BNL 7800

February 3, 1964

CONF-396-1

A Study of The Nuclear Reactions $Mg^{26}(p,t)Mg^{24}$ and $Mg^{26}(He^4,He^6)Mg^{24}$ *

M. E. Rickey,† H. E. Wegner and K. W. Jones
Brookhaven National Laboratory, Upton, New York

B. M. Bardin, C. Hoot and M. Kondo
University of Colorado, Boulder, Colorado

Facsimile Price $ 1.60
Microfilm Price $ .80
Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

A comparison of spectra and angular distributions is made for the two neutron pickup reactions $Mg^{26}(p,t)Mg^{24}$ at E_p = 28 MeV and $Mg^{26}(He^4,He^6)Mg^{24}$ at E_{α} = 40 MeV. The energies are such that the ground state pickup momentum transfers at 15° lab are equal permitting a study of the relative excitations for transitions to the discrete state observed. Comparisons are made for the ground (0+), 1.37 MeV(2^+), 4.12-4.23 MeV(4^+-2^+), 5.22 MeV(3^+) and 6 MeV(4^+) states. Unresolved structure at higher energies is compared in terms of its gross properties.

During the course of the measurements, higher charge particles were also observed consisting of Li^6, Li^7 and perhaps Be^7. The Li^6 - Li^7 yield was considerably stronger than the He^6 yield, and the energy distribution showed marked structure.

---

* Work performed under the auspices of the U. S. Atomic Energy Commission
† On Leave 1963-1964 from University of Colorado.

DISCLAIMER

I. INTRODUCTION

Many nuclear rearrangement collisions using very light nuclei are useful tools of nuclear spectroscopy. Single neutron pickup may be observed by the (p,d).(d,t) and (He^3,He^4) reactions. Comparisons of these reactions on the same targets are valuable since they provide critical tests of reliability of spectroscopic information extracted from the data.

In the case of the two neutron pickup reaction, only one reaction among those commonly studied is accessibly, namely the (p,t) reaction. If He^6 is included in the family of reaction products, the (He^4,He^6) analog reaction provides a supplementary means of studying the two neutron pickup process.

II. EXPERIMENTAL PROCEDURE

The (p,t) measurements were made with 28 MeV protons from the University of Colorado variable energy 52-inch sector-focussed cyclotron.[1] The (He^4,He^6) measurements were made with 40 MeV alpha particles from the Brookhaven 60 inch cyclotron.[2] The detectors were transmission mounted surface barrier counters.[3] Three detectors were used in each measurement: a thin Δ E detector, a stopping detector, and a veto counter to reject events associated with long range particles. Coincident pulses were required in the first two detectors with anti-coincidence in the veto counter. Δ E pulses were multiplied by E pulses formed by adding pulses from the Δ E and stopping detectors.[4] The product pulse was analyzed in a single channel analyzer to select the particles of interest. Fig. 1 shows the mass spectrum obtained for the Mg^{26}(He^4,He^6)Mg^{24} reaction. The E pulses corresponding to the proper coincidence and mass identification requirements were analyzed in a gated multi-channel pulse height analyzer.

III. RESULTS AND DISCUSSION

Fig. 2 shows typical spectra at two angles for the (He^4,He^6) measurements. The large kinematic shift together with the 65 micron thickness of the Δ E detector severely limited the accessible range of excitation energy at large angles. The background and poor resolutions at small angles leads to considerable uncertainty in the strength of small peaks. Fig. 3 shows typical (p,t) spectra. The lower background is a consequence of a larger cross section and better resolution.

There are a number of interesting features which arise in the comparison of the spectra. The 25° (He^4,He^6) spectrum (Fig. 2) indicates that at this angle the 6.44 MeV 0+ state of Mg^{24} is excited in this reaction. This level is also observed in the $C^{12}(O^{16},He^4)Mg^{24}$ reaction.[5] It is not observed at any angles studied in the (p,t) measurements, nor is it prominent at larger angles in the (He^4,He^6) measurements. Better data are needed to show with certainty that the level is excited; however, if such data bear out these conclusions, then the (He^4,He^6) reaction mechanism for the excitation of this level must be different than that for the (p,t) reaction. On the other hand, a level at 7.7 MeV is strongly excited by both the (p,t) and (He^4,He^6) reactions; there are many Mg^{24} levels in this region. Apparently one level or a narrow band has a large two neutron spectroscopic factor. The first T = 1 level of Mg^{24} is at approximately 9.5 MeV. This is the 4^+ analog of the ground state of Na^{24} (and Al^{24}).[6] There is no indication that this state is strongly excited by either the (p,t) or (He^4,He^6) reactions.

The strength of the (p,t) ground state transition in comparison to the excitation of the other levels is quite apparent. This is in marked contrast to the relative strengths of the various transitions in the (He^4,He^6) reaction. Similar behavior of the (d,t) and (He^3,He^4) reactions is noted in the work of Blair and Wegner.[7] This is perhaps an indication that the (He^4,He^6) reaction accentuates higher ℓ transfers as conjectured in the case of (He^3,He^4).

The excitation of the 5.22 MeV 3 + unnatural parity state occurs with surprising strength in the (He^4,He^6) reaction. Clement[8] concludes that (p,t) reactions are approximately forbidden if the orbital angular momentum of the picked up neutron pair is even and there is a parity change (or vice-versa). This selection rule is supported by the $C^{12}(t,p)C^{14}$ data of Jaffe et al,[8] who find such transitions decreased by a factor of 5 to 15. The 3^+ level in the $Mg^{26}(p,t)Mg^{24}$ is very weak compared to the ground state. It is only slightly diminished in the (He^4,He^6) measurements.

Bayman[9] has pointed out that this selection rule can be regarded as a consequence of the assumption that the two picked up neutrons in the target are in a relative s state together with an assumption regarding the interaction. If the angular momentum of the pair

$$\vec{L} = \vec{\ell}_1 + \vec{\ell}_2$$

is resolved into $\vec{\lambda}$, their relative angular momentum and $\vec{\Lambda}$, the angular momentum of their center of mass relative to the nucleus, then

$$\vec{L} = \vec{\lambda} + \vec{\Lambda}$$

and $\Delta\pi = (-1)^{\lambda+\Lambda}$

where $\Delta\pi$ is the change in parity. The parity of λ is unchanged in the reaction if the interaction between the incident particle and the neutrons depends only on the separation of the systems. The assumption that λ is even is then a consequence of the assumed spatial symmetry of the neutrons in the triton and He^6.

If we further assume that they are in a relative s state, the selection rule follows:

Violation of the selection rule for either (p,t) or (He^4,He^6) follows if:

1) there is a $\lambda = 2$ component in the wave function of the neutrons in the triton or He^6 in which case the $\lambda = 2$ can couple to Λ to form either even or odd L with the parity of Λ. (This is not inconsistent with a total orbital angular momentum of zero for the triton).

2) the interaction depends on spin or orbital angular momenta in addition to the position vector.

3) the reaction proceeds through compound nucleus formation or multiple processes.

In spite of the large differences between (He^4,He^6) and (p,t) in the ground state and 1.37 MeV state transitions, the 3^+ excitation is comparable in the two processes. This is probably fortuitous because of the great difference in distortion effects in the two reactions.

Fig. 4 shows the angular distributions of the resolved groups up to 6 MeV excitation in Mg^{24}. The curves are of laboratory cross-section as a function of laboratory angle. Theoretical fits to the data have not been attempted except that the (p,t) ground state angular distribution was found to agree in location of observed maxima and minima with $j_o^2(KR)$ for R = 5.9×10^{-13} cm.

The pickup momentum transfers for these processes for the energies of these measurements are comparable. For the (He^4,He^6) ground state transition $K \approx 0.2 \times 10^{13} cm^{-1}$ in the forward direction and increases to $\sim 3 \times 10^{13} cm^{-1}$ at 80° laboratory angle; for the (p,t) ground state transition K ranges from $\sim .5 \times 10^{13} cm^{-1}$ to $\sim 1.6 \times 10^{13} cm^{-1}$ over the same angular range. The kinematical region of the pickup is therefore comparable in the two cases.

Although the momentum transfer in the two reactions is similar, the relative excitations between the (He^4,He^6) and (p,t) reactions are quite different for the ground state and gradually become similar for the higher excited states, as shown in Fig. 4. Similar comparisons on other nuclei may lead to a better understanding of the reaction mechanisms and the wave functions involved.

Lithium fragments as reaction products have been studied in several laboratories. In the course of the (He^4,He^6) measurement, it was discovered that a large number of lithium nuclei were coming from the target. These were initially observed and identified by mass analysis with a 25 micron ΔE detector;[10] however, gated energy spectra were not recorded. Subsequently several spectra were measured with a single thin detector, 65 microns thick, and without mass identification. Fig. 5 shows a typical spectrum. The maximum alpha particle energy loss in this detector is $\sim$10 MeV and the He^6 fragments can lose at most $\sim$10.8 MeV. It was not possible to identify the pronounced structure since mass identification was not used. The relatively poor energy resolution is due to target thickness. (the target is $\sim$700 Kev thick for 20 MeV Li^6). The maximum observed energy is consistent with either Li^6 or Li^7 as an outgoing particle; however, higher mass and charge can also be present in the spectrum. The differential cross section for the maximum 5 MeV of the spectrum is 3.5 mb/sr at 35°, an intensity ratio of 100/1 relative to He^6 in this energy region.

We believe a considerable amount of this maximum 5 MeV of the spectrum to be due to Li^6 as a consequence of the earlier mass studies. Further work with good resolution and mass identification is needed for a definitive comparison.

ACKNOWLEDGEMENTS

The assistance and cooperation of C. P. Baker in providing the beam facility is appreciated.

REFERENCES

1. Lind et al, Nuclear Instruments and Methods, 18 and 19, 62 (1962).
2. M. E. Rickey and H. E. Wegner, BAPS II., 9, 78 (1964).
3. Oak Ridge Technical Enterprises Corp., P.O. Box 485, Oak Ridge, Tenn.
4. G. L. Miller and V. Radeka, IEEE Trans. Nucl. Sci. (to be published).
5. Hinds, Middleton, and Litherland, Proc. Phys. Soc., 77, 1210 (1961).
6. P. M. Endt and C. Van der Lean, Nucl. Phys., 34, 51 (1962).
7. A. G. Blair and H. E. Wegner, Phys. Rev., 127, 1245 (1962).
8. C. F. Clement, International Symposium on Direct Interactions and Nuclear Reaction Mechanisms, 458 (1962).
9. B. F. Bayman, private conversation.
10. Thanks are due to W. M. Gibson for the loan of a planar etched, Δ E counter 25 microns thick.

FIGURE CAPTIONS

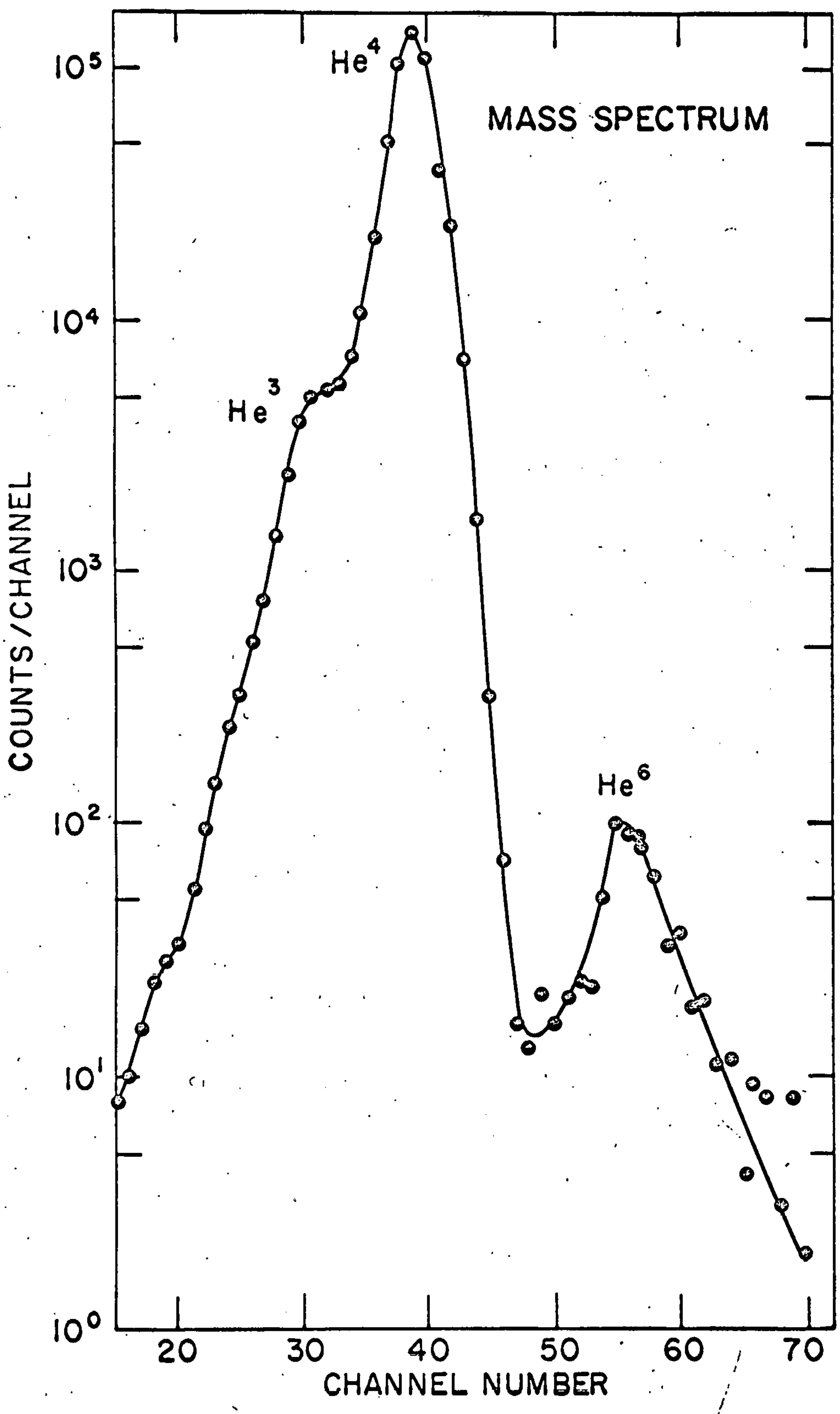
Fig. 1 Gated output from the multiplier circuit showing the mass resolution. The ΔE and E counters are thick enough to stop the most energetic He^6 particles but only those He^3 and He^4 particles with less than 20 to 22 MeV. More penetrating particles are eliminated by an anticoincidence counter.

Fig. 2 Energy spectrum of He^6 particles from 40 MeV alpha particles incident on a Mg^{26} target. The 52.5 degree spectrum shows the decreased background at back angles and the (3^+) 5.22 MeV state relatively strongly excited. The 25 degree spectrum shows the increased background at forward angles and the enhancement of the 6.44 MeV state which is not observed in the (p,t) measurements.

Fig. 3 Energy spectrum of tritons from 28 MeV protons incident on a Mg^{26} target. The two scattering angles chosen show the striking changes in intensity of different groups with angle. The channel number scale of the 60 degree spectrum is normalized to the 45 degree spectrum for ease of comparison.

Fig. 4 Comparison of angular distributions of He^6 particles from the $Mg^{26}(He^4,He^6)Mg^{24}$ reaction and tritons from the $Mg^{26}(p,t)Mg^{24}$ reactions. The comparison shows that the (p,t) reaction excites the ground and low lying states much more strongly than the higher states while the (He^4,He^6) reaction excites all of the states approximately equally, however with 1/100 of the intensity in the case of the ground state.

Fig. 5 Energy spectrum of nuclei with charge Z $\geq$ 3 observed at 35 degrees with 40 MeV alpha particles incident on a Mg^{26} target. The peaked structure persists at various angles; however, it is impossible to determine which heavy nuclei or reactions are responsible. Other measurements with a thinner ΔE detector indicated that Li^6 and Li^7 nuclei played a major role in the total yield.



MASS SPECTRUM
He4
He3
He6
COUNTS/CHANNEL
CHANNEL NUMBER
10⁵
10⁴
10³
10²
10¹
10⁰
20
30
40
50
60
70

FIGURE I

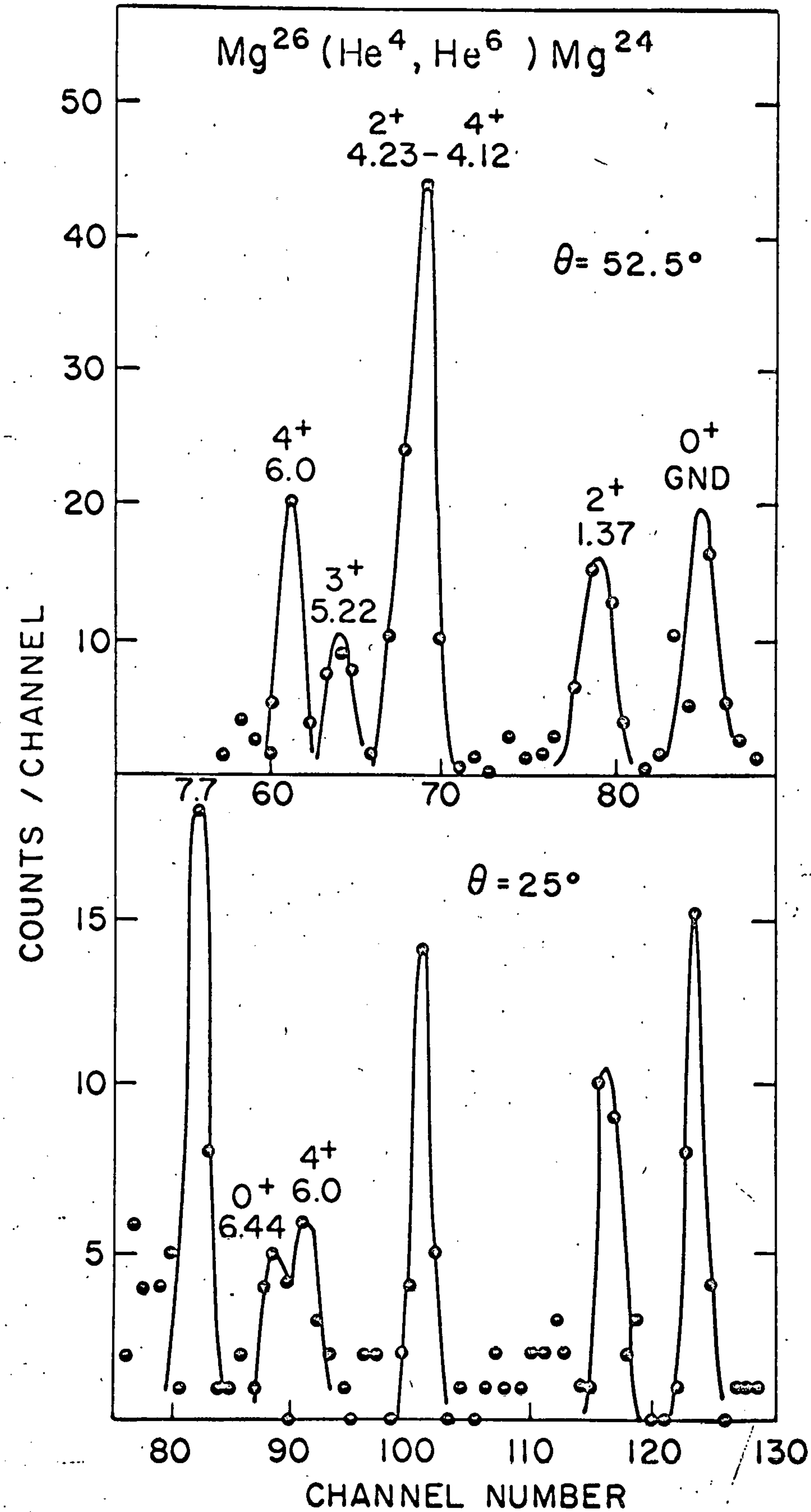
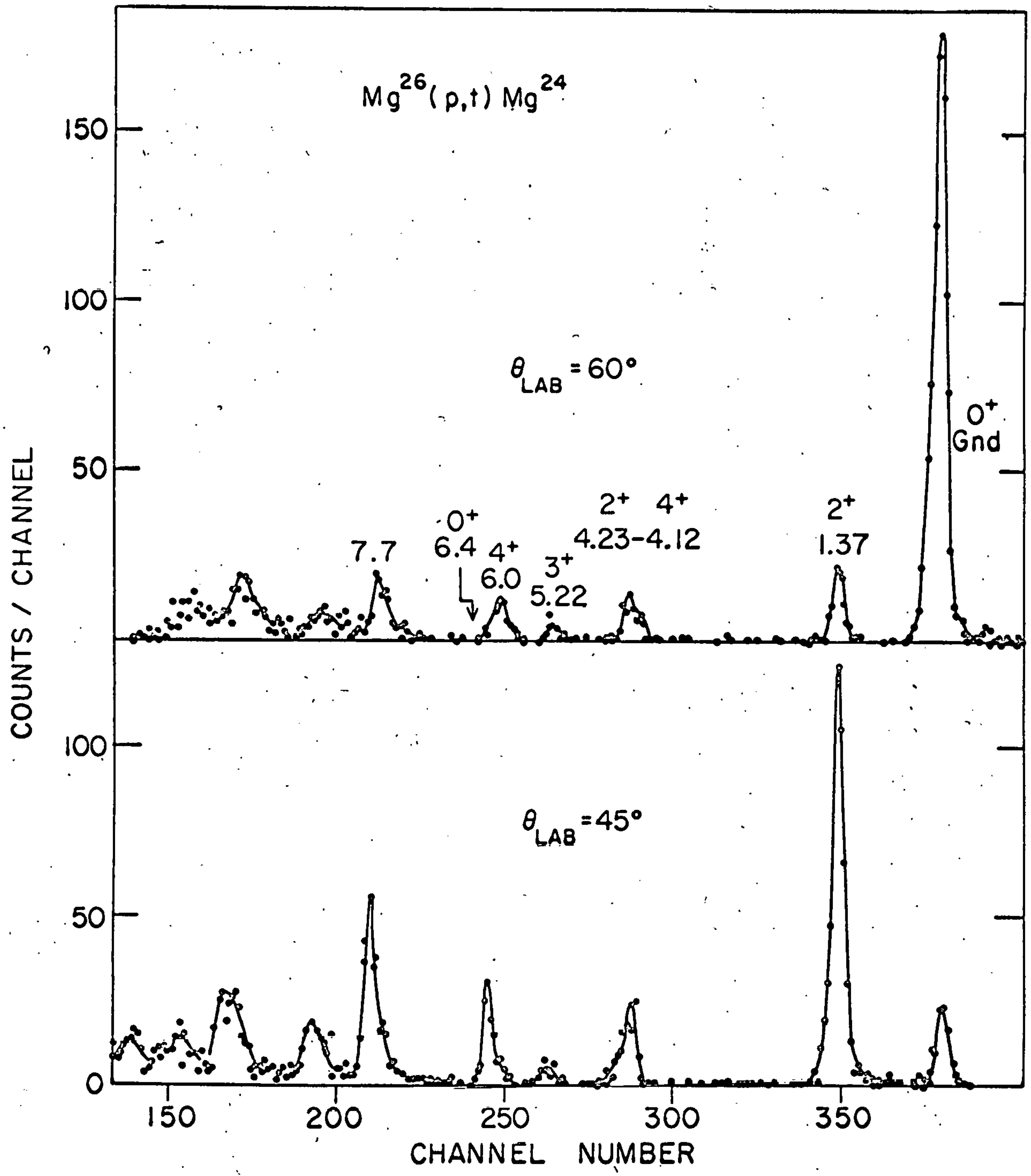
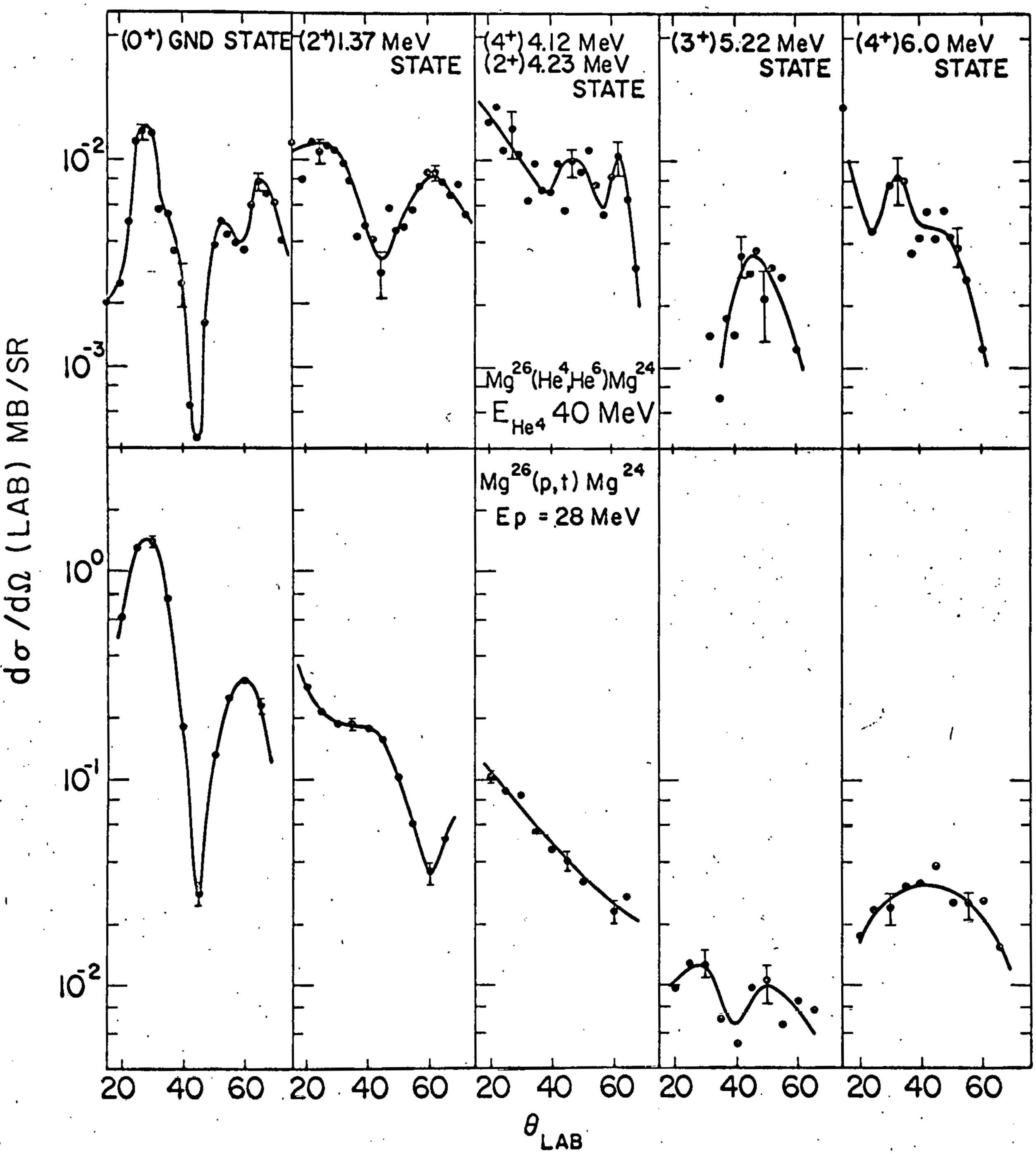

Mg26 (He4, He6) Mg24
50
40
30
20
10
2+
4.23 - 4.12
4+
θ= 52.5°
4+
6.0
3+
5.22
2+
1.37
0+
GND
60
70
80
7.7
θ = 25°
15
10
5
0+
6.44
4+
6.0
80
90
100
110
120
130
CHANNEL NUMBER
COUNTS / CHANNEL

FIGURE 2



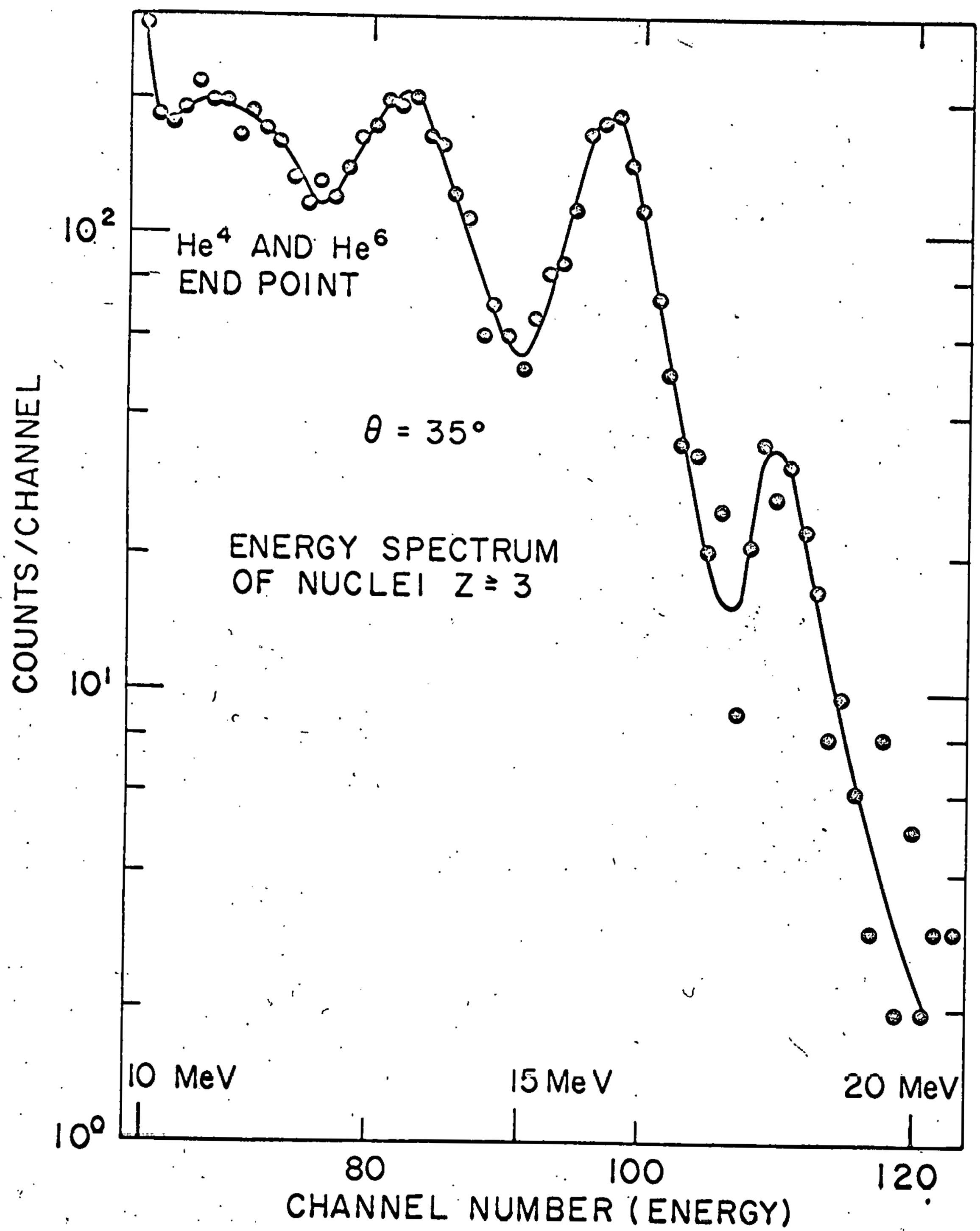
$Mg^{26}(p,t)Mg^{24}$
$\theta_{LAB}=60°$
$\theta_{LAB}=45°$
COUNTS / CHANNEL
CHANNEL NUMBER
150
100
50
0
200
250
300
350
0^+ Gnd
2^+ 1.37
2^+ 4^+
4.23–4.12
3^+ 5.22
4^+ 6.0
0^+ 6.4
7.7

FIGURE 3



(0+) GND STATE
(2+) 1.37 MeV STATE
(4+) 4.12 MeV
(2+) 4.23 MeV STATE
(3+) 5.22 MeV STATE
(4+) 6.0 MeV STATE
Mg26(He4,He6)Mg24
EHe4 40 MeV
Mg26(p,t) Mg24
Ep = 28 MeV
dσ/dΩ (LAB) MB/SR
θLAB

FIGURE 4



10^2
10^1
10^0
He^4 AND He^6
END POINT
θ = 35°
ENERGY SPECTRUM
OF NUCLEI Z ≥ 3
COUNTS/CHANNEL
10 MeV
15 MeV
20 MeV
80
100
120
CHANNEL NUMBER (ENERGY)

FIGURE 5