points. An experimental uncertainty of the magnitude of the differences of the separate measurements at each energy should be added to the statistical uncertainties shown in that figure.

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Nuclear Energy Levels in Mn55[†]

M. MAZARI,[*] A. SPERDUTO, AND W. W. BUECHNER
Physics Department and Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts
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Inelastically scattered protons from manganese targets bombarded with protons from an electrostatic accelerator have been studied with the high-resolution magnetic spectrograph. Forty-three excited states in Mn55 have been established in the region between the ground state and 4.0 Mev. The first five of these levels are at 0.127, 0.983, 1.289, 1.527, and 1.884 Mev.

THIS report describes the results of an investigation of the excited states of the nucleus Mn^{55}, carried out through studies of inelastically scattered protons. For this work, thin targets of manganese were prepared by evaporation of high-purity metal from a tungsten boat onto thin Formvar films. These targets were bombarded by the proton beam from the MIT-ONR electrostatic accelerator, and the charged-particle groups resulting from this bombardment were analyzed with the broad-range spectrograph. This equipment and details of the experimental procedure have been described in previous publications.[1-3]

Natural manganese consists entirely of the mass 55 isotope so that the analysis of the charged-particle groups observed was relatively simple. However, the proton spectrum was sufficiently complex so that measurements at various incident proton energies and at various angles were necessary to study various portions of the spectrum in detail. Observations were made with incident proton energies of 6.51, 6.77, 7.03, and 7.45 Mev and at angles of observation of 50, 90, and 130 degrees. Figure 1 shows a typical spectrum taken at 50 degrees with an incident energy of 7.03 Mev. Groups associated with elastic scattering from the various nuclei present in the target are identified by their chemical symbols. The variation of energy of these groups with angle of observation and incident proton

energy showed that, aside from the protons from elastic scattering from the tungsten, chlorine, sulfur, oxygen, nitrogen, carbon, and hydrogen impurities in the target, all the other peaks in the figure were from manganese. A group from the first excited state of S^{32} is coincident with group (9) from manganese at this energy and angle. Measurements at other angles and incident energies showed that, aside from group (1) in the figure, associated with an excited state at 0.127 Mev, there were none associated with manganese between the elastically scattered one and the one labeled (2) in the figure, which corresponds to an excited state in Mn^{55} at 0.983

TABLE I. Energy levels of Mn^{55} from the $Mn^{55}(p,p')$ reaction.

Level	Excitation energy (Mev)	Level	Excitation energy (Mev)
1	0.127±0.005	23	3.037±0.006
2	0.983±0.005	24	3.081±0.006
3	1.289±0.005	25	3.124±0.006
4	1.527±0.005	26	3.158±0.006
5	1.884±0.005	27	3.195±0.006
6	2.197±0.005	28	3.263±0.006
7	2.252±0.005	29	3.340±0.010
8	2.266±0.006	30	3.351±0.010
9	2.288±0.006	31	3.371±0.010
10	2.311±0.006	32	3.378±0.010
11	2.365±0.006	33	3.424±0.008
12	2.397±0.006	34	3.529±0.008
13	2.426±0.006	35	3.587±0.008
14	2.564±0.006	36	3.607±0.008
15	2.727±0.006	37	3.666±0.008
16	2.751±0.006	38	3.706±0.008
17	2.823±0.006	39	3.755±0.010
18	2.874±0.006	40	3.776±0.010
19	2.953±0.006	41	3.832±0.010
20	2.976±0.006	42	3.862±0.010
21	2.991±0.006	43	3.932±0.010
22	3.005±0.006		

1 Buechner, Braams, and Sperduto, Phys. Rev. 100, 1387 (1955).
2 Buechner, Mazari, and Sperduto, Phys. Rev. 101, 188 (1956).
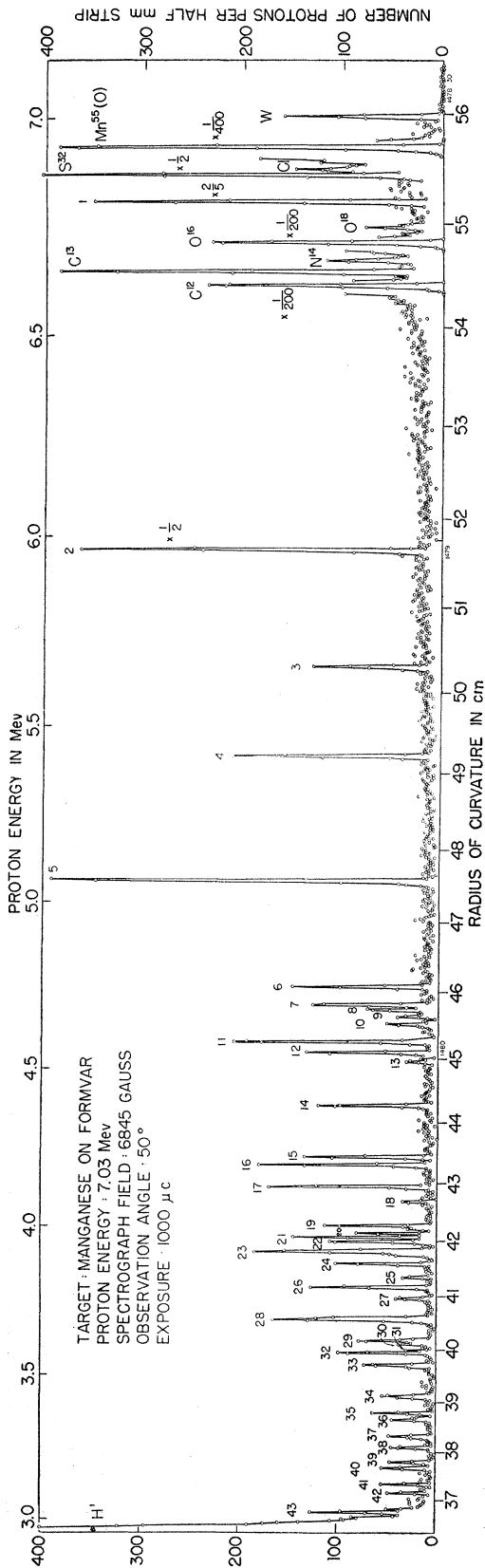3 C. P. Browne and W. W. Buechner, Rev. Sci. Instr. 27, 899 (1956).

FIG. 1. Typical spectrum of proton groups observed from a manganese target. In this case, the bombarding energy was 7.03 Mev, and the angle of observation was 50 degrees.
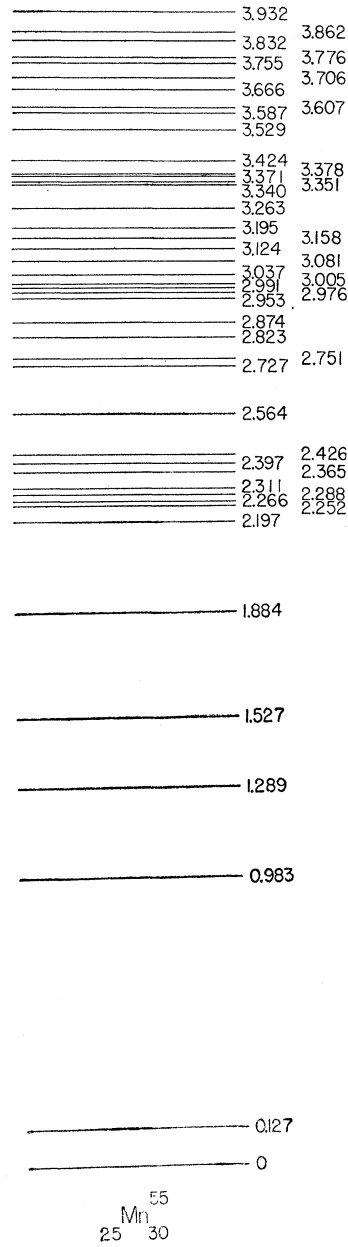

FIG. 2. Energy-level diagram for Mn^{55}.

Mev. In addition to the inelastically scattered protons, a number of low-intensity alpha-particle groups were observed. These were identified as originating in the $Mn^{55}(p,\alpha)Cr^{52}$ reaction and were investigated in a separate study, the results of which have been reported.[4]

The results of the present investigation are summarized in Table I. Except for the five highest energy levels, for which the results are based on two independent observations, all the groups were observed in at least three different bombardments, and the results listed are the mean values of all the observations. Except for

[4] Mazari, Buechner, and Sperduto, Phys. Rev. 107, 1383 (1957).

a few of the weaker groups, the deviations of the individual values from the ones listed were less than 5 kilovolts, although for group (29) there was a deviation of 8 kilovolts among the three observations on this group. Four of the observed peaks, (23), (28), (34), and (36), were wider than their neighbors in the spectra. It is probable that these groups consist of unresolved components, but no attempt was made in this work to use the smaller slit openings and thinner targets that would have been required for higher resolution. An energy-level diagram for Mn⁵⁵ is shown in Fig. 2. It is interesting to note the qualitative similarity of the level scheme of Mn⁵⁵ with those of other nuclei in the same mass region.[1,5] In Mn⁵⁵, as well as in V⁵¹ and Co⁵⁹, the other nuclei which have been carefully investigated, there are a relatively small number of levels between the ground state and approximately 2 Mev, and these are strongly excited in inelastic proton scattering, while above 2 Mev there is a very large number of levels that are only weakly excited.

Much of the previous work on Mn⁵⁵ has been summarized in the tabulations of Way et al.[6] The work most directly comparable with the present is that of Hausman et al.[7] who also studied inelastic proton scattering from manganese using an 8-Mev proton beam, the observations being made at 150 degrees. These workers reported levels at 0.13, 1.00, 1.30, 1.56, and 1.91 Mev, as well as ten other approximately equally spaced levels in the region up to 3.64 Mev. No detailed comparison is possible between the results for these higher excited states because of the limited resolution in the work of Hausman and his collaborators. There is good correspondence for the positions of the first five excited states, although these earlier results

are consistently higher than those reported here. Similar discrepancies have been found between the results of Hausman and those from this laboratory in the case of vanadium,[1] chromium,[4] and aluminum.[8]

Other results from studies of inelastically scattered particles are in good agreement with those presented here. Windham et al.,[9] from studies of inelastically scattered protons, have reported a value of 0.128 ±0.007 Mev for the first excited state. Inelastically scattered neutron groups have been reported by Cranberg and Levin[10] to correspond with levels in Mn⁵⁵ at 0.98, 1.29, and 1.53 Mev.

Other information regarding the excited states of manganese has been obtained from studies of the gamma radiations emitted under particle bombardment. A large number of workers have found a 0.128-Mev gamma ray resulting from proton, alpha-particle, and neutron bombardment of manganese targets. Higher energy gamma rays have also been reported from several investigations of inelastic neutron scattering.[11–14] These gamma rays have energies that correspond to various energy differences that can be found among the levels measured in the present work. This correspondence is not a sensitive check on the present values, however, because of the larger errors in the gamma-ray measurements.

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⁶ Nuclear Level Schemes, A =40 to A =92, compiled by Way, King, McGinnis, and van Lieshout, U. S. Atomic Energy Report TID–5300 (U. S. Government Printing Office, Washington, D. C., 1955).
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