

UNIVERSITY OF ILLINOIS  
535.846413C C1 V0  
GILLETTE /THE CONSTRUCTION AND USE OF



THE CONSTRUCTION AND USE OF AN IMPROVED  
SLOW NEUTRON VELOCITY SPECTROMETER

BY

FRANK NEWTON GILLETTE  
B.S., Bradley Polytechnic Institute, 1938

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN  
PHYSICS IN THE GRADUATE SCHOOL OF THE  
UNIVERSITY OF ILLINOIS, 1942

URBANA, ILLINOIS

University of Illinois Library

Manuscript Theses

Unpublished theses submitted for the Master's and Doctor's degrees and deposited in the University of Illinois Library are open for inspection, but are to be used only with due regard to the rights of the authors. Bibliographical references may be noted, but passages may be copied only with permission of the authors, and proper credit must be given in subsequent written or published work. Extensive copying or publication of the thesis in whole or in part requires also the consent of the Dean of the Graduate School of the University of Illinois.

This Thesis by Frank Newton Gillette has been used by the following persons, whose signatures attest their acceptance of the above restrictions.

A Library which borrows this thesis for use by its patrons is expected to secure the signature of each user.

<u>J. H. Mauler, U. of Chicago</u>	<u>7/30/42</u>
NAME AND ADDRESS	DATE

H. H. Feasler, Univ. of Chicago, 12/26/44

UNIVERSITY OF ILLINOIS

THE GRADUATE SCHOOL

May 8, 1942

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY  
SUPERVISION BY FRANK NEWTON GILLETTE

ENTITLED THE CONSTRUCTION AND USE OF AN IMPROVED  
SLOW NEUTRON VELOCITY SPECTROMETER

BE ACCEPTED\* AS FULFILLING THIS PART OF THE REQUIREMENTS FOR  
THE DEGREE OF DOCTOR OF PHILOSOPHY IN PHYSICS

*W. J. Goldhaber*

In Charge of Thesis

*P. Gerald Kruger*

Head of Department

Recommendation concurred in †

*P. W. Ketchum*      *G. M. Almy*  
*P. Gerald Kruger*      *J. H. Maulley*  
*R. Serber*  
*W. J. Goldhaber*

Committee  
on  
Final Examination †

\*Subject to successful final examination in the case of the doctorate.  
†Required for doctor's degree but not for master's.

1000-9-41-22037-S

1185948

#### ACKNOWLEDGMENTS

The author wishes to express his gratitude to Professor A. J. Haworth, originally director of this research, who designed many of the circuits used, to Professor J. H. Manley for his helpful advice and cooperation throughout most of the work, and to Professor M. Goldhaber who kindly consented to supervise the final stages of the work in the absence of Professors Haworth and Manley. The author is also indebted to Mr. F. B. Berger for his cooperation in carrying out parts of the work. The financial support of the Graduate School Research Board for equipment used in this research is also acknowledged.

THE CONSTRUCTION AND USE OF AN IMPROVED SLOW NEUTRON  
VELOCITY SPECTROMETER

TABLE OF CONTENTS

	Page
I. INTRODUCTION.....	1
II. DESCRIPTION OF CIRCUITS.....	4
III. PROCEDURE.....	15
IV. RESULTS.....	13
V. CONCLUSIONS.....	22
VI. BIBLIOGRAPHY.....	24
VITA.....	25

## I. INTRODUCTION

Due to the low magnetic moment of the neutron and its lack of electrical charge, determination of neutron energies by the common magnetic or electrostatic deflection methods is impossible. Consequently considerable work has been done in the development of timing devices adapted to the measurement of the time of flight of neutrons over a measured distance, from which the neutron velocity and energy can be determined.

Dunning, Pegram, Fink, Mitchell and Segre (1) have reported a mechanical velocity selector using rotating discs with cadmium sectors. This apparatus is limited in resolution by the speeds of rotation which are attainable.

All other investigations have used apparatus of an electrical nature to produce bursts of neutrons by permitting a beam of high energy particles to fall briefly on a suitable target. The resulting fast neutrons are slowed by some hydrogenous material. A detector placed as far from the source as intensity or other limitations will allow is in some way made to record only those neutrons arriving at some chosen time after production of the neutron burst.

Alvarez (2) used 60 or 120 cycle modulation of the oscillator voltage of a cyclotron to produce neutron bursts, and a coincidence circuit to determine the time of counting. The elapsed time between burst and counting was determined by a phase changing device.

Baker and Bacher (3) modulated the ion source of the cyclotron, producing a better defined neutron burst, and recorded

the delayed neutrons by modulating the pulse amplifier in such a way as to confine its output to the desired time interval.

Fertel, Gibbs, Moon, Thomson and Wynn-Williams (4) used modulation of the ion source of a Cockcroft-Walton type linear accelerator. The neutron pulses were recorded by photographing the screen of a cathode ray oscilloscope with a linear sweep upon which the neutron pulses were registered. The method of pulse registration on the screen was such as to prevent any very accurate determination of the time of arrival of neutrons at the detector.

Haworth, Manley and Luebke (5) used electrostatic deflection of the deuteron beam of a Cockcroft-Walton linear accelerator. They also recorded neutron pulses by photographing an oscilloscope screen upon which the pulses were impressed. However, the details of registration were greatly improved permitting much greater accuracy in the determination of time of flight. As is pointed out by Haworth, Manley and Luebke (5), their apparatus "possesses both advantages and disadvantages compared to those of other investigators. It is more precise than most in the matter of time delays, all of which are small and easily corrected for. The actual recording is superior to that of Fertel, Gibbs, Moon, Thomson and Wynn-Williams (4) to judge by their published oscillograms. The pulses are much sharper; the length of trace per cycle is much greater; and the presence of the time scale (on the trace) eliminates the necessity of measurements on the film. Compared to the direct counting method of Alvarez (2) and Baker and Bacher (3) it has the

advantage of obtaining the entire distribution record at once, thus reducing the time of using the apparatus and simplifying the problem of monitoring. The chief disadvantage is that considerable time is required to count the pulses recorded on the photographic film."

One of the two objects of the work reported in this thesis has been the development of apparatus for measuring the time of flight of neutrons which retains all the advantages listed by Haworth, Manley and Luebke (5), at the same time substituting direct counting for the photographic method of recording.

The second object was the application of the apparatus to the determination of the slow neutron capture cross section of manganese as a function of neutron velocity. A probable resonance in the region below 0.4 e.v. has been reported by Korvath and Salant (6), and it seemed worth while to locate this resonance more definitely, especially since manganese has been found useful in work on the capture of slow neutrons as a substandard, referred to the common standard boron. (Masetti (7), O'Neal and Goldhaber (8))

## II. DESCRIPTION OF CIRCUITS

The electrical circuits are shown schematically in the block diagram of Fig. 1, and in detail in Figs. 2-13.

A master oscillator feeds into a ten stage scaler which then provides various sub-frequencies which are used to control the other circuits. A fairly low frequency called the "cycle frequency," provides a "master pulse" which triggers the "beam pulse" circuit which allows the deuteron beam of the linear accelerator to fall upon the target.

The fast neutrons produced are slowed by paraffin surrounding the target and are detected after traversing a suitable distance by a BF<sub>3</sub> ionization chamber feeding into a four stage linear amplifier and a discriminator. The discriminator output feeds into a pulse shappener which feeds into the analyzer.

The analyzer sorts the pulses according to the time elapsed since the burst of fast neutrons was produced, and registers them upon one of ten Cenco impulse counters. Each counter is sensitive once during a cycle for a length of time determined by a higher frequency taken from the frequency scaler, called the "time scale" frequency. The counters are sensitive one after the other in a fixed sequence. However, the sensitive time of the entire group of counters may be either advanced or retarded with respect to the neutron burst by proper use of the delay circuit.

The various circuits are described in more detail below.

### FREQUENCY SOURCE

In obtaining various portions of the necessary data it was

found desirable to use a number of different cycle frequencies and a number of different time scale frequencies, all of which had to be known rather accurately. The method previously used in this laboratory was to construct oscillators, one for each of the desired frequencies. This method presented certain disadvantages, namely, that each had to be adjusted with great care, and that there was no very easy check which could be made during the course of an experiment to verify the constancy of the oscillators. In the present work these difficulties are avoided as follows.

A 100 kilocycle crystal oscillator (Fig. 2) is used to control the frequency of an electron coupled oscillator (Fig. 3) which is adjustable to either of two frequencies, 100 kilocycles or  $66 \frac{2}{3}$  kilocycles. The output of this oscillator is sharpened (Fig. 4) and fed into a ten stage Wifshutz-Lawson (9) scaling circuit (Fig. 5). The various plates of the scaling circuit then provide twenty different frequencies, all rigidly controlled by the crystal oscillator. The crystal frequency may be checked at any time by beating its output against the carrier wave of a radio station broadcasting at a frequency of 1000 kilocycles.

#### NEUTRON SOURCE

The Illinois linear accelerator, which has been described by Manley, Haworth and Luebke (10), is provided with electrostatic deflecting plates by means of which the beam of deuterons may be prevented from reaching the target of heavy water ice. With the beam permanently deflected only a very small

neutron intensity is observed. The deflecting voltage (about 300 volts) is then abruptly removed and reapplied to provide a square burst of fast neutrons. The control circuit is the "beam pulse" circuit (Fig. 3) which is keyed by a master pulse of the desired frequency taken from the frequency scaler. The beam pulse circuit is the regenerative trigger circuit mentioned by Heworth, Manley and Lubke (5) in a footnote. The voltage swing on the deflecting plates takes place so very rapidly that the beam of deuterons falls upon the target with a delay of not more than 5 micro-seconds. An exact knowledge of this delay is not important, as a determination of the over all delay was made and is discussed later. The length of the square neutron burst is continuously variable from 20 micro-seconds to 1000 micro-seconds.

Slow neutrons are obtained by surrounding the target with paraffin. The burst of slow neutrons escaping from the paraffin block is not square, but may be approximately represented by an exponential growth and decay of intensity. More will be said on this point in a later section.

#### DETECTOR

The detector is a parallel plate ionization chamber filled with  $\text{BF}_3$  at atmospheric pressure. It consists of three plates 19 cm. in diameter with a separation of 2 cm. between plates. The two outer plates are at a positive potential. The center plate coupled to the initial stage of a four stage linear amplifier receives a positive pulse due to the ionization produced

by the disintegration of boron resulting from the capture of a slow neutron by boron, the reaction being  $B^{10}(n, \alpha)Li^7$ . The chamber presents a sensitive volume of approximately 1100 cc. and detects about 6% of the incident neutrons.

The correct potential to apply to the two outer plates to obtain the best counting rate was found to vary widely from week to week. The reason for this variation is not entirely clear but is probably due to a slow leak in the chamber which permits the gradual infiltration of air and water vapor. Voltages from 500 to 2000 were used at various times. This change in voltage had no apparent effect upon the detector efficiency.

#### PULSE SHARPENER

The neutron pulses going into the analyzer should be as sharp as possible in order to minimize double counting, that is, counting the same pulse in two intervals, and they also should be of uniform height, since they are expected to fire any one of ten thyratrons, which may or may not have an equal range of firing voltages. If the pulses are of uniform height a long count of purely random impulses should show up any variation in the sensitivity of the thyratrons, and adjustments can be made until all are alike.

A circuit described by Huntoon (11), which gives an output pulse that is of uniform height and sharpness, independent of the input pulse, was used first, but it was found that the output pulse was about 40 micro-seconds long.

An attempt was made to improve on this by using a two tube trigger circuit involving a 6F8G double triode. One of the

tubes has its grid at ground and the other is biased below cut off. A negative pulse of any size or length causes a complete reversal of the roles of the two tubes. When in a time dependent upon the time constants of the two grid circuits the tubes return to their original states. Since the action of the circuit is all or none the plates of the triodes give square voltage waves of constant height and length.

The time constants were reduced as much as possible in order to shorten the output pulse. It was found that reduction of the pulse length below 20 micro-seconds resulted in an inequality in height of the pulses. The electrode capacitances of the tubes were so large that the plate swing could not reach full value before recovery of the grids started the return swing.

The arrangement finally used (Fig. 9) was still a two tube trigger circuit, using 6AC7 pentodes for the trigger tubes. Since the neutron pulses are fed into ten grids, enough power might be drawn from the trigger circuit to disturb its operation. The second of the trigger tubes was connected in such a way as to minimize this effect by using the cathode, control grid and screen grid as a triode in the trigger circuit, and taking the output signal from the plate. As a further precaution a buffer tube was introduced to follow the behavior of the trigger tube and provide the power demanded by the counting circuits. With the circuit constants shown in Fig. 9 the output pulse is very uniform in height and length for a very wide variety of input pulses. The total length of the pulse from

the beginning of the swing to the end of the return is 8 microseconds.

#### ANALYZER

The operation of the analyzer, shown in Fig. 13, is based on ten Lifshutz-Lawson (9) scales of two which have been slightly altered for this particular use. The bias is set low enough to provide two stable states for each pair of tubes, but the input pulses to the two grids of each stage are not identical. One grid of each pair receives the time scale pulse. The other grid receives a signal from a plate of the preceding stage. The operation is then as follows.

The time scale pulse registers on grid A of stage 1 making this tube non-conducting, whatever its previous state. As long as stage 1 is in this condition subsequent time scale pulses produce no effect. Then at some time which is adjustable with respect to the onset of the beam on the target, an initiating pulse arrives at grid B of stage 1, causing tube B to become non-conducting and tube A to become conducting. Upon the arrival of the next time scale pulse the two tubes again reverse roles. A pulse from plate A is fed to a triode which is biased well past cut off. A signal from the plate of this tube goes to grid B of stage 2 which then goes through the same cycle, and the tripping effect goes on down the set of ten stages.

During the time when tube B is non-conducting its plate is at a high positive level. The square wave from this plate is fed to the grid of another triode also biased below cut off

which serves to make the square wave even more square. The negative square wave on the plate of this triode is fed to one grid of a coincidence stage. Neutron pulses coming from the pulse sharpener are fed to the other grid of the coincidence tubes in all ten stages. If a neutron pulse arrives during the time when the square wave is on the coincidence tube of stage 1, the pulse from the plates of the coincidence tubes of stage 1 trips a thyatron and registers a pulse on counter 1.

It is obvious from the above that the sensitive time of the counters can be adjusted in length simply by changing the frequency of the time scale. With the circuit constants used sensitive times ranging from 20 micro-seconds to 480 micro-seconds were found to work satisfactorily. For times longer than 480 micro-seconds it would have been necessary to use a longer time constant on the coincidence tubes. This was tried but with these longer time constants it was found to be impossible to operate at very short sensitive times.

If the analyzer is to be used to determine a velocity distribution curve it is important that the various stages be sensitive during exactly equal intervals of time. This equality was checked by counting several hundred thousand radon pulses from a radium-beryllium source and it was found that no correction was necessary for interval length except for the first interval. The first interval is started by the initiating pulse which is provided by a time delay circuit (Fig. 10) triggered by the same pulse that puts the beam on the target. The delay is continuously adjustable from about 10 micro-seconds to per-

haps 1500 micro-seconds. In order to make the first interval begin on a time scale pulse the delay would have to be adjusted with very great accuracy. In order to avoid this possible source of error a dummy stage (Fig. 12) was provided. It is identical with the other ten stages except that it operates no counter. It is inserted between the master pulse and the first stage, being turned on by the master pulse and off by the next time scale pulse, thus starting stage 1 exactly on a time scale pulse. In most cases it was not desired to start counting until some time after the beam fell upon the target so that the delay and dummy could be used. However, in some of the earlier measurements of source-time distribution, counting was started at the same time as the beam, simply by eliminating the delay and dummy. In this case it was found that the first interval became sensitive about 7 micro-seconds late. This retardation was due to the fact that the pulse used to start the first stage was not of sufficient sharpness. In any data taken with this arrangement correction for the retardation was made in plotting the graph.

In order to eliminate this error entirely the dummy, but not the delay, was left in in later runs of source-time distribution, and the master pulse was taken from the delay circuit, thus delaying the beam pulse for a suitable time.

The various beam pulse and counter relationships that were used are represented in Fig. 15. The rectangle above the base line represents the time during which the beam is on the target, and the numbers below the line indicate the sensitive time of

each counter.

The delay circuit is triggered by a negative pulse from the frequency scaler. The frequency scaler also puts out a positive pulse which is amplified and inverted by the first tube of the delay circuit. The resulting negative pulse is large enough to trip the dummy and start the counting cycle at the wrong time. To eliminate this undesired pulse a delay follower (Fig. 11) was inserted. The delay follower has two stable states, being tripped one way when the delay begins and back at the end of the delay. Then the second negative pulse coming through the delay finds the delay follower already tripped and so it has no effect. This use of the delay follower imposes a restriction on the length of the delay, namely, that it can be no more than one-half the time of a complete cycle. If the delay is not over by the time the undesired pulse arrives the delay follower will respond to this pulse and the counting cycle will begin.

Another source of difficulty lies in the fact that, even after sharpening, the neutron pulses were about 8 micro-seconds long. The time required for one stage to go off and the next to go on is much less than 8 micro-seconds so that it is possible for a single pulse coming just about at the end of one interval to register in that interval and also in the next one. This would have to be taken into account in any measurements of an absolute nature, but since this work concerns only relative numbers, no correction was made for pulse length.

During operation the behavior of the circuits was checked

frequently by oscilloscopic observation. Remarkable stability was observed, only a few runs out of several hundred being rejected because of circuit trouble.

#### COUNTING DELAYS

There are many steps between the triggering of the beam pulse and the registry of a neutron on a counter in which one might reasonably expect a delay of a few micro-seconds. These delays could be measured individually with fair accuracy by feeding in a regular pulse to a given stage and comparing the output of that stage with its input on the oscilloscope. This method presents the objections that the errors of determination might add up to quite a large value, the pulses fed in would not be exactly the same as those occasioned by capture of a neutron, and it would not be possible to measure the collection time of ions in the BF<sub>3</sub> chamber. Therefore, the over all delay was measured with actual neutron pulses by a method used by Baker and Bacher (3).

The detector was surrounded by cadmium to exclude slow neutrons scattered back from the walls and was placed as close as possible to the source (the target) from which all paraffin had been removed. The counting interval was set at 40 micro-seconds, the cycle period at 640 micro-seconds, and the beam pulse was made 160 micro-seconds long. The beam pulse was delayed with respect to the initiating pulse so that the beam was on the target during the time counters 5, 6, 7 and 8 were sensitive. This arrangement is represented by Fig. 15a.

after the data had been corrected for background the intervals were added up in consecutive groups of four. These data are plotted in Fig. 14. The number 1 below the base line represents the summation of intervals 2, 3, 4 and 5 and so on. If the fast neutron burst is square and if there were no circuit delays, Fig. 14 should be an isosceles triangle with its vertex at 4. If the neutron burst is square, but circuit delays exist, the figure will be shifted by a time equal to the delays. Fig. 14 shows this to be the case. Measurements of the shift taken at the vertex and at the two intercepts with the small remaining background give an average of 55 microseconds for the delay.

### III. PROCEDURE

The geometry of the experiment is drawn to scale in Fig. 15. The larger portion of the data was obtained using the arrangement of Fig. 16A, in which the distance traversed by the neutrons was 248.5 cm. Attempts were made to produce a collimated beam of neutrons by using the borax filled and cadmium lined tubes shown. The ionization chamber was partially surrounded by borax and cadmium to reduce the number of neutrons reaching the detector from the walls of the room. Surrounding the target with borax and cadmium on all sides except that seen by the detector was also tried and was found to produce no appreciable reduction of background.

A manganese absorber was constructed by filling with powdered manganese a box constructed of two aluminum sheets  $1/32$ " thick separated at the edges by brass bars. The brass was outside the beam so that the absorption of the box could be neglected, the absorption cross section of aluminum being very small. The area of the manganese is 5260 sq. cm. and its weight is 3090 gm. giving an absorber thickness of  $6.45 \times 10^{22}$  atoms per sq. cm.

The detector response was determined for each interval with no absorber in the beam and then with the absorber in place. Let these two responses be denoted by  $N$  and  $A$  respectively. Then  $N/A$  equals  $1/T$  and the logarithm of this quantity is the cross section of manganese for neutrons of the energies detected in the interval.

To obtain E and A it was necessary to take runs of seven types as tabulated below. Each set of data was made up of many runs of 10 minutes or less in length, the first six being taken in a fixed rotation in order to minimize the effects of variation in beam intensity. The seventh group is independent of beam intensity and so was taken only two or three times a day.

RUN	ABSORBER	BEAM PULSE	COMPOSITION
N'	None	Off	e, d, e
N''	None	On	a, b, c, d, e
A'	Manganese	Off	e, d, e
A''	Manganese	On	a, b, c, d, e
B'	Boron and Cadmium	Off	d, e
B''	Boron and Cadmium	On	b, a, e
Background	Linear accelerator shut off completely		e

The detector will give pulses due to the five sources listed below. The letters given above under "Composition" refer to these groups indicating those which are present in the run. The boron and cadmium absorber used was of sufficient thickness to stop practically all neutrons of energies to which the detector would respond.

- a. Neutrons which are produced at the target during the "beam pulse on" time and proceed down the borax tubes to the detector.
- b. Neutrons produced at the target during the "beam pulse on" time, but which reach the detector by travelling outside the tubes, mostly being scattered back from the walls of the room.
- c. Neutrons produced by the stray beam (an undeflectable portion of the beam which strikes the target even during the

"beam pulse off" time) which reach the detector by way of the tubes.

- d. Neutrons produced by the stray beam which travel outside the tubes to the detector.
- e. The natural background of the ionization chamber.

Group "e" is proportional only to time, so it was subtracted from all runs before they were matched. Matching was accomplished on the basis of the monitor count taken along with each run. The monitor was a cylindrical BF<sub>3</sub> counter placed just behind the paraffin surrounding the target as illustrated in Fig. 16. Its use is made necessary by the fact that the deuteron beam varies both in intensity and its position of striking the target, causing an appreciable variation in neutron intensity. The monitor response will naturally be much greater for "beam pulse on" runs than for "beam pulse off" runs. The ratio between the two monitor counts would be constant if the beam were constant. This ratio is evaluated by assuming that variations in beam intensity will average out in the course of a day and using the total monitor counts for the entire day to determine the ratio.

The detector response should consist only of group "a" neutrons since it is only of this group that one knows both the time and place of production and the distance traversed in reaching the detector. Consideration of the composition of each set of runs shows that

$$N = (N'' - N') - (B'' - B') \quad \text{and} \quad A = (A'' - A') - (B'' - B').$$

## IV. RESULTS

The results of the experiment are shown in Fig. 17 in which the total cross section of manganese is plotted against the reciprocal of the velocity of the absorbed neutrons. The results of two experiments are shown.

The dots were obtained with the center of the detector at a distance of 129 cm. from the effective source of neutrons. The cycle period was 2560 micro-seconds and the time scale interval was 160 micro-seconds. The length of the beam pulse also was 160 micro-seconds, and counting was started at the end of the beam pulse as is represented schematically in Fig. 15C. The neutron source (Fig. 16B) was made up of three soft glass dewar flasks containing paraffin blocks surrounded by alcohol and dry ice, the purpose being the provision of greater numbers of neutrons in the low velocity end of the spectrum. The effective source of neutrons was assumed to be located at the dotted line. The absorbers were placed at the position X - X.

The horizontal bar points were obtained with the same cycle, time scale and beam pulse times, but the source-detector distance was 248.5 cm. and the source of slow neutrons was a paraffin block at room temperature (Fig. 16A). The effective source was assumed to be a plane 0.3 cm. inside the paraffin block.

In the experiment performed at a distance of 248.5 cm. there was an appreciable hang over of slow neutrons from one cycle into the first three intervals of the next cycle. The

data plotted in Fig. 17 have been corrected for this effect.

Other corrections must be made for the finite time during which neutrons leave the source, circuit delays, and the scattering cross section of manganese.

The zero of Fig. 17 has been taken as the time at which the beam pulse goes on. Due to the circuit delays discussed in an earlier section this point should be displaced 55 microseconds.

The straight line representing  $1/V$  absorption has an intercept of  $2.8 \times 10^{-24}$  sq. cm. at 55 micro-seconds. This value represents the effective scattering cross section of manganese. It is probably a little smaller than the true value since the beam falling upon the absorber is not perfectly collimated and neutrons are scattered into as well as out of the beam.

A check on this value has been obtained in the following way. Coltman and Goldhaber (12) have measured the absorption cross section of manganese in terms of the absorption cross section of boron. Assuming the boron cross section to be 600 they obtain a value of  $10.7 \pm 0.2$  for manganese.

Luebke (13) has measured the cross section of boron as a function of neutron velocity. His curve shows a fairly large and unexplained intercept at zero time. This intercept has been evaluated as  $70 \times 10^{-24}$  sq. cm.

Then if the respective intercepts are subtracted from Luebke's data and from that of the author the ratio of the absorption cross sections taken at corresponding points on the

two curves should be that obtained by Coltman and Goldhaber. The point labeled *x* was chosen because it lies in the most accurate portion of both curves, and a ratio of 0.0182 was obtained. That of Coltman and Goldhaber is 0.0178. The agreement seems quite satisfactory, especially in view of the uncertainty in the choice of intercept for Luebbe's curve. It might be put at any value from zero to 75. If a zero intercept is assumed the ratio becomes 0.0162, the agreement still being as good as the errors in the various experiments would demand.

Berger (14) has studied in some detail the variation of neutron intensity at the source as a function of time and of neutron energy and its effect upon the observed points using the arrangement of Fig. 16C. The dotted curve at the origin of Fig. 17C represents his source-time distribution averaged over all energies. This curve has been displaced 55 micro-seconds because of circuit delays.

The straggling of neutrons from the target for some time after the beam pulse goes off results in the reception in any very small time interval of neutrons of higher velocity than would be expected in that interval if there were no time spread in emission of neutrons from the source, but all were emitted at zero time. Thus the interval shows an absorption cross section corresponding to an average velocity which is higher than that used to plot Fig. 17.

Berger has calculated the magnitude of this effect and his results are embodied in Fig. 18. In this figure both

time delays and scattering have been taken into account, so that the plot is one of absorption cross section against time of flight, or  $L/V$ . The energy scale below the line represents the energy of the slowest neutrons which would be detected in a very narrow detector interval. The energy scale above the line shows the average neutron energy as calculated by Berger.

## V. CONCLUSIONS

The corrected experimental results have been plotted in Fig. 13. The variations of individual points are not sufficient to confirm the existence of a resonance level in the region below 0.4 e.v. as reported by Horvath and Salant (5), and within the limits of error of the present data a  $1/V$  law seems to represent the variation of the capture cross section of manganese satisfactorily. The validity of the data is questionable below 0.008 e.v. due to the very low intensity of neutrons of those energies in the beam. Only by obtaining considerably more data could these points be accurately determined with the neutron source used in this work.

The slow neutron velocity spectrometer developed as part of this work seems to meet quite adequately most of the requirements for such a device.

Time measurements have been made entirely automatic and accurate with the exception of the beam pulse length. The setting of this time is the only case in which oscilloscopic comparison with a standard signal is used. Only integral multiples of the time scale period were used in order to avoid interpolation.

Circuit delays are quite stable and may easily be compensated for. All, or at least a portion of considerable size, of the distribution is measured at the same time which simplifies the monitoring problem. The data are obtained simply by reading Cenco counters at suitable intervals, thus eliminating

the tedious tasks of photographic development and pulse counting.

The circuits are quite flexible, relatively little adjustment being required to obtain any desired combination of beam pulse and counting intervals.

The most serious objection to the circuits as used is the rather low resolution of the apparatus. However, this limitation is not imposed by the circuits, but by the intensity of the neutron source. If a sufficiently intense source were available the resolution could be improved by a factor of 10 or more without alteration of the existing circuits.

## VI. BIBLIOGRAPHY

1. Dunning, Pegram, Fink, Mitchell and Segre, Phys. Rev. 48, 704 (1935)
2. L. Alvarez, Phys. Rev. 54, 609 (1938)
3. Baker and Bacher, Phys. Rev. 59, 332 (1941)
4. Fertel, Gibbs, Moon, Thomson and Wynn-Williams, Proc. Roy. Soc. 175, 316 (1940)
5. Haworth, Manley and Luebke, Rev. Sci. Inst. 12, 591 (1941)
6. Horvath and Salant, Phys. Rev. 59, 154 (1941)
7. P. Rasetti, Phys. Rev. 58, 869 (1940)
8. O'Neal and Goldhaber, Phys. Rev. 59, 102 (1941)
9. Lifshutz and Lawson, Rev. Sci. Inst. 9, 83 (1937)
10. Manley, Haworth and Luebke, Rev. Sci. Inst. 12, 587 (1941)
11. Huntoon and Strohmeyer, Rev. Sci. Inst. 12, 35 (1941)
12. Coltman and Goldhaber, Publication postponed for the duration of the war.
13. E. A. Luebke, Ph. D. Thesis, University of Illinois (1941)
14. F. B. Berger, Ph. D. Thesis, University of Illinois (1942)

SUMMARY OF DATA

Data taken at 129 cm. Beam pulse 160 micro-seconds, time scale period 160 micro-seconds, cycle period 2560 micro-seconds.

Run	TIME INTERVALS										Total	Monitor g	Time (sec.)
	1	2	3	4	5	6	7	8	9	10			
N <sup>1</sup>	6677	6007	8599	8838	7314	5028	3837	3106	2737	2419	4742	488	1650
N <sup>2</sup>											54562	6324	6000
A <sup>1</sup>	5377	3916	4637	4230	3171	2187	1775	1589	1435	1397	3079	521	1600
A <sup>2</sup>											29714	6577	6000
B <sup>1</sup>	790	260	233	251	188	208	245	226	200	240	783	210	750
B <sup>2</sup>											2841	1825	1900
Back-ground											29		400
A	2007	2448	3271	2879	1859	912	515	337	189	152			
N	2822	3997	6716	6955	5431	3145	1954	1223	854	536			
1/T	1.44	1.63	2.05	2.42	2.92	3.45	3.80	3.63	4.52	3.53			

Data taken at 246.5 cm. Beam pulse, time scale and cycle period same as above. Data in table immediately below was taken in seven different groups. A, N, and I/T were calculated independently for each group, and not from the summation given below. The value of A, N, and I/T given below are the summations of the seven calculated values.

TIME INTERVALS

Run	1	2	3	4	5	6	7	8	9	10	Total	Monitor g	Time (sec.)
N <sup>*</sup>	7950	5030	5633	8789	1196	10393	8490	6816	5344	4372	6735	2762	6350
N <sup>*</sup>											74009	41218	16505
A <sup>*</sup>	7325	4008	3945	5533	6779	5855	4706	3585	2944	2470	5948	2837	6470
A <sup>*</sup>											47146	43884	17150
B <sup>*</sup>	5027	1946	1512	1470	1375	1390	1404	1392	1370	1408	5351	2872	6450
B <sup>*</sup>											18294	40436	15800
Back-ground											6087		9150
A	1492	1562	1941	3522	4687	3837	2752	1697	1099	652			
N	2270	2523	3566	6816	9223	8420	6517	8439	3381	2403			
I/T	1.52	1.61	1.84	1.93	1.97	2.19	2.37	2.85	3.08	3.69			

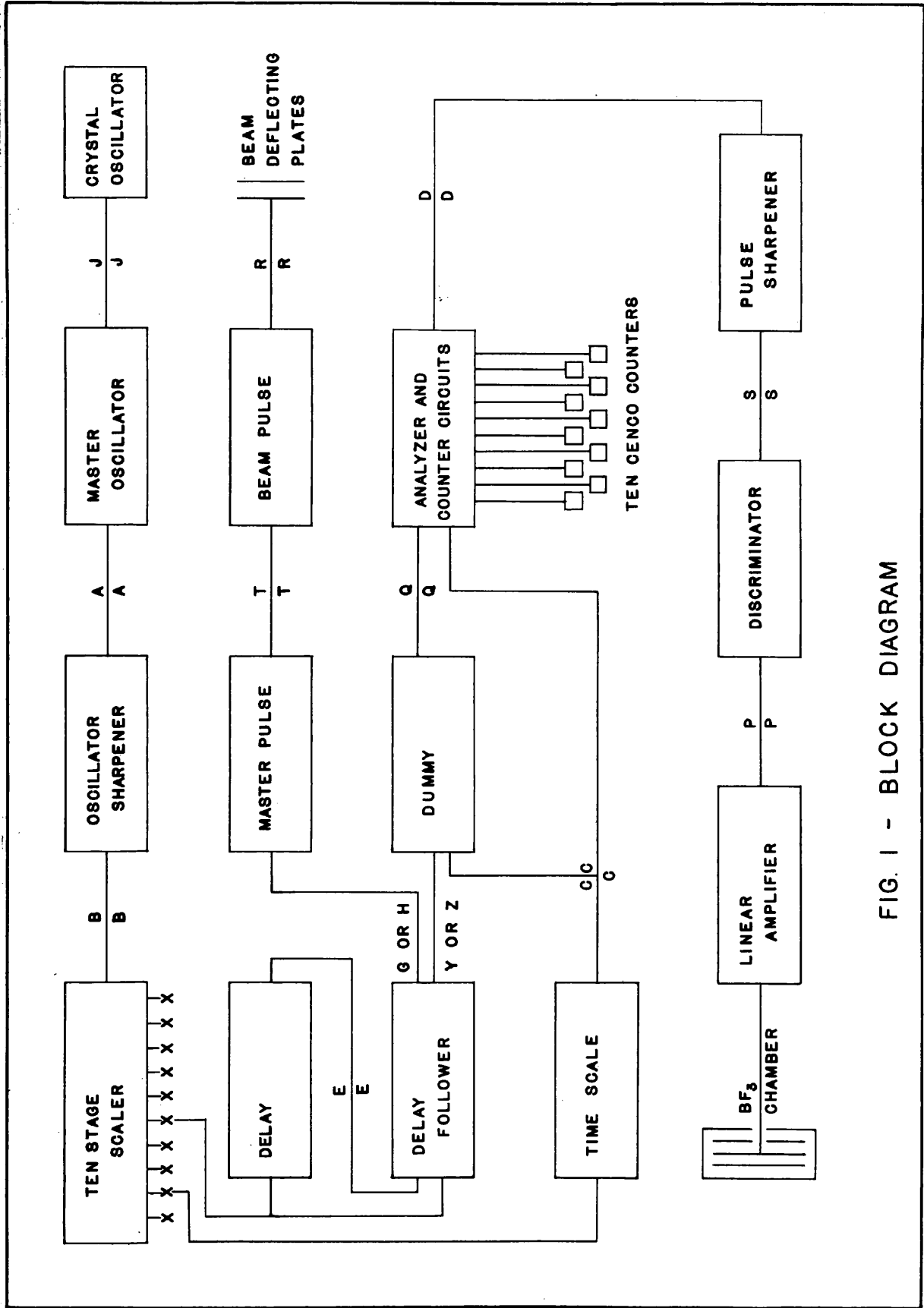


FIG. 1 - BLOCK DIAGRAM

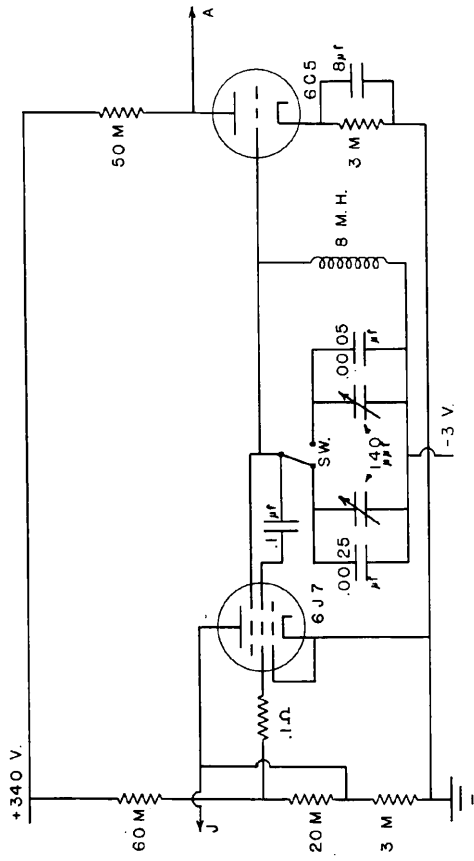


FIG. 2 - CRYSTAL OSCILLATOR

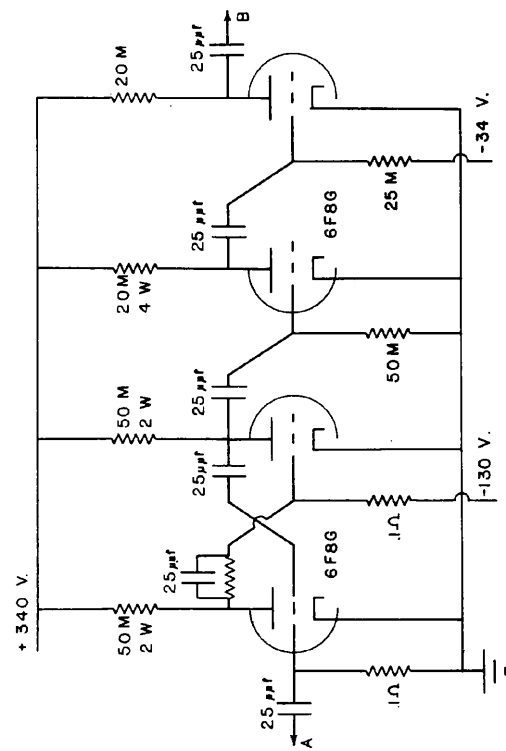


FIG. 4 - OSCILLATOR SHARPENER

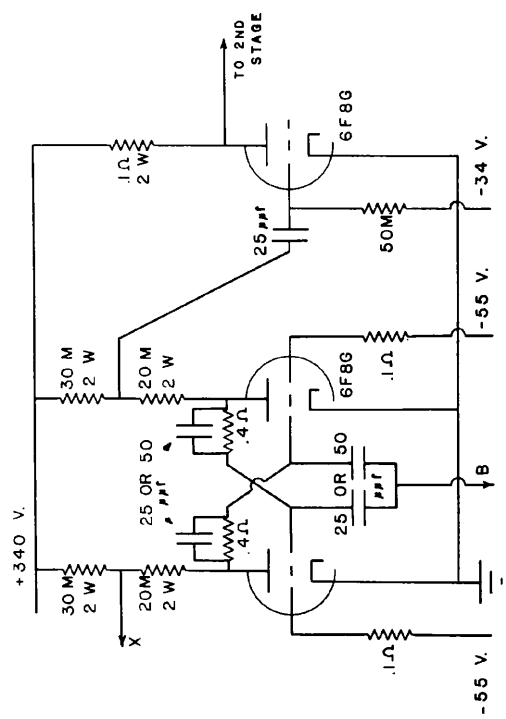


FIG. 3 - MASTER OSCILLATOR

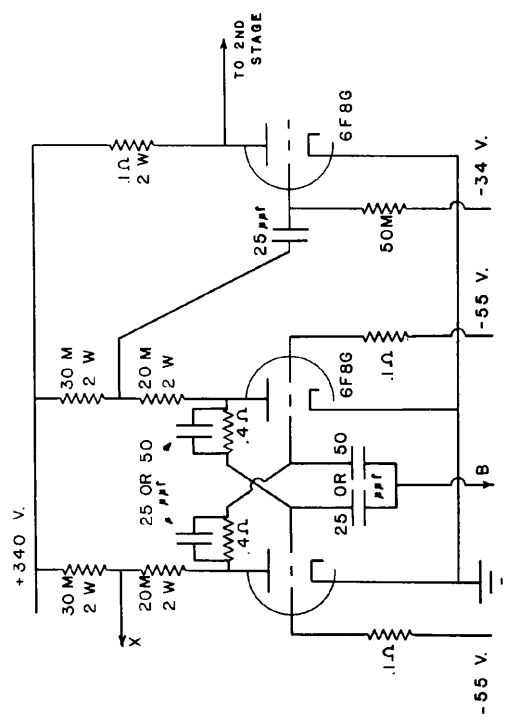


FIG. 5 - ONE STAGE OF TEN STAGE SCALER

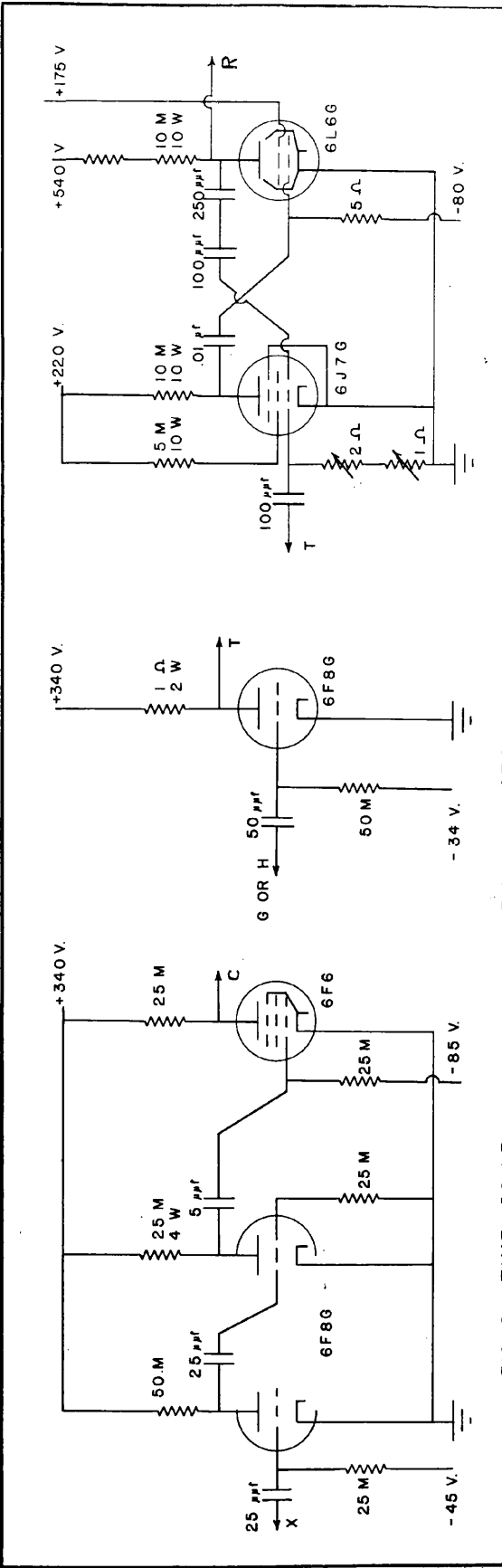


FIG. 6 - TIME SCALE

FIG. 7 - MASTER PULSE

FIG. 8 - BEAM PULSE

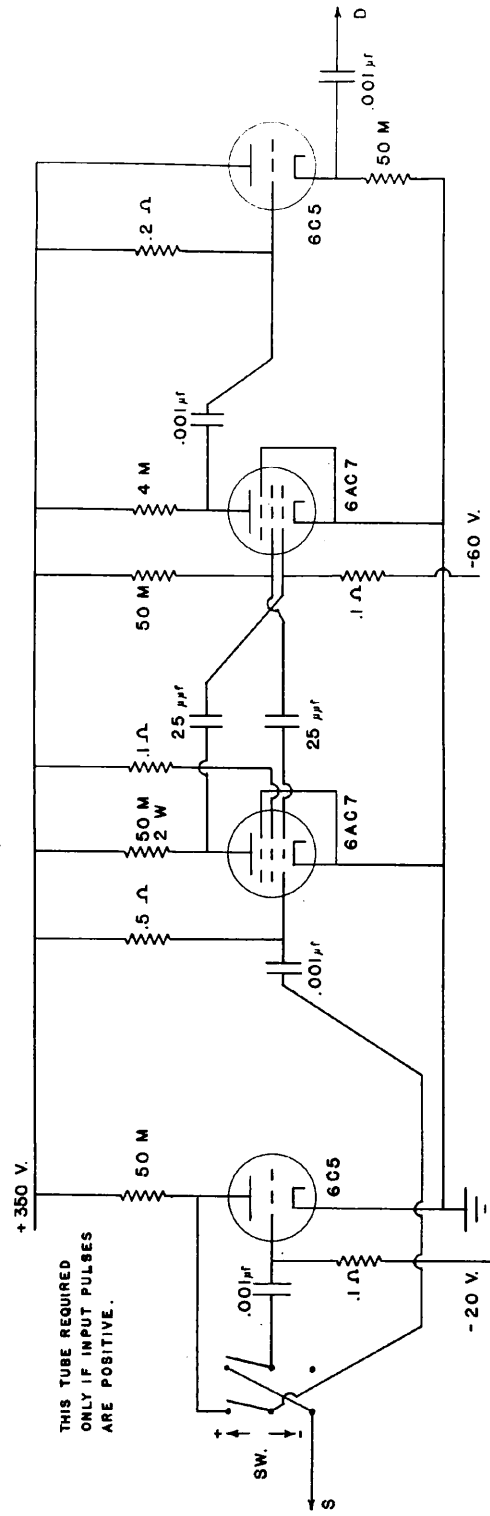


FIG. 9 - PULSE SHARPENER

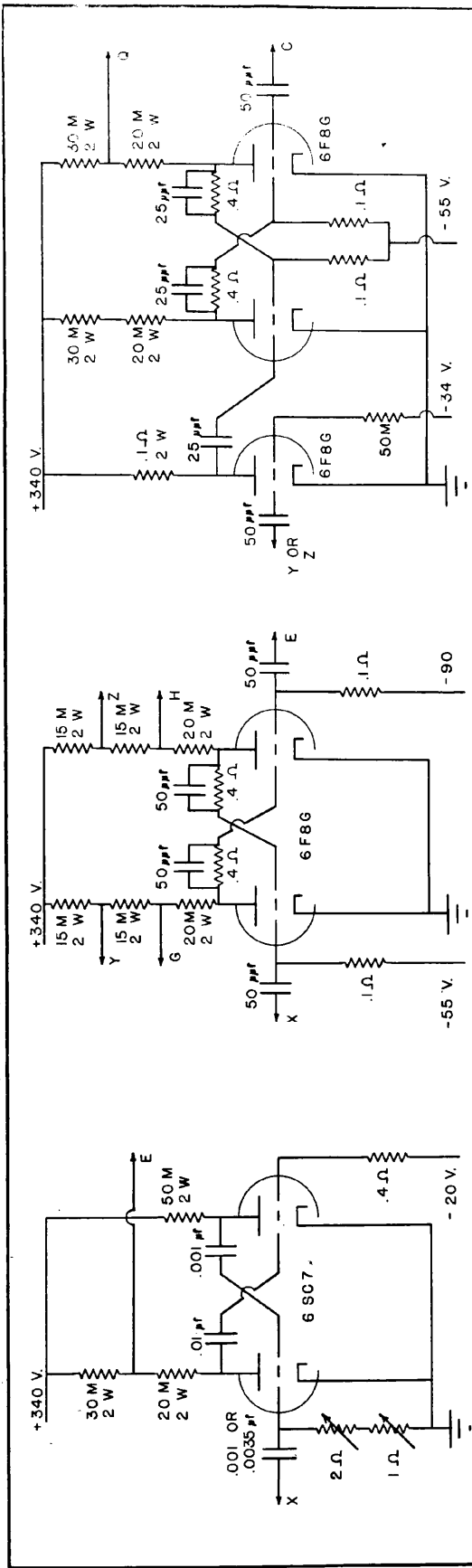


FIG. 10 - DELAY

FIG. 11 - DELAY FOLLOWER

FIG. 12 - DUMMY

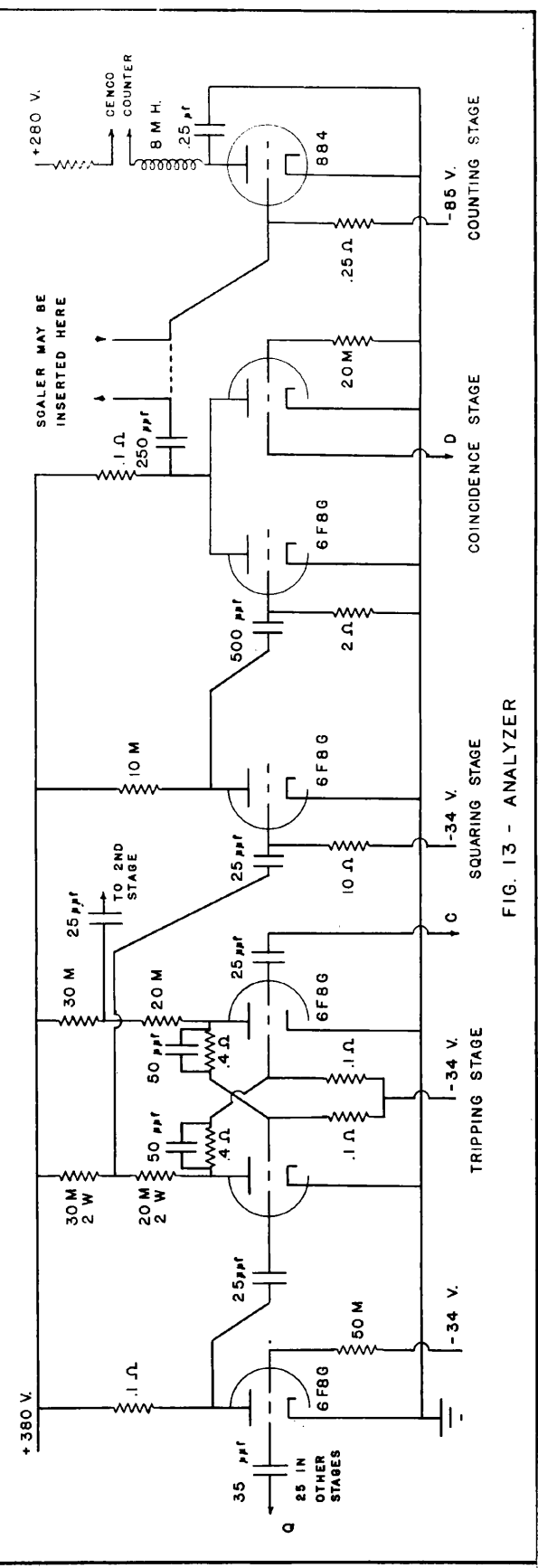
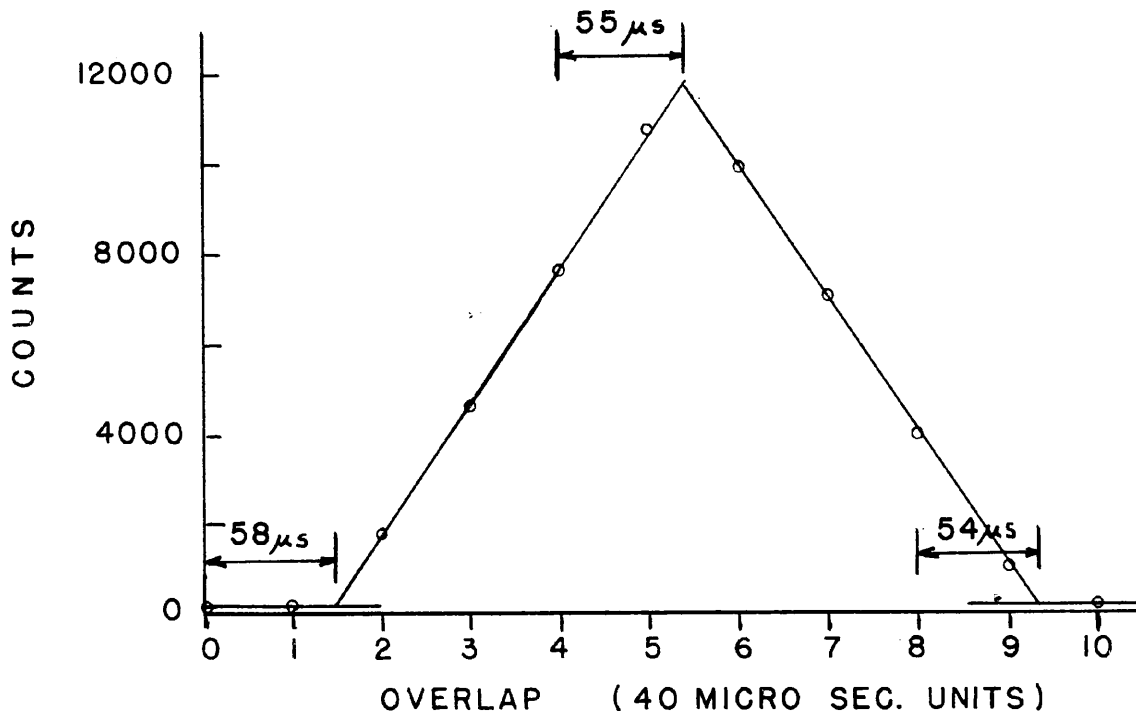
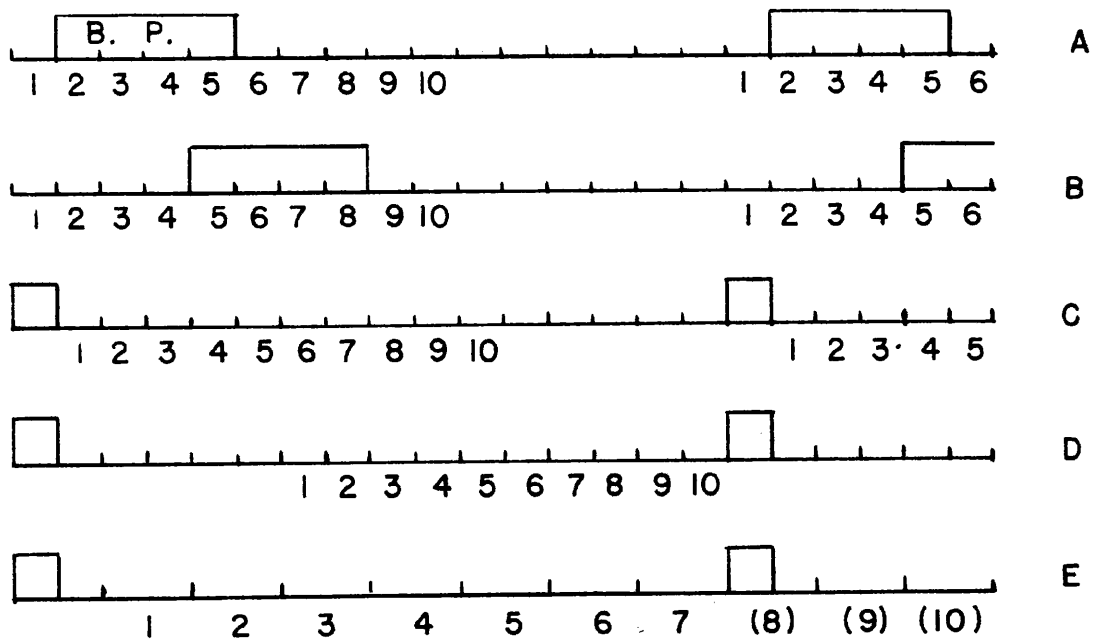


FIG. 13 - ANALYZER



DELAY

FIG. 14



TIME SCALE RELATIONSHIPS

FIG. 15

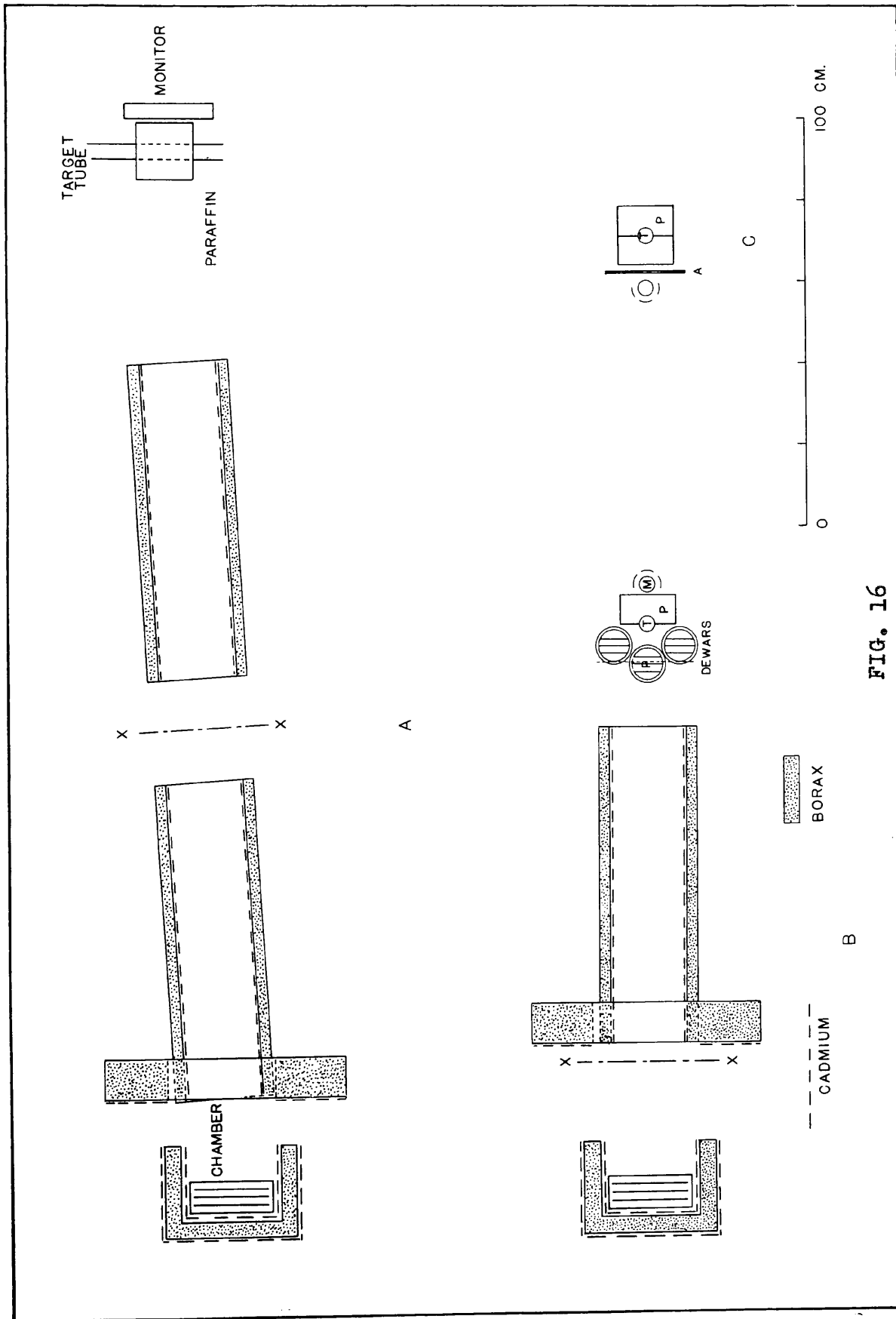


FIG. 16

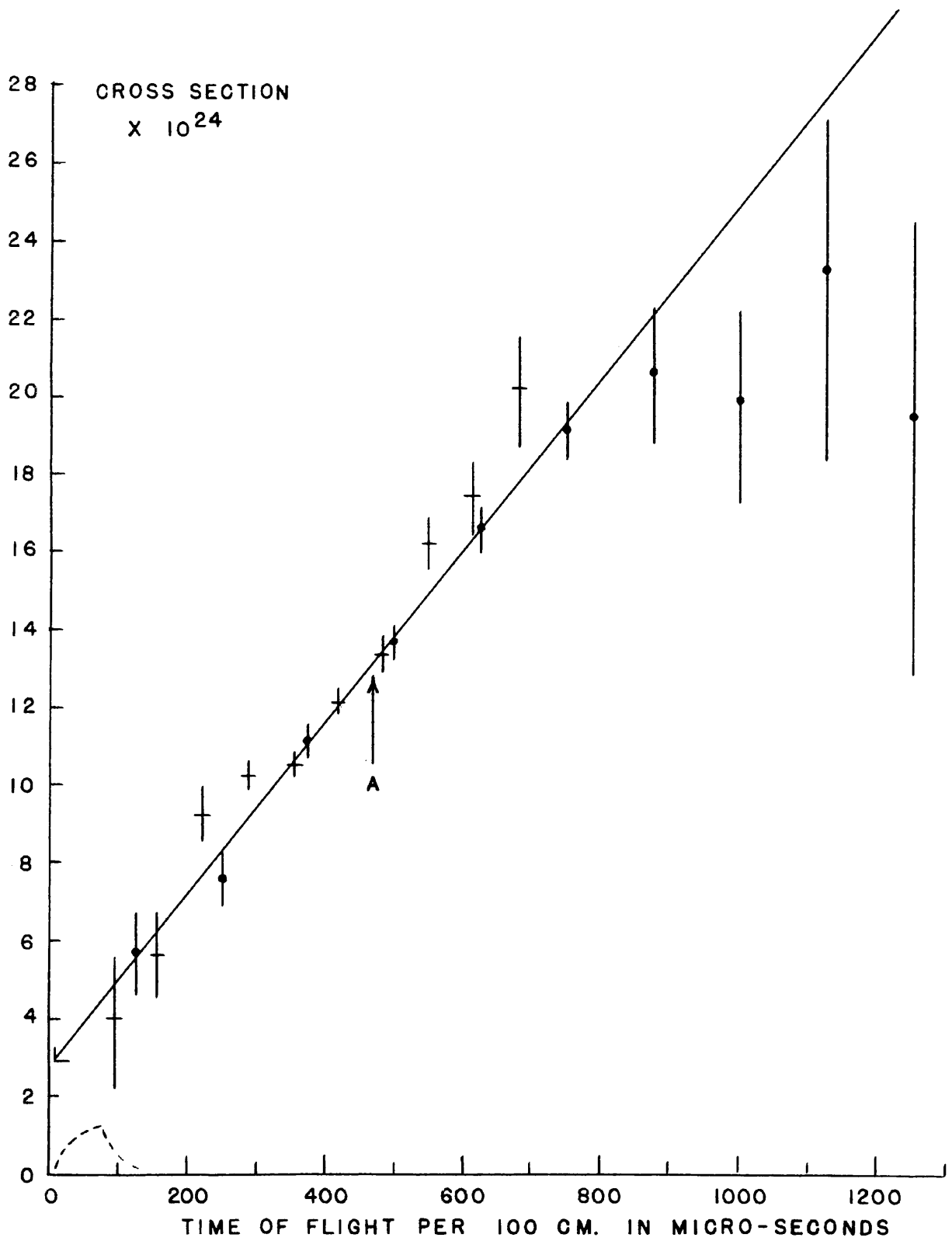


FIG. 17 - TOTAL CROSS SECTION OF MANGANESE

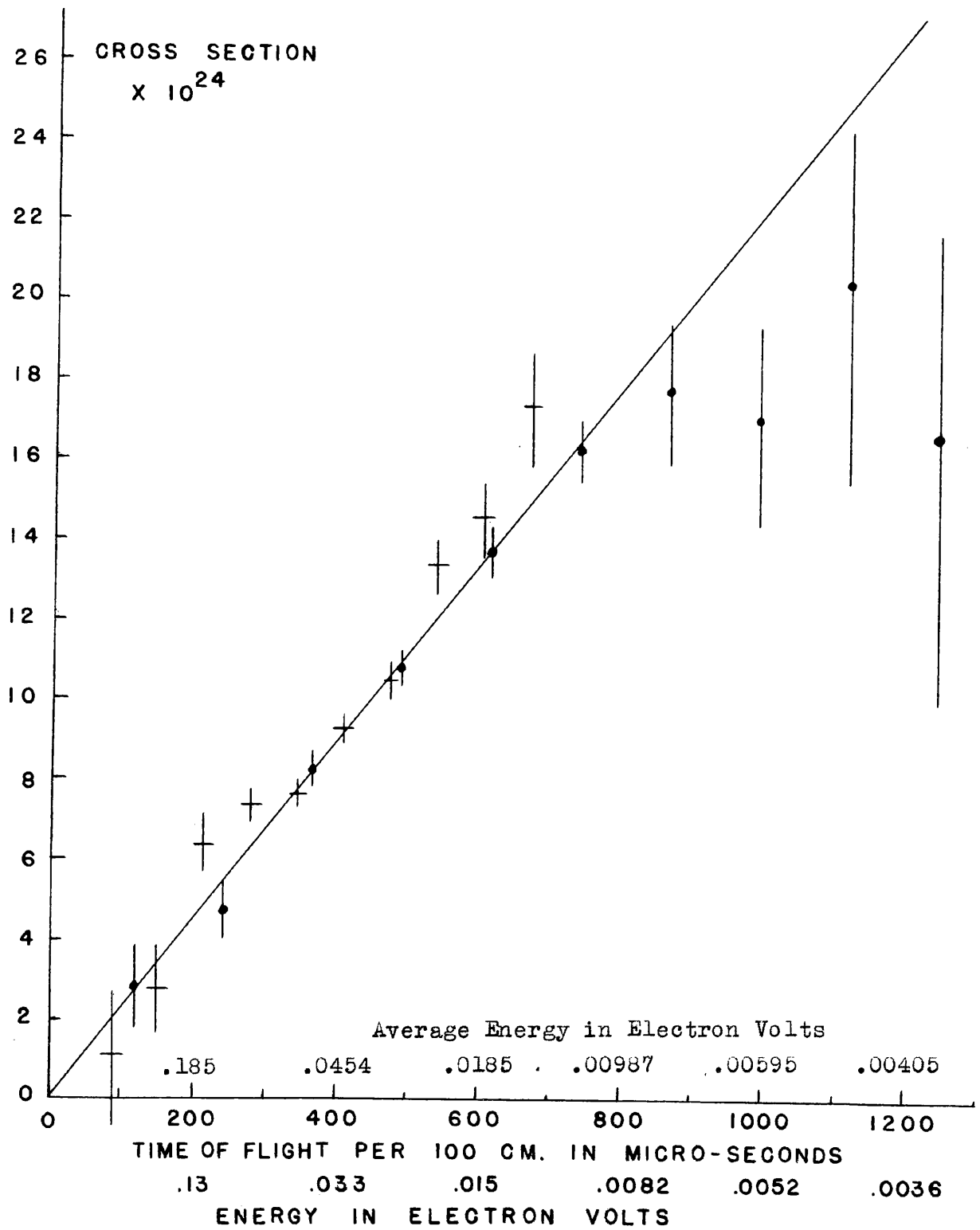


FIG. 18 - CAPTURE CROSS SECTION OF MANGANESE FOR SLOW NEUTRONS

## VITA

Frank Newton Gillette was born July 16, 1914 at La Harpe, Illinois. He received his elementary education in various public schools of Illinois, attending high school in Secoria, Illinois. He received the B. S. degree from Bradley Polytechnic Institute in 1938. He has done graduate work in physics at the University of Illinois since 1938. He held a research assistantship during 1938-39 and a fellowship during 1939-40. Since that time he has been a teaching assistant on half-time or three-quarter-time. He is affiliated with Sigma Xi and the American Physical Society.

ProQuest Number: 29404068

INFORMATION TO ALL USERS

The quality and completeness of this reproduction is dependent on the quality and completeness of the copy made available to ProQuest.



Distributed by ProQuest LLC (2022).

Copyright of the Dissertation is held by the Author unless otherwise noted.

This work may be used in accordance with the terms of the Creative Commons license or other rights statement, as indicated in the copyright statement or in the metadata associated with this work. Unless otherwise specified in the copyright statement or the metadata, all rights are reserved by the copyright holder.

This work is protected against unauthorized copying under Title 17, United States Code and other applicable copyright laws.

Microform Edition where available © ProQuest LLC. No reproduction or digitization of the Microform Edition is authorized without permission of ProQuest LLC.

ProQuest LLC  
789 East Eisenhower Parkway  
P.O. Box 1346  
Ann Arbor, MI 48106 - 1346 USA