by Ambrozy *et al.*[12] They give a value of

$$\tau=(1.5_{-0.2}^{+0.3})\times10^{-12}\text{ sec.}$$

Unified model calculations by Paul and Montague[13] have been carried out on Na^{23} and these give a value of

$$\tau(M1)=4\times10^{-13}\text{ sec}$$

for the 440 keV level as a "first trial." The lifetime as calculated by the Weisskopf formula gives the same result.

[12] B. Ambrozy, A. Faudrowicz, A. Jasinski, J. Kownacki, H. Lancman, and J. Ludziejewski, in *Proceedings of the Rutherford Jubilee International Conference, Manchester, 1961*, edited by J. B. Berks (Heywood and Company, Ltd., London, 1961), p. 281.

[13] E. B. Paul and J. H. Montague, Nuclear Phys. **8**, 61 (1958).

ACKNOWLEDGMENTS

The authors wish to express their grateful appreciation to Dr. J. F. H. Custers, Director of the Diamond Research Laboratory, for the generous use of the electron accelerator. We acknowledge also the assistance of V. Tullet in running the machine.

PHYSICAL REVIEW VOLUME 128, NUMBER 6 DECEMBER 15, 1962

Beta Spectrum of Mn^{56}†

D. A. Howe, L. M. Langer, E. H. Spejewski and D. E. Wortman
Indiana University, Bloomington, Indiana
(Received July 24, 1962)

A detailed magnetic spectrometer study of the beta spectrum of Mn^{56} was made with particular emphasis on the shape of the highest energy group. In spite of the high comparative half-life for this 3+ to 2+ allowed transition, no evidence was found for any contribution to the shape factor from higher order terms. The beta spectrum consists of the following groups: 2.838 MeV, 47%, $\log ft=7.1$; 1.028 MeV, 34%, $\log ft=5.3$; 0.718 MeV, 18%, $\log ft=5.5$; 0.30, $\approx$1.%, $\log ft=5.3$.

1. INTRODUCTION

The shape of the highest energy beta-ray group in the transformation of Mn^{56} is of interest because the relatively high comparative half-life for this transition implies that the influence of the allowed matrix elements is reduced and suggests that the contribution of twice forbidden matrix elements to the decay might become observable.

Earlier investigations have established the general features of the decay scheme.[1–5] The reported half-life is 2.58 h. The ground state of Mn^{56} has been determined to be 3+. The beta decay from this 3+ level to the ground state of Fe^{56} has not been observed. Beta branches to 2+ levels at 845, 2660, 2958, and 3388 keV are present. There is a conspicuous absence of any feeding of the known 4+ level at 2085 keV. The most intense beta group goes to the 845-keV level. Furthermore, the comparative half-life ($\log ft=7.1$) is rather high for an allowed transition.

In the present investigation, the beta spectrum of Mn^{56} was studied in detail with particular emphasis on the shape of the highest energy group.

2. SPECTROMETER

In this investigation, the 40 cm radius of curvature, shaped magnetic field spectrometer was used.[6] Certain improvements on the original design have been made, and these have been discussed in previous papers.[7–9] In addition, two other changes should be mentioned. First, the main defining baffles were replaced by $\frac{1}{16}$-in.-thick Ta baffles to further minimize any scattering from the baffle edges. Second, a commercial rotating coil gaussmeter[10] was used to measure the magnetic field.

The spectrometer was calibrated by means of the K internal conversion lines of Bi^{207} and Cs^{137} and also by means of the F line of ThB. The standard $H\rho$ values of these are 4657.9, 3381.28, and 1388.44 G-cm, respectively. The effective radius for each line was found to be 40.670, 40.674, and 40.677 cm, respectively. This is a variation of less than one part in 10 000, confirming the excellent linearity of the gaussmeter as claimed by the manufacturer.

An end window proportional counter with a loop anode was used as a detector. The counter window was 0.9-mg/cm² aluminized Mylar. Previous measurements[8] have shown that there is no inherent energy dependence

† This work was supported in part by a grant from the Office of Naval Research.

[1] A. A. Townsend, Proc. Roy. Soc. (London) **A177**, 357 (1941).

[2] L. G. Elliott and M. Deutsch, Phys. Rev. **69**, 321 (1943).

[3] K. Siegbahn, Arkiv Mat. Astron. Fysik **33A** No. 10 (1946).

[4] P. Kienle and R. E. Segel, Phys. Rev. **114**, 1554 (1959).

[5] W. J. Childs and L. S. Goodman, Bull. Am. Phys. Soc. **3**, 21 (1958); W. J. Childs, L. S. Goodman, and L. J. Kieffer, Phys. Rev. **122**, 891 (1961).

[6] L. M. Langer and C. S. Cook, Rev. Sci. Instr. **19**, 257 (1948).

[7] J. H. Hamilton, L. M. Langer, and W. G. Smith, Phys. Rev. **112**, 2010 (1958).

[8] O. E. Johnson, R. G. Johnson, and L. M. Langer, Phys. Rev. **112**, 2004 (1958).

[9] J. H. Hamilton, L. M. Langer, R. L. Robinson, and W. G. Smith, Phys. Rev. **112**, 945 (1958).

[10] Rawson-Lush Rotating Coil 820-Gaussmeter.

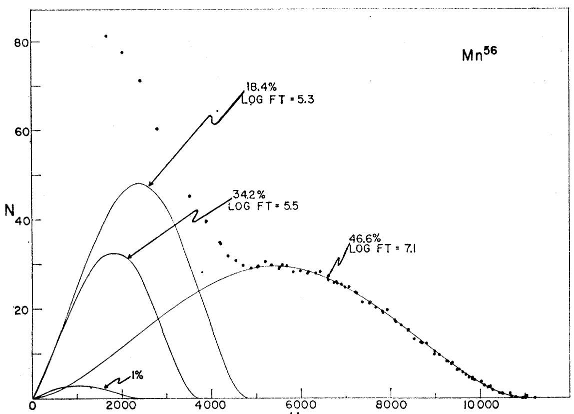


FIG. 1. Beta spectrum of Mn^{56}. The analysis is based on the Fermi-Kurie plots shown in Fig. 2.

in the sensitivity of the counter over the region of interest.

3. SOURCE PREPARATION

A four liter glass bottle containing an 80% saturated solution of $KMnO_4$ was irradiated with slow neutrons produced by bombarding a beryllium target with deuterons in the Indiana University cyclotron. A water moderator surrounded the bottle in order to reduce the number of fast neutrons reaching the $KMnO_4$. Immediately before the bombardment, the $KMnO_4$ solution was passed twice through a fritted glass filter in order to remove inactive MnO_2 precipitate. These steps are necessary in order to obtain a source of high specific activity. The $KMnO_4$ was irradiated for approximately 3 h. The radioactive Mn^{56} was separated from the inert Mn by the Szilard-Chalmers process.[11]

The desired activity was in the form of MnO_2 precipitate. Therefore, most of the MnO_2 was separated out by a simple filtration. The filtrate was washed with distilled water; next it was flushed out of the filter with

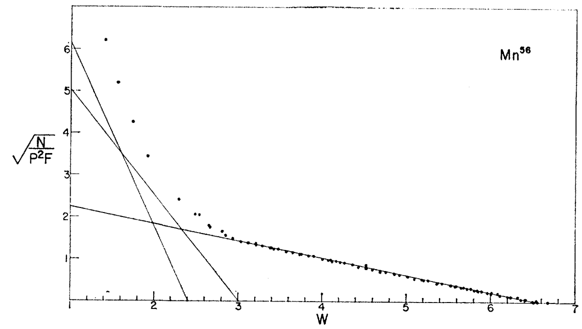


FIG. 2. Fermi-Kurie analysis for the beta spectrum of Mn^{56}.

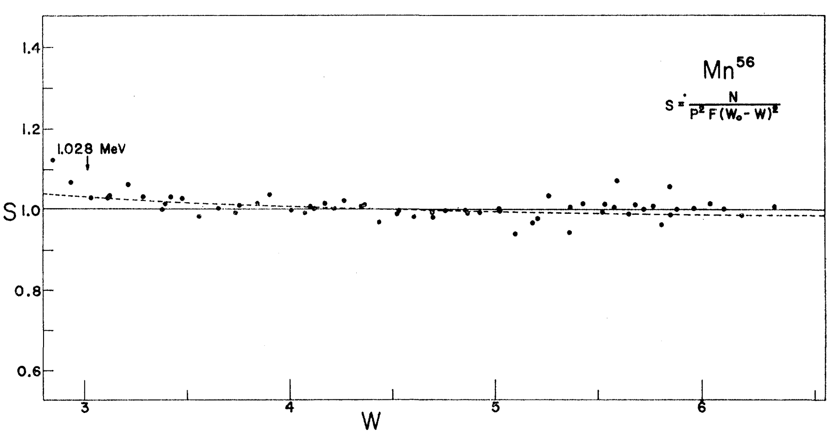
warm concentrated HCl. This solution was heated to drive off the excess HCl until a few drops of highly concentrated activity remained. This activity was liquid deposited onto a Mylar backing. Insulin was used to define the source.[12] The activity was very uniformly distributed over the 0.4×2.5 cm² source area. The source thickness, which was about 1 mg/cm², should not have introduced any measurable distortion into the shape of the spectrum. Finally, the MnCl source, which is deliquescent, was dried and covered with a thin (≈ 20 μg/cm²) zapon film. The source, thus prepared, was quickly inserted into the evacuated spectrometer.

The gamma-ray spectrum of Mn^{56} was observed with a NaI(Tl) crystal and a 400-channel analyzer. Gamma rays at 845, 1810, 2120, 2660, 2960, and 3380 keV were observed in agreement with the accepted decay scheme. The gamma spectrum was followed over several half-lives, and there was no evidence of any impurity. The half-life was found to be 2.6 h.

4. DATA AND RESULTS

Five Mn^{56} beta-ray sources were prepared from five bombardments of Mn^{55} as described above. At least two runs through the spectrum were made for each source. The β spectrum of Mn^{56} is shown in Fig. 1.

FIG. 3. Shape factor plot of the high-energy group of Mn^{56}. The solid line represents a theoretical shape factor expected for an allowed transition. The dashed curve shows the empirical $1+0.3/W$ shape factor which has been found for other decays.



[11] L. Szilard and T. A. Chalmers, Nature **134**, 462 (1934).
[12] L. M. Langer, Rev. Sci. Instr. **20**, 216 (1949).

The Fermi-Kurie plot is shown in Fig. 2. Each of these graphs contains data accumulated from the runs on different sources. The counting intervals for each point were from four to twenty minutes. The statistical accuracy of most of the points is about one percent.

In taking the data, emphasis was placed on the high energy group because of the interest in its shape. The end-point energy of this group is found to be 2.838 $\pm$0.005 MeV. In addition, the electron spectrum was resolved into four groups. The highest energy group at 2.838 MeV was found to have an intensity of 47% (log $ft=7.1$). The intensity of the next group at 1.028 MeV is 34% (log $ft=5.3$). The third group at 0.718 MeV makes up 18% of the decays (log $ft=5.5$). The intensity of the fourth group at 0.30 MeV was taken as 1% as determined by gamma-ray measurements. It was felt that the thickness of the source used in these experiments would have introduced appreciable distortion in the low-energy region occupied by the last group.

A shape factor plot is shown in Fig. 3 for the highest energy group. The beginning of the next group is marked at 1.028 MeV. An allowed shape factor, $S=1$, is shown along with an empirical shape factor,[7] $1+0.3/W$ (where W is the total β energy in mc^2 units), which has been found to fit all well-measured beta spectra. The experimentally observed spectrum is consistent with either of these shape factors.

5. CONCLUSION

The shape of the beta spectrum involved in the decay of Mn^{56} to the first excited state of Fe^{56} has been measured. No evidence for a deviation from the allowed shape was observed. However, measurements are also consistent with a shape factor of the form $1+0.3/W$. There is no evidence of a contribution from twice forbidden matrix elements.

ACKNOWLEDGMENTS

The authors wish to thank the Indiana University Cyclotron Group for making the bombardments. J. DiSalvo is thanked for helping with the chemical separation.

PHYSICAL REVIEW VOLUME 128, NUMBER 6 DECEMBER 15, 1962

Nuclear Excitation by 180° Electron Scattering*

R. D. EDGE† AND G. A. PETERSON‡
High-Energy Physics Laboratory, Stanford University, Stanford, California
(Received July 23, 1962)

We have studied magnetic multipole transitions in Be^9, B^{10}, B^{11}, C^{12}, N^{14}, O^{16}, and Si^{28} by measuring the energy spectra resulting from the scattering of 41.5-MeV primary electrons through an angle of 180°. At this angle of scattering, electric multipole transitions were greatly suppressed, and in addition, the background radiation tail accompanying the elastic peak was minimized. Inelastic electron scattering cross sections were obtained by comparing the inelastic peaks to the electron-proton elastic scattering peak and radiation widths were deduced by using virtual photon theory. Inelastic scattering peaks corresponding to excitation energies of 2.4 and 14.7 MeV were measured for Be^9; 7.9, 11.8, and 14.0 MeV for B^{10}; 2.1, 4.4, 4.9, 7.3, 9.1, 10.4, and 12.9 MeV for B^{11}; 15.1 MeV for C^{12}; 9.2 and 10.5 MeV for N^{14}; and 11.6 MeV for Si^{28}. No excitations were observed for O^{16} below 15 MeV, and no excitations were observed in Ca^{40} below the giant resonance for 160° electron scattering.

I. INTRODUCTION

IN nuclear excitation by electron scattering, in contrast to photon absorption, it is possible to uncouple the momentum and energy transfer so that a given type of multipole transition is enhanced by a proper choice of scattering kinematics. By observing electrons of energies of the order of 200 MeV, scattered through intermediate angles, Fregeau,[1] Helm,[2] and others[3] have studied electric multipole transitions. By observing 40-MeV electrons scattered through angles of 132° and 160°, Barber *et al.*[4] have studied magnetic dipole transitions. According to Schiff,[5] the optimum electron scattering angle for the detection of magnetic transitions with a minimum of electric multipole contributions is 180°.

An attendant feature of 180° electron scattering is the reduction of elastic scattering and the background spectrum of electrons resulting from scattering accompanied by radiation. This spectrum, sometimes referred to as the radiation tail, presents severe back-

* This work was supported by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the Air Force Office of Scientific Research.
† On leave of absence from the University of South Carolina, Columbia, South Carolina.
‡ Present address: Yale University, New Haven, Connecticut.
[1] J. H. Fregeau, Phys. Rev. **104**, 225 (1956).
[2] R. H. Helm, Phys. Rev. **104**, 1466 (1956).
[3] H. Crannell, R. Helm, H. Kendall, J. Oeser, and M. Yearian, Phys. Rev. **123**, 923 (1961); W. C. Barber, Ann. Rev. Nuclear Sci. (to be published).
[4] W. C. Barber, F. Berthold, G. Fricke, and F. E. Gudden, Phys. Rev. **120**, 2081 (1960).
[5] L. I. Schiff. Phys. Rev. **96**, 765 (1954).