PHYSICAL REVIEW VOLUME 93, NUMBER 5 MARCH 1, 1954

Radiation from Antimony 122

J. M. Cork, M. K. Brice, G. D. Hickman, and L. C. Schmid
Department of Physics, University of Michigan, Ann Arbor, Michigan

(Received November 30, 1953)

Neutron capture in enriched Sb^{121} yields radioactive Sb^{122} whose half-life is found to be 66.0±0.4 hr. In addition to the two previously observed gamma rays, present studies with scintillation and conversion electron spectrometers indicate the existence of six previously unreported gammas. The energies are 95, 553, 566, 616, 647, 694, 1100, 1200 kev with possibly something at 1.9 Mev. K/L intensity ratios for the conversion lines are observed only for the 553- and 566-kev gammas. The high-energy lines are observed only with the scintillation spectrometer. The beta spectrum is resolved into components with maximum energies at 2.00±0.03, 1.40±0.02, and 0.450 Mev, with possibly some other lower energy present.

Three gamma energies in Sb^{124} are evaluated by their conversion electrons as 603.6, 644, and 727 kev.

IN the early survey of radioactivities induced by slow neutron capture, Fermi *et al.* found[1] a beta-emitting product in antimony, whose half-life was 2.5 days and whose beta energy, as determined by absorption in aluminum, was about 1.6 Mev. Subsequent studies have shown[2] that this activity is undoubtedly in Sb^{122} being formed from Sb^{121} whose natural abundance is 57.2 percent. More recently several reports on the energies of the beta and the gamma radiations have appeared. These exhibit considerable variation in the value of the beta energies. In only one report is more than a single gamma ray mentioned. These results are summarized in Table I.

In the present investigation, antimony enriched in mass 121 up to about 99 percent was irradiated in the Argonne heavy-water pile. The gamma radiations were studied both with photographic magnetic and scintillation crystal spectrometers. The beta radiation has been analyzed by the large double-focusing magnetic spectrometer provided with a thin window counter. The half-life was determined from observation of the decay through several octaves by the use of an ionization electrometer.

BETA ENERGIES

The beta spectrum is found to be complex, consisting of at least three components. The composite Kurie plot is shown in curve *A*, Fig. 1. The curve shape at the upper limit suggests a unique first forbidden transition with ΔI equal to 2 and a change in parity. It is found that the high-energy part of the Kurie plot can be corrected to a straight line by means of the unique first-forbidden, tensor-type correction factor $C\sim(W_0-W)^2L_0+9L_1$, where the factors L_0 and L_1 are obtained from the tables of Rose *et al.*[3] A least squares fit to the corrected Kurie plot gives an upper energy limit of 2.00±0.03 Mev. The remainder after subtraction of this component is shown in Curve *B*. This residual curve is still complex, and its high-energy part does not exhibit the allowed shape. When the same correction factor as used above is applied, an upper energy limit of 1.40±0.02 Mev is found. Subtraction of this component gives a residual curve of maximum energy 450 kev (curve *C*). However, this energy value is influenced appreciably by the type of correction factor applied to curve *B*. The possibility of lower energy beta components is not excluded. The relative abundance of the three beta rays expressed in the order of decreasing energy is 36, 56, and 8 percent. The corresponding log *ft* values in the same order are 8.5, 7.7, and 6.7, respectively.

GAMMA ENERGIES

In the magnetic photographic spectrometers strong *K* and *L* electron lines appear with energies of 534.2 and 560.6 kev which, if in tellurium, yield a gamma ray at 566.0 kev. The *K* to *L* intensity ratio for the two lines is found to be 7.0±1.5. Weaker *K* and *L* lines are observed for a gamma ray of energy 553 kev, with a K/L value of approximately unity. Several additional single electron lines are found and interpreted as *K* lines in tellurium for gamma rays, following *K* capture in Sb^{122}. All observed lines died with the same half-life which was found to be 66.0±0.4 hr. The energies of these electron lines are 63.4, 584, 615, and 662 kev, yielding gamma rays with energies of 95.2, 616, 647, and 694 kev. The weakest line is that corresponding to

TABLE I. Previous data relative to Sb^{122}.

Author	Energy in Mev β_1	β_2	γ_1	γ_2
MC[a]	1.36	1.94		
RW[b]			0.57	
K[c]			0.568	
C[d]			0.568	
M[e]	1.19	1.77		
M[f]	1.46			
G[g]	3β's	(No values)	0.56	0.680

[a] L. Miller and L. Curtiss, Phys. Rev. **70**, 983 (1946).
[b] W. Rall and R. Wilkinson, Phys. Rev. **71**, 321 (1947).
[c] Kern, Zaffarano, and Mitchell, Phys. Rev. **73**, 1142 (1948).
[d] C. Cook and L. Langer, Phys. Rev. **73**, 1149 (1948).
[e] C. Mandeville and M. Scherb, Phys. Rev. **73**, 340 (1948).
[f] Macklin, Lidofsky, and Wu, Phys. Rev. **82**, 334 (1951).
[g] M. Glaubman and F. Metzger, Phys. Rev. **87**, 203 (1952).

---

[1] Amaldi, D'Agostino, Fermi, Pontecorvo, Rasetti, and Segrè, Proc. Roy. Soc. (London) **A149**, 522 (1935).

[2] Mitchell, Langer, and McDaniel, Phys. Rev. **57**, 1107 (1940).

[3] Rose, Perry, and Dismuke, Oak Ridge National Laboratory Report, No. 1459, 1953.

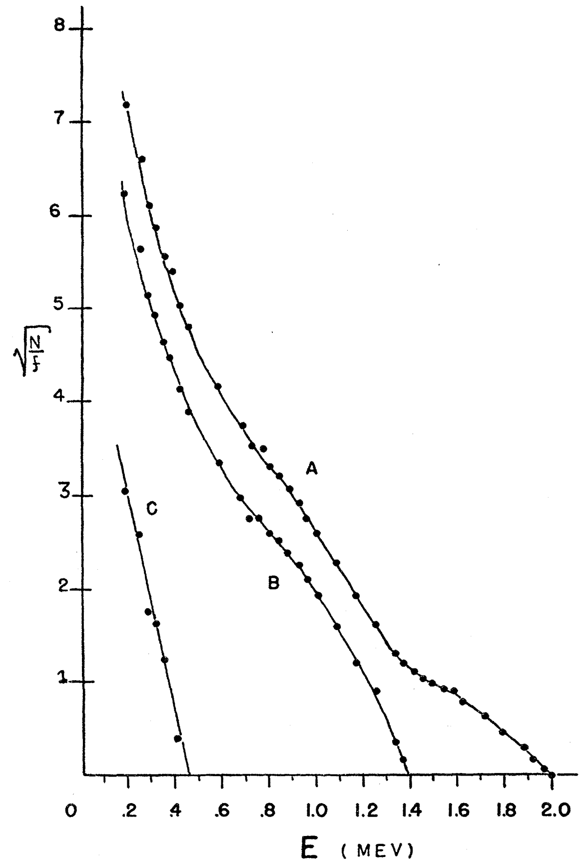

FIG. 1. Resolution of the beta radiation from Sb.[122]

the gamma ray at 647 kev. A lead radiator giving photoelectrons showed K and L lines only for the strong 566-kev gamma ray.

To insure that none of the observed electron lines could be attributed to Sb^{124}, which has been previously intensively studied,[4] spectrometric exposures were made of a strongly irradiated source of Sb^{123}. The strongest electron line is found to have an energy of 571.8 kev. This is a K line and it is accompanied by an L line of about one-tenth its intensity, at 598.6 kev, so that the energy of the gamma ray is 603.6 kev. Weaker conversion electron lines are observed for gamma rays of energies 644 and 727 kev. Even the very strongest line at 571.8 kev is not observable on the spectrograms obtained with Sb^{122}, hence it seems quite certain that none of the gamma rays attributed to Sb^{122} could be due to Sb^{124}.

Studies have also been made of the activity with a scintillation crystal spectrometer. Due to the increased sensitivity of this method, some slight response is obtained for radiation due to Sb^{124}, particularly at high energies. Peaks are obtained for gamma rays at 1.09 and 1.68 Mev with possibly something at 1.2 Mev and also at a higher energy such as 1.9 Mev, as shown by the singles curve A, in Fig. 2. After a decay of 7 days this trace has dropped to give the relative intensities shown in curve B, thus indicating that the 1.68-Mev gamma ray is in Sb^{124} with its longer half-life, while the 1.10-Mev gamma and possibly the 1.2- and 1.9-Mev transitions are in Sb^{122}. In the low-energy region, peaks are observed only for the gamma rays of energy 694, 566, and 27 kev. The last is due undoubtedly to the K x-rays of tellurium following K capture in antimony. The energy is evaluated by comparison with the known peaks due to Cs^{137} and Co^{60}. For the very strong 566-kev radiation both Compton electron and escape peaks are observed as shown.

COINCIDENCE STUDIES

By placing the radioactive source between two scintillation crystals each with its own output circuit, coincidence events could be observed. For gamma-gamma coincidences both crystals were made of NaI, thallium activated. For beta radiations a crystal of anthracene was employed. The window of one pulse-height analyzer could be adjusted to respond to gamma rays lying between definite energy limits and the other instrument could be swept through all of the gamma peaks in turn. In beta-ray studies the anthracene with its very thin window actuated one of the recording circuits. By interposing successive layers of aluminum between source and crystal the counting rate was reduced so as to obtain a Feather curve. Either the thickness required to reduce the intensity to half-value, or the thickness required to reduce to the gamma background, may be used empirically to give the beta upper energy limit.

In Fig. 2 is also shown a coincidence curve C, when one channel is set to respond only to the 566-kev radiation and the other channel is varied to respond to successive gamma rays. The 566-kev radiation is thus seen to be in sequence with the 694-kev gamma. No evidence could be obtained for the gamma-gamma coincidences except for the tellurium x-ray at 27 kev.

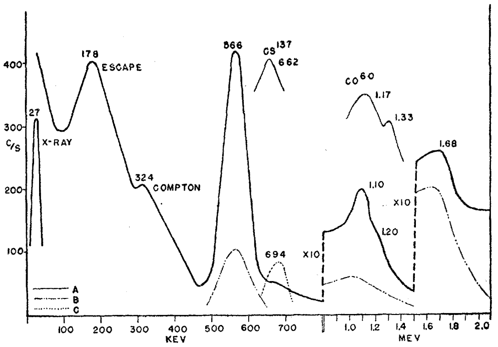

FIG. 2. Energy distribution with the scintillation spectrometer.

---

[4] Langer, Lazar, and Moffat, Phys. Rev. **91**, 338 (1953); Tomlinson, Ridgeway, and Gohalakrishnan, Phys. Rev. **91**, 484 (1953).

The beta activity as a function of the thickness of aluminum is shown in curve *A*, Fig. 3. The thickness required to reduce the activity to that of the gamma background cannot be sharply determined but it is approximately 0.9 g/cm^2 corresponding to an energy of about 1.9 Mev. By recording only coincidences between beta response and the 566-kev gamma ray as the absorber is varied in thickness, curve *B* is obtained. The cut-off thickness is now 0.6 g/cm^2 indicating an energy of 1.4 Mev. This indicates that the 566-kev gamma transition follows in sequence the 1.4-Mev beta decay. Attempts to observe other beta-gamma coincidences were not successful.

The ground level of the even-even $_{52}Te^{122}$ nucleus is undoubtedly a state of zero spin and even parity. If the uniquely forbidden 2.00-Mev beta transition goes directly to the ground state, then the 66-hour $_{51}Sb^{122}$ level is identified as having a spin of two and odd parity. There exists also in Sb^{122} a 3.5-minute isomeric state which has been reported[5] to decay by a 69-kev gamma to the more stable level. The Z^2/W value for the 566-kev radiation is 4.8. In this region a K/L ratio of approximately 7 cannot uniquely determine the type of radiation, and on this basis alone it might be an $E2$ or any type of magnetic transition. The observation of coincidences with beta rays requires a short lifetime which would exclude all magnetic transitions except $M1$, and possibly $M2$. For even-even nuclei the first excited state is usually a level with spin two and even parity, which allows an $E2$ transition to the ground state. The nature of none of the other gamma transitions can be resolved. The low K/L ratio for the 553-kev gamma ray suggests a high-order multipolarity for the transition, such as $E4$ or $M4$. A long lifetime should then be expected which may account for the absence of additional coincidences.

It is possible to arrange a level scheme that will accommodate most of the observed data. Cross-over transitions can be identified from the fact that certain gamma energies have values approximating the sums of others. For example, 566 plus 553, 566 plus 694, and 95 plus 553 will yield 1119, 1260, and 648, respectively, all of which are observed. No trace of positrons could be observed but there might conceivably be *K* capture leading to Sn^{122}. In this event some of the gamma rays might occur in tin. Level schemes that appear reasonable seem to require an additional low-energy beta ray which is beyond the resolution of the present work.

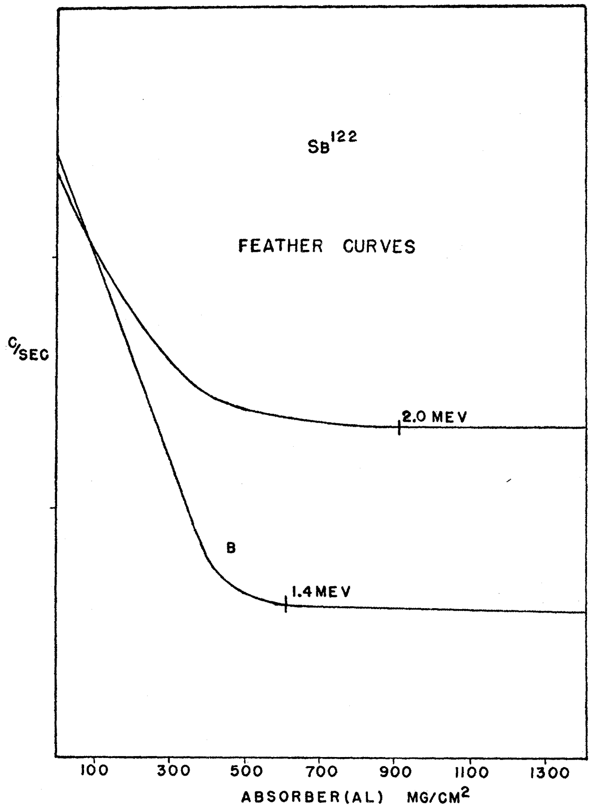

Fig. 3. Absorption of beta radiation observed with scintillation spectrometer.

This investigation received the joint support of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

---

[5] E. derMateosian and M. Goldhaber, Phys. Rev. **82**, 115 (1951); J. H. Kahn, Oak Ridge National Laboratory Report, No. 1089, November, 1951.