ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Progress Report

THE UNIVERSITY OF MICHIGAN CYCLOTRON

W. C. Parkinson
Associate Professor of Physics

P. V. C. Hough
Assistant Professor of Physics

Project 2170

U. S. ATOMIC ENERGY COMMISSION
CHICAGO OPERATIONS OFFICE
CONTRACT NO. AT(11-1)-275
LEMONT, ILLINOIS

July 1956

ABSTRACT

This report describes the experimental and theoretical research effort of the Michigan 42-inch cyclotron group over the period from August, 1955, to July, 1956. Four experimental problems received major attention: the development of a nuclear emulsion scanner, the determination of spin polarization in the (d,p) reaction, a high-resolution study of the P^{32} ground-state doublet, and the measurement of angular distributions in the $O^{17}(d,p)O^{18}$ reaction. The explicit numerical evaluation of an extended Butler theory of the stripping reactions is about 25% complete.

PERSONNEL

Faculty

K. M. Case
P. V. C. Hough
W. W. Meinke (Chemistry)
W. C. Parkinson

Graduate Students

O. V. Anders
R. V. Annable
D. R. Bach
O. M. Bilaniuk
W. J. Childs
D. Gardner
J. A. Green
R. Grismore
J. C. Hensel
C. R. Lubitz
W. Williams
R. O. Winder

Technical Staff

W. E. Downer R. D. Pittman H. H. Wright

I. INTRODUCTION

During the period covered by this report the principal effort of the cyclotron group has been devoted to work on four problems, the photographic plate scanner, polarization in the stripping reaction, the P^{32} ground-state doublet, and angular distributions in the $O^{17}(d,p)O^{18}$ reaction. Some time was spent in completing the work on the $O^{16}(d,p)O^{17}$ and the $O^{16}(d,n)F^{17}$ reactions reported last year, and work continued on the conversion of the neutron-spectrometer to automatic recording.

The cyclotron continued to operate in a satisfactory manner, with little time lost due to machine failures. Improvements in the machine and its associated instrumentation were of minor nature. These included the installation of a new oscillator filament transformer, a high-voltage power supply for the external beam deflection plates, a new focusing magnet generator, and an interconnection system for the instrumentation external to the cyclotron. The asphalt floor of the analyzer room was replaced with concrete, various electrical components were rewired and the circuit and operational diagrams revised.

In November, 1955, two new full-time members were added to the technical staff to replace a machinist and a cyclotron technician who left the project for other positions.

During the year three advanced graduate students in physics and one in chemistry completed the requirements for the Ph.D. degree and have left the project for permanent positions, two at Argonne National Laboratory, one at Knolls Atomic Power Laboratory of the General Electric Company, and one at the Research Laboratories of Standard Oil of California.

II. THE EXPERIMENTAL PROGRAM

A. Nuclear Emulsion Scanner

The instrument for automatic scanning of nuclear emulsions, mentioned briefly in our last report, has been developed further. It will detect tracks as dense as or more dense than those of 10 mev protons, provided they occur at an angle of not more than ± 45° relative to a line vertical in the field of view and provided the track has at least 10 μ projected length and a dip angle between 0° and about 70°. A standard Leitz microscope forms a real image of an emulsion scene on the photocathode of an Image Orthicon Camera Tube, as shown in Fig. 1. In Figs. 2, 3, 4, and 5 are reproduced successively a photograph of a monitor screen showing the television reconstruction of the original scene, the video blackness pulses which survive an initial screening process, the output of a counting circuit which counts in blocks of six the number of passes across a track, and, finally, the output of a circuit which fires after two groups of six have been counted. The fact that this final output is associated with the track and with nothing else in the original scene shows that the circuit has detected the track in the midst of background. In practice the final output will be used to run a register or trigger the recording of track angle and length. Figure 6 shows the circuitry which accomplishes the functions described.

So far, almost no data are available to determine the efficiency of the scanner for track detection or background rejection. The present program is aimed at the determination of these efficiencies at the earliest possible date. A Leitz microscope has been equipped with motor drive in one dimension, moving the stage continuously. Since the Image Orthicon Camera cannot record a rapidly moving scene, each field of view is illuminated with a 10-microsecond pulse of light from a xenon flashlamp. A circuit which artificially fills in gaps in a track, and therefore makes them appear continuous to the subsequent analysis circuitry, has been designed and is under construction. When it is finished, a program of practice scanning will be carried out.

A precision mechanical stage and microscope mount has been ordered from Gaertner Scientific Company for delivery at the end of August. A fully automatic drive will be incorporated into this instrument, as well as provision for relocating a field of view to within a few microns--either for human examination or for machine re-scanning. A device for maintaining the focus of the microscope at a fixed distance below the surface of the emulsion is under development.

B. Polarization of Protons in the (d,p) Reaction

Measurements have continued on the determination of the polarization of the outgoing proton in the (d,p) reactions. Preliminary results have been obtained for the ground-state proton group from the $C^{12}(d,p)C^{13}$ reaction.

Referring to Fig. 7, the 7.8-mev deuteron beam from the cyclotron is focused onto the target in the first scattering chamber. Protons from the

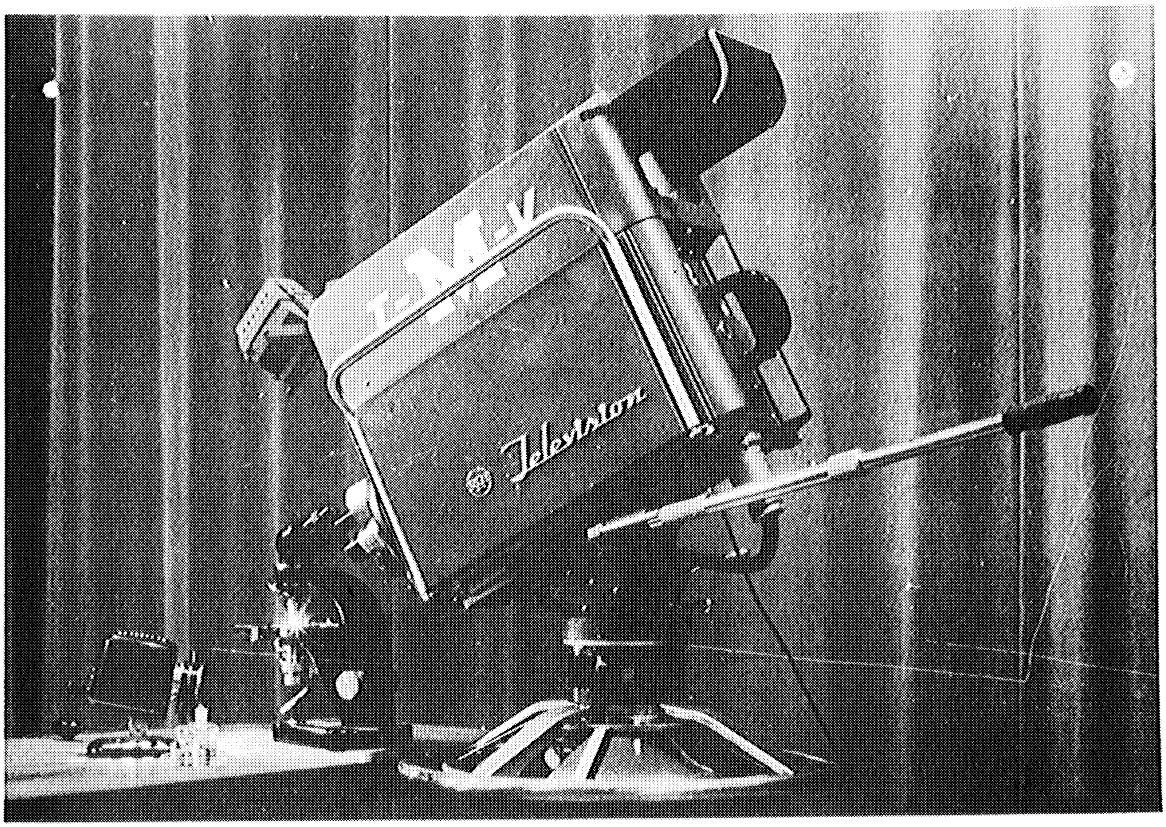

Fig. 1. The television camera and microscope of the emulsion scanner.

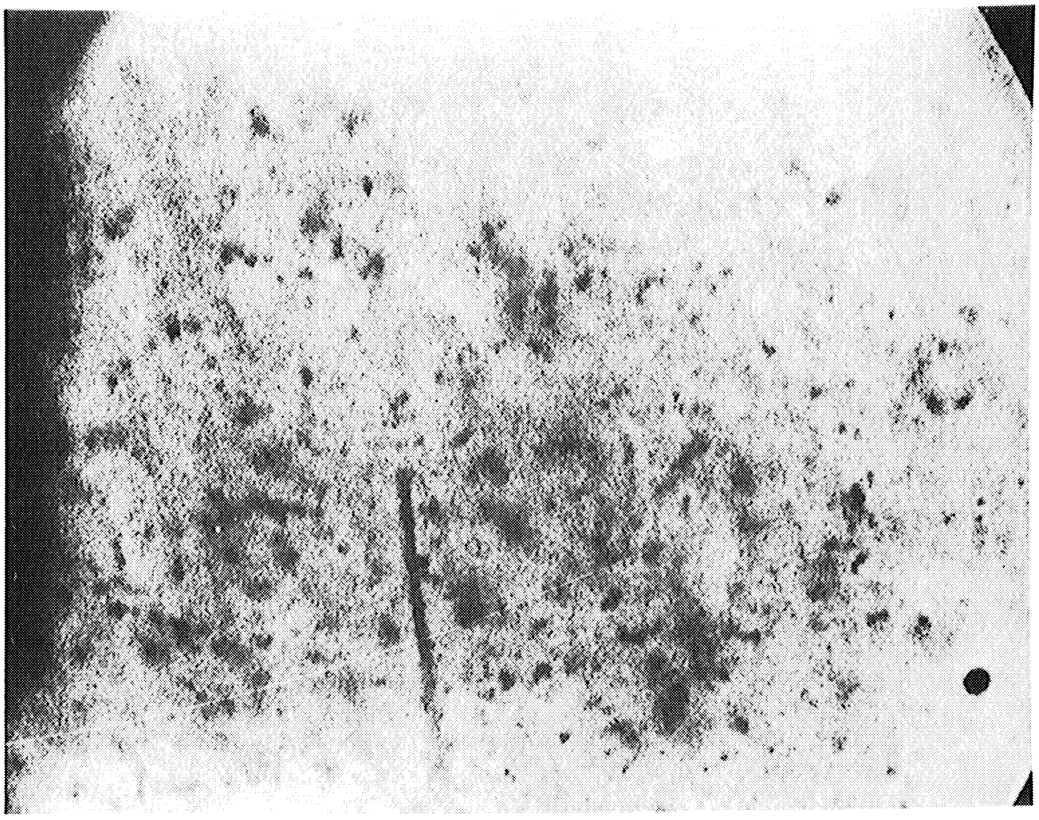

Fig. 2. Photograph of a monitor screen showing the television reproduction.

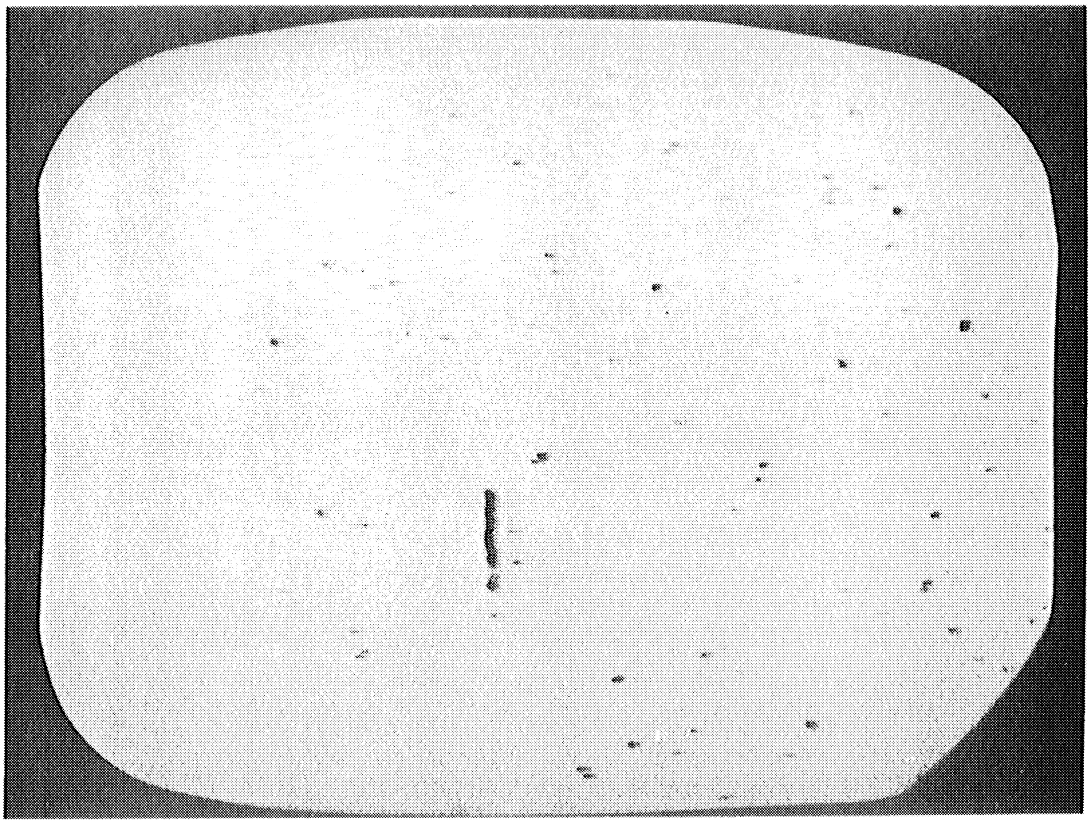

Fig. 3. Blackness peaks from the emulsion scene of Fig. 2 which survive an initial screening process.

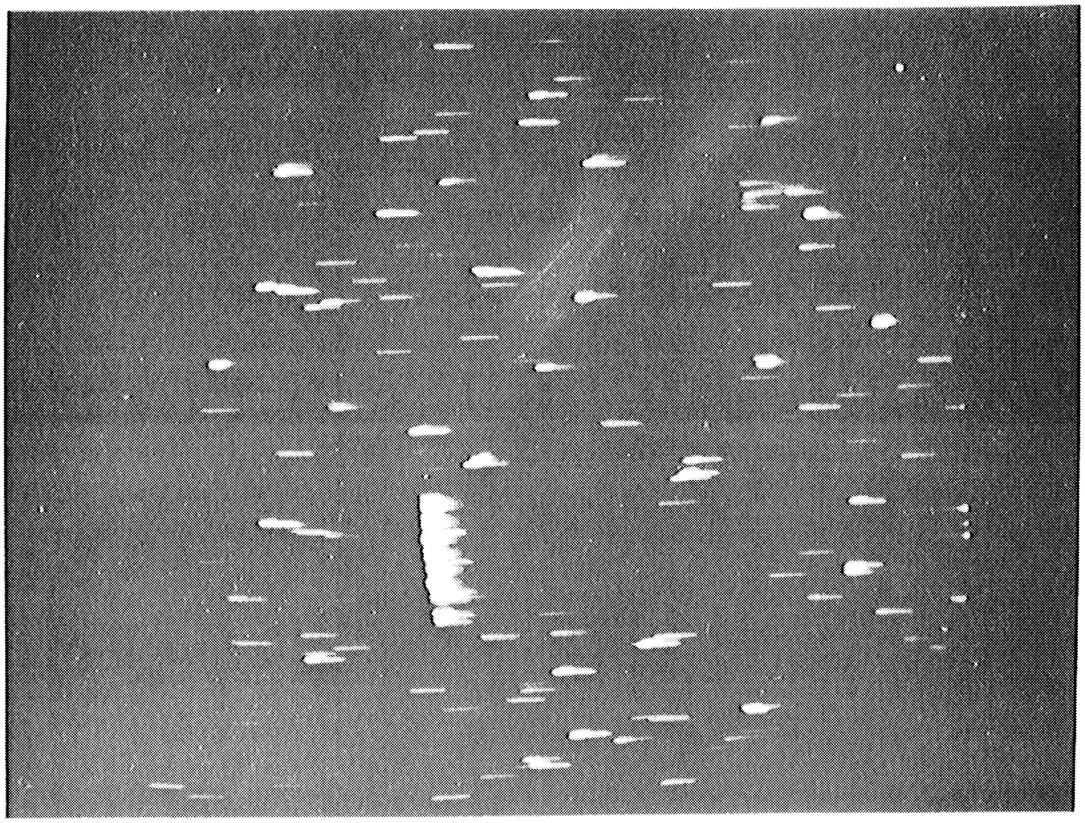

Fig. 4. The output of a counting circuit which counts screened blackness peaks in groups of sixes.

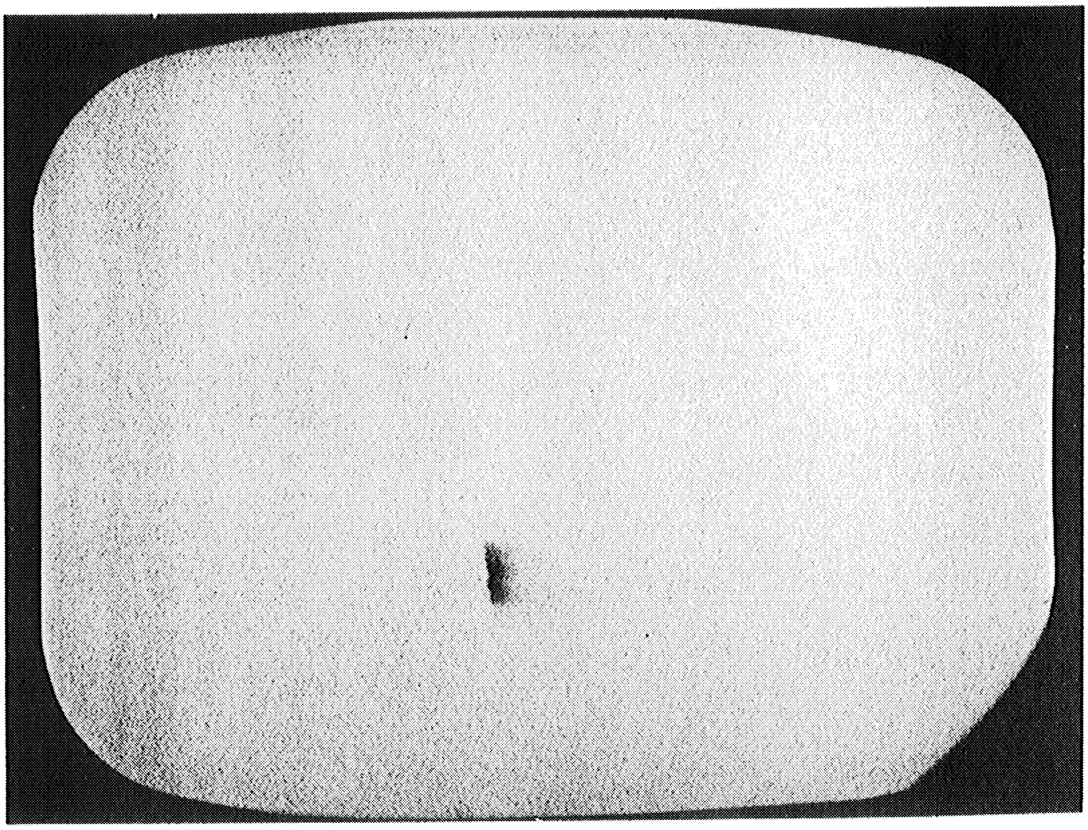

Fig. 5. Final output of the track recognition circuit, indicating the existence and position of a track.

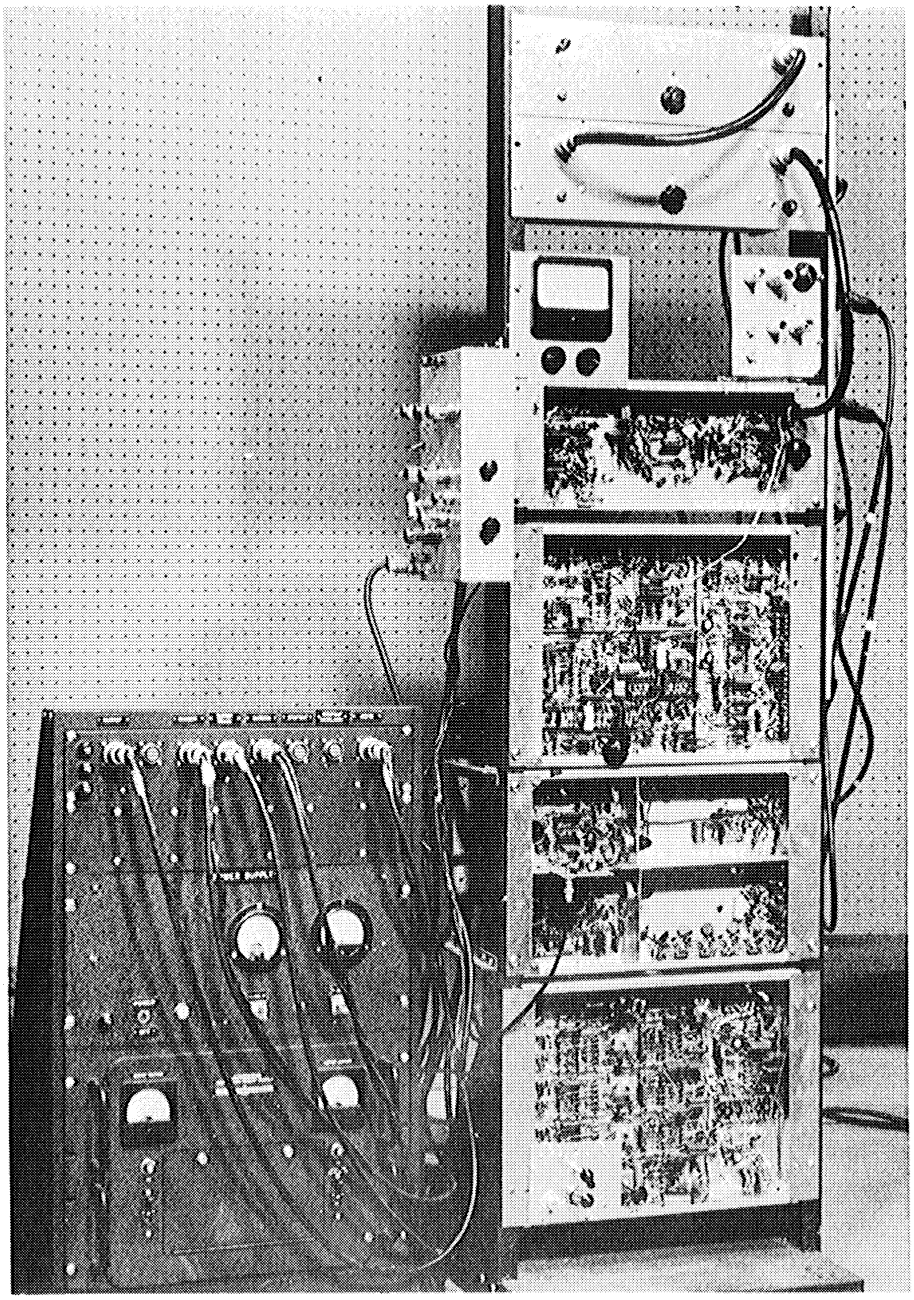

Fig. 6. The analysis circuitry of the scanner.

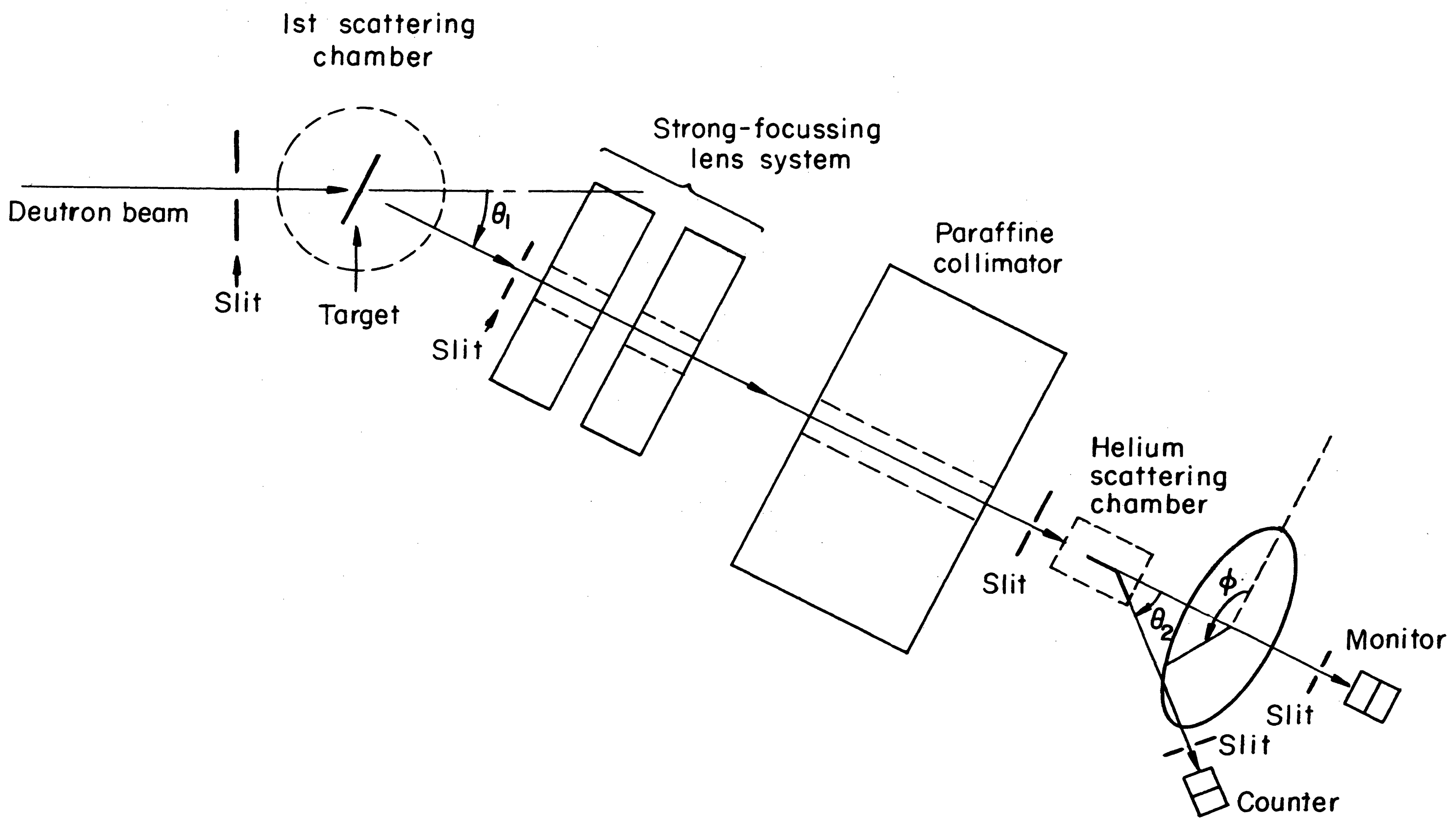

Fig. 7. The geometry for polarization measurements.

(d,p) reaction at the scattering angle Θ_1 are focused by the quadrupole lenses into the second scattering chamber containing helium under high pressure. Before entering the second chamber the protons are collimated by lead stops and slowed by absorber foils to a mean energy of 7.0 mev. The protons elastically scattered at $\Theta_2 = 50°$ from the p1/2 state of Li^5, which serves as the polarization detector, are detected by a double proportional counter telescope. The nonscattered protons pass through the helium chamber into a monitor counter. The helium chamber is constructed so as to allow rotation (in ϕ) about the axis of the incoming protons.

Because the counting rate may be as low as one or two counts per minute, background counts from the cyclotron and competing (d,n) reactions are a major problem. Strong-focusing magnets are used to permit introduction of shielding without loss of solid angle. They increase the proton beam intensity at the second scattering chamber by a factor of 25 over that obtained at the same position without magnets. The factor would be much higher except for a circumstance peculiar to magnet of this type in that part of the proton beam which diverges in the first section is lost before it can be refocused in the second section of the lens system. A larger aperture would correct this situation.

The helium scattering chamber, machined from a solid block of aluminum, is capable of withstanding helium pressures of 20 atmospheres before rupture of the thin nickel windows. Two ports, 180° apart in azimuth and at a polar angle of 50°, permit data to be taken simultaneously at angles ϕ and $\phi + \pi$. Measurements indicate that asymmetries due to beam position and instrumentation are less than 1%.

Discharges in the counters due to charge leakage along the surface of the glass feed-through insulators were observed frequently with amplitudes sufficient to overload the amplifier and cause "background" coincidence counts. A re-entrant type insulator with a leakage path of four inches has eliminated the difficulty. The "background" counting rate due to all causes was reduced to about one count in five minutes. Preliminary data taken using C^{12} as a target indicate that the ground-state protons emitted at 15° have a polarization of -0.20 ± 0.10 at $\Theta_1 = +15°$. This is in substantial agreement with the results of Juveland and Jentschke.[1] The negative sign indicates that the direction of spin polarization is opposite to the orbital angular momentum, which is perpendicular to the scattering plane and for $\Theta_1 > 0$ has a downward sense. The polarization measured at -15° is of the same magnitude but of opposite sign and confirms the fact that the effect observed is due to polarization and not a

---

[1] A. C. Juveland and W. Jentschke, Bull. Am. Phys. Soc., II-1, 193 (1955).

geometrical or beam asymmetry. The sign of the polarization agrees with the calculations of Cheston[2] and is opposite that predicted by Newns.[3]

The study is presently being extended to the ground and first excited states of B^{11}. These states are of interest because of the anomalous angular distributions observed[4] for the first excited states of B^{11} and C^{11} and because the angular distributions interpreted by the Butler theory both indicate that the captured neutron carries in one unit of orbital angular momentum. Since B^{10} has a spin of 3, the spins j_f of the first excited states of B^{11} and C^{11} are restricted to $3/2 \leq j_f \leq 9/2$. This cannot be reconciled with the shell-model prediction of $j_f = 1/2$.

A possible explanation proposed by A. P. French is that the reaction proceeds not as in the usual stripping reaction but rather by an "exchange" process in which the proton in the deuteron exchanges with a proton in the nucleus. Such exchange, to conserve angular momentum in forming a spin 1/2 state, would require the outgoing proton spin to be oriented opposite to that of the proton from the incoming deutron, the difference in angular momentum being imparted to the nucleus. By comparing the signs of polarization of the ground state, which from all evidence is formed in the normal manner, and the first excited state it should be possible to test the validity of the exchange concept.

C. Angular Distributions for $O^{17}(d,p)O^{18}$

Theoretical predictions concerning the parities and nuclear spins of excited states in O^{18} have recently been made by Elliot and Flowers[5] and by Redlich.[6] The angular distributions of protons from $O^{17}(d,p)O^{18}$ provide one of the ways to check these predictions and distributions corresponding to the ground state and the first excited state of O^{18} have been measured.

The ground-state angular distribution (Fig. 8) fits the Butler curve for $\ell_n = 2$ using a nuclear radius of $r_o = 5.2 \times 10^{-13}$ cm, and thus establishes even parity for the ground state.

---

[2] W. B. Cheston, Phys. Rev., 96, 1590 (1954).

[3] H. C. Newns, Proc. Phys. Soc., A66, 477 (1953).

[4] N. T. S. Evans and W. C. Parkinson, Proc. Phys. Soc., A67, 684 (1954) and Maslin, Calvert, and Jaffe, Liverpool University (private communication).

[5] J. P. Elliot and B. H. Flowers, Proc. Roy. Soc. (London), A229, 536 (1955).

[6] M. G. Redlich, Phys. Rev., 99, 1427 (1955) and 95, 448 (1954).

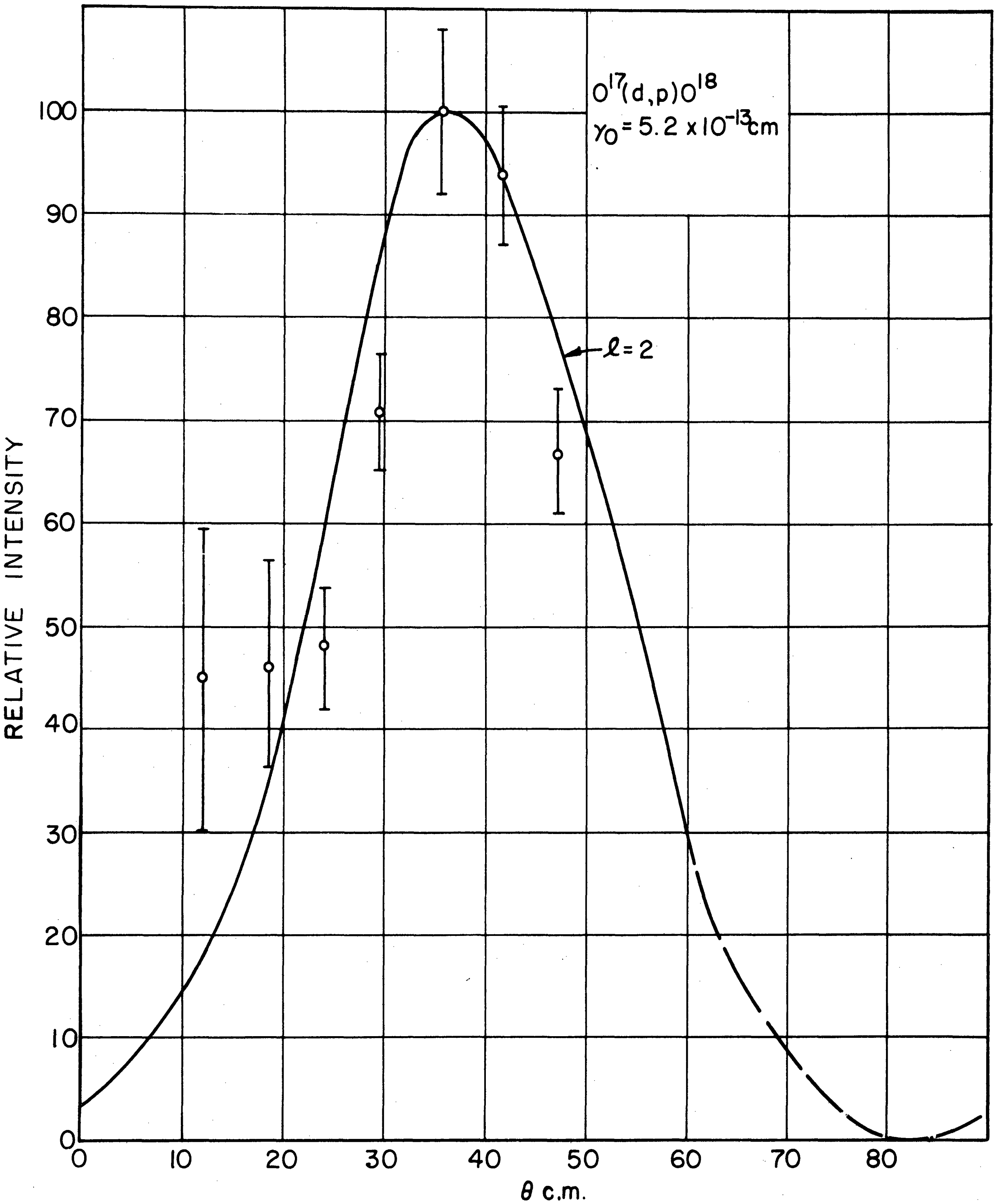

Fig. 8. Ground-state angular distributions for $O^{17}(d,p)O^{18}$.

Although further work is needed to confirm the assignment, preliminary data indicate that the first excited state consists of a mixture of s and d waves. This implies a spin of 2 + for the state, in agreement with theory. Figure 9 shows the experimental angular distribution, with points so far only at angles greater than 15°. The strong rise in the forward direction is the evidence for s-wave admixture.

The proton group associated with the first excited state has about six times the intensity of the ground-state group.

The main difficulties of this investigation arise from the low concentration of O^{17} in the target material, the weakness of the ground-state transition and the interference of $H^2(d,p)\ H^3$ with $O^{17}(d,p)O_2^{18}$ at small angles.

D. The P^{32} Ground-State Doublet

Interest in the ground-state doublet of P^{32} centers around the purity of the wave functions for both members of the doublet. On the basis of the shell model the neutron added to P^{31} to form the ground state of P^{32} should carry in two units of orbital angular momentum. The selection rules, however, allow an admixture of $\ell = 0$. For the upper member of the doublet, presumed to be formed by coupling the spin of the added neutron to the odd proton to yield a total spin of 2+, conservation of momentum prohibits any $\ell = 0$ admixture. It was not possible to verify this assignment in the earlier measurements[7] since the doublet was not resolved. The doublet, now well resolved, is shown in Fig. 10 for 30° scattering angle. The angular distributions obtained for each of the levels (Fig. 11) must be considered as preliminary. The uncertainty indicated by the error bars for each point is based only on the number of counts and does not represent uncertainties due to the instrumentation. In particular, the system of monitoring the deuteron beam to the target has not been carefully checked for reliability under the conditions for which the data were taken. There seems little doubt, however, that while the ground state does contain perhaps as much as 2-3% $\ell = 0$ admixture, the 77-kev level is essentially a $\ell = 2$ capture with no $\ell = 0$ admixture. The results agree with the interpretation that the two levels form a "spin-spin doublet" corresponding to the odd proton and added neutron coupling anti-parallel or parallel to form the $J = 1+$ and $J = 2+$ states, respectively.

---

[7] Parkinson, Beach, and King, <u>Phys</u>. <u>Rev</u>., <u>87</u>, 387 (1952).

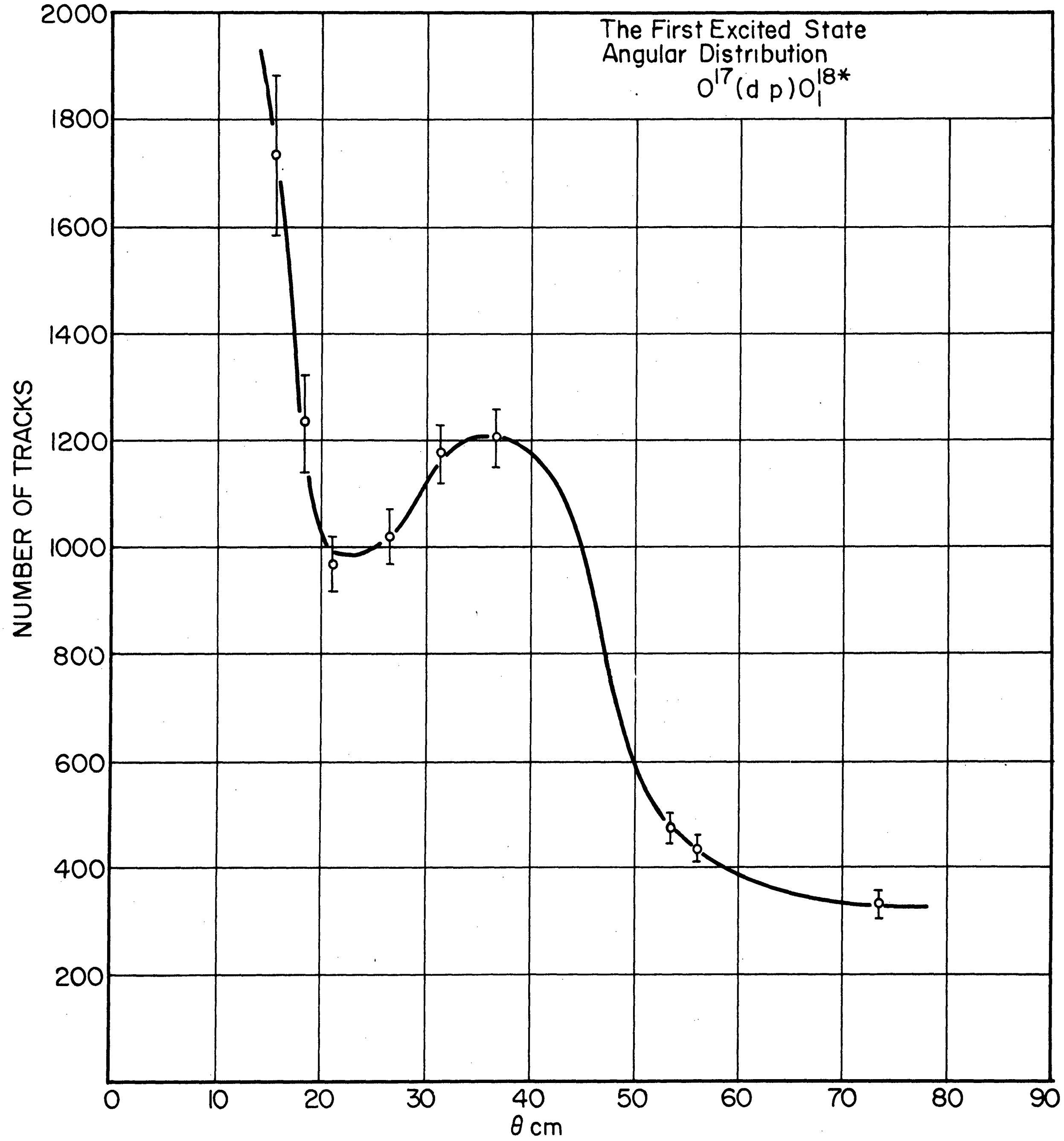

Fig. 9. First excited state angular distributions for $O^{17}(d,p)O^{18}$.

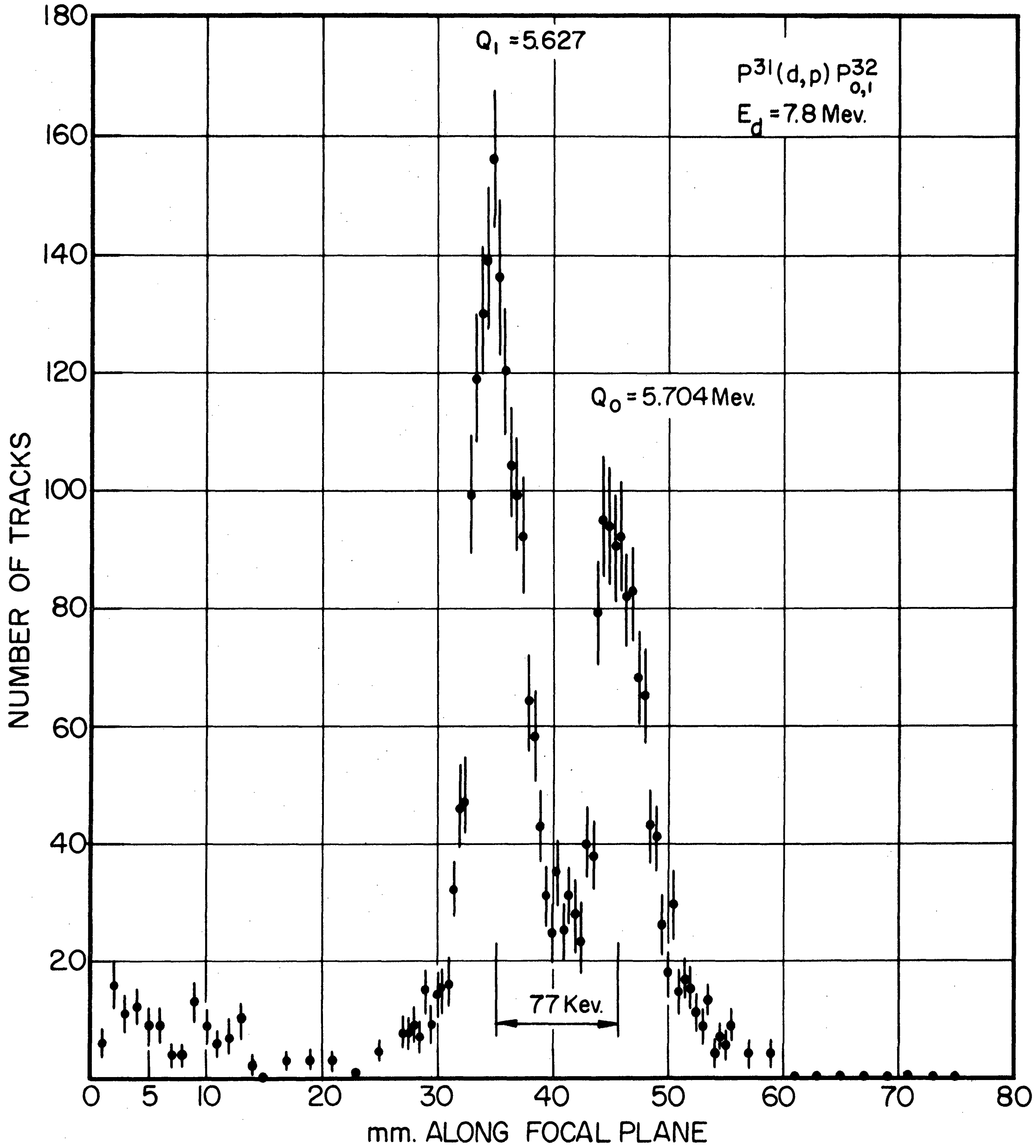

Fig. 10. The ground-state doublet of P^{32}.

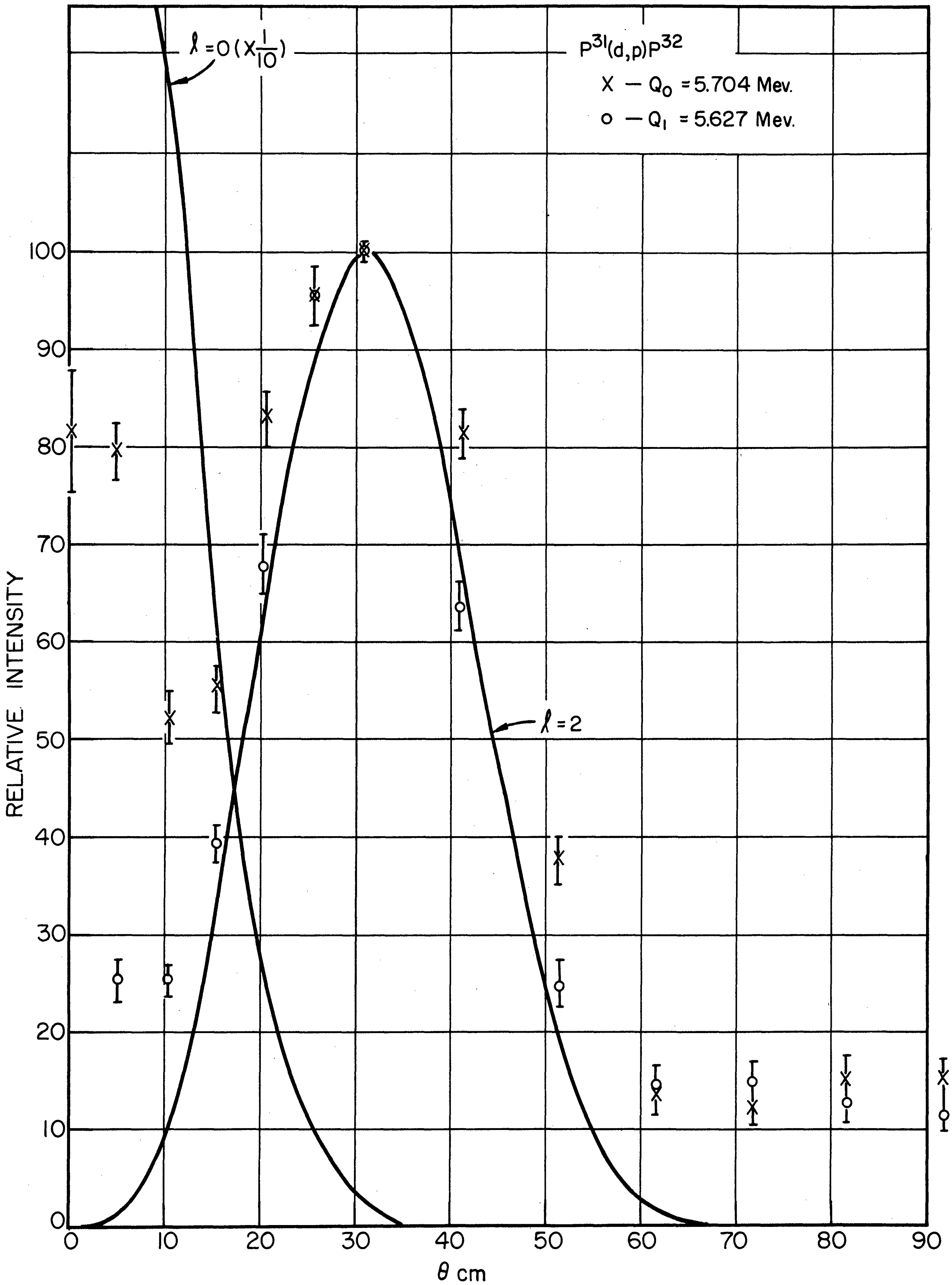

Fig. 11. Angular distributions for the ground-state doublet of P^{32}.

E. The $O^{16}(d,p)O^{17}$ and $O^{16}(d,n)F^{17}$ Reactions

Preliminary results on the study of these mirror reactions were included in the 1955 Progress Report. The work as originally planned has been completed and the results are in the process of publication. Angular distributions were obtained for the seven lowest levels of O^{17} and the results interpreted on the basis of the shell model. Part of the spectrum of F^{17} has been obtained. The spectrum will be completed and angular distributions obtained when the conversion of the neutron spectrometer to automatic recording is completed (Section II-F). Perhaps the most significant result of the $O^{16}(d,n)F^{17}$ study is that while the excitation energy of the fifth excited state is in agreement with the published work of the Wisconsin[8] group, because of its small natural width it cannot be interpreted as (d3/2+) single-particle level corresponding to the spin-orbit companion of the (d5/2+) ground state. It is believed that the sixth excited state is the single-particle (d3/2+) level. The angular distributions should give a definite answer to this question.

F. The Neutron Time-of-Flight Spectrometer

During this past academic year progress on the automatic recording feature of the neutron time-of-flight spectrometer was limited due to lack of technical assistance. However, considerable effort is being devoted to it this summer. A time-to-pulse-height converter and a 100-channel pulse-height selector modeled after the Los Alamos design are under construction. It is expected that the converter will be ready for use by late September and will be used at first with the atomic 20-channel pulse-height analyzer. The first application of the instrument will be to the measurement of the angular distributions of the neutron groups in the $O^{16}(d,n)F^{17}$ reaction (Section II-E). It is anticipated that with automatic recording considerable data will become available on (d,n) stripping reactions for comparison with the corresponding (d,p) reactions.

G. (d,a) Reactions in Middle-Weight Nuclei

During the period from October, 1955, to June, 1956, ten bombardments, some as long as six hours in duration, were made for the chemistry group under the direction of W. W. Meinke.

---

[8] Jackson and Galonsky, Phys. Rev. 89, 370 (1953).

Absolute cross sections for the formation of several radionuclides at well-defined deuteron bombarding energies have been measured. The elements irradiated include titanium, zinc, molybdenum, and zirconium. Details of this work will be given in the progress report of Project No. 7, AEC Contract AT (11-1)-70.

H. Miscellaneous

1. Determination of the Incident Beam Direction.—A retractable finger probe has been installed at the entrance to the analyzer magnet. By moving the analyzer until the current to the probe is maximized, the zero degree position of the analyzer can be determined with an accuracy of about 0.1°.

2. Measurement of Incident Beam Energy.—A method for measuring the cyclotron beam energy, suggested by D. R. Bach and R. Hockney[9], has been applied. The method requires the determination of the momentum difference of protons from $Li^6(d,p)Li_0^7$ and deuterons from $Li^7(d,d)Li^7$ at some angle for which this difference is small. For 7.8-mev deuterons a near coincidence of momenta occurs at 69.5°, as shown in Fig. 12. The peak separations, together with Equation 5 of Reference 9, give the beam energy to an accuracy of ± 10 kev.

3. Analyzer Field-Stabilization and Momentum Calibration.—A unique and reproducible correspondence between the resonance frequency of a nuclear moment field-stabilizer and the momentum of analyzed particles has been obtained by the installation of the nuclear-moment probes in a cut-out of the vacuum chamber between the analyzer pole pieces. Figure 13 shows the double ridge contour which establishes the uniform field across the sample. The knowledge of incident beam energy and angle together with the known Q's of a number of (d,p) reactions have allowed the construction of a momentum frequency calibration curve.

4. Reaction Kinematics.—Tables and curves of proton energy vs reaction angle have been calculated for the (d,p) reactions listed in Table I. In plotting the curves, a fixed deuteron beam energy of 7.771 mev has been assumed, but a first-order correction term is provided which allows simple calculation of proton energies accurate to 5 kev, for any deuteron energy between 6 and 10 mev. The curves are plotted on semi-transparent paper so that by superimposing sheets the interference of groups from different reactions can be seen at once. A reasonably complete file of tables and curves is being established.

---

[9] Bach, Childs, Hockney, Hough, and Parkinson, Rev. Sci. Inst. (to appear in July, 1956, issue).

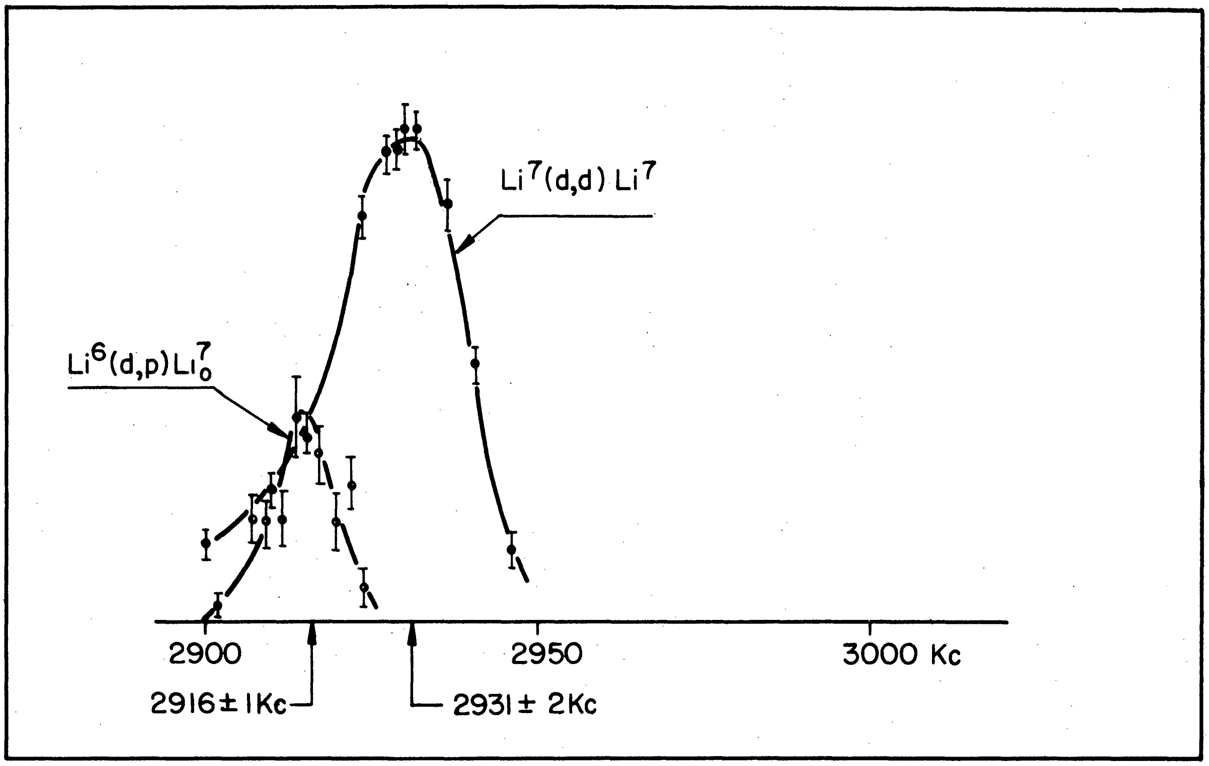

Fig. 12. The Li^6(d,p)Li$^7_0$ and Li^7(d,d)Li^7 group at 69.5°.

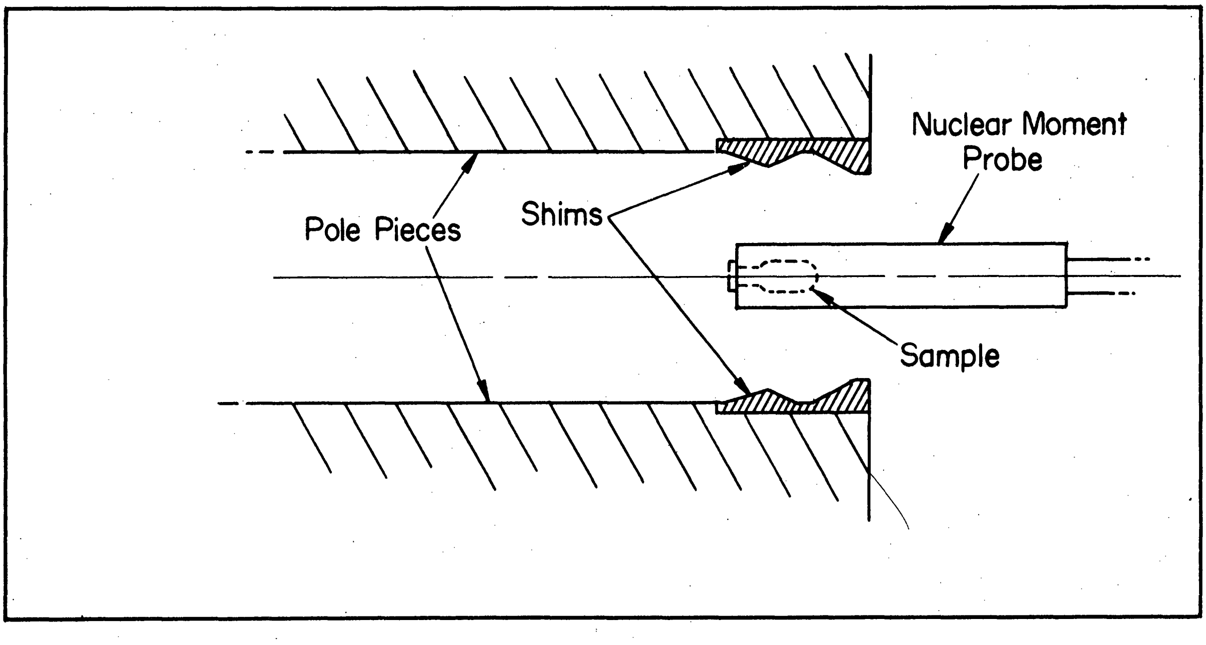

Fig. 13. The contour required to establish uniform field for the proton-moment probe sample.

TABLE I

(d,p) REACTIONS FOR WHICH PROTON ENERGY-ANGLE TABLES AND CURVES HAVE BEEN CONSTRUCTED.

Residual Nucleus	Q Values (mev)
H^3	4.032
Li^7	5.027, 4.549, 0.417
Li^8	0.188, -1.162, -2.468
C^{13}	2.723, -0.365
C^{14}	5.942, -0.149, -0.781
O^{17}	1.918, 1.046
O^{18}	5.821, 3.835, 2.266
F^{20}	4.375, 3.725
A^{28}	5.496, 5.463, 4.521, 4.481, 4.128, 3.873, 3.359, 3.298, 3.228, 3.012
Si^{29}	6.246, 4.968, 4.219, 3.820, 3.176, 2.623, 2.168
Si^{30}	8.388, 6.149, 4.873, 4.602
Si^{31}	4.364, 3.607, 2.665
K^{40}	5.576, 5.544, 4.776, 4.683, 3.47
Ca^{41}	6.140, 4.19
K^{42}	5.12, 4.50, 3.94, 3.15
Fe^{57}	5.46, 4.22, 3.81

5. Teflon Films.—A number of Teflon films $(C_2F_4)_n$, of thickness between 50 and 250 μgm/cm^2, have been fabricated for use as fluorine targets. An aqueous dispersion of Teflon was made available to us by the du Pont corporation through the courtesy of Professor W. W. Meinke of the University Department of Chemistry. The fabrication process, suggested by du Pont, is as follows. Aluminum foil is dipped in the dispersion and allowed to dry at room temperature. The foil is then heated for thirty minutes at 350°C, sintering the Teflon coat into a continuous film. The aluminum is then removed by immersion in HCl. The film thickness is varied by adjusting the concentration of Teflon in the dispersion.

III. THE THEORETICAL PROGRAM

A. Extension of the Butler Theory

Numerical calculation is proceeding on the various integrals which arise in an extended Butler theory of the stripping reaction. It appears to be feasible to tabulate the functions required for including the following effects in the calculated angular distributions: (a) the nuclear interaction between the outgoing proton and the nucleus, (b) the coulomb interaction, and (c) proton exchange. The computation program is approximately 25% completed.

B. Universal Stripping Curves

It has been found that by a suitable transformation the usual Butler formula which depends on five variables (E_d, Q, r_0, M, Θ) can be made to depend on only two dimensionless parameters. This permits its complete tabulation in compact form. This undertaking is essentially complete. The tables supersede the monograph described in the 1955 report.[10]

C. Survey of Stripping Data

This survey, based on the simple Butler theory, has been greatly facilitated by the existence of the tables described under (B). The trial-and-error procedure of finding the nuclear radius and ℓ-value which give the best fit to the experimental data is eliminated, since with the aid of the tables the value of the radius required to fit the maximum or minimum of the angular distribution can be found by inspection.

---

[10] Lubitz and Parkinson, Rev. Sci. Inst., 26, 400 (1955).