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Radioactivity of Sc^{44}†

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The decay of Sc^{44} has been reinvestigated using a NaI gamma-ray spectrometer and a magnetic-lens spectrometer adapted to coincidence measurements. The main transition from the Sc^{44} ground state is to the first excited level of Ca^{44} at 1.159±0.003 Mev. The probability for positron emission is 0.932±0.015, in agreement with the theoretical value of 0.928 for an allowed transition ($E_{\max}=1.471\pm0.005$ Mev). The conversion coefficients of the 1.16-Mev gamma ray and of the isomeric transition in Sc^{44} are $6.3\pm0.3\times10^{-5}$ and 0.139±0.003, compatible with $E2$ and $E4$ transitions, respectively. A weak allowed decay leads to a level in Ca^{44} at 2.54±0.03 Mev. The continuous spectrum of low-energy electrons previously reported by J. A. Bruner was found to depend strongly on the thickness of the source and the backing. For the thinnest sources the intensity was found to be $\frac{1}{3}$ of that previously reported. Coincidence measurements showed that more than $\frac{2}{3}$ of the electrons are not coincident with both the positrons and the gamma rays and are, therefore, not emitted in the process of positron decay. It is concluded that there is no indication for a disagreement between the experiment and the theory of atomic excitation during beta decay.

I. INTRODUCTION

THE decay of the isomeric pair Sc^{44} has been investigated most thoroughly by Bruner and Langer.[1] The metastable state has a half-life of 57±2 hr and emits a strongly converted gamma ray of 271.3 ±0.7 kev. The ground state, with a half-life of 4.0±0.1 hr, decays into an excited state of Ca^{44} at 1.16 Mev by emitting a positron group of 1.463±0.005 Mev maximum energy. From the external photoelectron spectrum the intensity of the annihilation radiation is found to be about equal to that of the 1.16-Mev gamma ray. The fraction of decays proceeding by positron emission, N_{β^+}/N_γ, would be about $\frac{1}{2}$, in crude agreement with the value $\frac{1}{3}$ derived by Hibdon, Pool, and Kurbatov[2] from absorption measurements. This large electron capture probability is, as pointed out most recently by Zweifel,[3] in disagreement with the theoretical K-capture branching of 6.2% for an allowed positron decay ($\log ft=5.3$). It was decided to redetermine this branching ratio and to measure the conversion coefficients of the gamma rays. Furthermore, a search for transitions to higher excited states of Ca^{44} was undertaken.

A low-energy continuous negatron spectrum was observed by Bruner[4] to accompany the positron decay. The total number of electrons between 30 and 150 kev was 4% of the positron intensity. From the fact that the intensity was independent of the source thickness and the spectrometer used, and after excluding a number of possible explanations, Bruner came to the conclusion that the electrons were emitted in the process of positron decay. Their number, however, greatly exceeds that predicted by the theories of atomic excitation during beta decay[5-7] which, on the other hand, have been found to be in essential agreement with experiments on the K and L ionization[8-13] and the emission of low-energy electrons[14,15] in several cases of negatron emission and electron capture. For Sc^{44} the formulas of Migdal[6] yield a total ionization probability of about 5% (which may be too large according to the L-shell results of Levinger[7]). Since the energy distribution of the emitted orbital electrons shows a rapid decrease for energies above the ionization potential, the number of electrons above 30 kev would be of the order of 10^{-4} per decay or less. It seemed possible that, despite the precautions taken by Bruner, the observed electrons may have been of a secondary nature. His experiment was repeated and an attempt to determine the origin of the electrons was made by measuring the radiations coincident with them.

II. APPARATUS

The experiments were performed with the aid of a lens-type spectrometer which was adapted to coincidence measurements. Figure 1 shows the instrument and the block diagram of the circuitry.

The effective solid angle of the spectrometer is about 2% of 4π. For sources of $\frac{1}{8}$-, $\frac{1}{4}$-, and $\frac{1}{2}$-inch diameter the total widths of a conversion line at half-maximum are 1.7, 2.7, and 6.2% respectively, the width of the annular focus being the same as the source diameter. Negatrons or positrons can be rejected by obstructing 200° of the azimuth at the first antiscattering baffle and intercepting the transmitted beam of the undesired

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[1] J. A. Bruner and L. M. Langer, Phys. Rev. **79**, 606 (1950).

[2] Hibdon, Pool, and Kurbatov, Phys. Rev. **67**, 289 (1945).

[3] P. F. Zweifel, Phys. Rev. **96**, 1572 (1954).

[4] J. A. Bruner, Phys. Rev. **84**, 282 (1951).

[5] E. L. Feinberg, J. Phys. (U.S.S.R.) **4**, 423 (1941).

[6] A. Migdal, J. Phys. (U.S.S.R.) **4**, 449 (1941).

[7] J. S. Levinger, Phys. Rev. **90**, 11 (1953).

[8] T. B. Novey, Phys. Rev. **89**, 672 (1953).

[9] G. Charpak, Compt. rend. **237**, 243 (1953).

[10] F. Boehm and C. S. Wu, Phys. Rev. **93**, 518 (1954).

[11] J. A. Miskel and M. L. Perlman, Phys. Rev. **94**, 1683 (1954).

[12] G. A. Renard, Compt. rend. **238**, 1991 (1954).

[13] W. Rubinson and J. J. Howland, Phys. Rev. **96**, 1610 (1954).

[14] F. T. Porter and H. P. Hotz, Phys. Rev. **89**, 938 (1953).

[15] G. Charpak and F. Suzor, J. phys. radium **15**, 378 (1954).

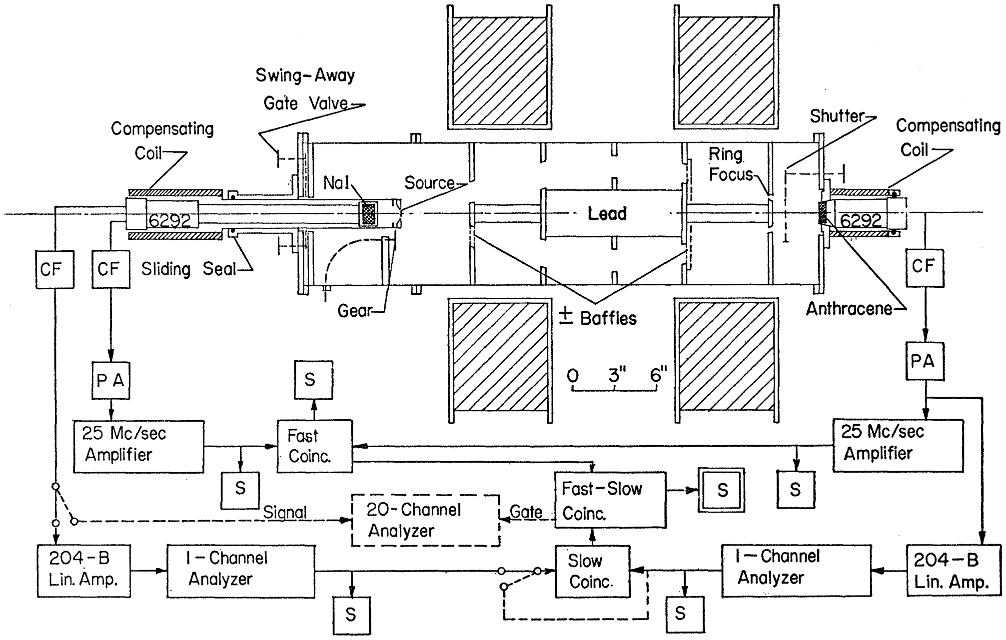

FIG. 1. Lens spectrometer and block diagram of coincidence circuit. CF = cathode follower, PA = preamplifier, S = scaler.

sign after it has rotated clockwise through 90°. The particles of the right sign rotate counter-clockwise through 90° and are transmitted by the second baffle. This system has the disadvantage of reducing the solid angle by 5/9, but it is easier to construct and may give rise to less scattering than the helicoidal type of baffles. Since the "± baffles" destroy the azimuthal symmetry of the instrument an error in the mean energy of the transmitted electrons may be introduced by a nonsymmetric distribution of the active source material. The azimuthal symmetry is restored, therefore, by rotating the source at a speed of about 10 rpm.

The coil current is provided by a selenium rectifier capable of furnishing 10 amp at 1000 v. It is regulated electronically with a circuit similar to that given by Elmore and Sands,[16] with a bank of forty 6AS7 tubes in series with the coils. This system has proved to be trouble free in its five years of operation. Short-period fluctuations are less than 0.05%, slow drifts less than 0.1% per hour even at full load. With 7.5 kw dissipated in the coils electrons of 3.7 Mev can be focused if the coil separation is as shown in Fig. 1. For the same source-detector distance, 30 inches, the energy range can be extended to about 5.7 Mev, with some loss in resolution and solid angle, by pushing the coils together.

The transmitted particles are detected with an anthracene crystal of $\frac{1}{4}$-inch thickness, the radiations coincident with them either with an anthracene or a NaI scintillator. The magnetic fields produced by the spectrometer coils at the photomultipliers are compensated with the aid of solenoids connected in series with the spectrometer. The variation of the response of the source-end multiplier, with a 12-inch light piper, is less than $\frac{1}{2}\%$ for spectrometer energies up to 2 Mev.

The coincidence circuitry is of the usual fast-slow type. In the fast channels, 25-Mc/sec amplifiers designed by Elmore[17] and similar preamplifiers with a gain of ten are used. The pulses are diode-limited at the plate of the fourth stage of the main amplifier and delay-line clipped at the plate of the fifth stage. The shaped output pulses are about 12 volts in amplitude with a length of 50 mμsec at the base. The fast coincidence circuit of the Garwin[18] type is followed by an amplifier and a discriminator which permits an adjustment of the resolving time between 20 and 50 mμsec. Two slow systems are used. (a) Slow coincidences are made between the outputs of single-channel analyzers in both channels and are then mixed with the fast coincidences. (b) Coincidences between the analyzed pulse coming from the spectrometer detector and the fast coincidences are used to gate a 20-channel analyzer (Model 520, Atomic Instrument Company), giving thus the pulse-height distribution in the crystal behind the source due to radiation coincident with the electrons focussed in the spectrometer.

III. PREPARATION OF SOURCES

Sc^{44} was produced by the reaction $K^{41}(\alpha,n)Sc^{44}$, bombarding metallic potassium with the circulating 19-Mev alpha beam of the cyclotron. Since potassium melts at 60°, efficient cooling had to be provided. The target holder was a copper block through which about nine gallons of water per minute were passed. The potassium

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[16] W. C. Elmore and M. Sands, *Electronics, Experimental Techniques* (McGraw-Hill Book Company, Inc., New York, 1949), p. 392.

[17] W. C. Elmore and R. Hofstadter, Phys. Rev. **75**, 203 (1949). We are indebted to Dr. Hofstadter for the diagram of the amplifier.

[18] R. L. Garwin, Rev. Sci. Instr. **21**, 569 (1950).

was cut to a thickness of about $\frac{1}{2}$ mm and wedged into a dove tailed groove milled in the copper block. Beam currents of 15 μa were tolerable and bombardments of 100 μa-hr were sufficient for spectrometer sources.

Carrier-free scandium was separated from the potassium by dissolving the sample in ethyl alcohol, evaporating to dryness, then dissolving the residue in 0.1*N* HCl, adding $FeCl_3$, and scavenging $Sc(OH)_3$ with $Fe(OH)_3$. The precipitate was dissolved in 6*N* HCl and the iron removed by an ether extraction. Two types of sources were used in the spectrometer measurements. The most uniform and thinnest sources were obtained by depositing the acid phase which contains the Sc^{44} onto a tantalum strip and evaporating it to dryness. The tantalum was then heated in a vacuum and the active material deposited onto a 0.0001-inch Al foil (0.7 mg/cm^2) placed at a distance of about $\frac{1}{8}$ inch. The foil was masked so that the active material would be confined to a $\frac{1}{4}$-inch disk. Considerable difficulty was experienced with this method of source preparation since the scandium apparently tended to alloy with the tantalum.

Sources on thinner backings were prepared by evaporating the acid to dryness, dissolving the dry residue in water, to which some insulin had been added as a wetting agent, and depositing the solution on a 60-μg/cm^2 formvar film. These sources were fairly uniform as judged from the autoradiographs and showed no crystal clumps larger than 1μ under the microscope. To prevent charging effects the sources were covered with a 10-μg/cm^2 nylon film and a semiopaque layer of aluminum was evaporated thereon. A small grounded copper sheet at the edge of the source holder was held in contact with the aluminized layer.

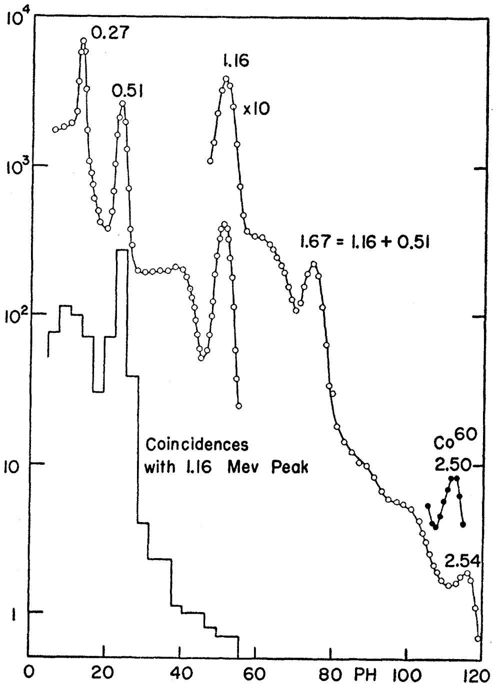

FIG. 2. Pulse-height distribution from Sc^{44} in NaI gamma-ray spectrometer.

IV. DECAY SCHEME

(1) Positron Spectrum

The allowed Fermi plot of the positrons is straight from 200 kev to the endpoint, which was determined to be at 1.471±0.005 Mev, in reasonable agreement with the value of 1.463±0.005 given by Bruner and Langer.[1] (All errors given in this paper are standard errors.) No evidence of higher-energy positrons was found.

(2) Gamma-Ray Spectrum

The pulse-height distribution from a NaI spectrometer, measured with the twenty-channel analyzer, is shown in Fig. 2. In addition to the 271-kev transition from the 57-hr isomer, the annihilation radiation, and the known 1.16-Mev gamma ray which follows the positron decay (addition peak at 1.67 Mev), a weak line at 2.54±0.03 Mev is observed. The sum peak of Co^{60}, at 2.50 Mev, is used for the calibration of the spectrometer in this energy region. The ratio of the 2.54-Mev and the 1.16-Mev peaks is the same for the 4-hr and the 57-hr components, which shows that the 2.54-Mev radiation is emitted from the ground state. The intensity ratio of the two gamma rays was calculated using the absorption coefficients of NaI given by Bell, Davis, Hughes, and Jordan[19] and the photopeak efficiency curve given by Bell, Heath, and Davis,[20] extended to higher energies with the aid of Na^{24}. The intensity of the 2.54-Mev gamma ray is 0.12±0.02% of the main transition. No positive evidence for the transition from the 2.54-Mev to the 1.16-Mev level is found in either the gamma-ray spectrum itself or the spectrum of the radiation which is coincident with the 1.16-Mev gamma ray (see Fig. 2). An upper limit of 0.5% is set for the intensity of this transition.

(3) Positron Branching Ratio

An approximate value for the positron branching ratio was obtained by comparing the relative intensities of the annihilation radiation and of the nuclear gamma ray for Sc^{44} and for Na^{22} with the aid of the NaI spectrometer. For Na^{22}, the ratio N_{β^+}/N_γ is known to be 0.901±0.005.[21] The result for Sc^{44}, obtained from the comparison of the photo peaks, was $N_{\beta^+}/N_\gamma=0.90\pm0.04$. While this work was in progress, Langevin and Marty[22] determined the branching ratio by the same

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[19] Bell, Davis, Hughes, and Jordan, Oak Ridge National Laboratory Report ORNL-1415, 8, September 20, 1952 (unpublished).

[20] Bell, Heath, and Davis, Oak Ridge National Laboratory Report ORNL-1415, 10, September 20, 1952 (unpublished).

[21] R. Sherr and R. H. Miller, Phys. Rev. **93**, 1076 (1954).

[22] H. Langevin and N. Marty, J. phys. radium **15**, 127 (1954).

method, with the results: $N_{\beta^+}/N_\gamma=1.0\pm0.1$ from the photo peaks, 0.95 ± 0.15 from the total pulse-height distributions. The obvious difficulties of the method are in the proper analysis of the pulse-height distributions and in the uncertainty concerning the difference in the NaI response for the 1.16-Mev gamma ray of Sc^{44} and the 1.28-Mev gamma ray of Na^{22}.

These difficulties are avoided if the probability of a positron being coincident with the nuclear gamma ray is determined directly by measuring coincidences between the positrons focused in the magnetic spectrometer and the 1.16-Mev photo peak from the NaI crystal behind the source. The single counting rate in the gamma-ray channel is $n_\gamma=N_\gamma\epsilon_\gamma$, with ϵ_γ the gamma-ray efficiency and N_γ the rate of decay to the 1.16-Mev level of Ca^{44}. The counting rate in the spectrometer detector, for a current setting I, is given by $n_{\beta^+}=N_{\beta^+}CIf(I)$, where C is a spectrometer constant and $f(I)$ is proportional to the momentum distribution of the positrons, normalized to

$$\int_0^{I_{\max}} f(I)dI=1.$$

If there is no angular correlation between the positrons and the gamma rays the coincidence counting rate is $n_{\beta^+,\gamma}=n_{\beta^+}\epsilon_\gamma$, and one obtains

$$\int_0^{I_{\max}} \frac{n_{\beta^+,\gamma}}{n_\gamma}\frac{dI}{I}=C\frac{N_{\beta^+}}{N_\gamma}.$$

The spectrometer constant C was determined with the aid of Na^{22} and Au^{198}. The isotropy of the $\beta-\gamma$ angular distribution has been checked experimentally for Au^{198},[23] and is expected theoretically for Na^{22} because the positron transition is allowed. In the case of Au^{198}, coincidences between the 1.09-Mev beta spectrum and the photopeak of the 411-kev gamma ray were measured. An amount of $3.4\pm1\%$ was subtracted from n_γ in order to account for the Compton background of the weak higher-energy gamma rays and for that part (1.4%) of the 411-kev gamma ray that is not in coincidence with the main beta group.[24] The integration of the coincidence spectrum was performed by extrapolating the measured spectrum to low energies (where the counting rates are low and where, in the case of Au^{198}, the soft partial spectrum interferes) with the aid of Fermi plots, using Coulomb functions with a screening correction.[25] The results for the spectrometer constant, $C=(2.44\pm0.02)\times10^{-4}$ (Na^{22}), and $C=(2.46\pm0.03)\times10^{-4}$ (Au^{198}), are in very good mutual agreement.

The branching ratio of Sc^{44} obtained with this value of the spectrometer constant is $N_{\beta^+}/N_\gamma=0.932\pm0.015$, consistent with the calculated value of 0.928.

(4) Conversion Coefficients

The knowledge of the positron branching permits the determination of the conversion coefficients of the gamma rays by direct comparison of the intensities of the conversion lines and of the positron spectrum. From the conversion line, the energy of the first excited state of Ca^{44} was found to be 1.159 ± 0.003 Mev. The total conversion coefficient of the gamma ray is $(6.3\pm0.3)\times10^{-5}$, indicating an $E2$ transition since the calculated K-conversion coefficients are[26] 6.2×10^{-5} for an $E2$, 4.9×10^{-5} for an $M1$ transition.

The total conversion coefficient of the 271-kev isomeric transition was found to be 0.139 ± 0.003. From the tables of Rose, Goertzel, and Swift,[27] one obtains coefficients for conversion in the K, L_{I}, and L_{II} shells of 0.129, 0.010, and 0.0008 for $E4$, 0.119, 0.010, and 0.0005 for $M4$ radiation. The L_{III} coefficients have not yet been calculated accurately, but they are probably small. (For the magnetic case, the $L_{\text{III}}/L_{\text{I}}$ curves of Tralli and Lowen[28] give a value of 0.001.) If one neglects L_{III} and M conversion, the total theoretical conversion coefficients are 0.140 for an electric, 0.130 for a magnetic transition. The experimental value seems to indicate an $E4$ transition, in agreement with the shell-model expectation.[29]

(5) Discussion

The decay scheme is shown in Fig. 3. The transition to the 2^+ state of Ca^{44} at 1.16-Mev is allowed; from the absence of the ground-state transition, the Sc^{44} ground state is assigned 2^+ or 3^+. The ft value of the electron capture to the 2.54-Mev state is between 2×10^5 and 10^6. It could, then, conceivably be a first forbidden transition with $\Delta I=0$. From a 2^- or 3^- state, however, one would expect a strong electric dipole transition of 1.38 Mev to the 1.16-Mev level, which is not observed. It is reasonable to assume that the 2.54-Mev level is

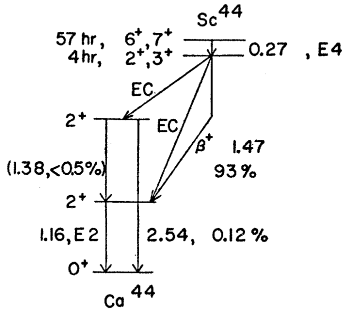

FIG. 3. Decay scheme of Sc^{44} (energies in Mev).

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[23] S. L. Ridgway, Phys. Rev. **78**, 821 (1950).

[24] P. E. Cavanagh, Phys. Rev. 82, 791 (1951).

[25] *Tables for the Analysis of Beta Spectra*, National Bureau of Standards Appl. Math. Series **13**, June 2, 1952.

[26] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **83**, 79 (1951).

[27] Rose, Goertzel, and Swift (privately circulated tables).

[28] N. Tralli and I. S. Lowen, Phys. Rev. **76**, 1541 (1949).

[29] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).

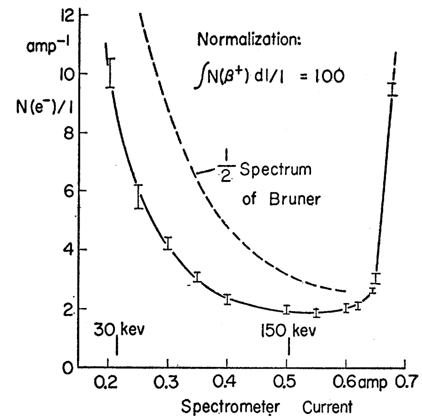

FIG. 4. Low-energy electron spectrum of a Sc^{44} source deposited from an aqueous solution on a 60-μg/cm² formvar film.

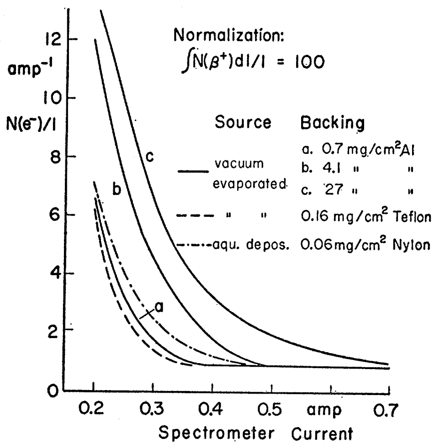

FIG. 5. Influence of source preparation and backing on the low-energy electron spectrum of Na^{22}.

reached by an allowed transition and that its spin is 1^+ or, preferably, 2^+. Higher spin values are improbable because of the low intensity of the 1.38-Mev radiation.

The level at 2.54-Mev is probably identical with that observed by Schiffer[30] at 2.58±0.05 Mev in the (α,p) reaction with K^{41}. The spectrum of the radiations of Sc^{44} gives no indications for transitions to any of the other levels in Ca^{44} above that at 1.16 Mev.

V. LOW-ENERGY ELECTRONS

(1) Energy Distribution and Intensity

Figure 4 shows the electron spectrum obtained in the lens spectrometer from a thin $ScCl_3$ source deposited on a 60-μg/cm² formvar film. The total intensity between 30 and 150 kev is 1.3±0.1% of the positron intensity, smaller by a factor of three than the value reported by Bruner.[4] This difference immediately excludes the possibility that the electrons which he observed are emitted in the process of positron decay.

(2) Influence of Source Backing

In an attempt to explain the difference between the two measurements the influence of source preparation and backing thickness on the electron spectrum was investigated. For convenience, a Na^{22} source was substituted. The decay schemes of the two nuclides are quite similar except for the occurrence of the isomeric transition in Sc^{44}. The latter, however, does not seem to be responsible for most of the low-energy electrons since their intensity was observed to follow closely the ground-state decay. Nevertheless, the minimum number of electrons (i.e., for thinnest source and thinnest backing) was found to be two to three times higher for Sc^{44} than for Na^{22}. No explanation has been found for this difference except for the possibility that even the vacuum evaporated $ScCl_3$ sources were considerably thicker than the NaCl sources. The results for Na^{22} are shown in Fig. 5. The two broken curves show the considerable influence of the source thickness (or inhomogeneity) in the case of the source prepared by deposition from an aqueous solution. The influence of the backing thickness—full curves—seems to be important only at thicknesses exceeding those commonly employed.

(3) Coincidence Measurements

The origin of the electrons was investigated by measuring the fraction coincident with either the full-energy gamma-ray peak in a NaI scintillator or with the upper end ($E_{\beta^+}>0.9$ Mev) of the positron spectrum detected in an anthracene crystal placed about one inch behind the source. For the evaluation of these measurements it is assumed that there is no angular correlation between the radiations involved.

Let n_e be the counting rate of low-energy electrons in the spectrometer, ϵ_γ the probability that a 1.16-Mev gamma ray gives rise to a full-energy pulse in the NaI crystal, and f_γ the fraction of electrons that are coincident with the gamma ray. Then coincidences are counted at a rate $n_{e,\gamma}=n_e f_\gamma \epsilon_\gamma$. Therefore,

$$f_\gamma = n_{e,\gamma}/n_e\epsilon_\gamma$$

and, similarly, the fraction of electrons coincident with positrons is

$$f_{\beta^+} = n_{e,\beta^+}/n_e\epsilon_{\beta^+}.$$

The counting efficiencies ϵ_γ and ϵ_{β^+} are calculated from the counting rates in the scintillation counters and the source strength which is obtained from the positron intensity in the spectrometer and the known spectrometer constant.

In principle, these measurements should be performed for various electron energies. Because of the prohibitively long counting times involved the spectrometer was set to focus electrons of only one energy, 77 kev,

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[30] J. P. Schiffer, Phys. Rev. 97, 428 (1955).

close to the center of gravity of the electron distribution.

Both e,γ and e,β^+ coincidences were measured for two different thin Sc^{44} sources, with compatible results. The average coincidence fractions are $f_\gamma = 40 \pm 9\%$, $f_{\beta^+} = 84 \pm 12\%$. This means that 60% of the electrons, not being in coincidence with the full-energy gamma rays, must have been produced by the gamma ray, presumably by Compton effect in the neighborhood of the source or in the baffle system. 93% of these, or a fraction of 56% of the total number, would be preceded by positron emission and thus be in coincidence with the positrons. This leaves $84 - 56 = 28 \pm 15\%$ of the electrons coincident with both the positrons and the gamma ray, as they should be if emitted in the process of positron decay. Even this fraction of the electrons, however, could be produced by inelastic scattering of the positrons such that the positrons still have an energy in excess of 0.9-Mev and can be recorded in the crystal.

(4) Summary

The number of low-energy electrons between 30 kev and 150 kev which might be attributed to atomic excitation during the positron decay of Sc^{44} has been reduced from 4% to about 0.4% (1.3%×0.28). At these low intensities the techniques employed here are unreliable and there is, thus, no evidence for an electron intensity higher than predicted by the theory.

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Production of Y^{89m}, Ba^{137m}, and Hg^{199m} by Inelastic Neutron Scattering*

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Isomeric states in Y^{89} (913 kev), Ba^{137} (661 kev), and Hg^{199} (527 kev) have been excited by inelastic scattering of monoenergetic neutrons. The shape of the excitation curves agrees rather well with the prediction of the strong interaction theory, but the theoretical cross sections are, at least in the cases with simple decay schemes, considerably larger than the experimental ones.

INTRODUCTION

ONE of the many different ways of studying the inelastic scattering of neutrons is through the measurement of the excitation of metastable states of nuclei. The cross section for the production of a metastable state by inelastic neutron scattering depends strongly on the angular momentum difference between this state and the ground state and depends to some extent on the relative parity of these two states. In addition, the cross section depends on the presence of other excited states.

If spin and parity of the metastable state are known from other studies, especially from measurements of the internal conversion of the gamma-ray transition, an investigation of the absolute cross section for excitation with monochromatic neutrons represents a test of the available nuclear models as applied to reaction theory.

If, on the other hand, a theory exists which successfully explains experiments of this kind, the study of the energy dependence and of the absolute value of the cross section will enable one to assign spin values to the metastable states and to other levels affecting the excitation of the metastable state by their competition. Breaks in the excitation curve indicate levels above the metastable state, and the sign of the change of slope at these breaks indicates whether the de-excitation of these levels proceeds through the metastable state or whether it bypasses this level.

As long as one is interested in a test of theoretical predictions, one would like as simple a level scheme as possible. The metastable state should preferably be the first excited state. This would eliminate all of the uncertainties stemming from the competition of other levels, the properties of which are often not very well known.

Previous investigations on Cd^{111}, In^{115}, and Au^{197} [1–3] involved relatively complicated level schemes. Margolis[4] compared the predictions of the strong-interaction theory[5] with these experimental data and, in view of

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* Supported by the U. S. Atomic Energy Commission.

[1] Francis, McCue, and Goodman, Phys. Rev. **89**, 1232 (1953).

[2] A. A. Ebel and Clark Goodman, Phys. Rev. **93**, 197 (1954).

[3] Martin, Diven, and Taschek, Phys. Rev. **93**, 199 (1954).

[4] B. Margolis, Phys. Rev. **93**, 204 (1954).

[5] W. Hauser and H. Feshbach, Phys. Rev. **87**, 366 (1952).