.}$$

derived from the free particle model of the nucleus[19] is used in the calculation of the widths for proton, neutron, and Li^8 emission from argon, the following result is obtained:

$$\frac{\Gamma n + \Gamma p}{\Gamma_{Li^8}} \approx \left(\frac{10^4}{5}\right)_{200\text{ Mev d}}, \left(\frac{10^4}{2.2}\right)_{80\text{ Mev d}} \qquad \sigma\text{ geom} = 0.8 \times 10^{-24}\,\text{cm}^2$$

This ratio should be near that of the cross sections for proton or neutron emission (about the geometrical) to the cross section for Li^8 emission. It is evident that the Li^8 cross section turns out to be a factor of 2 higher than found for E_A equal to 190 Mev and its reduction at E_A equal to 80 Mev is half the experimental decrease. In the calculation the classical formula

$$\sigma(E_A, \epsilon) = \sigma_{\text{geom}}\left(1 - \frac{V}{\epsilon}\right)$$

for the cross section was used. V is the potential barrier of the particle with respect to the nucleus B. The influence of the barrier on the evaporation process is described in this term.

It is surprising that the order of magnitude of the results can be predicted on such a crude model. The important quantity in these calculations is of course the entropy. There is practically no experimental knowledge of its variation at the high energies here involved and the free particle model was used rather arbitrarily in the calculations.

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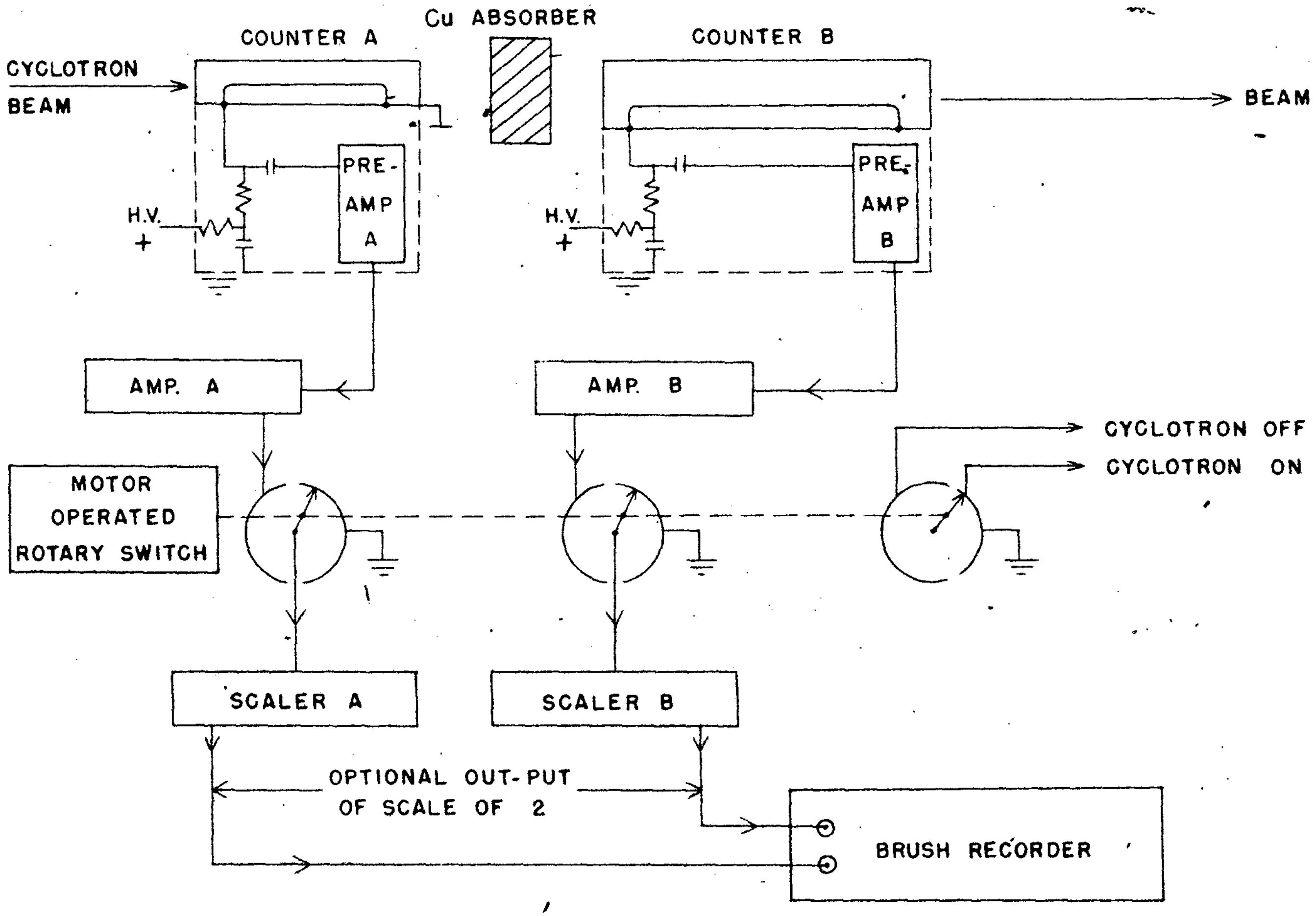
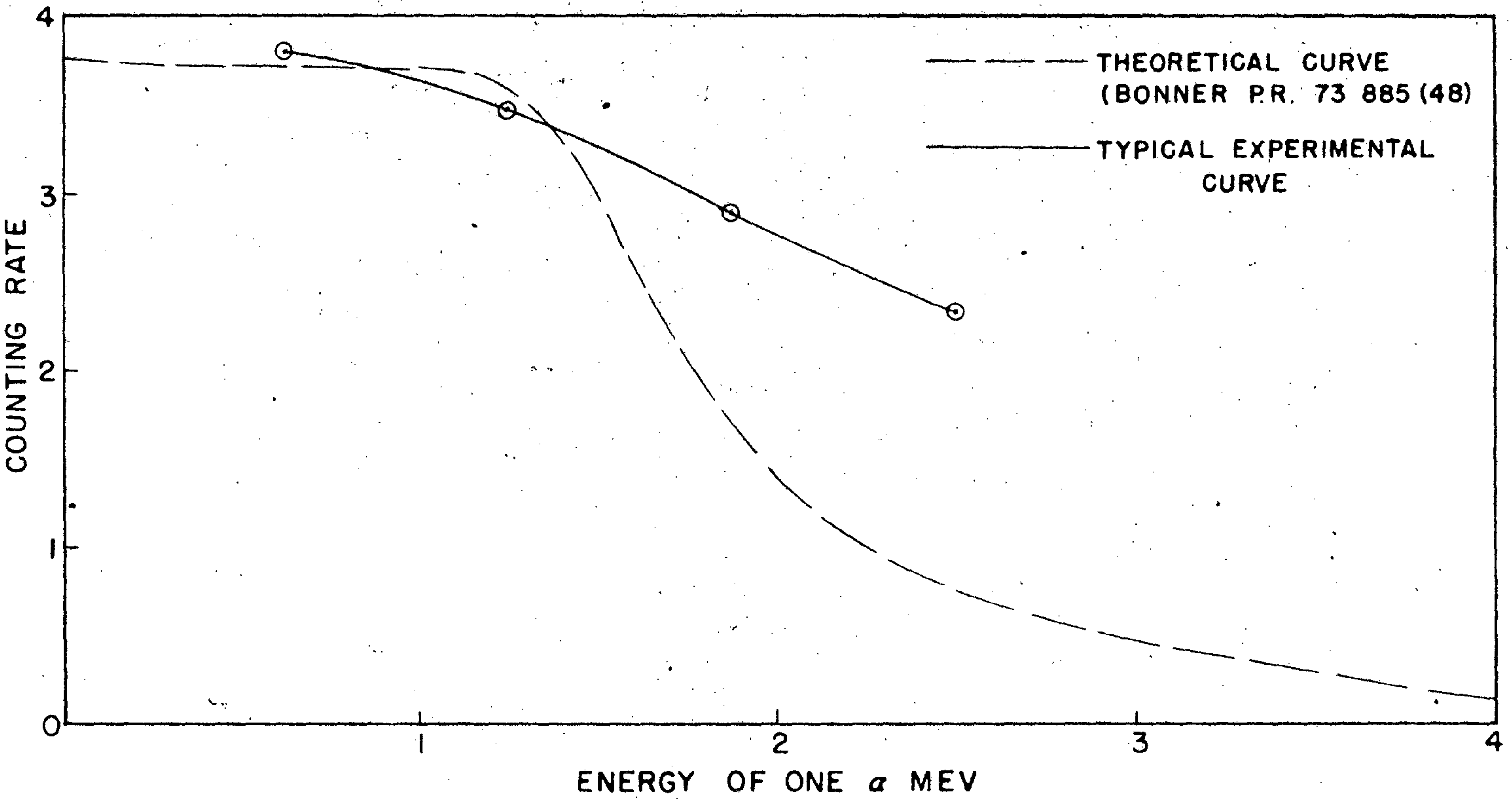


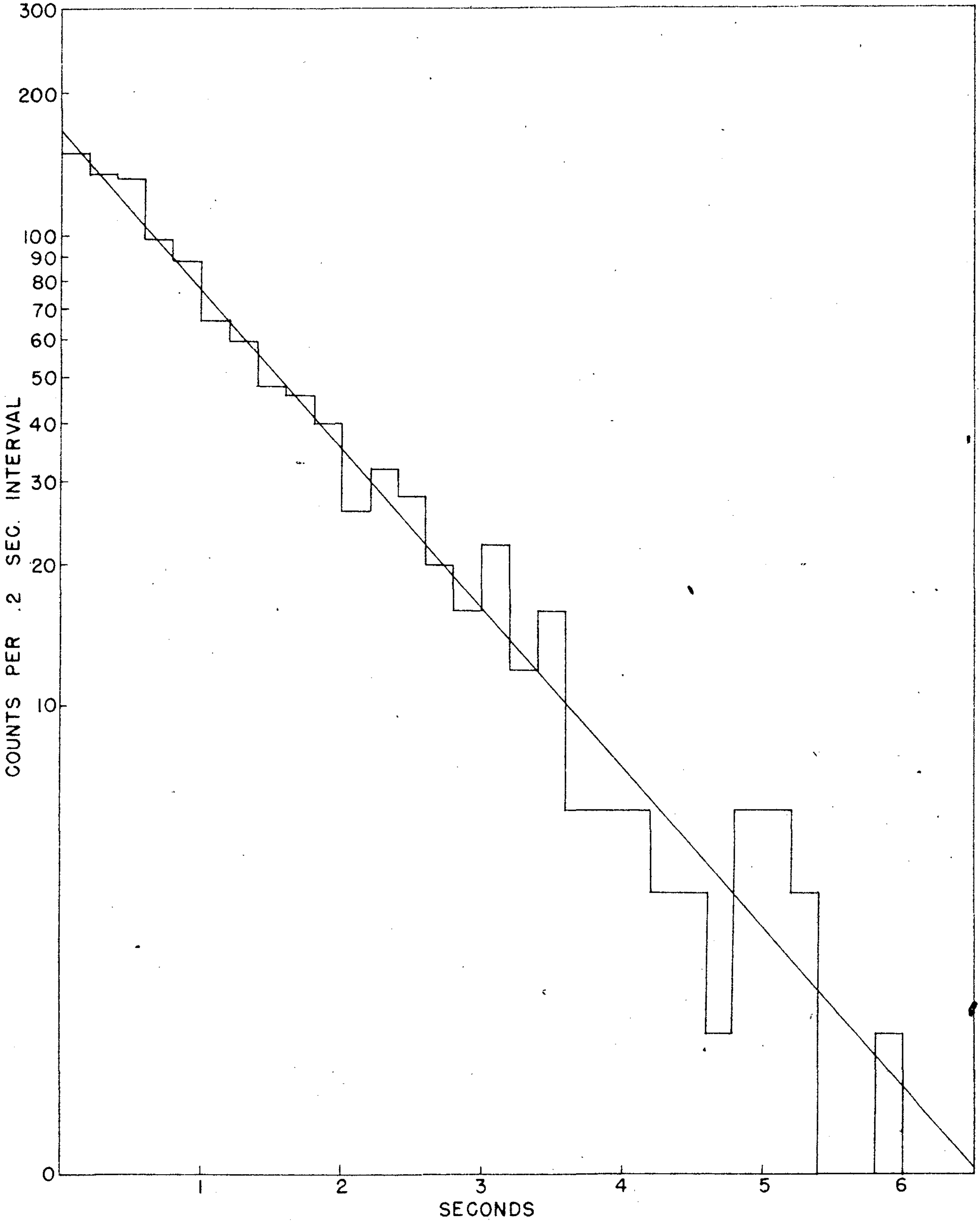
SCHEMATIC DIAGRAM OF APPARATUS

FIG. 1



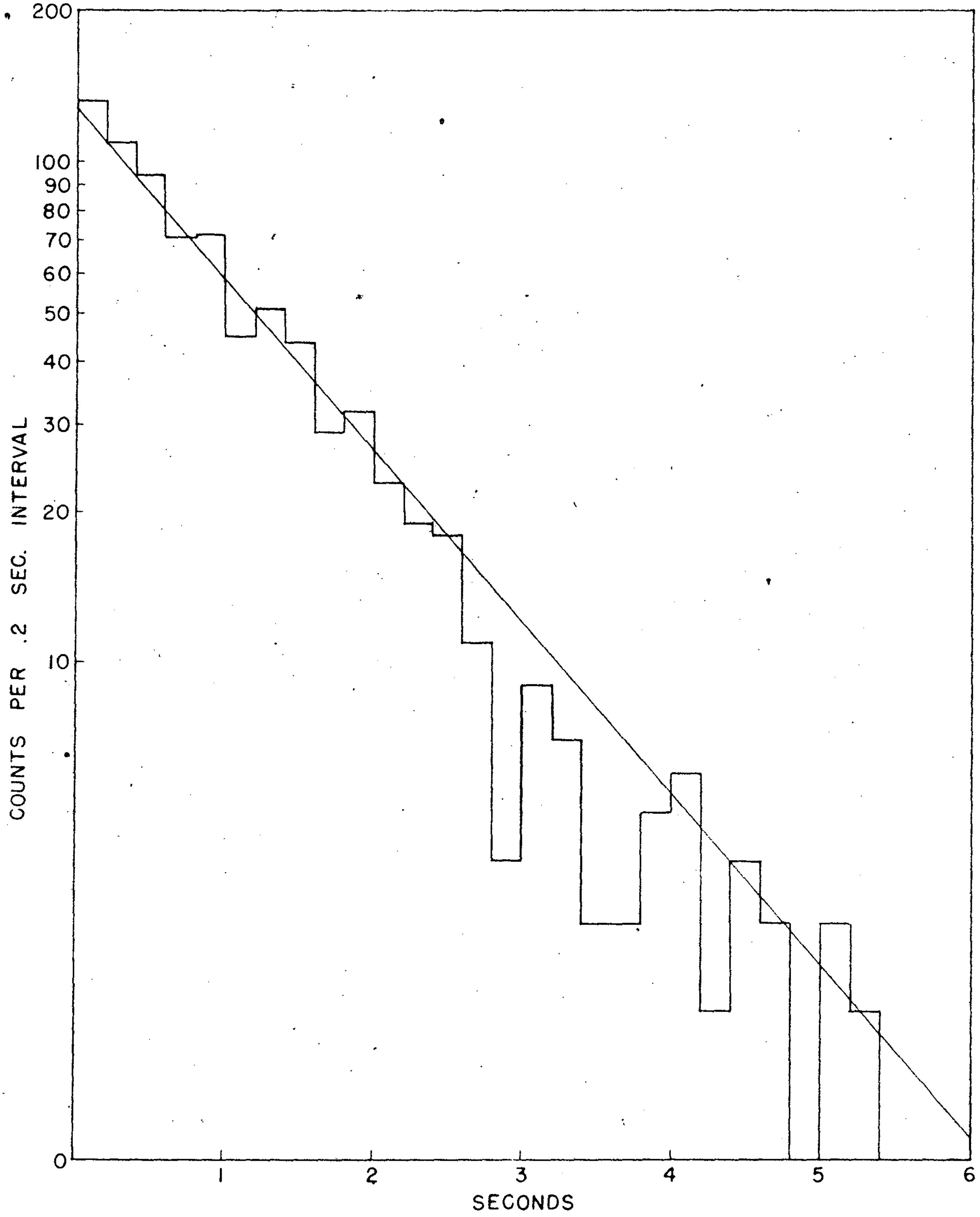
BIAS CURVE OF A SINGLE Be^8 α

FIG. 2



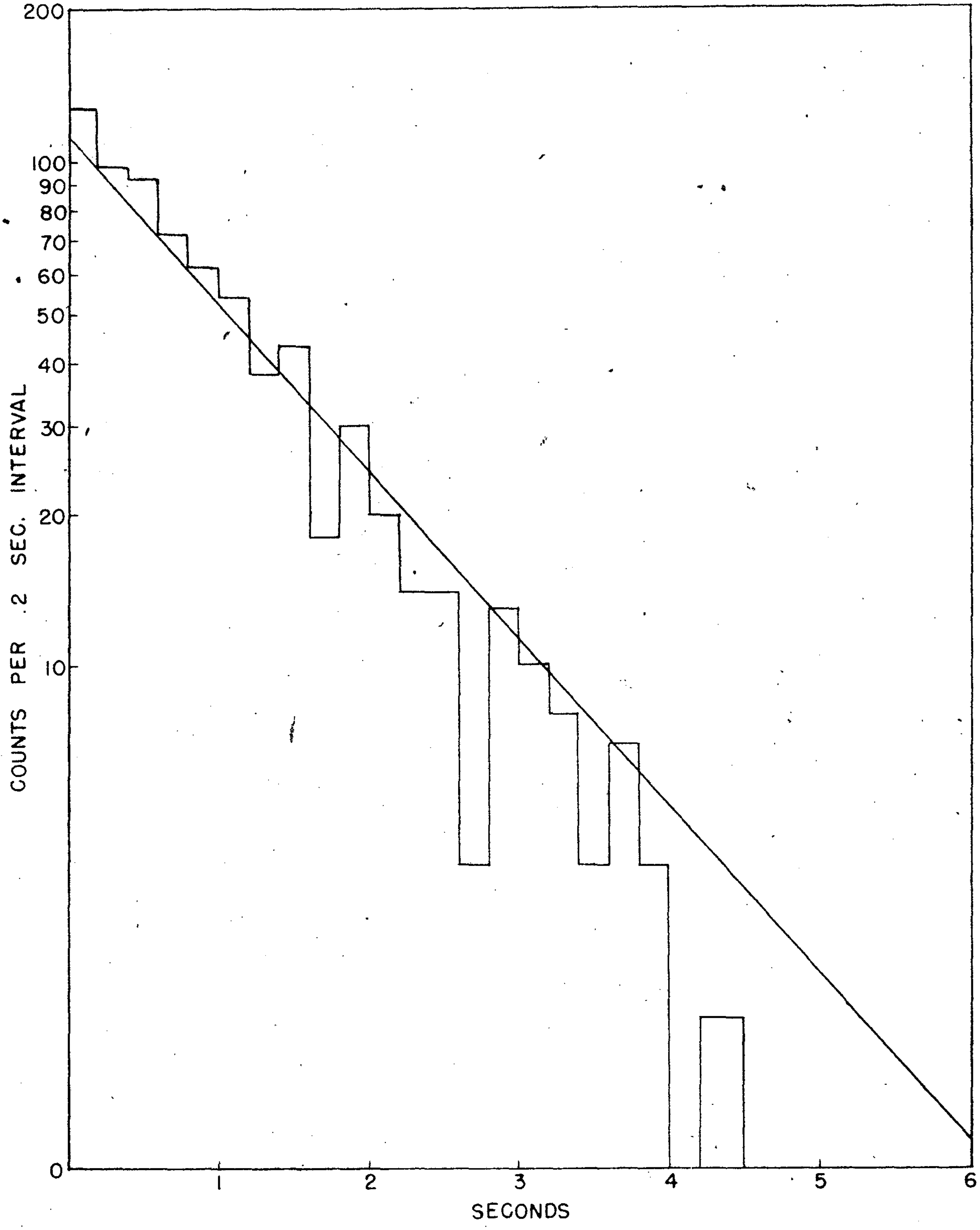
340 MEV PROTONS ON METHANE (CH_4)

FIG. 3



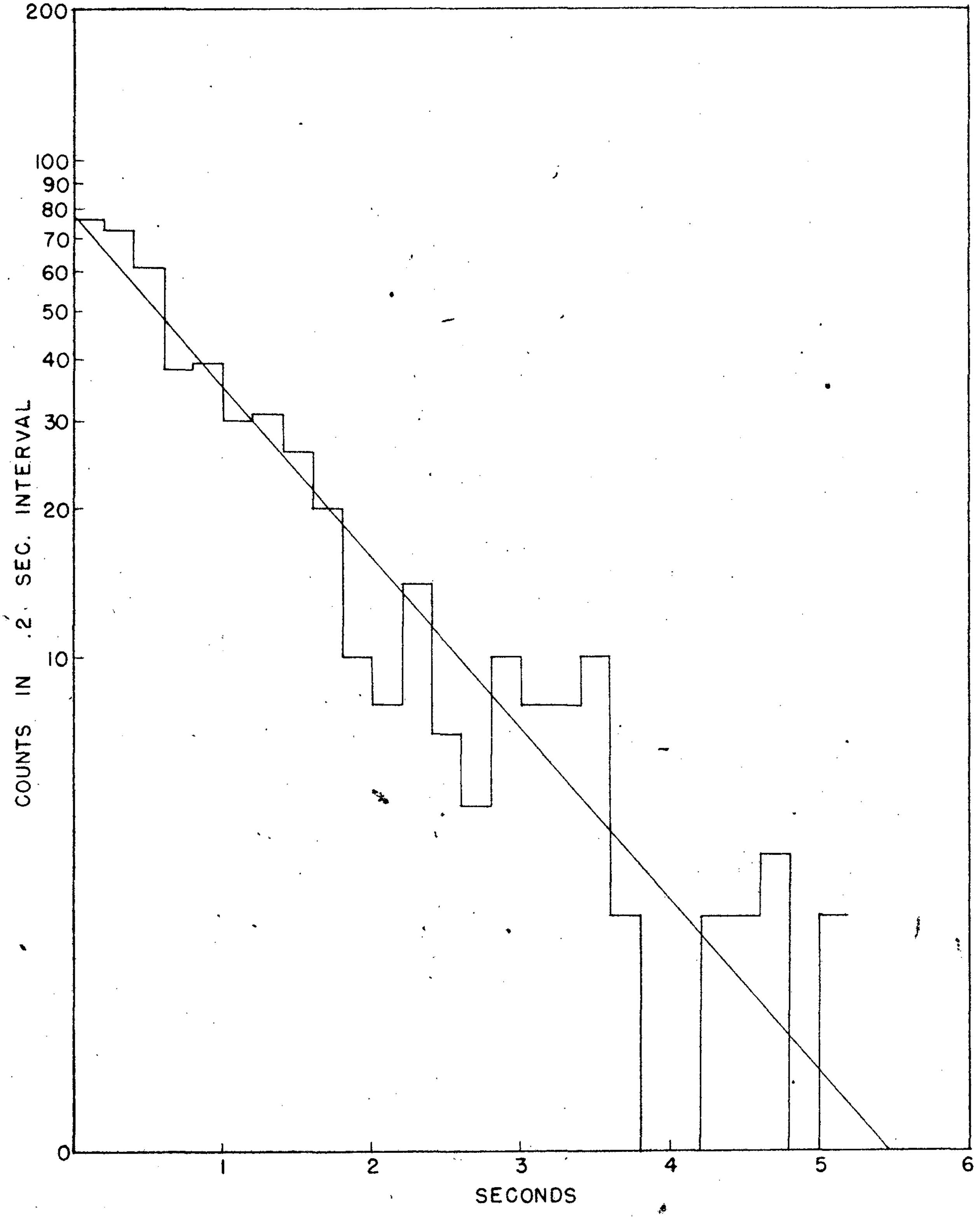
190 MEV DEUTERONS ON NITROGEN

FIG. 4



340 MEV PROTONS ON NEON

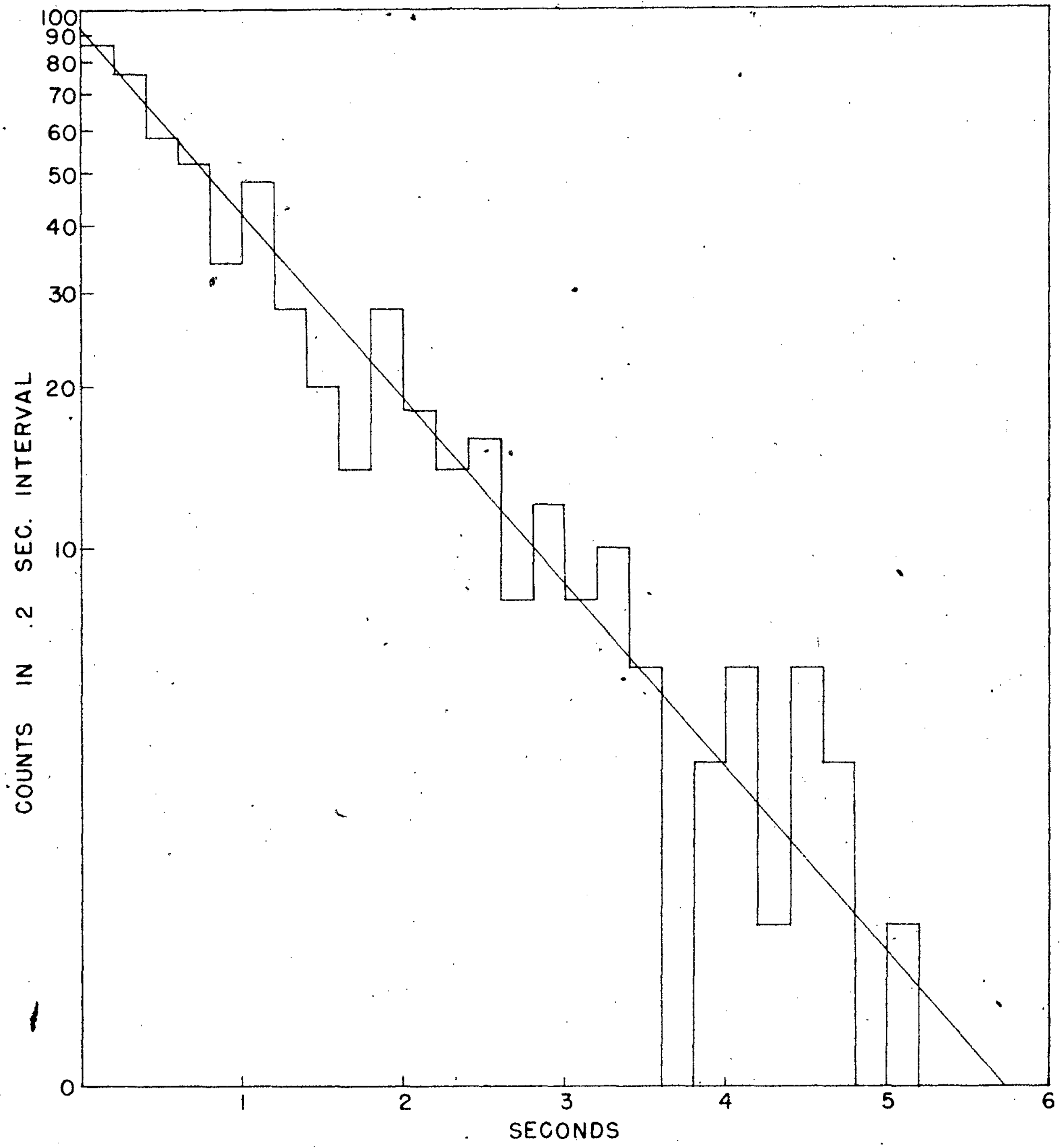
FIG. 5



190 MEV DEUTERONS ON ARGON

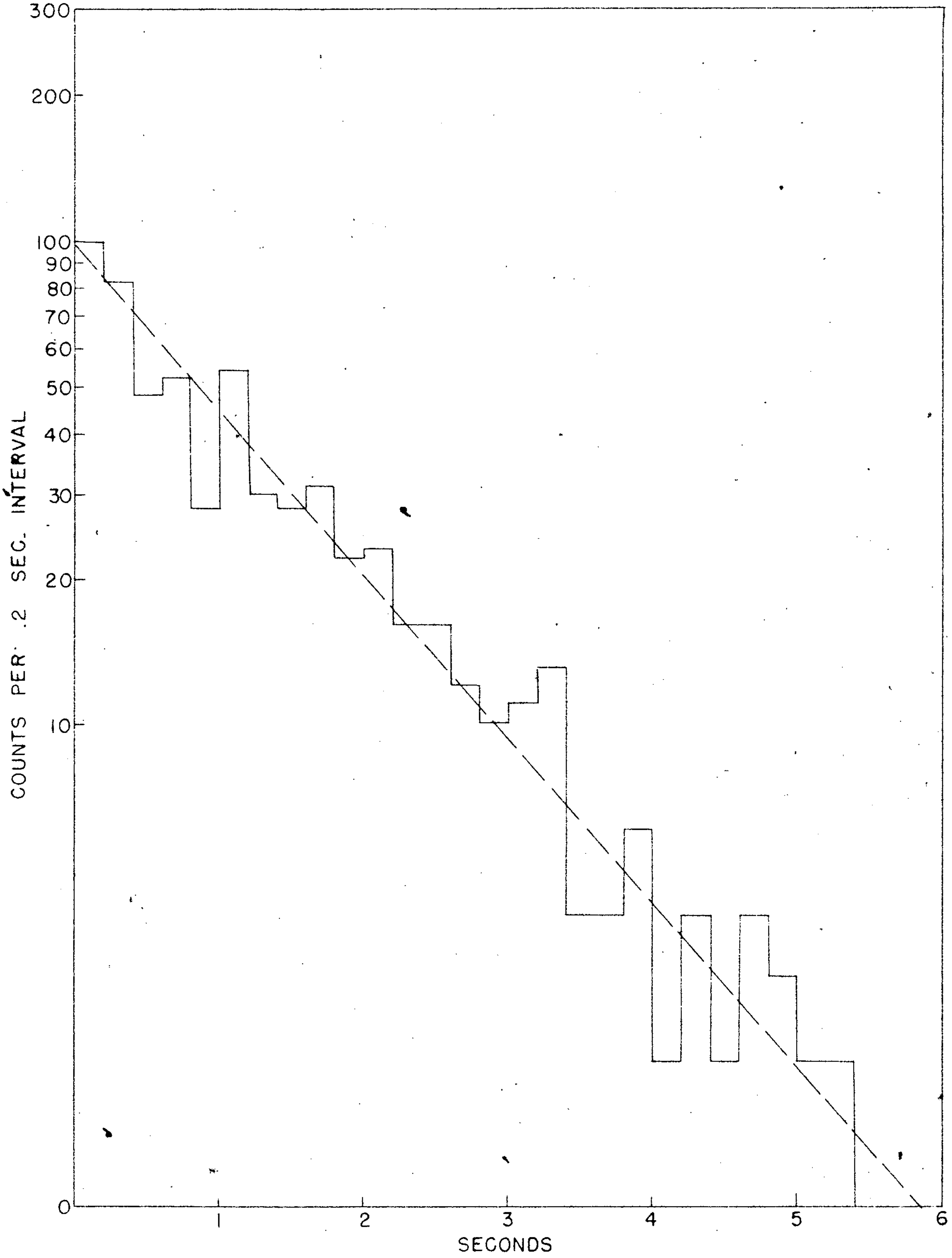
FIG. 6

14093-1



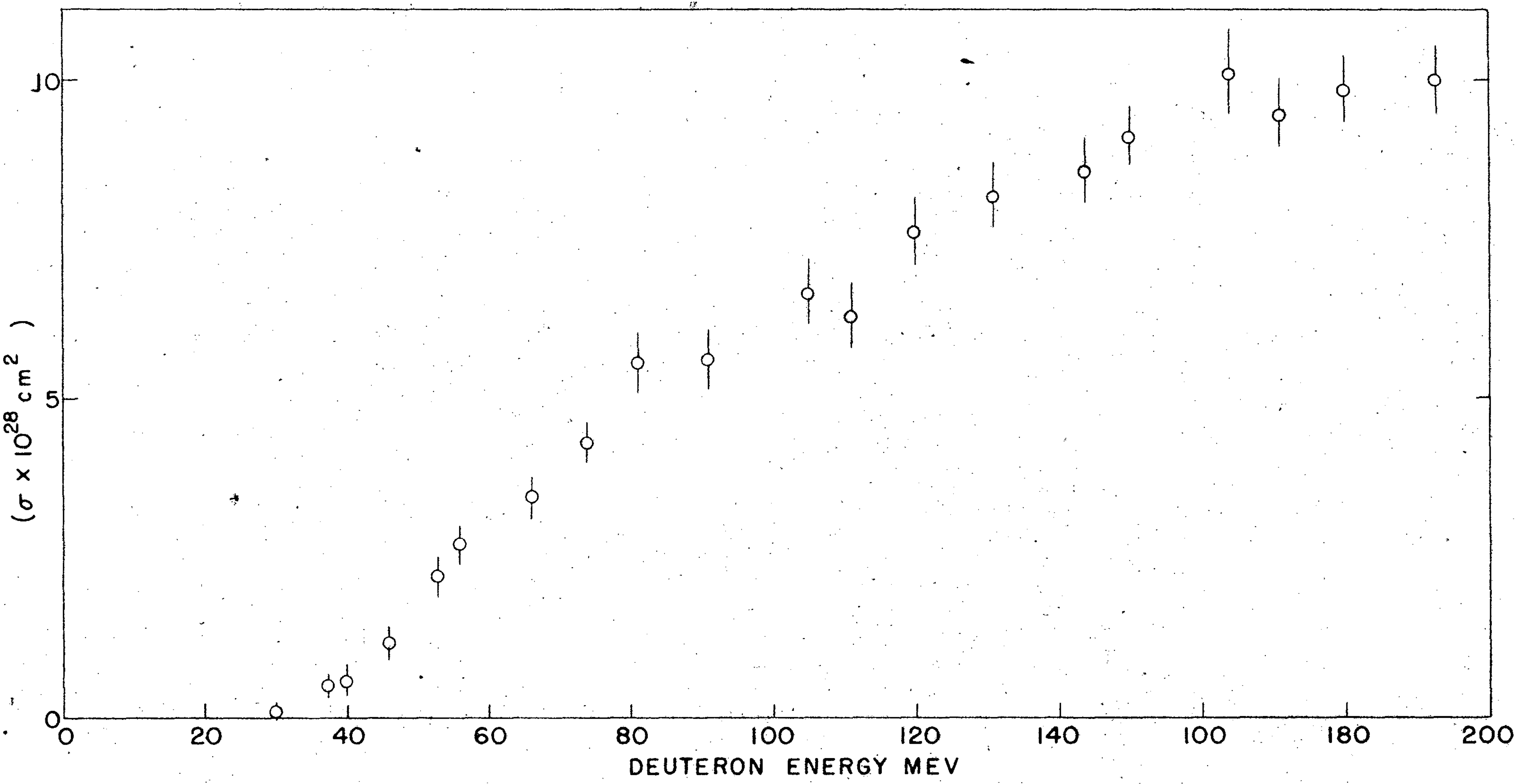
190 MEV DEUTERONS ON KRYPTON

FIG. 7



190 MEV DEUTERONS ON XENON

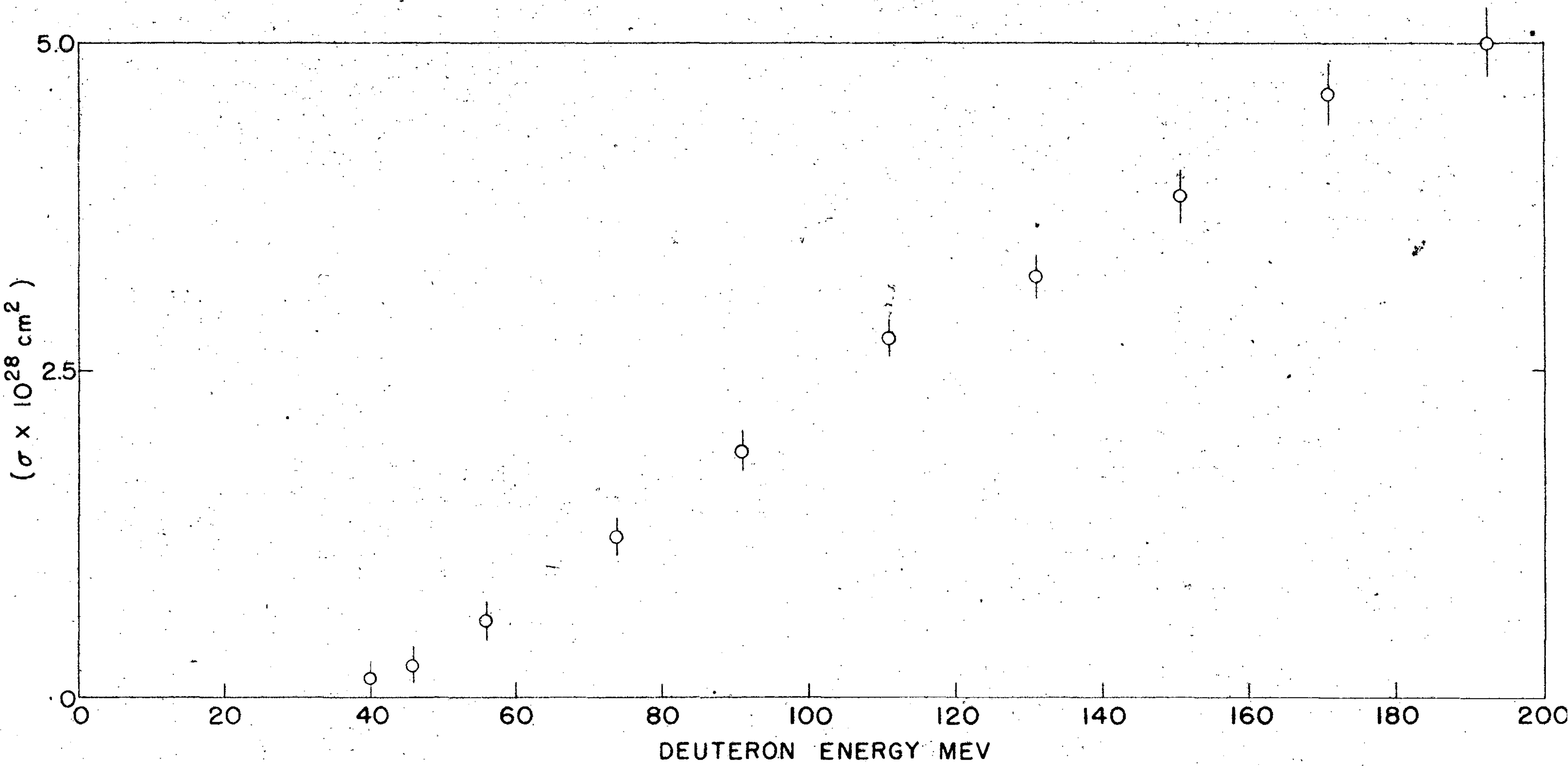
FIG. 8



EXCITATION FUNCTION $C(d, Li^8)$

FIG. 9

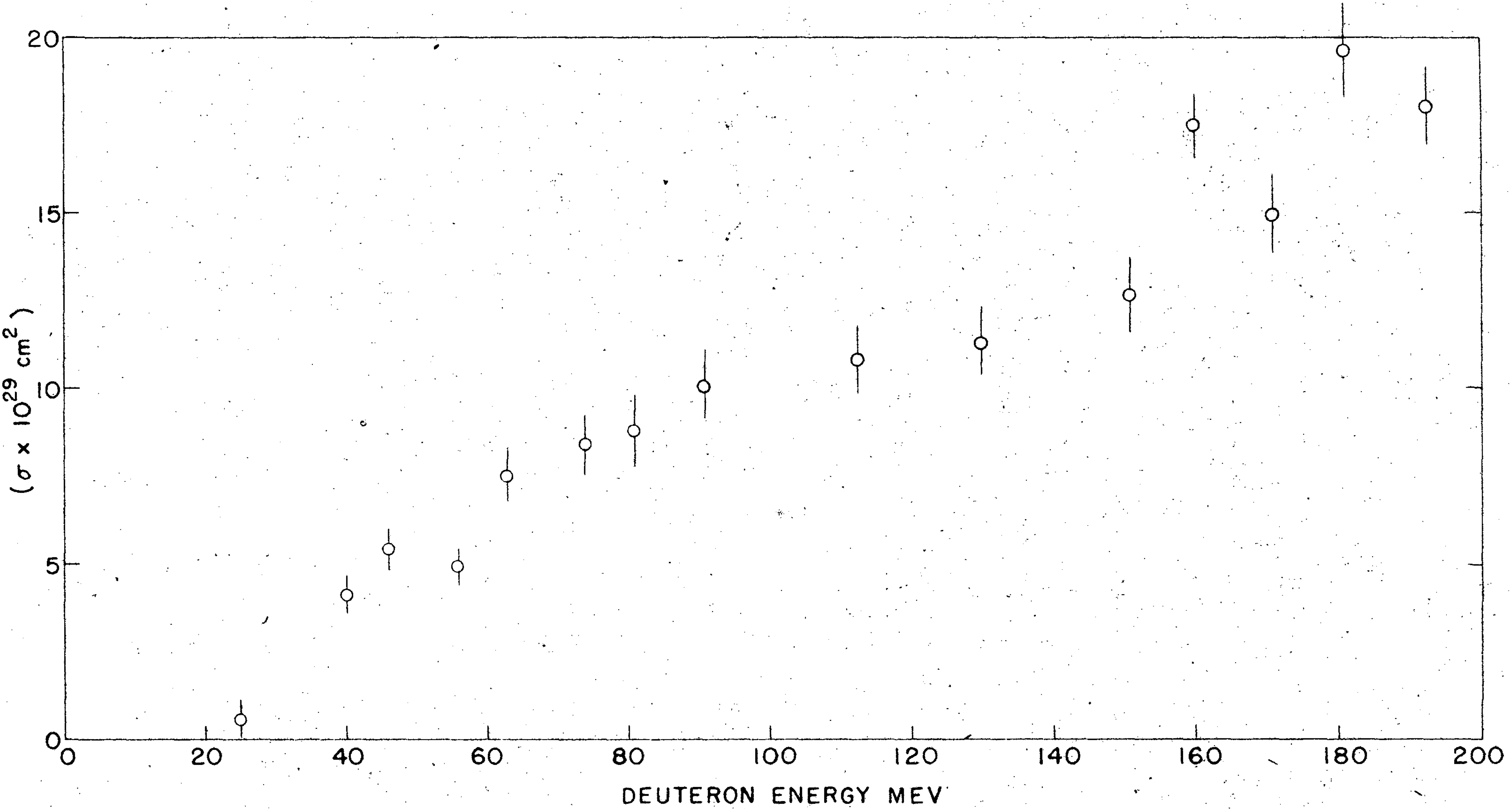
14141-1



EXCITATION FUNCTION N(d, Li^8)

FIG. 10

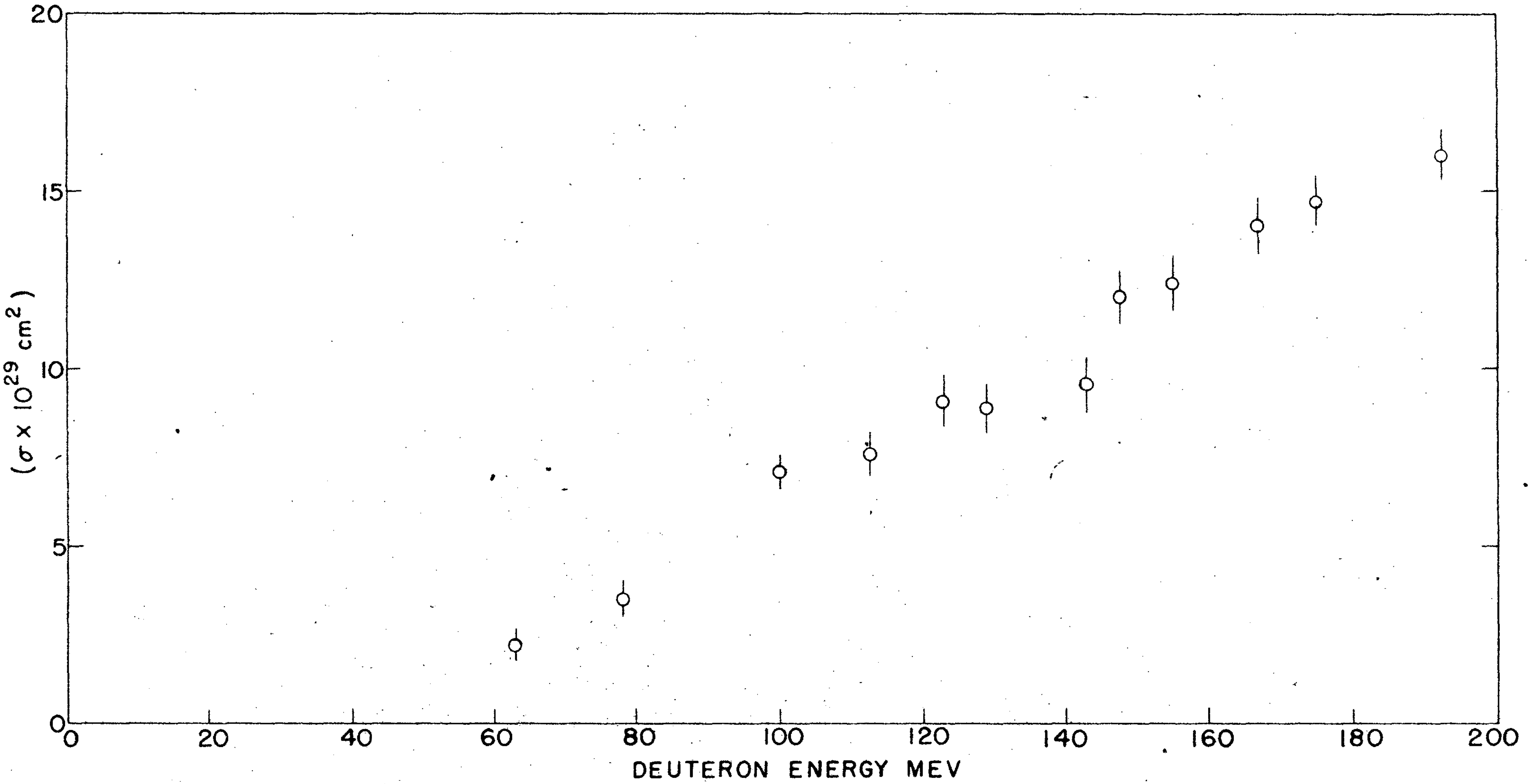
14140-1



EXCITATION FUNCTION Ne (d, Li^8)

FIG. 11

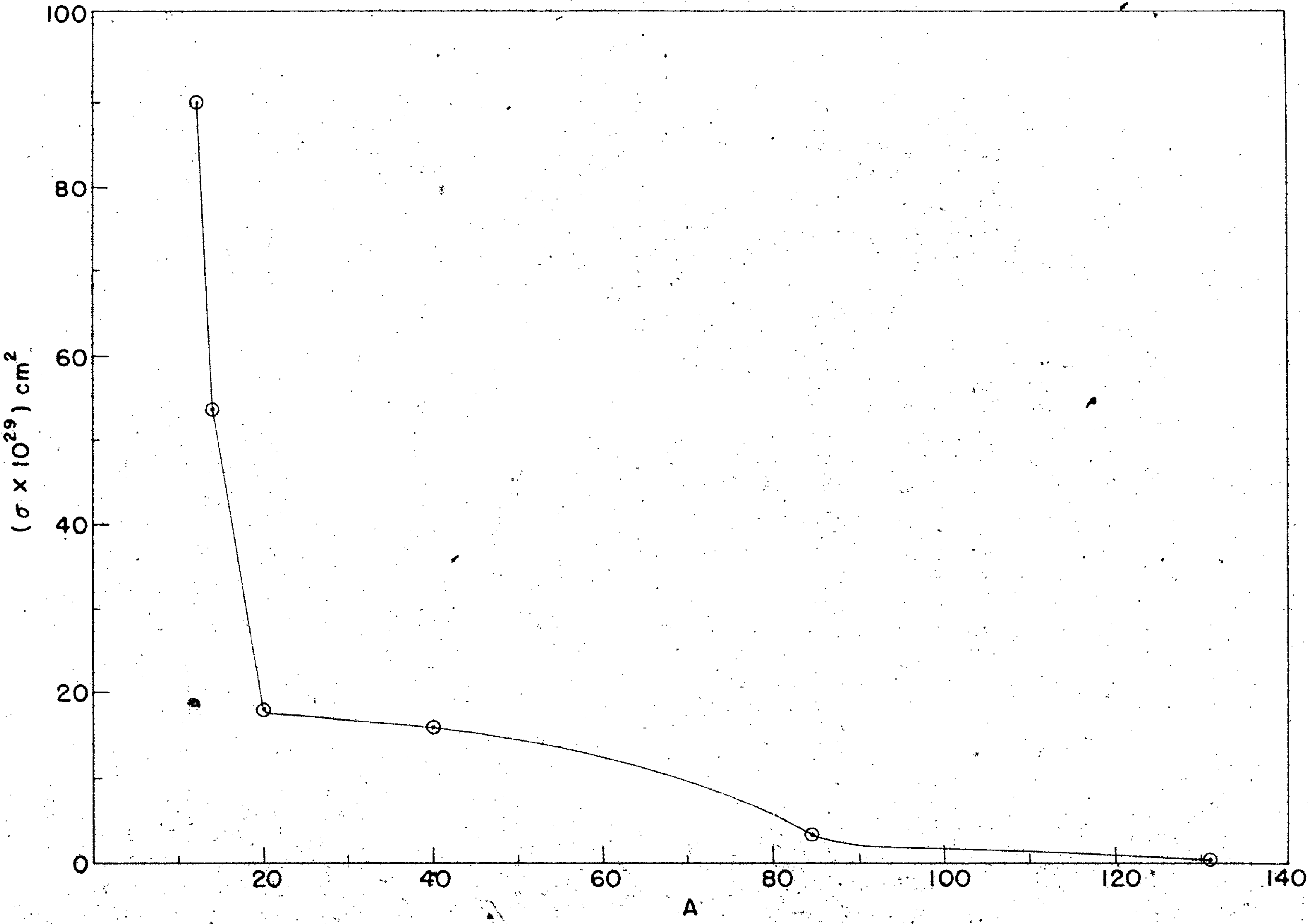
14138-1



EXCITATION FUNCTION A(d, Li^8)

FIG. 12

14139-1



VARIATION OF σ (Li^8) FOR 190 MEV DEUTERONS AS A FUNCTION OF A.

FIG. 13

14088-1