Polarization of Neutrons from the D(d,n)He^3 Reaction * †

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Measurements of the polarization of the DD reaction neutrons for deuteron energies less than 600 Kev are in fair agreement with the theoretical predictions of Fierz[1] and Blin-Stoyle[2]. Several theoretical calculations of the maximum polarization by Blin-Stoyle[3] and Cini[4] are also in good agreement with the experimental data of Pasma[5] and Meier, Sherer, and Trumpy[6].

A recent measurement by Kane[7] at an average deuteron energy of 93 Kev gave a neutron polarization which was considerably higher than would be expected from an extrapolation of the theory to this energy. Our measurements in this energy region, which strongly support those made by Kane, also indicated polarizations which are higher than expected. In fact, at an average deuteron energy of 99 Kev, the polarization was 11.1% where the expected value was only about 5%.

The polarization of the neutrons was determined by observing the right-left asymmetry in scattering from carbon.

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FIRST SLIDE

The first slide shows the direction of positive polarization, which is in accordance with the Basel convention, for a negative angle of emission, i.e., $\vec{k}_d \times \vec{k}_n$. The positive direction of the "induced" carbon polarization, similarly, is $\vec{k}_n \times \vec{k}_n'$.

The right-left scattering asymmetry is defined to be

$$\mathcal{A} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} ,$$

Where σ_R and σ_L are the differential scattering cross sections for right and left scattering events respectively.

If we define the right-left counting ratio to be r, then

$$r = \frac{\sigma_R}{\sigma_L} \quad \text{and} \quad \mathcal{A} = \frac{r^- - 1}{r^- + 1} .$$

r^- indicates that the ratio was arbitrarily computed for the angle $-\Theta_1$. The reversal of $\vec{P}_n$ in going from $-\Theta_1$ to $+\Theta_1$ was used to eliminate both the geometrical and electronic asymmetries. Measurements of the right-left counting ratio at both $+\Theta_1$ and $-\Theta_1$ give two equations from which the instrumental asymmetry can be eliminated, i.e.,

$$r^- = \sqrt{\frac{L_e^+ \, R_e^-}{R_e^+ \, L_e^-}} ,$$

Where the quantities $L_e^{\pm}$ and $R_e^{\pm}$ are the experimentally observed counting rates of the scattered neutrons. Since the differential cross section for the scattering of an incident beam of polarized neutrons can be written as

$$\sigma = \sigma_u \left(1 + P_n P_s \vec{n}_1 \cdot \vec{n}_2\right) ,$$

it follows that,

$$\mathcal{A} = P_n P_s .$$

SLIDE TWO

In this particular experiment the induced polarization of carbon was calculated from the phase shifts of Meier, Sherer, and Trumpy at an average neutron energy of 2.7 Mev. If the carbon polarization is known at a particular scattering angle, the neutron polarization can be calculated from the measured asymmetry. Our observations were made at a scattering angle of 45° in the center of mass system. At this angle the induced polarization of carbon is approximately 89%. It should be noted here that in order to lower the calculated neutron polarizations, it would be necessary to raise the carbon polarization. Obviously, this cannot exceed 100%.

The geometric and electronic asymmetries in the measurement were removed by rotating the collimator about the target. Corrections for the finite size of the scatterer and detector were computed by the Plaskett method. The maximum correction applied was 12%. A check for any residual asymmetry which might not have been eliminated by rotation, was made by measuring the asymmetry at a scattering angle for which $P_c = 0$. The carbon polarization curve indicates that this should occur at 87 degrees in the center of mass system. The asymmetry at this angle was found to be -0.00775 ± 0.015. Although this is a negligible residual asymmetry, the negative sign at this angle would require a correction that would raise the calculated neutron polarization.

SLIDE THREE

The source of neutrons was a heavy ice target. D_2O vapor from an expansion chamber was deposited on the walls of a target Dewar of liquid air. Since the target was infinitely thick, the average deuteron energy was not the machine energy. As can be seen, the beam was also unanalyzed. The lack of magnetic beam analysis introduces an uncertainty in the average deuteron energy because of the unknown molecular content. The neutron distribution from an infinitely thick target as a function of deuteron energy and as a function of neutron energy can be seen in the next slide. The acceleration potential is 170 Kev for the case shown.

SLIDE FOUR

The distribution of neutrons from the molecular contaminant is similar to that of the pure atomic beam. The median deuteron energy has been calculated for a pure deuteron beam and a pure molecular beam --- that is, one in which only singly ionized molecules are considered. These two median energies represent the maximum error limits on the average deuteron energy. The energy reported here is the unweighted average of these two median energies. It is likely that the true average energy is somewhat higher. However, in view of the uncertainty in the amount of molecular contaminant, the average of the two extreme cases is presented. This average deuteron energy gives an average neutron energy of 2.73 Mev ± 0.05 Mev.

The carbon polarization curve as a function of energy can be seen in the next slide.

SLIDE FIVE

The experimental points are those of Bucher[8] et. al., and seem to substantiate the phase shifts of Meier, Sherer, and Trumpy. It should be noted that the neutron energy 2.73 Mev is in the flat portion of the theoretical curve due to Meier. If the phase shifts of Wills[9] had been used, the polarization of the neutrons would have been further increased.

SLIDE SIX

The results are shown here with some previously reported values of Pasma and Kane. The maximum value is 11.1% at 99 Kev. (7.8% at 81.5 Kev and 6.0% at 67.5 Kev). The solid curve was calculated from the theoretical expressions given by Blin-Stoyle. It includes S and P wave contributions and is of the form,

$$P_n = C \frac{A(E) \sin\theta \cos\theta}{1 + A(E)\cos^2\theta}$$

C has been chosen so that P_n will pass through the 400 Kev point of Pasma. The angular distribution coefficient A(E) was taken from the data of Fuller, Dance, and Ralph[10]. It is possible that variations in the energy dependent coefficients A(E) could account for the observed values. However, it appears more likely that C is a function of energy.

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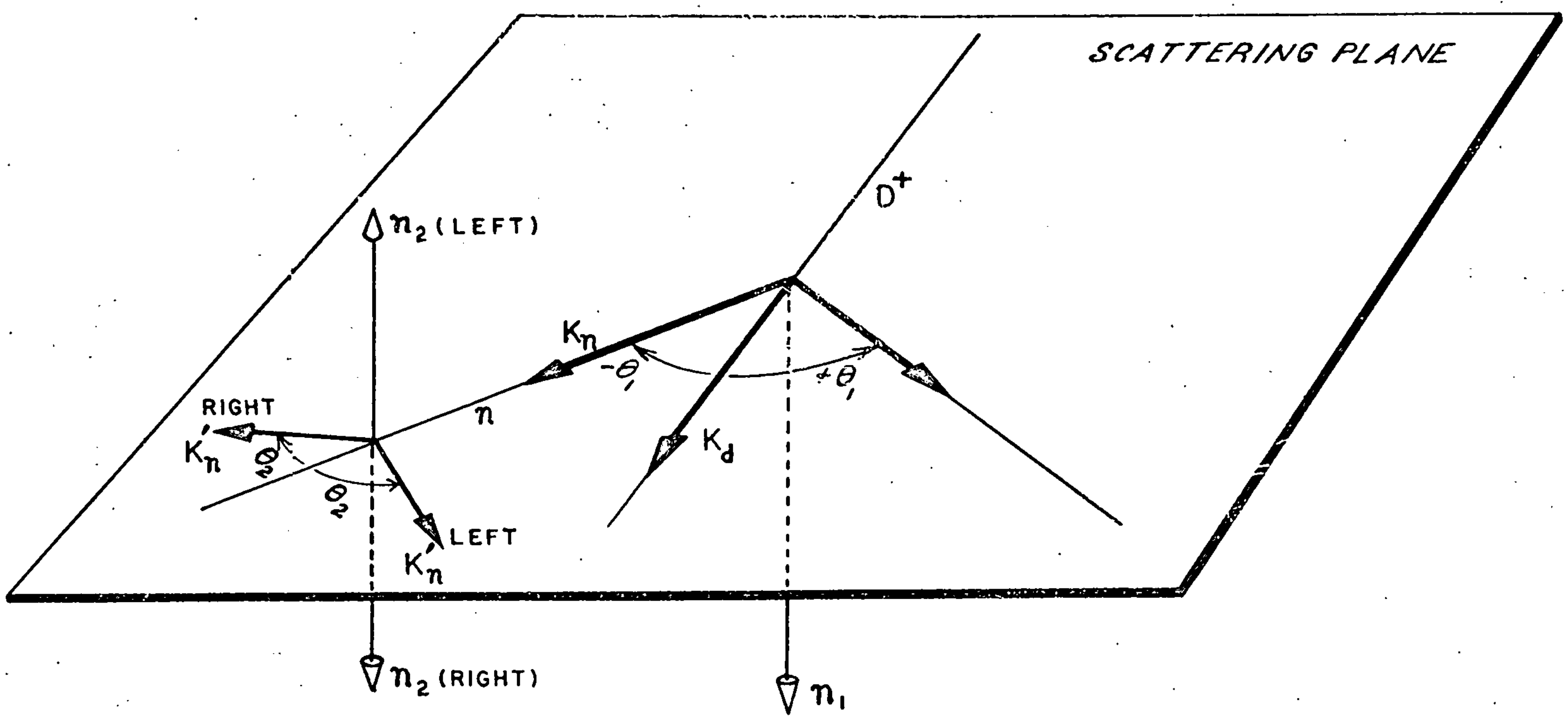
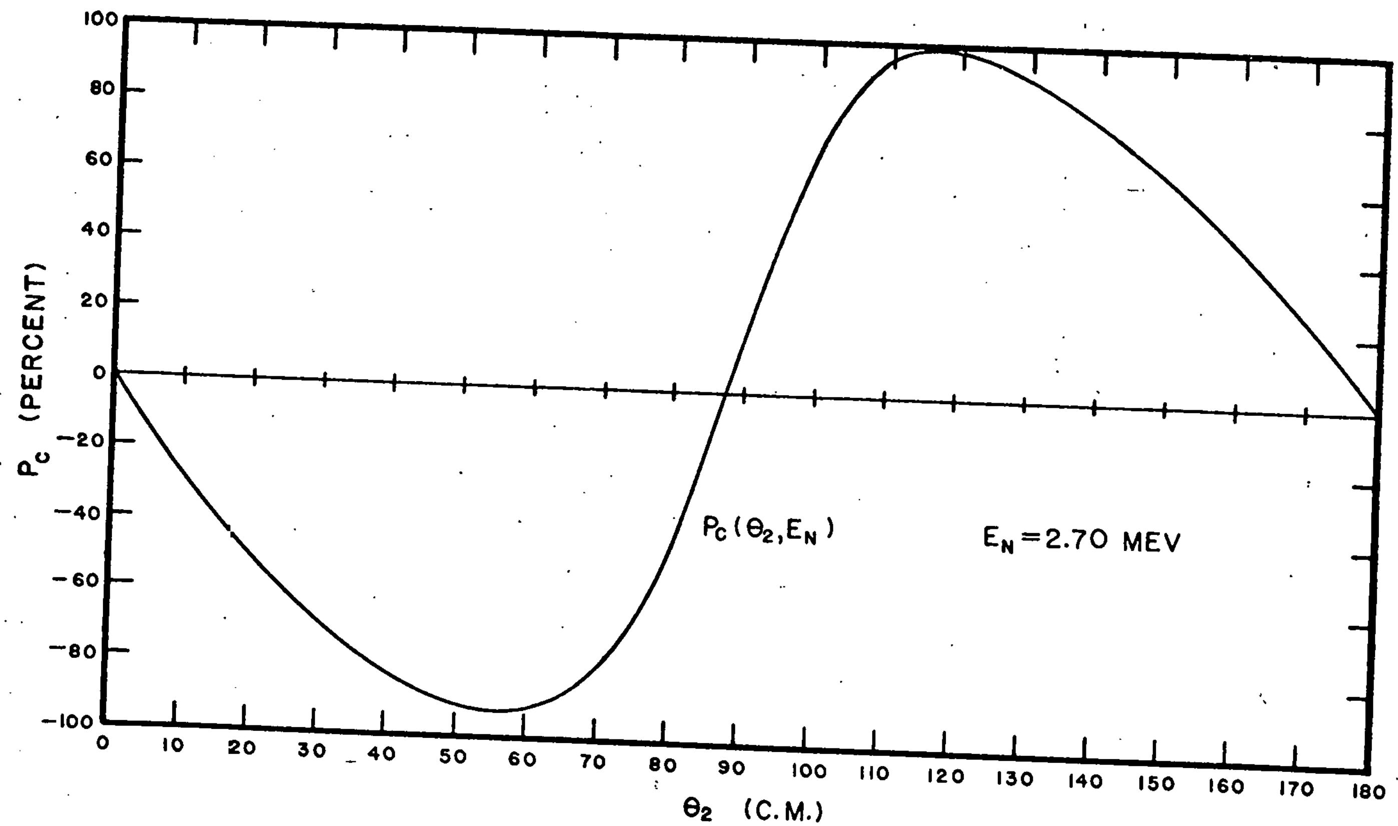
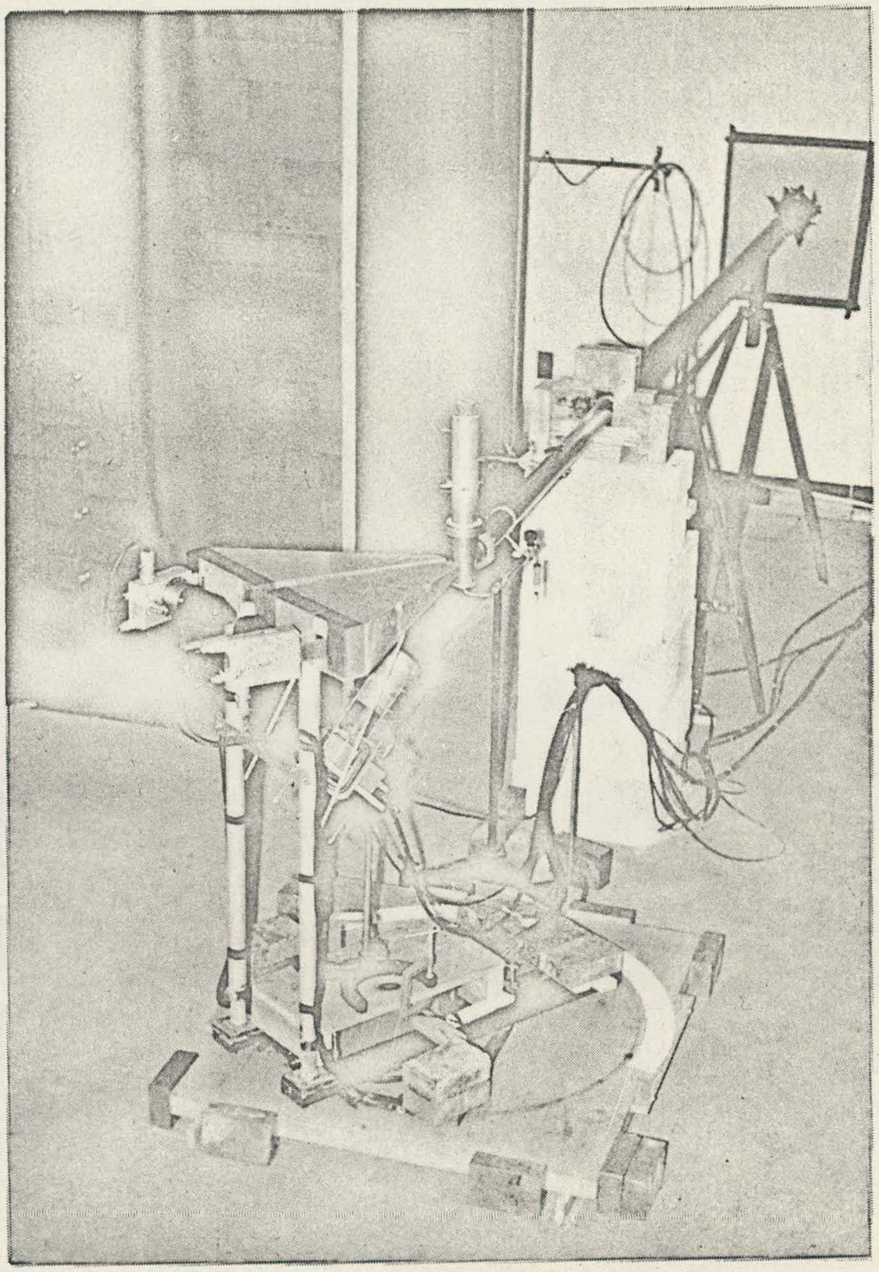

SCATTERING PLANE
D+
n2 (LEFT)
Kn
-θ1
+θ1
RIGHT
K'n
θ2
n
Kd
θ2
LEFT
K'n
n2 (RIGHT)
n1

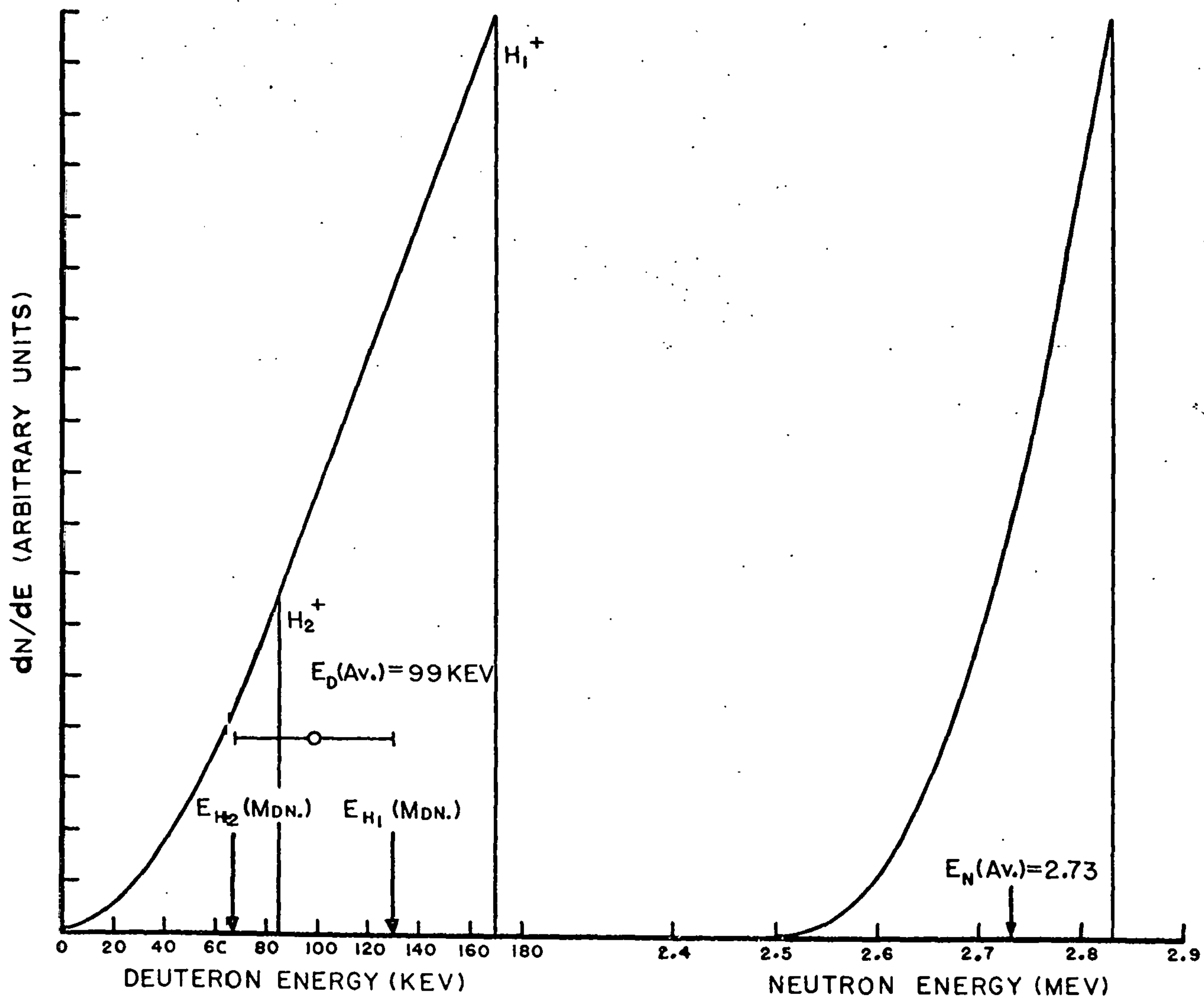
FIRST SLIDE


100
80
60
40
20
0
-20
-40
-60
-80
-100
P_c (PERCENT)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Θ_2 (C.M.)
$P_C(\Theta_2, E_N)$
$E_N = 2.70$ MEV

SLIDE TWO



SLIDE THREE


dN/dE (ARBITRARY UNITS)
H1+
H2+
ED(Av.)=99 KEV
EH2 (MDN.)
EH1 (MDN.)
EN(Av.)=2.73
0 20 40 6C 80 100 120 140 160 180
2.4 2.5 2.6 2.7 2.8 2.9
DEUTERON ENERGY (KEV)
NEUTRON ENERGY (MEV)

SLIDE FOUR

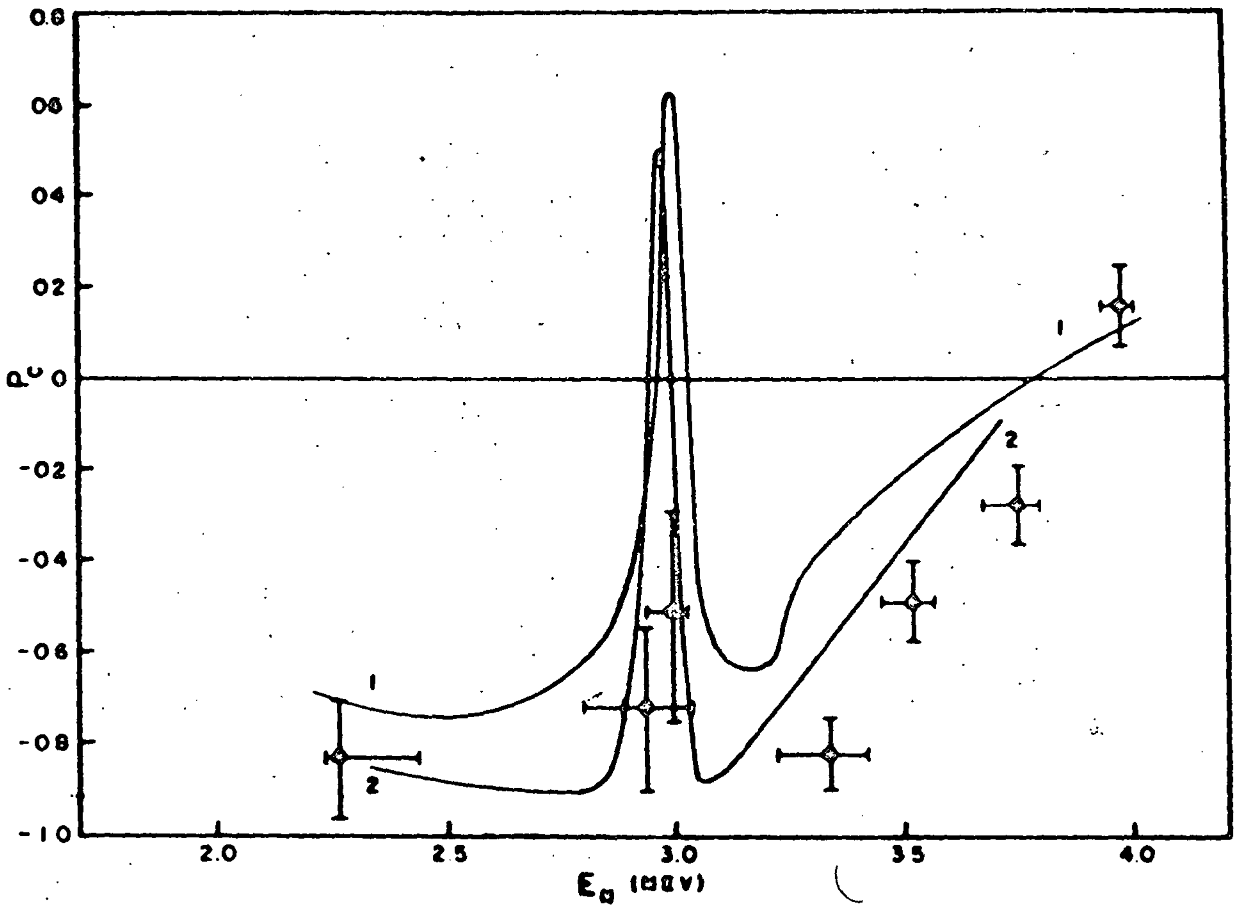
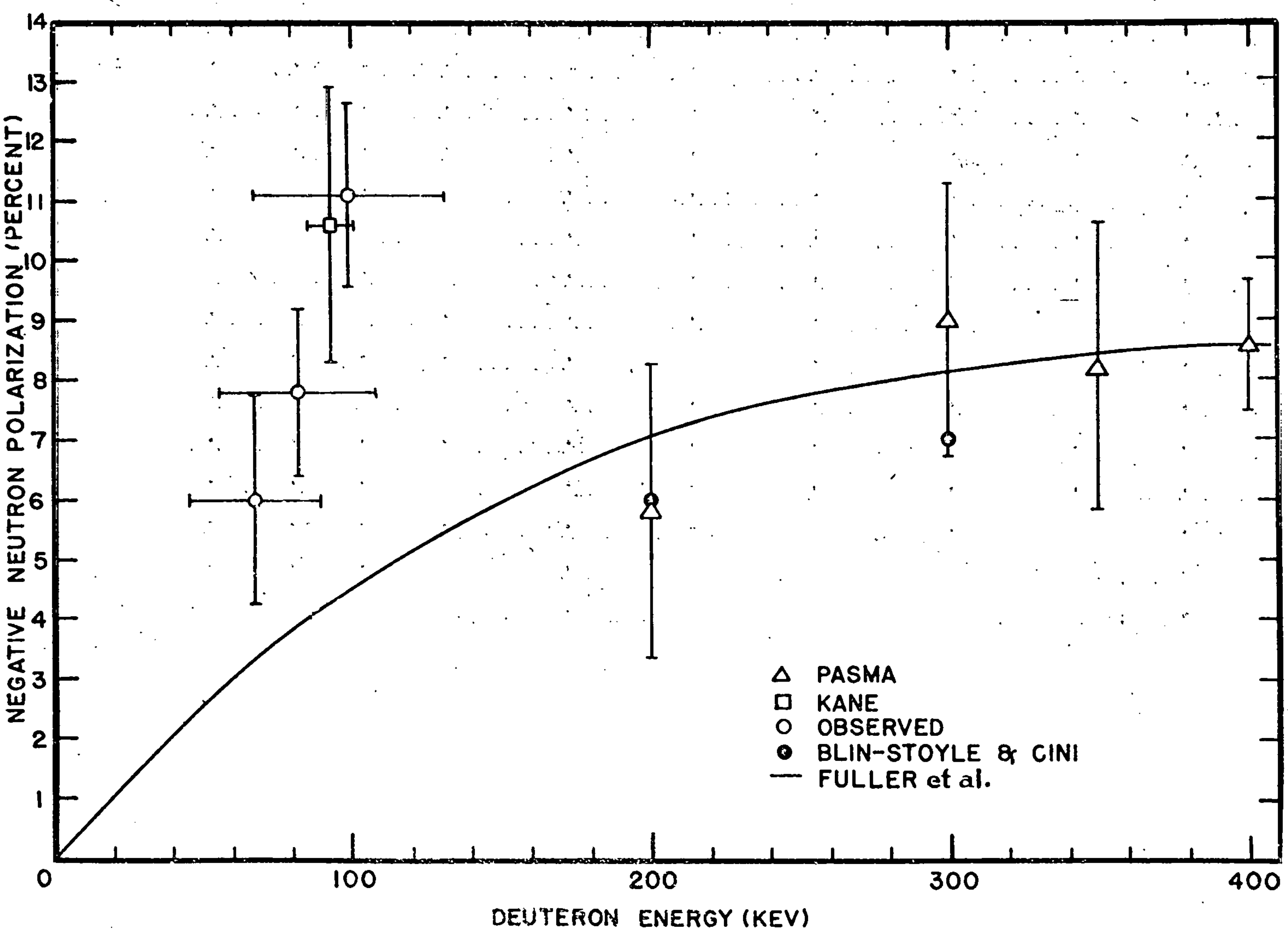


Figure 8

The polarization of neutrons scattered at 45° from carbon. Curve 1 was computed from the phase shifts of WILLS *et al.* [8]; curve 2 from those of MEIER *et al.* [6].

SLIDE FIVE



NEGATIVE NEUTRON POLARIZATION (PERCENT)
DEUTERON ENERGY (KEV)
0
100
200
300
400
1
2
3
4
5
6
7
8
9
10
11
12
13
14
PASMA
KANE
OBSERVED
BLIN-STOYLE & CINI
FULLER et al.

SLIDE SIX