Half-Lives of Some Nuclear States in the Millimicrosecond Region*

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A time-to-pulse height converter, fast coincidence arrangement, and multichannel analyzer were used to measure half-lives of some nuclear states in the millimicrosecond range. The half-lives of the following nuclear states were measured: the 325-kev level in V^{51}, $(2.80\pm0.04)\times10^{-10}$ sec; the 555-kev level in Mn^{52}, $(1.85\pm0.07)\times10^{-9}$ sec; the 1490-kev level in Co^{57}, $(1.00\pm0.05)\times10^{-9}$ sec; the 245-kev level in Se^{77}, $(1.30\pm0.08)\times10^{-9}$ sec; the 155-kev level in Sb^{119}, $(0.83\pm0.2)\times10^{-9}$ sec; the 123-kev level in Cs^{131}, $(4.15\pm0.08)\times10^{-9}$ sec; and the 103-kev level in Eu^{153}, $(3.8\pm0.02)\times10^{-9}$ sec. The well-known level of Ta^{181} at 48 kev gives $(1.10\pm0.02)\times10^{-8}$ sec and that of Gd^{154} at 122 kev, 1.15×10^{-9} sec. A comparison with the results given by theory is made.

INTRODUCTION

IT is well known that transition probabilities of electromagnetic radiations resulting from the transition of a nucleus from one excited level to another depends strongly on the multipole character and the energy of excitation of the levels concerned. The multipole character, in turn, depends on the characters of the levels involved in the transition, namely their spins and parities. Expressions for the transition probability have been derived in terms of the amount of angular momentum carried away by the electromagnetic radiation, and the energy difference between the levels. These expressions depend on the wave functions ascribed to the states, and hence are dependent on the nuclear model chosen. The single particle model has been used by Weisskopf[1] and Moszkowski.[2] Such formulas are limited in their range of applicability, due to the limitations of the model. Bohr and Mottelson[3] have applied the collective model of the nucleus to the calculation of transition probabilities in the region of intermediate and heavy elements. It is the purpose of this paper to describe a few measurements of half-lives of excited states which lie in the millimicrosecond region and to compare them with the predictions of the theories cited above. Some of the half-lives have been measured by other workers using techniques other than that described herein. Some others are of interest on account of the fact that the isotopes themselves have been investigated entirely in this laboratory. The remaining are expected to have half-lives in the range of interest of the present experiment.

EXPERIMENTAL ARRANGEMENTS

The measurements were made with a time-to-pulse height converter similar in practically all respects to the one described by Green and Bell.[4] In measuring the half-life of a given nuclear level, two radiations, A and B, are chosen, one of which terminates on the level in question and the other proceeds from it. The source is placed symmetrically between two NaI(Tl) crystals used in conjunction with 14-element RCA 6810 A photomultipliers. A block diagram of the apparatus is shown in Fig. 1.

Pulses from the anode of each photomultiplier pass through a limiter and are then fed to the time-to-pulse height converter and to a fast coincidence circuit. The anode pulse from the photomultiplier cuts off the steady plate current maintained in a Western Electric 404 A pentode (see Fig. 2). The load in the plate circuit of the tube is a branched 125-ohm coaxial cable type RG 63/U, whose length can be suitably adjusted to give a pulse of the required duration and delay.

The delay between such clipped pulses is measured by the time-to-pulse height converter. It uses a 6BN6 gated beam tube (see Fig. 2) whose two control grids are biased to just cut off the anode current. Positive pulses from the two scintillation counters A and B are applied to the two grids and the plate current flows during the interval in which the pulses overlap. An integrating circuit converts this into a pulse height

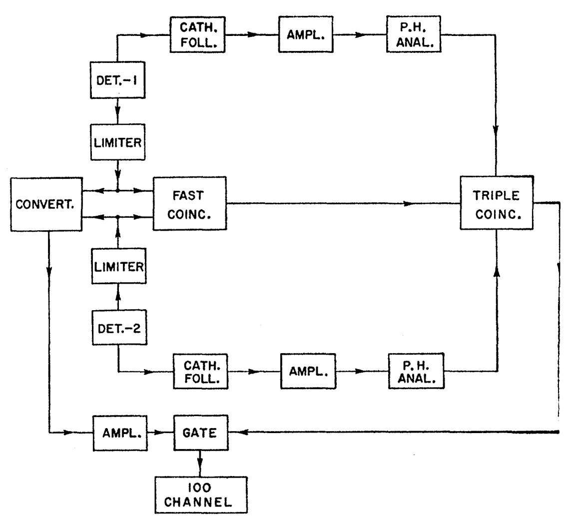

FIG. 1. Block diagram of apparatus for measuring half-lives.

* Supported by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] V. F. Weisskopf, Phys. Rev. 83, 1073 (1951).
[2] S. A. Moszkowski, *Beta- and Gamma-ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1955), Chap. 13, p. 391.
[3] A. Bohr and B. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. 27, No. 16 (1953).
[4] R. E. Green and R. E. Bell, Nuclear Instruments 3, 127 (1958).

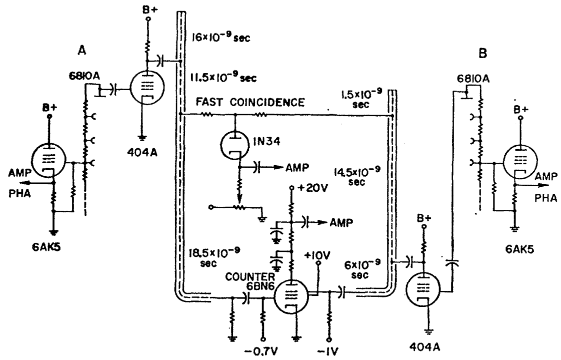

FIG. 2. Time-to-pulse height converter with clipping cables.

proportional to the delay between A and B. The fast coincidence circuit shown in Figs. 1 and 2 acts as a supervisory circuit and insures that radiation A precedes B. The action of this circuit is discussed in detail by Green and Bell[4] and will not be further elucidated here.

The energy selection of the radiations concerned is accomplished by taking the out-put at the tenth dynode of the photomultiplier. The pulse so obtained is amplified, and the energy chosen at the out-put of a single-channel pulse-height analyzer. The out-puts of the two pulse-height analyzers, and that of a fast coincidence circuit which operates on the limited pulses from the 404-A pentodes are fed to a slow triple coincidence circuit. The out-put from the triple coincidence circuit opens the gate in a 100-channel pulse-height analyzer to which the pulses from the time-to-pulse height converter are fed. The 100 channel analyzer, therefore, records the number of events $A \rightarrow B$ as a function of the pulse height, which in turn is proportional to the delay between A and B.

The apparatus is calibrated with the help of prompt coincidences between the positron annihilation quanta of a Na^{22} source. Known delays are inserted in branch B, and the "prompt" peaks are recorded. The displacement of the prompt peaks on the analyzer is found to be proportional to the delays up to 30×10^{-9} sec. In addition, the slope of the prompt curve corresponding to 0.14×10^{-9} sec half-life gives a lower limit to the half-life measurable by this device (see Fig. 3).

MEASUREMENTS

The method extensively used for measuring half-lives has been the delayed coincidence technique. Since not many measurements have been made by the present method, it was felt necessary to compare the results of the two methods for well-known cases. The 482-kev level in Ta^{181}, and 123-kev level in Gd^{154} are well-known cases and could be used as suitable check points. The values quoted are 1.10×10^{-8} sec[5] for Ta^{181} and 1.2×10^{-9}

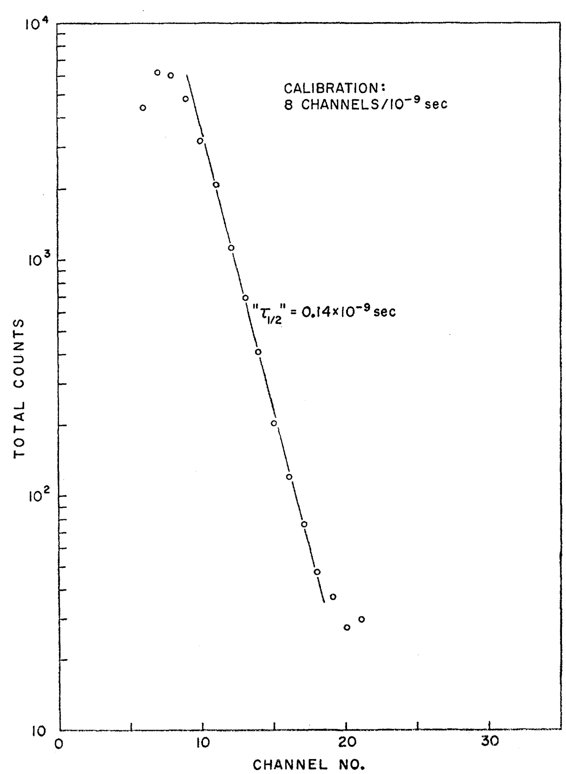

FIG. 3. "Prompt" decay: annihilation radiation of positrons from Na^{22}.

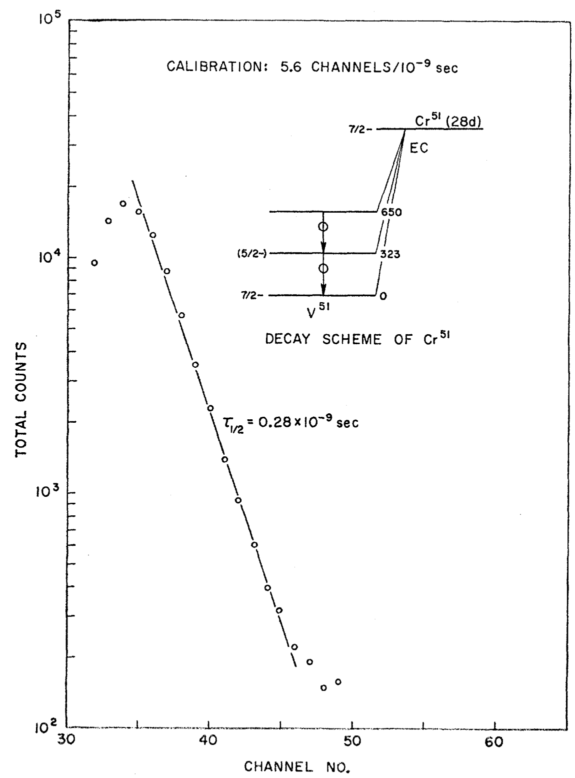

FIG. 4. Decay curve for 323-kev level in V^{51}.

[5] T. C. Engelder, Phys. Rev. 90, 259 (1953).

sec[6] for Gd^{154}. We have measured these half-lives using, in the former case, the 133-kev and 482-kev gamma rays, and in the latter, the 875-kev and 123-kev transitions. The values obtained are $(1.10\pm0.02)\times10^{-8}$ sec, and $(1.15\pm0.03)\times10^{-9}$ sec.

LIFETIMES OF OTHER STATES

The 323-kev Level in V^{51}

The 28-day Cr^{51} decays entirely by electron capture to V^{51}. Most of the transitions are to the ground state and only about 9% to the first excited 323-kev state and approximately 1.5×10^{-3}% to the 650-kev excited state. Hence, there are two gamma rays of approximately equal energies. The half-life has been measured previously by Schopper[7] using the resonance fluorescence capture technique obtaining a value 1.0×10^{-10} sec, and Sunyar, using the delayed coincidence technique, who obtained a value of 2.8×10^{-10} sec.

The present measurement gives a value $(2.8\pm0.4)\times10^{-10}$ sec, a typical curve being shown in Fig. 4, in agreement with Sunyar.

The 555-kev Excited Level in Mn^{52}

Mn^{52} is formed by orbital electron-capture and positron decay in Fe^{52} with a half-life of 8 hours. The decay scheme as established by Juliano *et al.*[8] is shown in Fig. 5.

The half-life of the 555-kev level was measured using the 511-kev gamma radiation produced by the annihilation of positrons and the 165-kev transition to the 390-kev level. The delay curve shown in Fig. 5 corresponds to a half-life of $(1.85\pm0.07)\times10^{-9}$ sec.

The 1490-kev Level in Co^{57}

Co^{57} is the daughter of the 36 hr Ni^{57}. The Ni^{57} source was prepared by bombarding chemically pure iron with 22-Mev alpha particles from the Indiana University Cyclotron. The iron was soldered to a copper probe and bombarded for 60-μa hr. Nickel was separated chemically from a bombarded target.

Ni^{57} is a positron emitter, and 14% of the positron decay is to the level of interest. The measurement of the half-life could, therefore, be achieved by measuring the delay between the annihilation gamma rays and the 127-kev transition to the 1363-kev level. The curve so obtained is shown in Fig. 6. It corresponds to a half-life $(1.00\pm0.05)\times10^{-9}$ sec. Since the gamma ray following the state to be measured is of low energy (127 kev), the time variation in the collection of the electron in the photomultiplier may make this half-life appear too

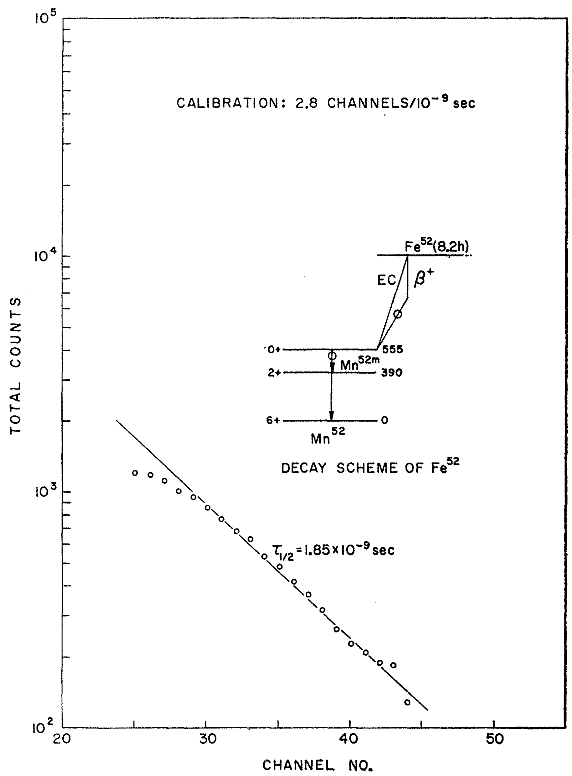

FIG. 5. Decay curve for 555-kev level in Mn^{52}.

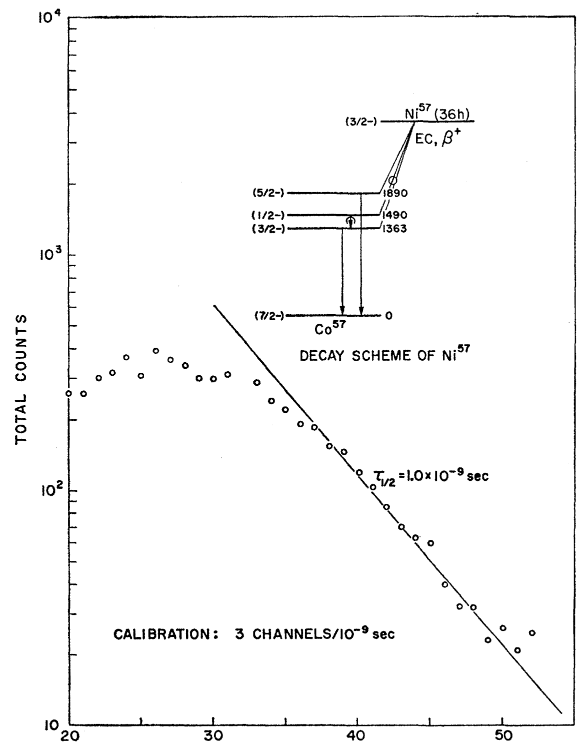

FIG. 6. Decay curve for 1490-kev level in Co^{57}.

[6] A. W. Sunyar, Phys. Rev. **98**, 653 (1955).
[7] H. Schopper, Z. Physik **114**, 476 (1956).
[8] J. O. Juliano, C. W. Kocher, T. D. Nainan, and A. C. G. Mitchell, Phys. Rev. **113**, 602 (1959).

long. The value stated must be considered an upper limit.

The 246-kev Level in Se^{77}

Se^{77} is the product of electron-capture from Br^{77}. A decay scheme for this isotope has been proposed by Temmer and Heydenburg,[9] which is in agreement with another given by Way *et al.*[10]

In a recent investigation by Girgis *et al.*[11] in addition to discovering one more high-energy level, a 576-kev transition from the 820-kev level to the 245-kev level with an intensity ratio 0.22 to that of the 245-kev radiation is reported. In earlier investigations,[10] such a radiation, if any, was believed to be of low intensity. If such a radiation exists, it would be ideally suited for the present measurement of the half-life of the 245-kev level. With certain modifications, part of the apparatus was used to verify this. The output of the linear amplifier in branch A was fed directly to the 100 channel analyzer, and calibrated from 0–700 kev. The bias in the triple coincidence circuit was reduced so that it acted as a simple coincidence circuit. Into this were fed the output of the fast coincidence and that of the single channel analyzer in branch B, which was adjusted to give pulses corresponding to a 245-kev gamma ray. The output opened the gate of the 100 channel analyzer, which now recorded all radiations that were in coincidence with the 245-kev gamma radiation. The intensity of the 576-kev radiation was thus confirmed.

A target of chemically pure arsenic powder was bombarded with alpha-particles for seven hours and the Br^{77} was chemically separated in the form of AgBr. The result of the measurement is shown in Fig. 7. The insert shows the decay scheme due to Girgis *et al.*[11] The half-life obtained is $(1.30\pm0.08)\times10^{-9}$ sec.

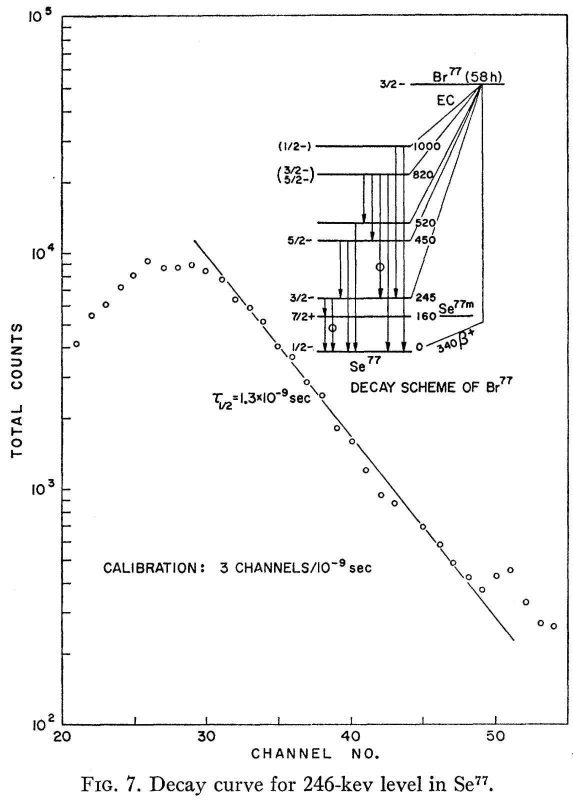

FIG. 7. Decay curve for 246-kev level in Se^{77}.

The 153-kev Level in Sb^{119}

Sb^{119} is the daughter of Te^{119} which decays with two half-lives, viz., 4.9 days and 16 hours. This isotope has been investigated and a decay scheme for it has been established by Kocher *et al.*[12] The decay scheme of the 4.9-day component so established is shown in Fig. 8 (insert). The most intense transition to 153-kev level is the 1.22-Mev gamma ray proceeding from the 1.37-Mev level. Using these two radiations, the half-life is found to be $(0.83\pm0.02)\times10^{-9}$ sec. One of the runs is shown in Fig. 8.

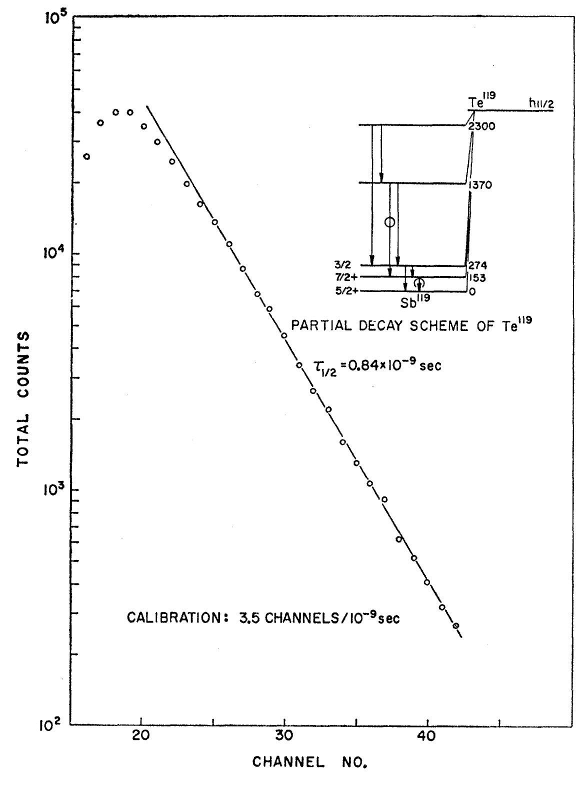

FIG. 8. Decay curve for 153-kev level in Sb^{119}.

[9] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **104**, 967 (1956).

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

[11] R. K. Girgis, E. Ricci, and R. Van Lieshout, Nuclear Physics **13**, 485 (1959).

[12] C. W. Kocher, A. C. G. Mitchell, C. B. Creager, and T. D. Nainan, Phys. Rev. **120**, 1348 (1960).

The 124-kev Level in Cs^{131}

Cs^{131} is the daughter of the 12-day Ba^{131} which decays entirely by electron capture. Vartapetian *et al.*[13] and Coleman[14] have measured the half-life by the delayed coincidence method and have found it to be $(4.0\pm0.3)\times10^{-9}$ sec and $(4.1\pm0.6)\times10^{-9}$ sec, respectively.

The present measurement used a pure Ba^{131} source obtained from the Oak Ridge National Laboratory. The delay between the 496-kev gamma ray due to the transition from the 620-kev level to the 124-kev level, and the 124-kev gamma ray was measured and the half-life obtained was $(4.15\pm0.08)\times10^{-9}$ sec. One of the several runs is shown in Fig. 9, where the number of counts is plotted against channel number calibrated in terms of delay.

The 103-kev Level in Eu^{153}

Eu^{153} is the daughter of the 47-hour Sm^{153}. The half-life of the 103-kev level has been measured by Graham and Walker[15] and by Vergnes and Marty.[16] They have both obtained a value 4.0×10^{-9} sec. McGowan[17] has measured the half-life to be 3.4×10^{-9} sec.

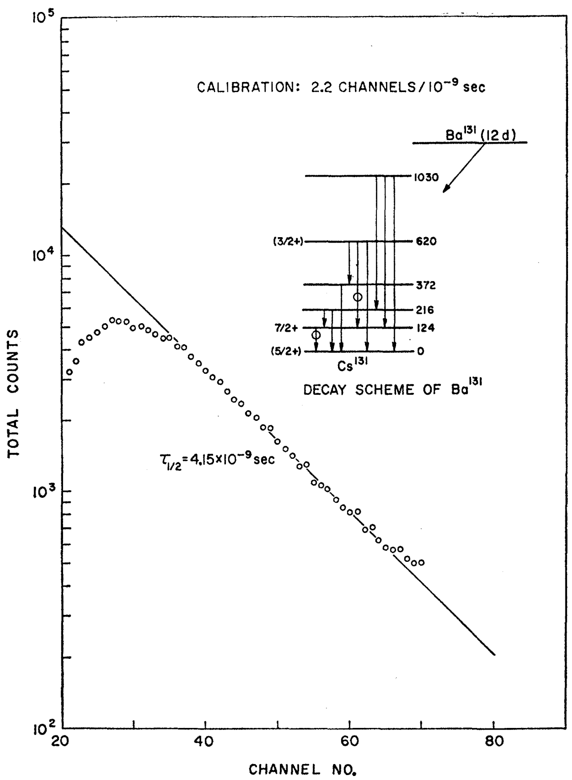

FIG. 9. Decay curve for 124-kev level in Cs^{131}.

TABLE I. Summary of results.

	Level (kev)	Previous results (sec)	Present measurement (sec)
V^{51}	323	1.0×10^{-10} 2.8×10^{-10}	$(2.8\pm0.04)\times10^{-10}$
Mn^{52}	555		$(1.85\pm0.07)\times10^{-9}$
Co^{57}	1490		$(1.00\pm0.05)\times10^{-9}$
Se^{77}	246		$(1.30\pm0.08)\times10^{-9}$
Sb^{119}	153		$(0.83\pm0.02)\times10^{-9}$
Cs^{131}	124	$(4.0\pm0.3)\times10^{-9}$ $(4.1\pm0.6)\times10^{-9}$	$(4.15\pm0.08)\times10^{-9}$
Eu^{153}	103	4.0×10^{-9} 3.4×10^{-9}	$(3.80\pm0.02)\times10^{-9}$

The present experiment was done on a pure sample of Sm^{153} obtained from the Oak Ridge National Laboratory. The 70-kev transition from the 173-kev level and 103-kev transition to the ground state were the gamma rays used. The result of five runs yielded a mean value $(3.80\pm0.02)\times10^{-9}$ sec. A typical curve is shown in Fig. 10.

The results are collected in Table I.

DISCUSSION

It is difficult to compare the experimental results with theoretical expectations since theory, especially as applied to the single-particle model, may give results which may be off by several orders of magnitude. In

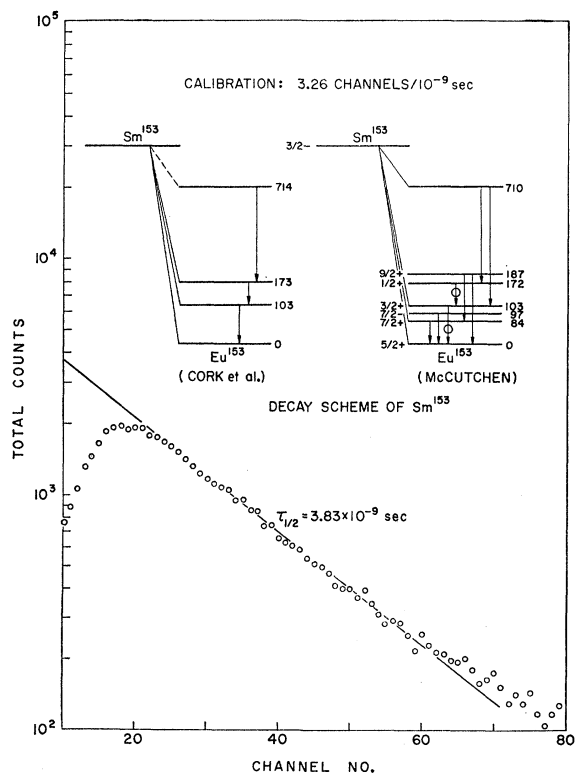

FIG. 10. Decay curve for 103-kev level in Eu^{153}.

[13] H. Vartapetian, L. Dick, R. Foucher, and N. Perrin, Comptes rend. **242**, 103 (1956).
[14] C. F. Coleman, Phil. Mag. **46**, 1135 (1955).
[15] R. L. Graham and J. Walker, Phys. Rev. **94**, 794(A) (1954).
[16] M. Vergnes et N. Marty, J. phys. radium **17**, 908 (1958).
[17] F. K. McGowan, Phys. Rev. **93**, 163 (1954).

those cases in which missing states are known, or approximately so, it is interesting, nevertheless, to compare them with the appropriate theory. In comparing the experiments with theory it is convenient to divide the nuclei into three groups: (a) those which lie near closed shell and for which the single particle model, modified by seniority considerations (several particles outside a closed shell), is expected to hold (V^{51}, Mn^{52}, Co^{57}, Se^{77}); (b) those in which the transition is thought to be *l*-forbidden (Sb^{119}, Cs^{131}); and (c) those in the collective region (Eu^{153}).

(a) For nuclei near closed shells, the single particle transition probabilities are taken to be those proposed by Moszkowski[2] and modified for the fact that there may be several particles outside a closed shell by the seniority statistical factor.[18] The transitions to be considered here are of the $E2$ or $M1$ type.

V^{51}. This nuclide has 28 neutrons and 23 protons. Estulin and Moiseeva[19] have measured the internal conversion coefficient for the transition, and find that the transition is mostly $E2$.

The seniority statistical factor is calculated by ascribing an initial state

$$I_i=\tfrac{5}{2}(\tfrac{5}{2}^1,\ I_1=\tfrac{5}{2},\ S_1=1)(\tfrac{7}{2}^2,\ I_2=0,\ S_2=0),$$

and final state

$$I_f=\tfrac{7}{2}(\tfrac{5}{2}^0,\ I_1=0,\ S_1=0)(\tfrac{7}{2}^3,\ I_2=\tfrac{7}{2},\ S_2=1),$$

for which one obtains a value $S=\frac{3}{4}$. The theoretical half-lives are then found to be

$$T_{\frac{1}{2}}(E2)=2.12\times10^{-9}\ \text{sec},$$
$$T_{\frac{1}{2}}(M1)=0.68\times10^{-12}\ \text{sec}.$$

Comparing with the measured half-life (2.8×10^{-10} sec), and assuming a mixture of $M1$ and $E2$ radiations, one obtains the mixing ratio to be 99.8% $E2$.

Mn^{52}. The 555-kev level in Mn^{52} was assigned a 0+ state on the basis of the allowed character of the 804-kev positron transition from Fe^{52}. The 390-kev gamma-radiation going to the ground state in Mn^{52} is well known to be an $E4$ transition. The ground state of Mn^{52} is known to have the character 6+. Thus, the 390-kev level could be assigned a 2+ character, and hence the 165-kev gamma-radiation carries away two units of angular momentum and involves no parity change. Mn^{52} is an odd-odd nucleus with 25 protons and 27 neutrons. In the ground state the protons and neutrons are both in the $f_{7/2}$ subshell, and one can ascribe a configuration to the 390-kev (2+) state and the 550-kev (0+) state. We take it to be $(f_{\frac{5}{2}})^1(f_{7/2})^4$ protons, $(f_{\frac{5}{2}})^1(f_{7/2})^6$ neutrons for the 555-kev level, and $(f_{7/2})^5$ protons, $(f_{\frac{5}{2}})^1(f_{7/2})^6$ neutrons for the 390-kev level. This gives a statistical factor $S=\frac{1}{2}$. The expected half-life corrected for internal conversion would be $T_{\frac{1}{2}}(E2)=1.71\times10^{-7}$ sec.

Co^{57}. Konijn *et al.*[20] have studied the gamma-ray spectrum in the decay of Ni^{57}, and from the conversion coefficients and angular correlation studies, have concluded that the radiation is predominantly $M1$, the $E2$ mixing ratio being 0.05 ± 0.05. Konijn *et al.*[21] have found, from the measurements of the positron spectra, that the 1363- and 1490-kev levels have characters $\frac{3}{2}$- and $\frac{1}{2}$-, respectively. The 1490-kev transition to the $\frac{7}{2}$ ground state is of type $M3$, and has negligible probability compared to the 127-kev transition involving a spin change of 1 unit. The Moszkowski formula gives a value 1.18×10^{-11} sec for an $M1$ type radiation. This is nearly 100 times smaller than the observed value, taken as an upper limit. Since the radiation is known to be almost entirely $M1$, there is no possibility of correcting this by an $E2$ admixture. The single particle model calculation being a rough estimate, one cannot expect its predictions to hold accurately. Similar instances of retarded $M1$ transitions are quite frequent.

Se^{77}. The 245-kev level is the second excited state of Se^{77}, above the isomeric state of 160 kev, whose half-life is well known to be 17.5 sec. It is well established that that transition is of type $E3$. The ground state is known to be $\frac{1}{2}$- from atomic spectral data. Thus, one would assume that the 160-kev level has the character $\frac{7}{2}$+. Temmer and Heydenburg[9] have shown, from Coulomb excitation measurements, that the 245-kev level is excited by an $E2$ transition. They have concluded, on the basis of the anisotropy of angular correlation measurements, that the 245-kev level is de-excited by an $M1+E2$ mixture of radiations. Of the two possible modes of de-excitation of the 245-kev level, viz., to the 160-kev level or to the ground state, the former is of negligible probability, being of the $M2$ type. The transition to the ground state would have a half-life 1.5×10^{-8} sec, if it were completely $E2$, and 1.7×10^{-12} sec if $M1$, using the statistical factor $S=\frac{1}{2}$. The observed value corresponds to 99% $E2$ for this transition.

Cs^{131} and Sb^{119}. The 123-kev transition in Cs^{131} with 55 protons and 76 neutrons has a K-conversion coefficient $\alpha_K=0.39$.[22] Two values of K/L ratios have been reported, viz., 3.6[23] and 6.0.[24] Rose's[25] tables give a K-conversion coefficient 0.56 for $E2$ type and 0.43 for $M1$ type radiations and K/L ratios 3.0 and 8.0, respectively. Thus, an $E2+M1$ mixture is indicated. Lindqvist and Karlsson[26] have, on the basis of the

[18] S. Goldhaber and J. Weneser, *Annual Review of Nuclear Science* (Annual Reviews, Inc., Palo Alto, 1955), Vol. 5, p. 1.
[19] I. V. Estulin and E. M. Moiseeva, Soviet Phys.—JETP **1**, 463 (1955).

[20] J. Konijn, B. Van Nooijen, P. Mostert, and P. M. Endt, Physica **22**, 887 (1956).
[21] J. Konijn, H. L. Hagedorn, and B. Van Nooijen, Physica **24**, 129 (1958).
[22] H. Vartapetian, Compt. rend. **243**, 1512 (1953).
[23] J. M. Cork, J. M. LeBlanc, W. H. Nester, and M. K. Brice, Phys. Rev. **91**, 76 (1953).
[24] M. W. Elliott, L. S. Cheng, J. R. Haskins, and J. D. Kurbatov, Phys. Rev. **88**, 263 (1952).
[25] M. E. Rose *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).
[26] T. Lindqvist and E. Karlsson, Arkiv Fysik **12**, 519 (1957).

496→123-kev cascade anisotropy, shown that the transition is 97±1% $M1+3\pm1\%$ $E2$. The 123 kev radiation is a transition from a $g_{7/2}$ state to a $d_{\frac{5}{2}}$ and is l-forbidden. The 153-kev radiation in Sb^{119} (51 protons, 68 neutrons) is also a transition from a $g_{7/2}$ state to a $d_{\frac{5}{2}}$ state and should have similar characteristics.

Arima *et al.*[27] have derived for the transition probability for l-forbidden $M1$ transition:

$$\lambda=0.414\times10^4W^3[m^2/(2j+1)]\ \text{sec}^{-1},$$

where the square of the matrix element is given by

$$m^2=\langle j'|\textstyle\sum\boldsymbol{\mu}|j\rangle^2.$$

Here j and j' are the total angular momenta of initial and final state, and $\sum\boldsymbol{\mu}$ the summation of the magnetic moment operators of all the nucleons in the nucleus. Thus

$$m^2=\frac{2j+1}{0.596\times10^9W^3T_{\frac{1}{2}}(M1)},$$

$$T_{\frac{1}{2}}(M1)=T_{\frac{1}{2}}(\text{obs})(1+\delta^2+\delta^2\alpha_2+\beta_1);$$

$$[\delta^2=\lambda(E2)/\lambda(M1)].$$

Here α_2 and β_1 are the total $E2$ and $M1$ conversion coefficients, obtained from Rose's tables. Table II gives a comparison between the single-particle model matrix element, that of Arima *et al.*, and the experimental matrix-element for an $M1$ transition.

It is seen that the experiments are more in agreement with the calculation of Arima *et al.* than the single-particle model.

Eu[153]. Mihelich[28] measured the K/L ratio for the 103-kev transition to be 6.5±1.0, which is slightly less than the expected value 7.6 for $M1$, but larger than 1.25 expected for $E2$ transition. Lee and Katz[29] have obtained a value $\alpha_K=0.62\pm0.15$, while Marty[30] gives $\alpha_K=1.2\pm0.1$, and both these authors report a K/L ratio in agreement with Mihelich. McGowan[17] reports a K-conversion coefficient $\alpha_K=1.14\pm0.02$. From these results, the mixing ratio $E2/M1=2.0$.

Two decay schemes have been proposed so far for the decay of the 47-hr Sm^{153}, one by Cork *et al.*[31] and the other, among others, by McCutchen.[32] Both of these decay schemes are shown in the insert of Fig. 10. If we assume the former decay scheme, the the 1.03-kev level is the first excited state. One could then apply the collective model formula due to Bohr and Mottelson,[3] and the values are

$$E2:\quad T_{\frac{1}{2}}=4.20\times10^{-8}\ \text{sec};$$

$$M1:\quad T_{\frac{1}{2}}=8.0\times10^{-10}\ \text{sec}.$$

Comparison with the experimental value gives $E2/M1=2$.

Bernstein and Graetzer[33] have measured the internal conversion electrons following Coulomb excitation of Eu^{153}, and they have calculated the reduced transition probability $B(E2)$ for the excitation of the 103-kev state to be $0.14_{-0.06}^{+0.09}$. This may be compared with the excitation transition probability formula on the basis of the collective model given by Huus, Bjerregard, and Elbek,[34] and which gives $B(E2)=0.29$. Thus, a large admixture of $E2$ transition is suggested by their results in agreement with the present measurement.

TABLE II. Transition matrix elements for Sb^{119} and Cs^{131}.

Isotope	Experimental matrix element for $M1$ transition	Single-particle model matrix element ($M1$)	Retardation factor	Matrix element by formula of Arima *et al.*
Sb^{119}	0.115	17.0	150	0.373
Cs^{131}	0.056	2.74	250	0.091

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