neutron configurations. Only the $d_{5/2}$ proton configuration value is rather arbitrary and this is not too important since both Pm^{147} and Pm^{149} have spins of 7/2, making it most likely that the 61st proton in Pm^{148} is in a 7/2+ configuration. The sign of μ for Nd^{147} was inferred from the Schmidt value. By coupling the g values shown in Table VI we calculated the empirical values of the magnetic moments shown in column 5 of Table V. Comparison of these values with the experimental results shows that good agreement is obtained if the ground state ($I=1$) of Pm^{148} is in a nominal $(g_{7/2}f_{5/2})$ configuration and the excited state ($I=6$) has a nominal $(g_{7/2}f_{7/2})$ configuration. The coupling of spins in these configurations is contrary to Nordheim's rules but since we are dealing with multiple-particle configurations rather than single-particle configurations this disagreement may not be important.

VIII. ABSOLUTE TEMPERATURE SCALE FOR CMN

A careful inspection of Fig. 2 will show that the axial data points, with the exception of the lowest temperature point, could be fitted slightly better by a curve with a small negative curvature in $I(\theta)$ vs T^{-1} indicating "saturation" of the nuclear alignment. Such a curve would be physically reasonable; it would correspond to a much larger value of P' than does the curve actually drawn in Fig. 2. If the lowest temperature point were in reality at a much lower temperature still, it would lie on the "saturation" curve. If the $T-T^*$ relationship for CMN were considerably in error, the lowest temperature point could appear to be at too high a temperature. There is some evidence that the $T-T^*$ relationship for CMN might be in error in just this way, the lowest point lying at a temperature much lower than 0.003°K.[38,39]

A more thorough analysis of the data in Fig. 2 tends to refute this interpretation for two reasons: (1) there is no detectable P_4 term in the angular distribution at the lowest temperature (Fig. 3), whereas the "saturation" curve would require the distribution $I(\theta)\approx 1 +0.17P_2(\cos\theta)-0.03P_4(\cos\theta)$ at this temperature; and (2) the magnitude of the limiting value for the coefficient of the P_2 term is +0.40 for this decay sequence, the saturation curve would require a value of +0.18.

We conclude, then, that the data for Pm^{144} qualitatively substantiate the magnetic temperature scale for CMN given by Daniels and Robinson.[12] It should be noted that this experiment is not highly sensitive to small inaccuracies in the $T-T^*$ scale, nor was the ultimate possible accuracy obtained. Still this measurement provides independent confirmation, by a unique method, that the $T-T^*$ relation for CMN is essentially correct.

[38] R. P. Hudson, R. S. Kalser, and H. E. Radford, in *Proceedings of the VII International Conference on Low Temperature Physics* (University of Toronto Press, 1961), p. 100.
[39] D. de Klerk, in *Handbuch der Physik*, edited by S. Flügge (Springer-Verlag, Berlin, 1956), Vol. 15, 118.

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Scattering of He^3 from He^3†

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The elastic scattering of He^3 particles from a He^3 target has been investigated for bombarding energies between 3 and 12 MeV. Excitation curves were obtained for center-of-mass scattering angles 30.6°, 54.8°, 70.1°, and 90°; and angular distributions were measured at bombarding energies of 3.03, 5.90, 7.91, 9.92, and 11.93 MeV. The excitation curves are without structure and all decrease with increasing energy in a smooth, monotonic fashion. The five angular distributions exhibit marked disagreement with theoretical predictions based on the resonating group structure method.

1. INTRODUCTION

THE resonating group structure method developed by Wheeler[1] has been applied successfully to many scattering reactions among the very light nuclei. The most prominent of these successes have been the scattering of nucleons from[2–4] H^2, H^3, He^3, and He^4 and the scattering of alpha particles from helium.[5] In all these cases, the experimental and theoretical results are in qualitative agreement over a wide range of bombarding energies. Since the method has been applicable both to the case of the scattering of nucleons from

† Supported in part by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. A. Wheeler, Phys. Rev. **52**, 1107 (1937).
[2] H. S. W. Massey, *Progress in Nuclear Physics* (Butterworths Scientific Publications Ltd., London, 1953), Vol. 3, p. 235; and *Nuclear Forces and the Few-Nucleon Problem* (Pergamon Press, New York, 1960), Vol. 2, p. 345.
[3] P. G. Burke, *Nuclear Forces and the Few-Nucleon Problem* (Pergamon Press, New York, 1960), Vol. 2, p. 413.
[4] H. H. Bransden, *Nuclear Forces and the Few-Nucleon Problem* (Pergamon Press, New York, 1960), Vol. 2, p. 527.
[5] E. W. Schmid and K. Wildermuth, Nucl. Phys. **26**, 463 (1961).

composite particles and to the case of the scattering of identical composite particles, one might suspect that the scattering of He^3 from He^3 would offer no special difficulty.

Experimental data[6,7] at several bombarding energies above 20 MeV have been shown to disagree with the resonating group calculations of Bransden and Hamilton.[8,9] The present work was initiated to see if this disagreement was also present at lower energies. For the new results, as for those at considerably higher energy, the data do not agree with the predictions.

2. EXPERIMENTAL

The data consist of four excitation curves at center-of-mass angles 30.6°, 54.8°, 70.1°, and 90°; and angular distributions at 3.03, 5.90, 7.91, 9.92, and 11.93 MeV. These results are summarized in Figs. 1–5. The points below 5 MeV were taken with the singly charged He^3 beam from the ONR tandem accelerator, while the points above 5 MeV were obtained with the doubly charged beam. A gas scattering chamber employing two solid-state detectors was used in this work. One counter was fixed at a laboratory scattering angle of 30° as a monitor; the angular position of the other was variable. The collimator of this moving counter has an angular resolution of $\pm 1°$ and covers the laboratory scattering angles between 10° and 170°. The He^3 target was isolated from the high vacuum system by a 2500-Å nickel foil before the beam collimator and by a 10 000-Å nickel foil in front of the Faraday cup. The significant contaminants contained in the gas were kept to a very low level by a liquid-nitrogen-cooled charcoal trap in the bottom of the chamber. A description of this apparatus and the experimental techniques has been presented recently[10]; hence, they will not be discussed in detail here.

TABLE I. Variation of the statistical uncertainty.

$\theta_{c.m.}$	Energies below 5 MeV (%)	Energies above 5 MeV (%)
30.6°	0.3–0.6	0.3–1.0
54.8°	1.2–2.0	1.2–1.6
70.1°	2.0–3.0	1.6–2.0
90.0°	2.5–3.0	2.0–2.5

The energy scale given has an uncertainty of ± 15 keV, while the rms uncertainty in the values of the differential cross section is estimated to be less than $\pm 5\%$, excluding statistical uncertainties. The range of statistical uncertainties encountered is summarized in Table I.

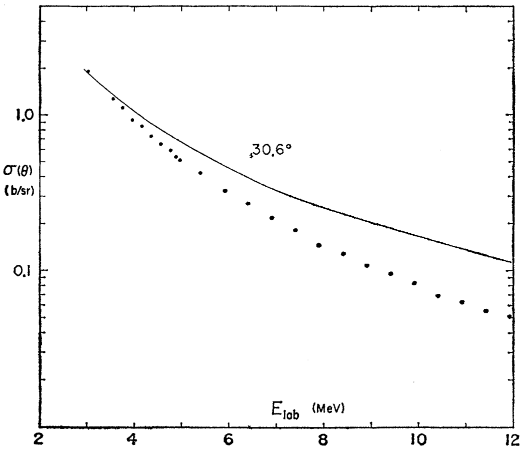

FIG. 1. Excitation curve for the elastic scattering of He^3 from He^3 at the center-of-mass angle 30.6°. The cross section is in units of barns per steradian and is in the center-of-mass system. The solid line is the Mott scattering cross section.

3. CONCLUSIONS

The excitation curves shown in Figs. 1 and 2 are seen to be free of any structure that would indicate the

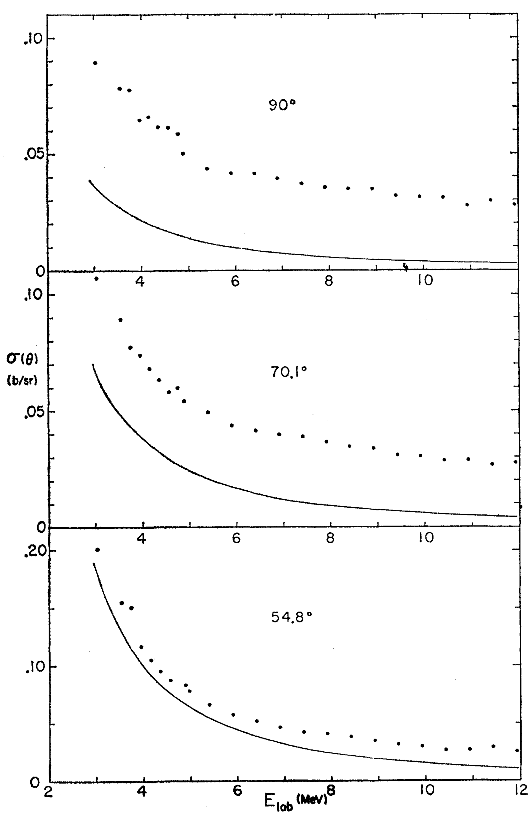

FIG. 2. Excitation curves for the elastic scattering of He^3 from He^3 at center-of-mass angles 54.8°, 70.1°, and 90°. The units and symbols have the same significance as those of Fig. 1.

[6] J. L. Gammel, J. E. Brolley, L. Rosen, and L. Stewart, in *Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, 1960*, edited by D. A. Bromley and E. Vogt (University of Toronto Press, Toronto, 1960), p. 215.

[7] D. Bredin, J. B. A. England, D. Evans, J. S. C. McKee, P. V. March, E. M. Mosinger, and W. T. Toner, Proc. Roy. Soc. (London) **A258**, 202 (1960).

[8] B. H. Bransden and R. A. H. Hamilton, *Nuclear Forces and the Few-Nucleon Problem* (Pergamon Press, New York, 1960), Vol. 2, p. 555.

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[10] T. A. Tombrello and L. S. Senhouse, Phys. Rev. **129**, 2252 (1963).

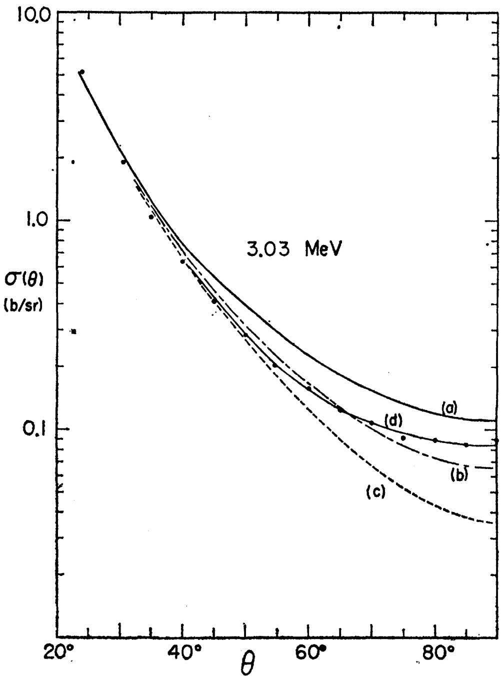

FIG. 3. The angular distribution for the elastic scattering of He^3 from He^3 at a bombarding energy of 3.03 MeV. The angles and differential cross sections are in the center-of-mass system. The lines labeled by (a), (b), (c), and (d) are, respectively: (a) the theoretical predictions based on a Serber force mixture; (b) the theoretical predictions based on a symmetrical force mixture; (c) Mott scattering; (d) the fit given by the derived phase shifts, $\delta_0=-24.1°$, $\delta_1=1.1°$, and $\delta_2=-3.8°$.

presence of excited states of the compound nucleus, Be^6, for excitation energies between 13 and 17.5 MeV. That the nuclear interaction is, however, not negligible in this energy range is evidenced by the difference between the Mott scattering cross section (solid lines) and the experimental points.

TABLE II. A summary of the phase shifts used for comparison with the experimental data. All values (a) and (b) were obtained from reference 8.

E_{He^3} (MeV)	Character	δ_0	δ_1	δ_2	δ_3
3.03	(a) Serber force	$-45°$	$-6°$	$0°$	$0°$
	(b) Symmetrical force	$-15°$	$-2°$	$0°$	$0°$
	(c) Mott	$0°$	$0°$	$0°$	$0°$
	(d) Phase shift analysis	$-24.1°$	$1.1°$	$-3.8°$	$0°$
5.90	(a) Serber force	$-74°$	$-15°$	$4°$	$0°$
	(b) Symmetrical force	$-33°$	$-9°$	$0°$	$0°$
7.91	(a) Serber force	$-86°$	$-28°$	$7°$	$0°$
	(b) Symmetrical force	$-44°$	$-22°$	$-2°$	$0°$
9.92	(a) Serber force	$-95°$	$-39°$	$10°$	$-3°$
	(b) Symmetrical force	$-55°$	$-32°$	$-5°$	$0°$
11.93	(a) Serber force	$-101°$	$-47°$	$12°$	$-4°$
	(b) Symmetrical force	$-64°$	$-41°$	$-7°$	$-1°$

The lines labeled (a) and (b) shown with the experimental angular distributions in Figs. 3, 4, and 5 represent the theoretical predictions based, respectively, on the Serber and symmetrical exchange mixtures for the nucleon-nucleon interaction. It is to be noted that neither choice provides reasonable agreement with the data. These curves were calculated using the phase shifts given in reference 8; the values used are summarized in Table II.

At 3.03 MeV, the angular distribution is dominated by the Mott scattering cross section [curve (c)], thus making difficult a realistic comparison of the theoretical and experimental results. Consequently, a phase-shift analysis of this angular distribution was made with the

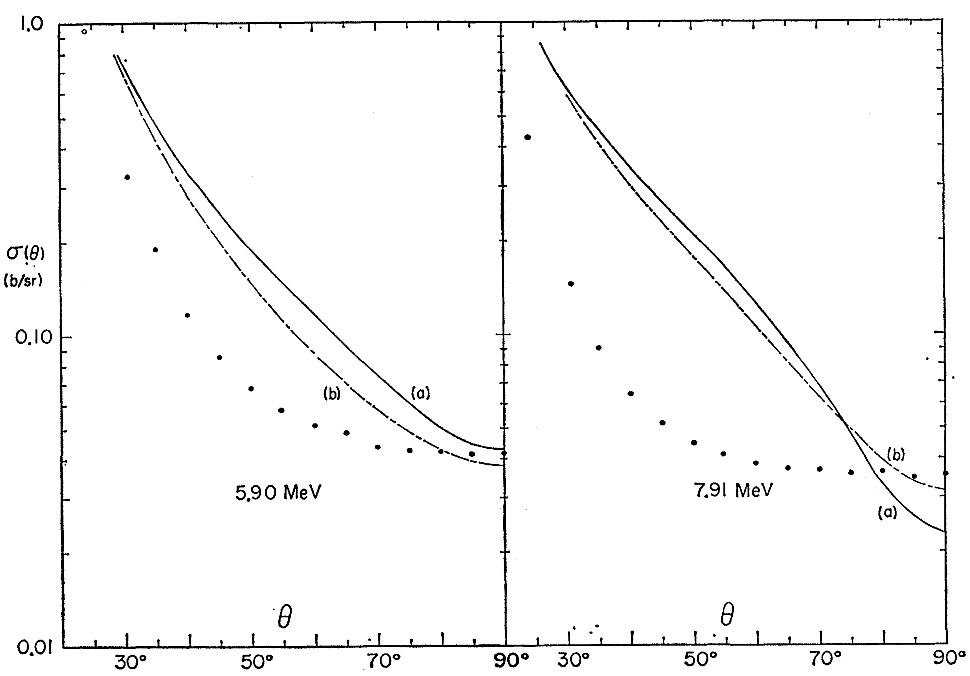

FIG. 4. The angular distributions for the elastic scattering of He^3 from He^3 at bombarding energies of 5.90 and 7.91 MeV. All symbols have the same significance as those given in Fig. 3.

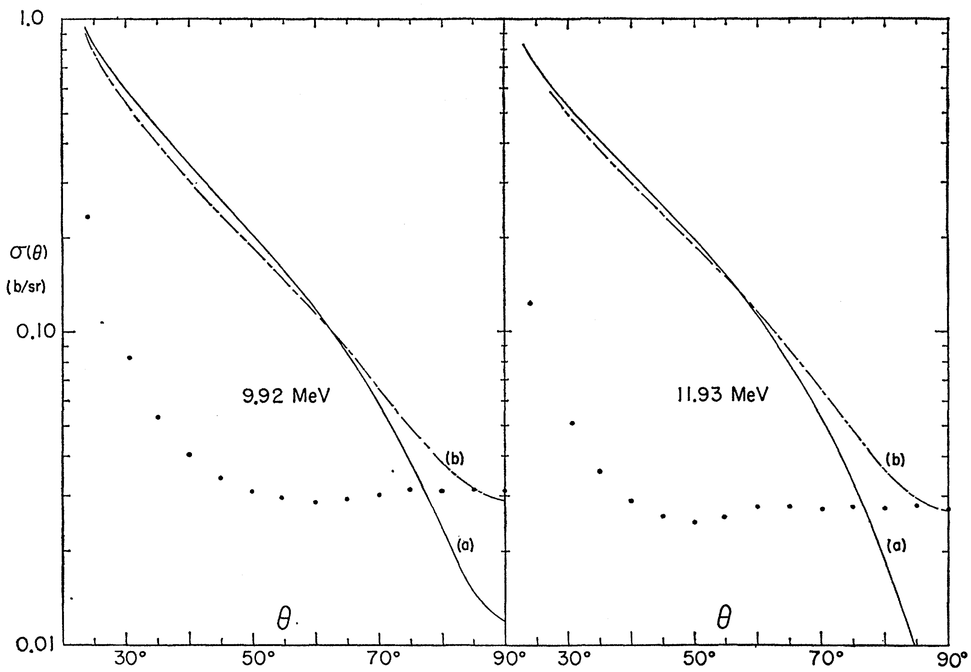

FIG. 5. The angular distributions for the elastic scattering of He^3 from He^3 at bombarding energies of 9.92 and 11.93 MeV. All symbols have the same significance as those given in Fig. 3.

same implied limitations as the theoretical calculations: The effect of the open reaction channel is neglected; and the triplet phase shifts are assumed to be unsplit. The resulting fit to the data is given by curve (d) in Fig. 3, and the derived phase shifts are listed in Table II. The S-wave phase shift obtained lies between those obtained for the Serber and symmetrical exchange force parameters. Because both the derived and predicted P- and D-wave phase shifts are small, no significant comparison of their values is possible.

There are several possible explanations for the lack of agreement between theory and experiment:

(1) The nucleon-nucleon potential used produces no effective spin-orbit interaction between the particles, and thus the triplet phase shifts ($l=1, 3, 5, \cdots$) remain unsplit in the calculation. This assumption could be checked by a measurement of the polarization of the scattered particles using He^4 as the analyzer in a double scattering experiment.[11,12]

(2) It is evident that the validity of the resonating group structure method depends closely on the extent that the configuration employed remains well defined. In all cases where this method has proved successful while using only a single configuration in the expansion of the wave function, that configuration chosen has been one of the most tightly bound of the possible forms. This does not hold for the present case, however, and it is quite likely that for such high excitations in Be^6 the wave function will include appreciable admixtures of the more tightly bound "two-body" configurations, Li^5+p and $He^4+(2p)$. Apart from the considerable new difficulties due to the fact that neither Li^5 nor $(2p)$ is stable, these extra configurations could be included in the expansion of the wave function in the same way that Burke and Laskar[13] consider the three open channels in the compound nucleus He^4.

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[12] T. A. Tombrello and P. D. Parker, following paper [Phys. Rev. **130**, 1112 (1963)].

ACKNOWLEDGMENTS

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[13] P. G. Burke and W. Laskar, Proc. Phys. Soc. (London) **77**, 49 (1961).