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PRELIMINARY RESULTS ON THE CROSS-SECTION OF

THE REACTION $T^3(d,n)He^4$ BETWEEN 1.0 MEV AND

2.5 MEV DEUTERON ENERGY

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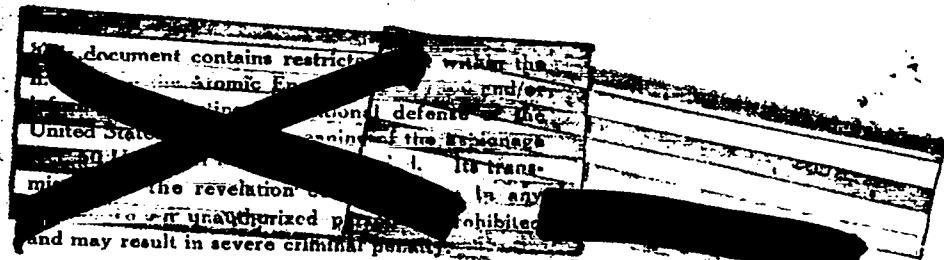
Abstract

Results on the absolute total and differential cross sections for $T^3(d,n)He^4$ at deuteron energies of 1.0 Mev, 1.5 Mev, 2.0 Mev and 2.5 Mev are reported and the use of this reaction as a neutron source is discussed.

PRELIMINARY RESULTS ON THE CROSS SECTION OF THE REACTION $T^3(d,n)He^4$

BETWEEN 1.0 MEV AND 2.5 MEV DEUTERON ENERGY

Introduction

In the past measurements on the reaction cross section of $D^2(T,n)He^4$ have been made by Bretscher and French[1] from about 18 kev triton energy to about 120 kev and by Baker, Holloway, Schrieber, and King[2] from about 300 kev to about 900 kev. Both groups of experimenters accelerated tritons onto thick deuterium oxide targets, at a time when tritium was very rare. The experiments reported show that this reaction has an extremely large cross section somewhere near 200 kev triton energy where there is a resonance maximum. The Q for the reaction is + 17.6 Mev.

The reaction $T^3(d,n)He^4$ has been studied for deuterons of energies 1.0 Mev to 2.5 Mev (triton energies $3/2\ E_d$) both to determine the differential and total reaction cross sections and to study the use of this reaction as a source of high energy neutrons.

Method

The availability of small but sufficient quantities of tritium made the acceleration of deuterons of energies above 1 Mev on to gaseous tritium seem the logical method of producing the reaction and observing the reaction products, alpha-particles and neutrons. A special target allowing angular distribution measurements of alpha-particles to be made in a small gas volume has been described [3] and Fig. 1 shows the essentials.

Cooling coils

Filling lead
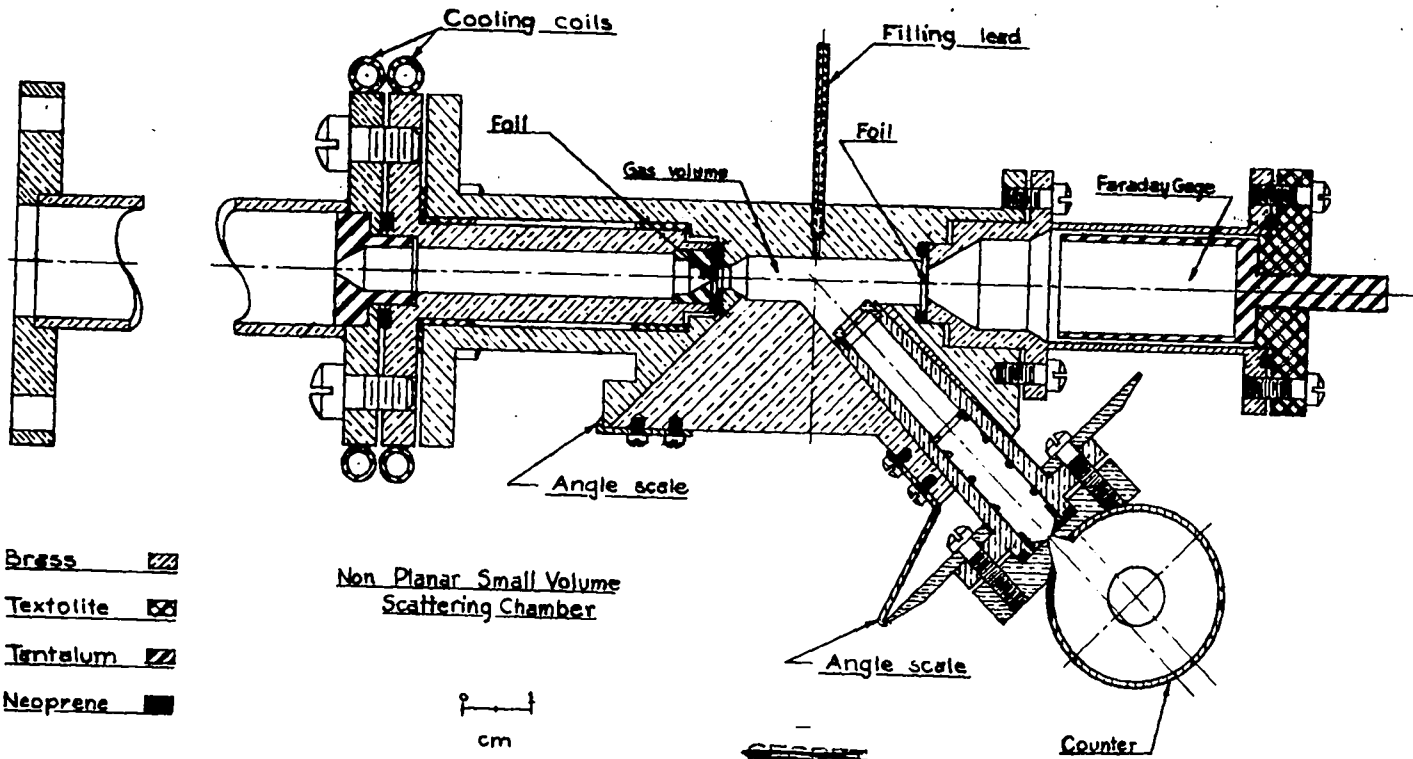
Foil

Foil

Gas volume

Faraday Gage

Angle scale

Brass

Textolite

Tantalum

Neoprene

Non Planar Small Volume
Scattering Chamber

Angle scale

Counter

cm

SECRET

FIGURE - 1

Fig. 1

Fig. 2 is a schematic diagram of the tritium storage and handling
system used; heated uranium shavings provided a completely satisfactory
method of evolving the tritium stored as UH_3 in the cold uranium when not in
use. Since the total amount of gas available at one time was only about
10 to 15 cm^3 at NTP the mercury lift through the 500 cm^3 bulb was used to
make a complete transfer of gas at maximum efficiency from uranium pump to
target and vice versa possible. Auxiliary connections could be made to
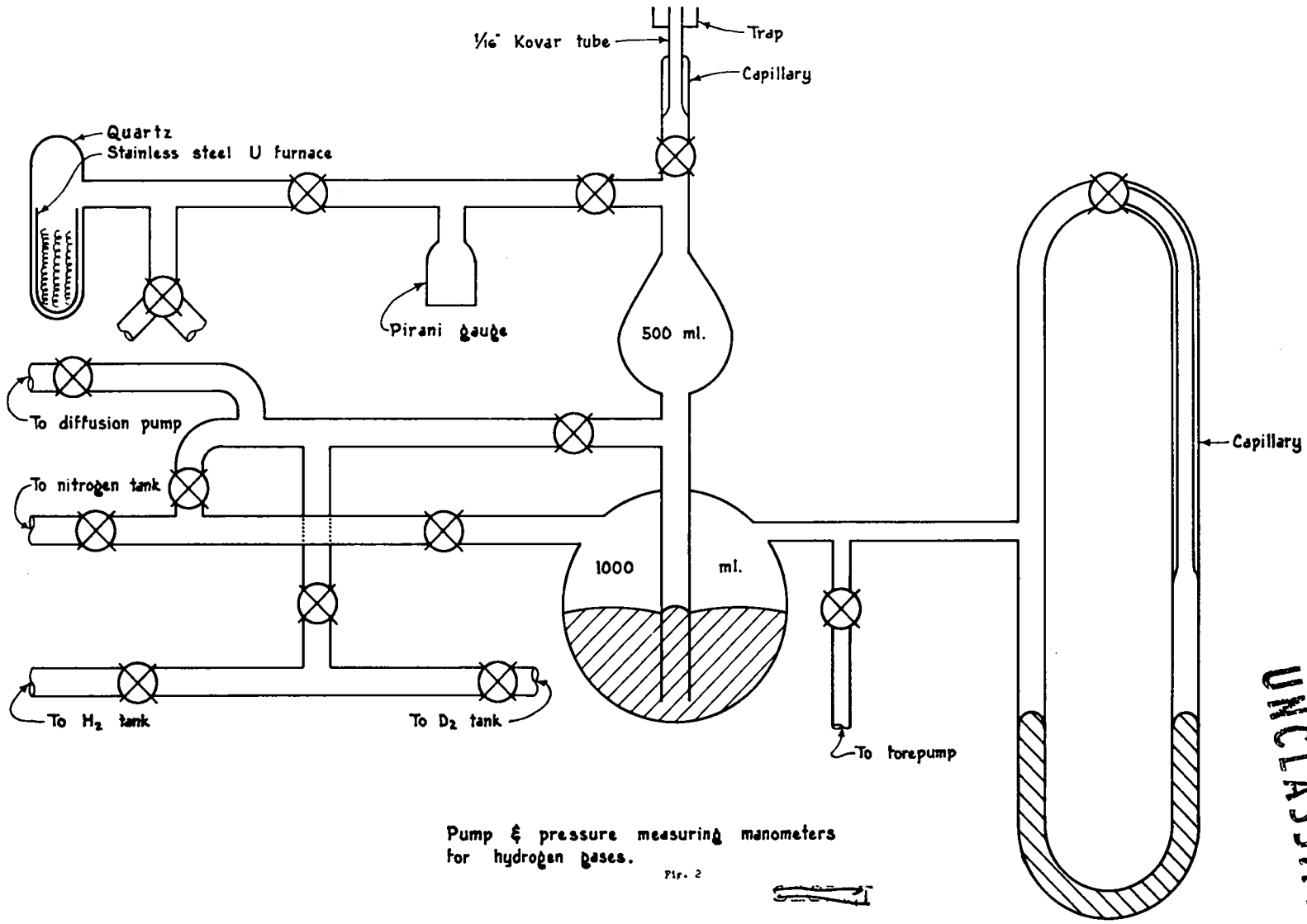supplies of hydrogen and deuterium gas as shown in the figure.

To guard against the possibility of breaking one of the thin
aluminum foils sealing the precious target gas from the accelerating tube
vacuum and thus losing it, the high gas impedance tube and trip valve shown
in Fig. 3 were used to connect target to accelerating tube. This device was
to work by having the increase in gas pressure of a broken foil fire either an
ion gauge or spark plug as shown, which in turn would trip the valve at the
other end of the tube before an appreciable amount of the gas escaped through
the high impedance gas flow tube. The gas was then to be recovered by the
uranium pump. Up to the present time this device has not had the necessity
of firing under the conditions for which it was designed.

Reaction Cross Section

Since it was known that the tritium samples contained varying
amounts of ordinary hydrogen and since at this time, early in 1947, no
sound method for analysis existed, the method of proton-proton scatter-
ing described in LA-625[4] was devised and has been successfully used
since this time. The tritium concentration must be known to fix the
absolute cross section for the reaction.

The reaction product observed at a given deuteron energy was

½₆" Kovar tube — Trap

Capillary

Quartz
Stainless steel U furnace

Pirani gauge

500 ml.

To diffusion pump

To nitrogen tank

To H₂ tank   To D₂ tank

1000   ml.

To forepump

Capillary

Pump & pressure measuring manometers
for hydrogen gases.
Fig. 2

Rubber stopper

Sylphon

3/8" or 3/16" tubes 2" long.

Ion guage

Rack & pinion for resetting.

Trigger cam.

2" I.D. 40" long.

Spark plug.

Trigger latch.

Rotary relay.

Neon sign trans.

Trap

Al. foils

To U pump

Relay for D.C.

Revised ion guage circuit

Protective system
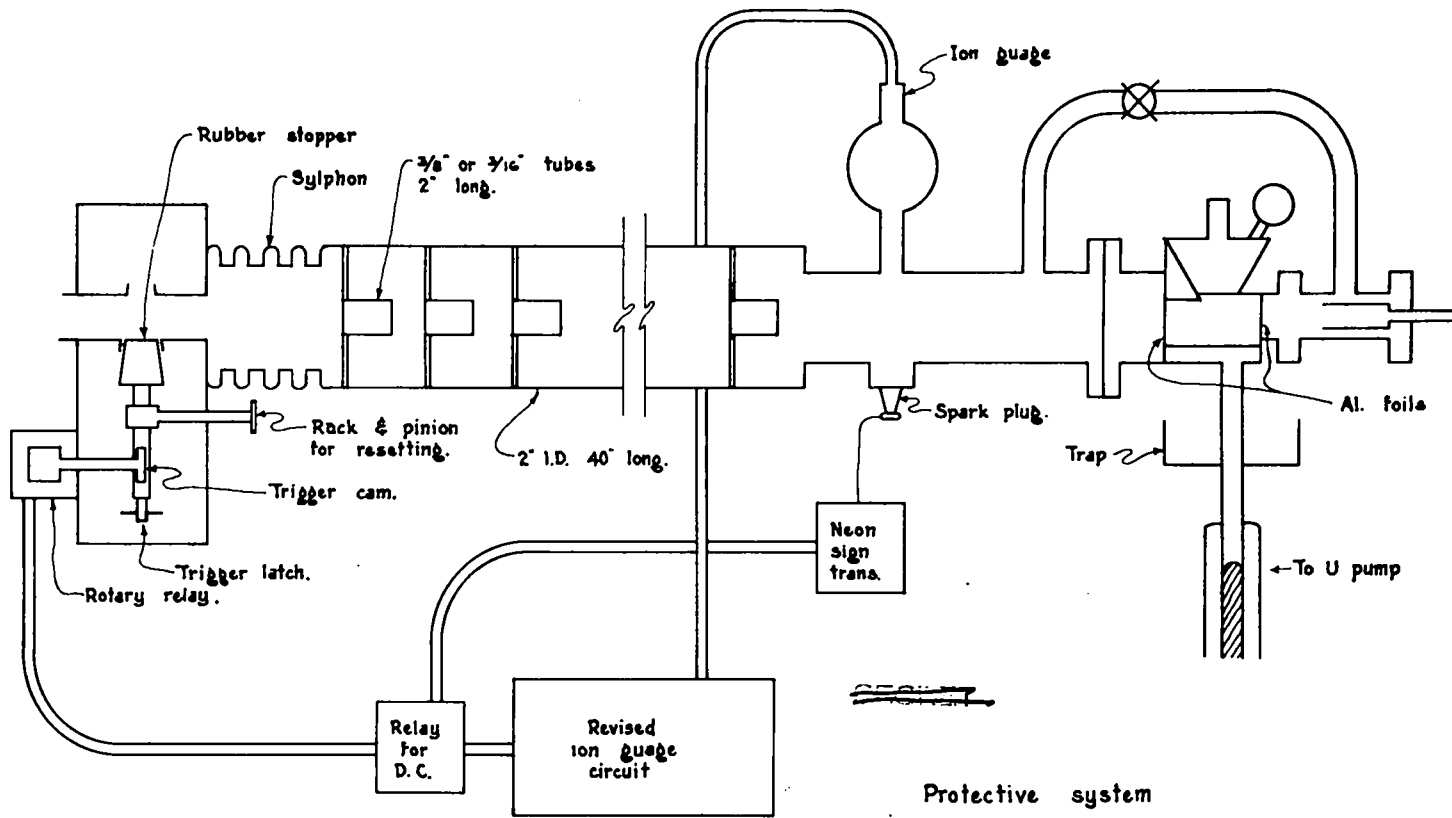
Fig. 3

the alpha-particle emitted at the angle determined by the proportional
counter setting, which lay between 45° and 135° in the laboratory co-
ordinate system.   In Fig. 4 is shown alpha-particle energy as a function
of detector angle, together with the energies of particles which can be
scattered or recoil into the counter at the same angle, because the rela-
tive energy losses of these particles in the counter compared to that for
the alpha-particle determines counter voltage, gas and amplifier gain,
counter window thickness and target gas pressure for optimum observation
of the alphas.   These curves are of course different for each deuteron energy,
but only the one for $E_d = 2.0$ Mev is shown, since in general they are similar.

Since transformations to the center of mass coordinate system are
of interest for total yield determinations and for understanding of the
reaction itself, the solid angle factor for transformation [5] from lab-
oratory to center of mass system is calculated from

$$\left[\frac{\sigma_{CM}(\phi)}{\sigma_{LAB}(\theta)}\right]_\alpha = \frac{d\Omega_{LAB}}{d\Omega_{CM}} = \cos(\phi + \theta_\alpha)\frac{\sin^2\theta_\alpha}{\sin^2\phi}$$

where

$\sigma(\theta_\alpha)$ = cross section in cm^2 per unit solid angle.

$\dfrac{d\Omega_{LAB}}{d\Omega_{CM}}$ = ratio of laboratory to center of mass solid angles
    for alpha particles.

$$\pi - \phi = \theta_\alpha + \sin^{-1}\frac{\sin\theta_\alpha}{0.612\sqrt{\dfrac{E_d + 28.9}{E}}}$$
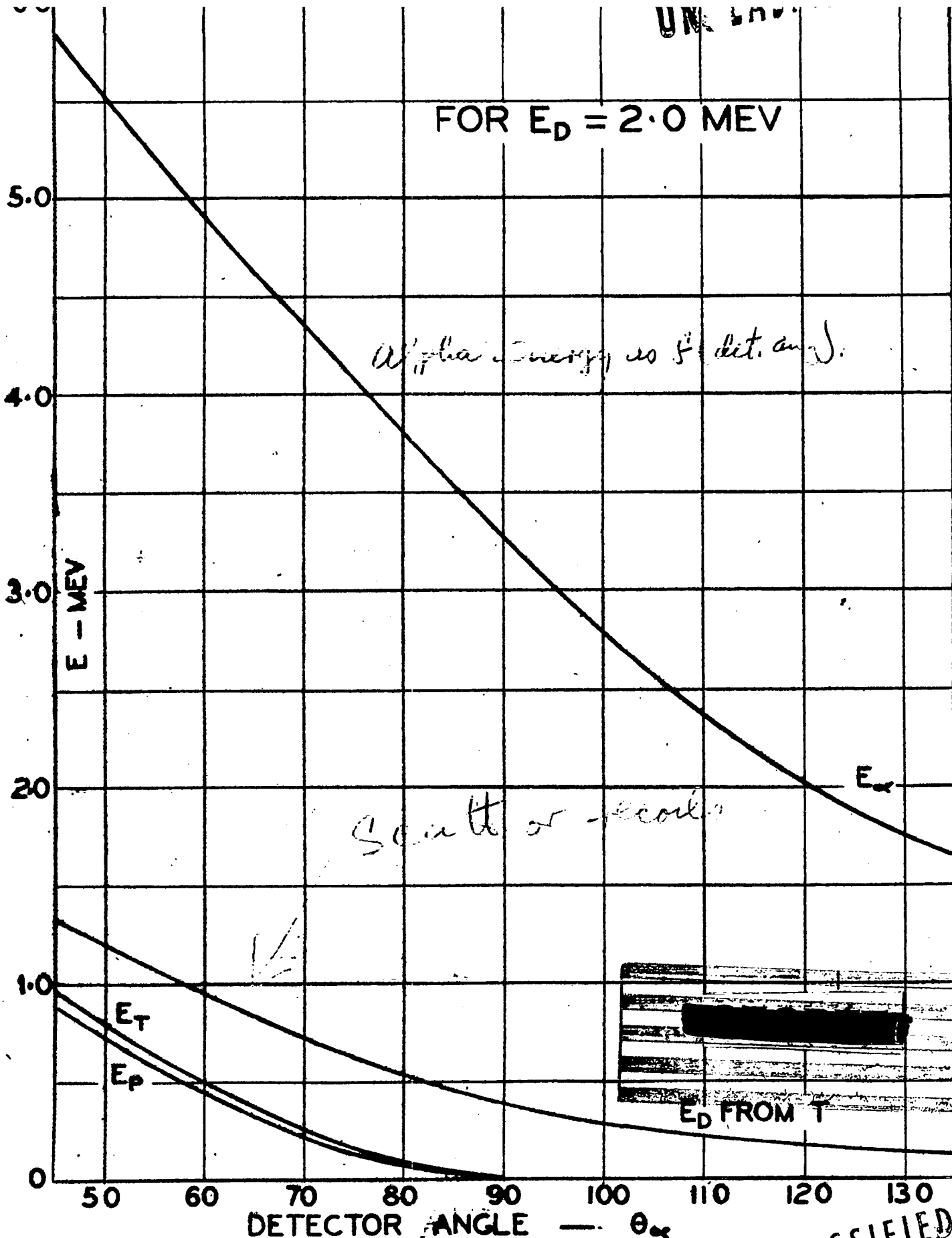, ϕ being the center of mass angle.

FOR $E_D = 2 \cdot 0$ MEV

Fig. 4

In Fig. 5 is shown a typical pulse height distribution curve showing the alpha-particle group resolution in two runs. This varies with deuteron energy and angle, of course.

The data shown in Fig. 6 gives the laboratory system differential cross sections as a function of angle over the range so far studied. The values of $\sigma(\theta_\alpha)$ are obtained from

$$\sigma_\alpha\left(\theta_\alpha, E_d\right) = \frac{N_\alpha \sin\theta_\alpha}{g N_d N_T}$$

where

θ_α = laboratory coordinate system angle of observation at the deuteron energy E_d;

N_α = number of alphas during a run or per microcoulomb of deuterons;

N_d = number of deuterons during a run or per microcoulomb of charge;

N_T = number of tritons per cm^3 of target gas;

$g = \dfrac{\pi a^2 \cdot 2b}{R_o h}$ is the counter geometry factor[6], where

πa^2 = area of counter hole, radius a;

$2b$ = width of defining slit;

R_o = distance from hole to intersection of normal to hole with axis of deuteron beam;

h = distance from hole to slit.

In Fig. 7 are shown the center of mass coordinate system differential cross sections plotted at the appropriate angles in the same system. Although the data is still somewhat scanty, the angular distribution is definitely not symmetric about 90 degrees in the center

Fig. 5

T(D,N)HE^4

DIFFERENTIAL CROSS SECTION FOR α'S IN LABORATORY COORDINATES

$E_D = 1\cdot0$ MEV
$E_D = 1\cdot5$ MEV
$E_D = 2\cdot0$ MEV
$E_D = 2\cdot5$ MEV

θ_α

FIG 6

$T(D_A N)\alpha$

DIFFERENTIAL CROSS SECTION FOR α'S
IN CENTER OF GRAVITY COORDINATES

—+— $E_D = 1.0$ MEV
—•— $E_D = 1.5$ MEV
—□— $E_D = 2.0$ MEV
—×— $E_D = 2.5$ MEV

CROSS SECTION—BARNS PER Ω

CENTER OF GRAVITY ANGLE—DEGREES
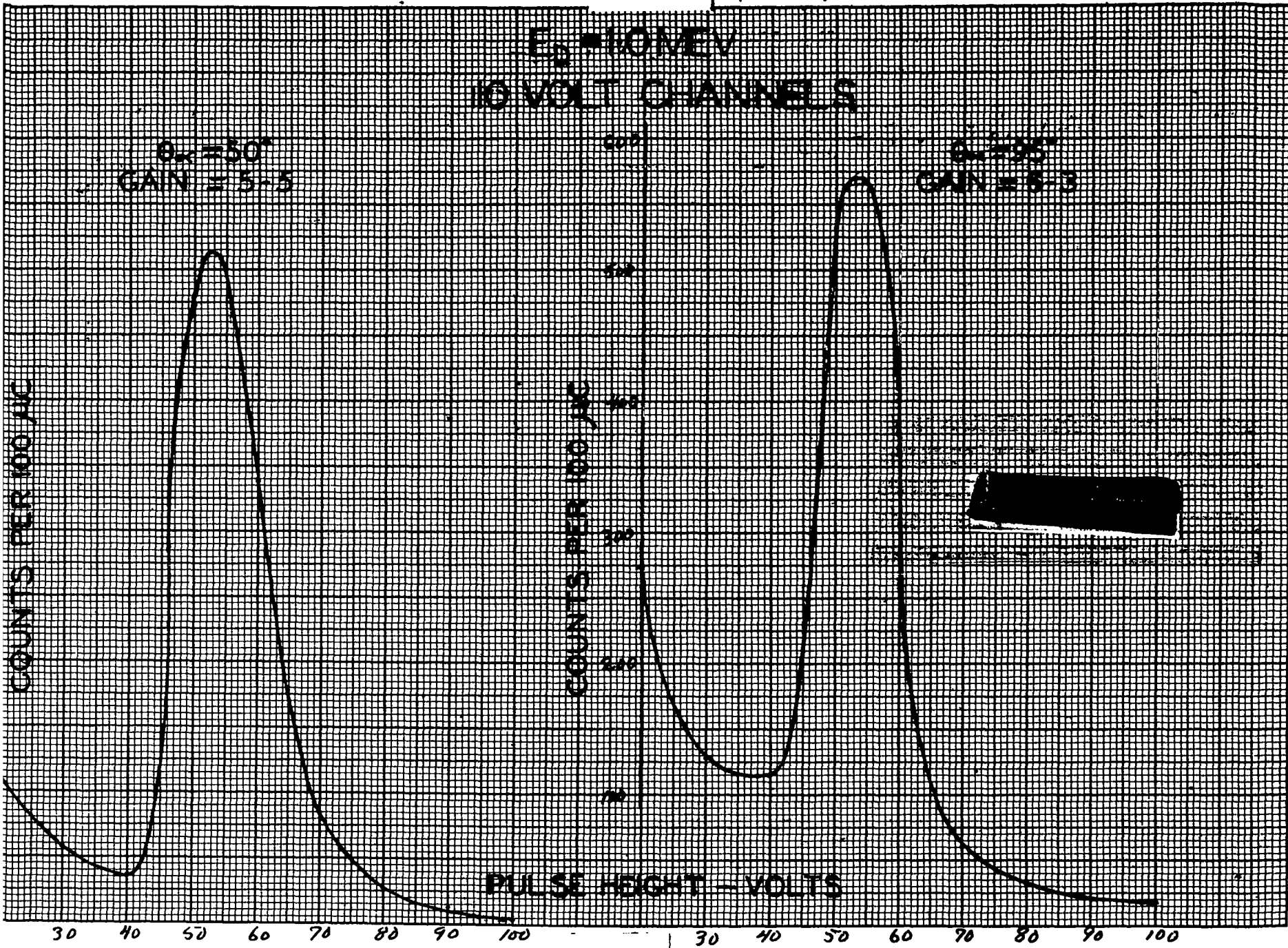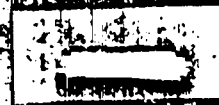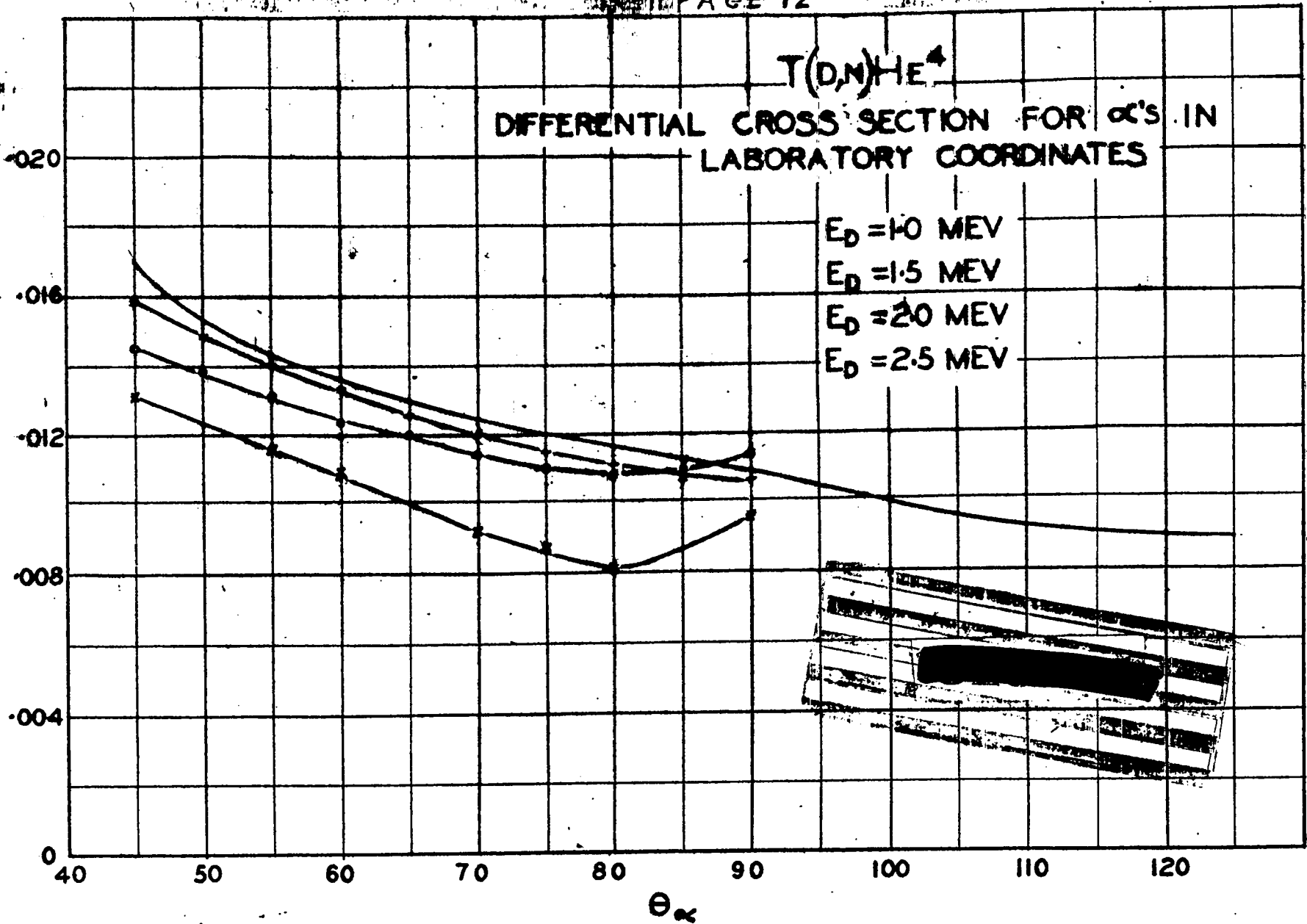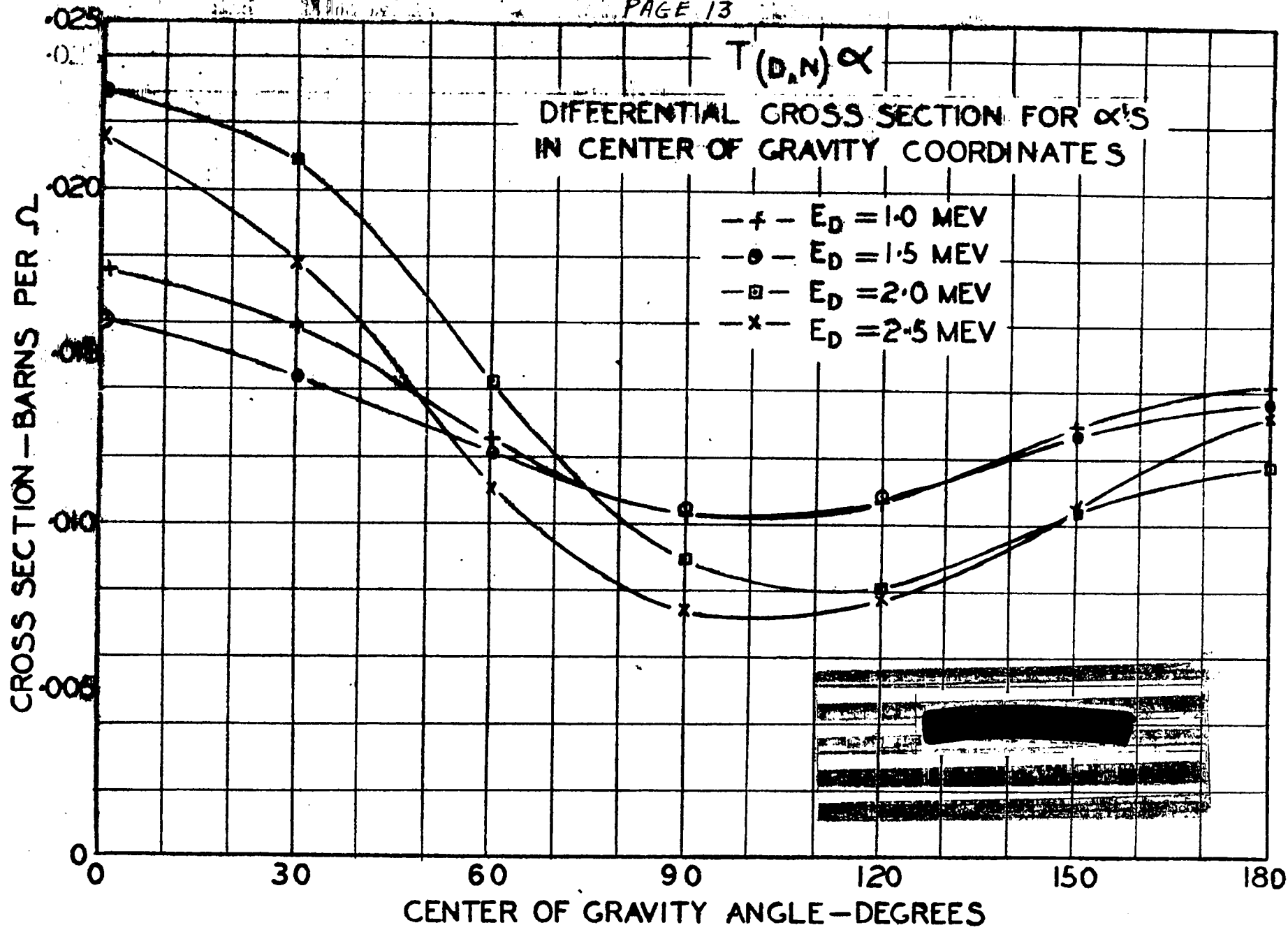
Fig. 7

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of mass system. If a fit is made to a power series in $\cos \phi$ one finds a reasonably adequate representation of the data given by

$$\sigma(\phi) = A(E) + B(E) \cos \phi + C(E) \cos^2 \phi$$

indicating an interaction between S and P wave. Until more data is obtained one can approximately fix the total reaction cross section by integration of the theoretical curve for $\sigma(\phi)$, i.e.

$$\sigma_{E_d}(\text{total}) = 2\pi \int_0^\pi \sin \phi \; \sigma(\phi) \; d\phi = 2\pi \left[2\,A(E_d) + 2/3\; C(E_d) \right]$$

which gives the following values at 1 Mev:

$$\sigma_{1.0}(\phi) = 0.0103 + 0.0017 \cos \phi + 0.0056 \cos^2 \phi$$

$$\sigma_T (1.0 \text{ Mev}) = 0.15 \pm 0.02 \text{ barns};$$

at 1.5 Mev:

$$\sigma_{1.5}(\phi) = 0.0104 + 0.0012 \cos \phi + 0.0045 \cos^2 \phi$$

$$\sigma_T (1.5) = 0.15 \pm 0.02 \text{ barns};$$

at 2.0 Mev:

$$\sigma_{2.0}(\phi) = 0.0089 + 0.0061 \cos \phi + 0.0090 \cos^2 \phi$$

$$\sigma_T(2.0) = 0.15 \pm 0.02 \text{ barns};$$

at 2.5 Mev:

$$\sigma_{2.5}(\phi) = 0.0074 + 0.0042 \cos \phi + 0.01 \cos^2 \phi$$

$$\sigma_T(2.5) = 0.135 \pm 0.03 \text{ barns.}$$

The measurements at 2.5 Mev are the least satisfactory and the total cross section derived from them is undoubtedly inaccurate. The total

S E C R E T

cross sections are plotted at the corresponding triton energies in Fig. 8, together with the results of Bretscher and French [1] and of Baker, Holloway, Schreiber and King [2]. The theoretical curves plotted, are Breit-Wigner fits to either one or both sets of data, and indicate the importance of knowing the width of the resonance. The target shown has had considerable use as a thick target with deuterons incident on the gas at about 600 kev and being completely stopped in the gas; if one assumes that the broad resonance of the earlier two sets of measurements combined is correct the integrated neutron yield from the thick target per microcoulomb of deuterons is in fair agreement with the calculated, whereas the narrow resonance assumed by Bretscher gives a value of yield less than half that observed. The measurements are being continued into the low energy region, but at values below about 600 kev the straggling and window thickness begin to make such measurements poor.
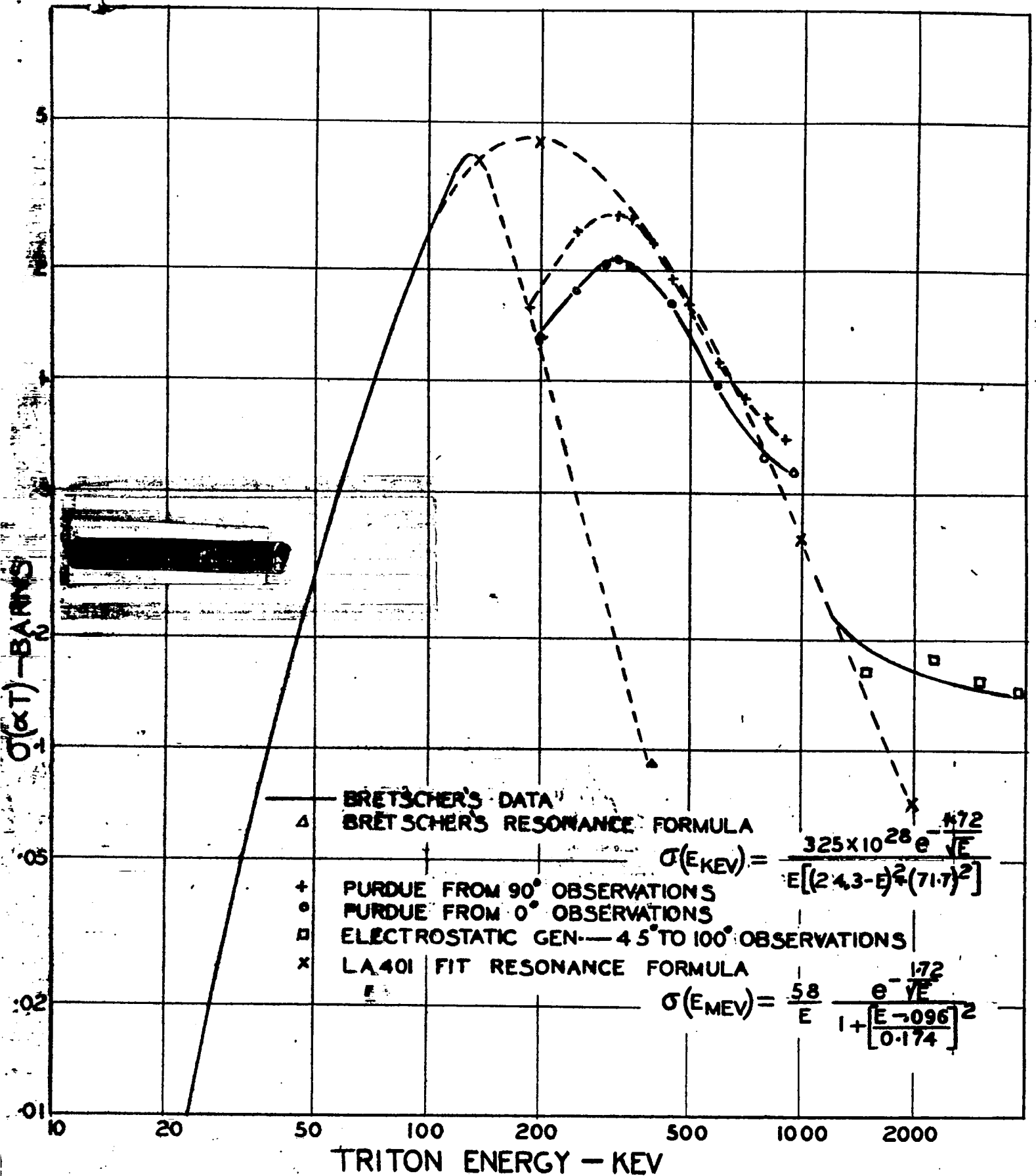
Since the cross sections at energies above 1.0 Mev deuteron energy are still reasonably large, in fact considerably better than the corresponding $D^2(d,n)He^3$ cross sections, thin targets of tritium gas make a satisfactory neutron source of energies variable between about 13 Mev and 18.5 Mev on the Los Alamos electrostatic generator. Absolute flux measurements are immediately possible with the present target from the relation

$$\sigma_{dT}(\theta_n) = \sigma_{dT}(\theta_\alpha) \frac{d\Omega_\alpha}{d\Omega_n} = k_{\alpha n} \sigma_{dT}(\theta_\alpha)$$

and the relationship between neutron and alpha angle

$$\sin\theta_n = \sqrt{\frac{E_\alpha}{E_n}} \sqrt{\frac{M_\alpha}{M_n}} \sin\theta_\alpha$$

S E C R E T

BRETSCHER'S DATA
△ BRETSCHER'S RESONANCE FORMULA

$$\sigma(E_{KEV}) = \frac{325\times10^{28}\,e^{-\frac{1.72}{\sqrt{E}}}}{E\left[(243-E)^2(71.7)^2\right]}$$

+ PURDUE FROM 90° OBSERVATIONS
⊙ PURDUE FROM 0° OBSERVATIONS
□ ELECTROSTATIC GEN.—45° TO 100° OBSERVATIONS
× L.A.401 FIT RESONANCE FORMULA

$$\sigma(E_{MEV}) = \frac{58}{E}\ \frac{e^{-\frac{1.72}{\sqrt{E}}}}{1+\left[\frac{E-0.96}{0.174}\right]^2}$$

$\sigma(\alpha T)$ —BARNS

TRITON ENERGY — KEV

where $\qquad E_\alpha = (17.6 + E_d) - E_n(\theta_n)$

and where

$$\frac{d\Omega_\alpha}{d\Omega_n} = k_{\alpha n} = \frac{\cos(\phi+\theta_\alpha)}{\cos(\phi-\theta_n)}\frac{\sin^2\theta_\alpha}{\sin^2\theta_n}$$

Fig. 9 shows the realtionship between E_n and θ_n as a function of deuteron energy; Fig. 10 gives k_{an} as a function of θ_α for different E_d and also shows θ_n as a function of θ_α for various values of E_d. The neutron energies have been calculated from

$$E_n = \frac{4}{25} E_d(2.50 + \cos^2\theta_n) + 14.02 + \sqrt{\frac{E_d}{5}}\left\{112.1 + \frac{16}{25} E_d(5 + \cos^2\theta_n)\right\}^{1/2}\cos\theta_n,$$

assuming a $Q = +17.6$ Mev. In this case it is preferable to use the equation above than the nomographs of McKibben[5] since the large Q makes it impossible to read neutron energies with any accuracy from the usual type of chart.

One feels reasonably well assured that the neutrons are mono-ergic in this reaction, at least to energies well above 3 Mev deuteron energy, since there are no indications in other work of excited states of He^4 at such low energies. The alpha-particle group observed in this work appears sharp, but the presence of pulses from scattered deuterons, protons and tritons does not allow examination of the whole energy spectrum of the alphas in this experimental arrangement.

It is not feasible with the present alpha-particle counting geometry to observe at laboratory angles below 45 degrees or above 135 degrees, but neutron detectors can now be calibrated on an absolute scale
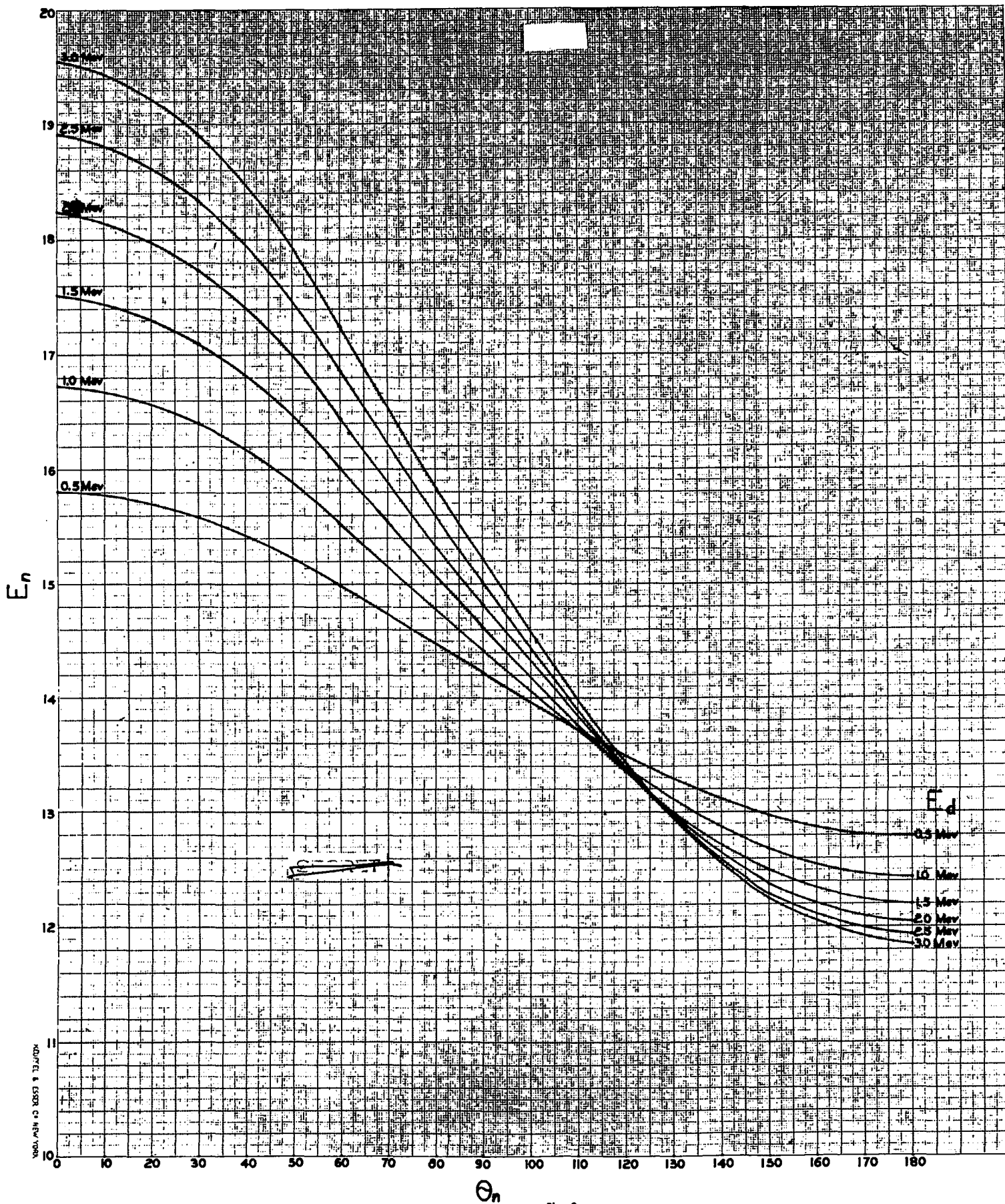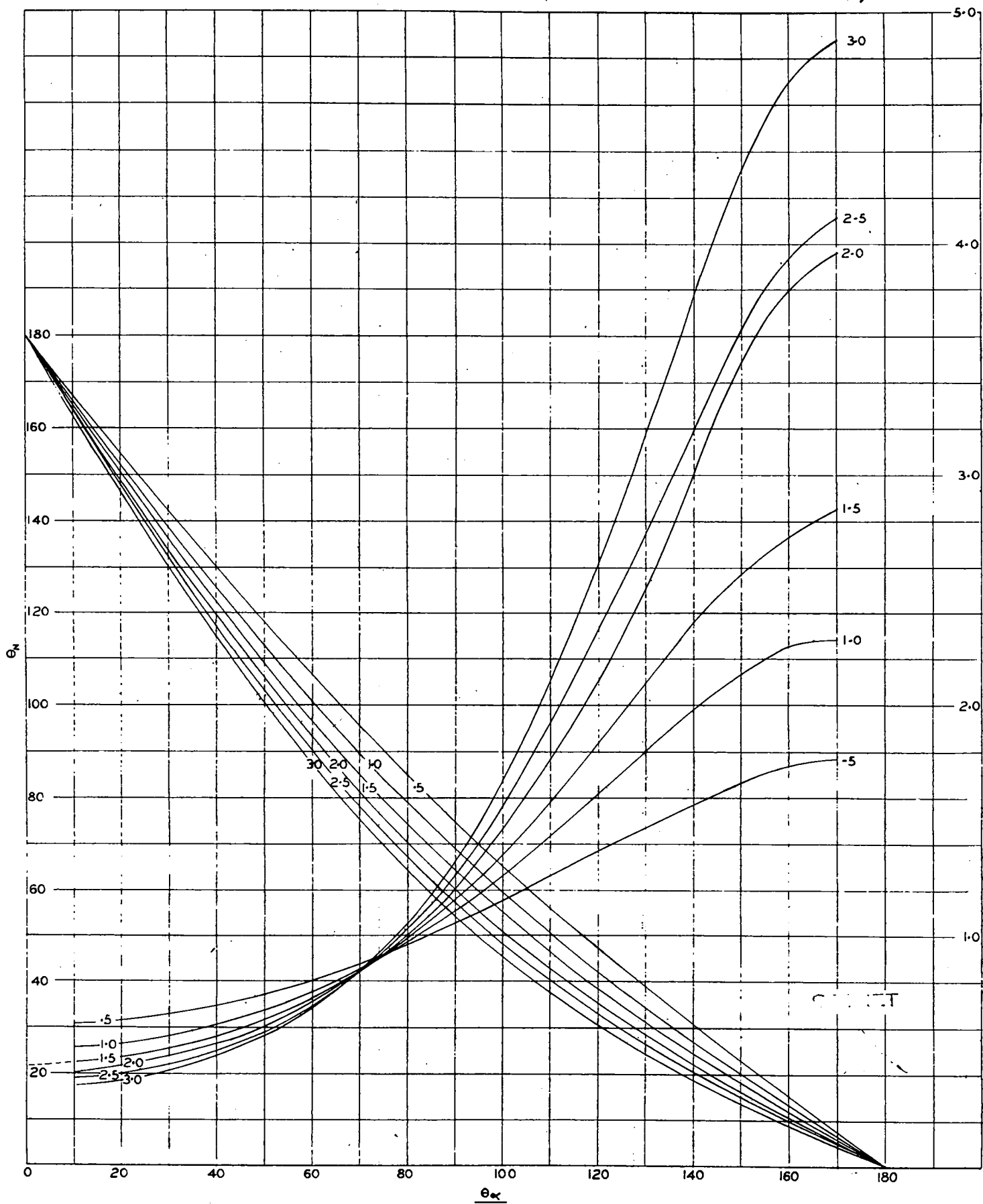
Fig. 9

Fig. 10

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within the above angular range to allow extension of the measurements to

cover nearly all of 145 degrees which should be sufficient to fix the

total cross section with good accuracy.

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References

(1) Bretscher and French, LA-582, LA-581.

(2) Baker, Holloway, Schreiber and King, LAMS-11.

(3) Taschek, Report in preparation.

(4) Taschek, LA-625.

(5) McKibben, Report in preparation.

(6) Breit, Thaxton and Eisenbud, Phys. Rev. $\underline{55}$, 1018 (1939).

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