energies. These electron binding energies must be those appropriate to orbitals in an uranium atom (or uranium oxide molecule) bound to the metal substrate. Even for the free atom the binding energies in the outermost shells are not well established, but for such a bound atom the minimum binding energy would appear to be the electronic work function of the surface. Though the orbitals of the ejected electrons are not known, it is clear that conversion can only be occurring in the P and Q shells in which binding energies for the free atom range from a few up to about 50 ev. Since only about one electron is ejected per disintegration there must be few Auger electrons accompanying each conversion electron. If we take the upper energy limit of the electrons as 19 ev, we may reasonably assume it to correspond to a conversion electron from the least bound shell and add only about 4 ev for the metal work function to obtain an upper limit of 23 ev for the transition energy.

For the decay of a $\frac{1}{2}+$ state of 23-ev excitation to a $\frac{7}{2}-$ state by $E3$ transition, the theoretical lifetime for photon emission is $\sim 10^{15}$ years, if one uses Weisskopf's formula. The experimental lifetime of 26 minutes corresponds to a conversion coefficient $\alpha_3 = 10^{19}$. For whatever the comparison may be worth, one notes that the theoretical value for the threshold K conversion coefficient for hydrogen (13.6 ev transition energy) for $E3$ transition is[8] $\alpha_3 = 2\times 10^{15}$.

[8] B. I. Spinrad, Phys. Rev. **98**, 1302 (1955).

As stated in the introduction, no photon counts were observed through a 2-μg/cm^2 optically transparent absorber. However, the process of conversion in the outer shells might reasonably be expected to be accompanied by the emission of photons in the optical or ultraviolet range, of the order of one such photon per electron. A source of U^{235m} on a 3-mm brass disk was placed on an Eastman 103 a-F ultraviolet sensitive plate for one hour. No image was observable on developing, despite over 10^7 disintegrations having irradiated the emulsion. As a spot should be visible with about 10^8 photons on this area, the result is credible. Examination of the photon spectrum with a photomultiplier cooled to liquid nitrogen temperature should be undertaken.

For the anomalous rotational band based on the $\frac{1}{2}-$ level ($\frac{3}{2}-$ level at 12.5 kev, $\frac{5}{2}-$ level at 50.8 kev),[9] one calculates a decoupling parameter[10] $a = -0.628$.

It is interesting to consider the experimental possibility of exciting this very low-lying state by Coulomb excitation by using moderate-energy intense beams of ions or electrons.

ACKNOWLEDGMENTS

Mr. Howard Ruhde of the Metallurgy division kindly prepared the evaporated plutonium emanating source.

[9] K. N. Shliagin, Zhur. Eksptl. i Teort. Fiz. **30**, 817 (1956) [translation: Soviet Phys. JETP **3**, 663 (1956)].

[10] A Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 16 (1953).

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Excited States in Mn^{56}†

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An electrostatic accelerator and a broad-range magnetic spectrograph were employed to investigate the excited states of Mn^{56} by means of the $Mn^{55}(d,p)Mn^{56}$ reaction. The proton groups from thin manganese targets were observed at 10, 30, and 60 degrees with an incident deuteron energy of 7.0 Mev and at 20 degrees with 6.6-Mev deuterons. In the region of excitation in Mn^{56} up to 7 Mev, 124 excited states were found. The ground-state Q-value for the reaction is 5.047±0.005 Mev, and the first excited state is at 0.025±0.004 Mev.

FOR some time, this laboratory has been engaged in a general program of nuclear spectroscopy, and recently much of the research has been concerned with the determination of the energy-level schemes of the nuclei between mass numbers 40 and 70. The present paper reports the results of studies on the excited states of Mn^{56} carried out through the $Mn^{55}(d,p)Mn^{56}$ reaction.

Previous investigations of the bound states of Mn^{56} have been carried out through the (d,p) and (n,γ) reactions. The results of these studies have been summarized,[1] and they indicate the existence of sixteen

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[1] *Nuclear Level Schemes*, $A = 40$–$A = 92$, compiled by Way, King, McGinnis, and van Lieshout, Atomic Energy Commission Report TID-5300 (U. S. Government Printing Office, Washington, D. C., 1955).

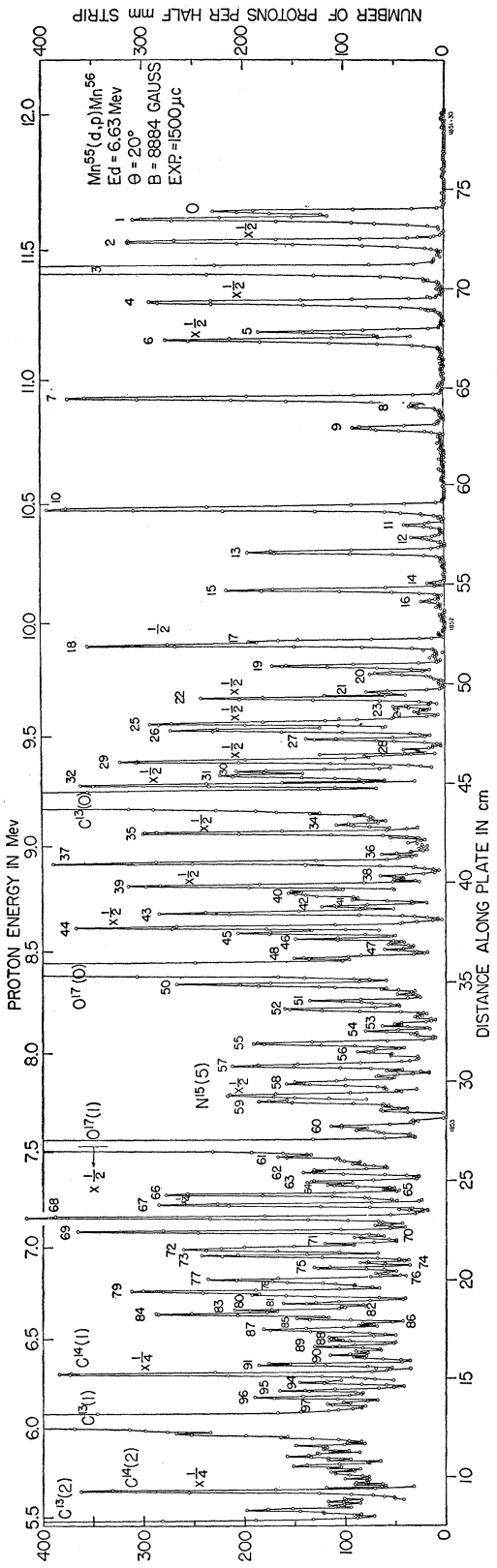

Fig. 1. Proton groups observed at 20 degrees from a thin manganese target bombarded with 6.5-Mev deuterons.

excited states in the region between the ground state and an excitation energy of 5.2 Mev. This is a surprisingly low density of states for an odd-odd nucleus in this region of the periodic table, and the present results show that the level scheme of Mn^{56} is, as would be expected, considerably more complex than was indicated by the previous reaction studies.

In the present work, the MIT-ONR electrostatic accelerator was used to provide the deuteron beam, and the protons emitted from the bombarded manganese targets were analyzed with the broad-range spectrograph. This equipment and the techniques employed in its use for studies of (d,p) reactions have been described in other publications.[2,3] The thin targets for this work were prepared by the evaporation of high-purity manganese metal onto thin Formvar foils which were supported by wire frames. Optical spectroscopic analysis of the manganese showed only small amounts of magnesium, copper, and calcium as contaminants. In a parallel investigation of inelastic proton scattering from manganese, the same targets were employed, and a mass analysis carried out through studies of elastically scattered proton groups showed only the additional contamination of hydrogen, carbon, nitrogen, sodium, sulfur, and chlorine normally present in the Formvar and of tungsten deposited during the evaporation process. The identification of the proton groups observed during the course of the (d,p) studies was based on the change in energy of the groups with angle of observation and bombarding energy.

The distributions in energy of the protons emitted at angles of 10, 30, and 60 degrees, with respect to the beam, were measured using a deuteron energy of 7.0 Mev, and at 20 degrees, with respect to the beam, with 6.6-Mev deuterons. The results obtained at 20 degrees are shown in Fig. 1. With such a high density of groups, it was inevitable that, at each angle of observation, some were obscured by the intense peaks from the carbon and oxygen contamination. The angles used were chosen so that every region in the spectrum could be studied in at least two of the exposures. The highest energy group observed at each of the four angles of observation was assumed to be associated with the ground-state transition in $Mn^{55}(d,p)Mn^{56}$. The Q-values calculated from each of these observations agreed to within 1 kev, the average value being 5.047 Mev. The Q values for the other groups associated with manganese were calculated, and the average value for each group, as determined from the various exposures in which it was observed, was subtracted from the ground-state Q value to give the corresponding excitation energy in Mn^{56}. The excitation energies obtained in this way are listed in Table I.

In general, the individual Q-values for a particular group differed from the average used for calculating

[2] Buechner, Mazari, and Sperduto, Phys. Rev. **101**, 188 (1956).
[3] C. P. Browne and W. W. Buechner, Rev. Sci. Instr. **27**, 899 (1956).

TABLE I. Excited states of Mn^{56}. $Q_0=5.047\pm0.005$ Mev. Energy measurements were made for proton groups emitted at 10°, 30°, and 60° relative to the beam ($E_d=7.0$ Mev) and at 20° relative to the beam ($E_d=6.6$ Mev).[a]

Level[a]	E_x (Mev)	Level[a]	E_x (Mev)
1	0.025±0.004	51*	3.375±0.008
2	0.108±0.004	52	3.413±0.008
3	0.207±0.004	53*	3.492±0.008
4	0.336±0.004	54*	3.526±0.008
5	0.447±0.004	55	3.582±0.008
6	0.479±0.009	56	3.622±0.008
7	0.712±0.004	57	3.691±0.008
8	0.750±0.004	58*	3.776±0.008
9	0.835±0.004	59	3.872±0.010
10	1.161±0.004	60	3.994±0.008
11	1.233±0.004	61*	4.160±0.008
12	1.290±0.004	62	4.229±0.008
13	1.345±0.004	63	4.283±0.008
14*	1.481±0.006	64	4.300±0.008
15	1.504±0.006	65	4.323±0.008
16*	1.556±0.006	66	4.352±0.008
17	1.725±0.006	67	4.404±0.008
18	1.739±0.006	68	4.471±0.008
19*	1.832±0.006	69	4.547±0.008
20*	1.865±0.006	70	4.580±0.008
21	1.947±0.006	71	4.608±0.008
22	1.973±0.006	72	4.628±0.008
23	2.013±0.006	73	4.673±0.008
24	2.036±0.006	74	4.709±0.008
25	2.082±0.006	75	4.738±0.008
26	2.111±0.006	76	4.765±0.008
27	2.156±0.006	77	4.796±0.008
28	2.231±0.006	78	4.818±0.008
29	2.250±0.007	79	4.862±0.008
30	2.295±0.007	80	4.886±0.008
31	2.315±0.007	81	4.923±0.008
32	2.359±0.007	82	4.942±0.008
33	2.388±0.007	83	4.966±0.008
34*	2.545±0.007	84	4.986±0.008
35	2.578±0.007	85	5.012±0.008
36*	2.685±0.007	86	5.038±0.008
37	2.718±0.007	87	5.065±0.010
38*	2.782±0.007	88	5.112±0.010
39	2.821±0.007	89	5.157±0.012
40	2.851±0.007	90	5.204±0.012
41	2.866±0.007	91	5.257±0.012
42	2.919±0.007	92	5.292±0.012
43	2.951±0.007	93	5.340±0.012
44	3.017±0.007	94	5.359±0.012
45	3.044±0.007	95	5.404±0.012
46	3.075±0.008	96	5.438±0.012
47*	3.133±0.008	97	5.472±0.012
48*	3.164±0.008	98	5.518±0.012
49	3.239±0.008	99	5.548±0.012
50	3.288±0.008	100	5.590±0.012

[a] The asterisk denotes levels for which energy measurements were made only in the 20° exposure.

the excitation energy by less than 3 kev, although, for thirteen of the groups, one of the Q-values used in making the average differed from the mean by 4 kev, and in nine cases the difference was 5 kev. For levels No. 59, 87, and 96, the maximum deviation was 6 kev; while, for levels 91 and 94, the maximum deviation observed was 7 kev. Fourteen of the groups were observed with an intensity sufficient for an energy measurement only in the 20-degree exposure. The associated levels are indicated in Table I by asterisks.

Table I summarizes the data in the region of excitation between the ground state and 5.6 Mev. Also recorded during the various exposures were proton groups that had energies corresponding to excited states in Mn^{56} up to 7 Mev. In the region between 5.6 and 7 Mev, evidence was found for at least twenty-four excited states. The proton groups corresponding to this range of excitation energies were, however, for the most part composed of several unresolved components, and we do not feel it worth while to present the data for this region.

The data in the present experiment were taken over a considerable interval of time, and the various exposures were made with different targets whose thicknesses were not accurately determined. Consequently, it is not possible to draw any direct conclusions regarding the angular distributions of the proton groups. However, the angular distributions of the groups associated with the ground state and with the first, second, third, fourth, and sixth excited states were the same within approximately 25%.

The highest energy gamma ray observed by Bartholomew and Kinsey[4] in their study of neutron-capture radiation in Mn^{56} was 7.261±0.006 Mev. This is somewhat lower than would be predicted on the basis of the present measurements for the ground-state transition in the (n,γ) reaction. While these two measurements are in agreement within the experimental errors, the close proximity of the 25-kev first excited state in Mn^{56} raises the question as to whether the highest energy neutron-capture gamma ray arose from a transition to the ground state or to the first excited state. That it is actually associated with the ground-state transition is indicated by the close agreement between the energies for the second, third, and sixth excited states obtained in the present measurements and those deduced from the assumption that the highest energy gamma ray originated in the ground-state transition.

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[4] G. A. Bartholomew and B. B. Kinsey, Phys. Rev. **89**, 386 (1953).