Coincidence and Absorption Measurements on Cs^{134}, I^{124}, Au^{199}, and Ca^{45}

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The beta-ray spectrum of Cs^{134} was investigated by absorption and beta-gamma-coincidence measurements. Beta-rays of 0.60 Mev and about 90 kev were observed. In I^{124}, the maximum energy of the beta-rays was found to be 2.30 Mev and beta-gamma-coincidences showed the beta-spectrum to be simple. A maximum gamma-ray energy of 2.24 Mev was observed with several lower energy gamma-rays indicated. Gamma-gamma-coincidences were found, but coincidences between beta-particles and internal conversion electrons could not be detected. Au^{199} exhibited a beta-ray of 0.32 Mev, and the beta-gamma-coincidence rate per beta-ray was independent of absorber thickness. A maximum gamma-ray energy of about 0.21 Mev was found by coincidence absorption of photoelectrons and coincidences between beta-particles and internal conversion electrons. Gamma-gamma-coincidences were obtained. The 43-minute isomeric state of Hg sometimes attributed to Hg^{199} was not observed to grow from Au^{199}. Ca^{45} was found to have a single beta-ray of 0.22 Mev and no gamma-rays.

1. INTRODUCTION

COINCIDENCE and absorption measurements have been made on Cs^{134}, I^{124}, Au^{199}, and Ca^{45}. Cs^{134} has been investigated recently by Elliot and Bell[1] and Siegbahn and Deutsch.[2] Very little information has been available on I^{124}, but recent investigations on Au^{199} have been done by Peacock and Wilkinson[3] with a spectrometer, and by Mandeville, Scherb, and Keighton[4] using coincidence methods. Ca^{45} has been investigated by Solomon and Glendenin[5] and by Matthews and Pool.[6]

2. APPARATUS AND PROCEDURE

The coincidence apparatus used consisted of two Geiger-Müller tubes each connected to a pre-amplifier and then to one channel of a two-channel coincidence counting apparatus similar in principle to that of Jurney and Mitchell.[7] A resolving time of about 0.6 microsecond was used in all coincidence experiments described in this paper.

The arrangement of the counters with respect to the source was that generally used for coincidence and absorption measurements.[8] In general, cylindrical lead cathode counters were used for counting gamma-rays. However, for counting very low energy gamma-rays (of the order of 0.1 Mev), two silver cathode glass counters were used.

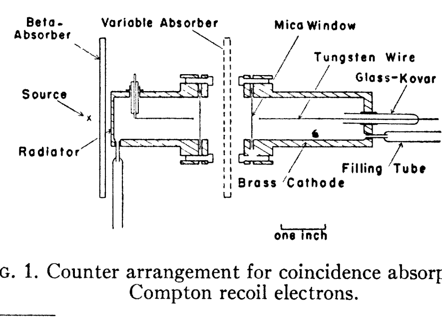

FIG. 1. Counter arrangement for coincidence absorption of Compton recoil electrons.

For counting beta-particles an end window counter with a mica window of 5.6 mg/cm² thickness was generally used. For counting very low energy particles (about 0.1 Mev) windows of condenser paper coated with Formvar were used. These windows had a thickness of 0.8 mg/cm² and the counters and source were placed in an airtight chamber which could be evacuated. Using this technique, beta-particles with ranges as low as 1 mg/cm² could be counted, corresponding to about 23-kev electron energy. All range energy relations for electrons were obtained from the curve of Glendenin.[9]

Coincidences between beta-particles and internal conversion electrons were measured using two end window counters in the evacuated chamber described above. The windows of the counters had a surface density of 0.8 mg/cm². In all cases the absorbers were placed before both counters.

The energy of the highest energy gamma-ray was determined by the coincidence absorption in aluminum of Compton recoil electrons. A special "Compton Counter" was devised for these experiments and is shown in Fig. 1. Using an end window counter with a 5.6-mg/cm² window, the center wire was introduced from the side rather than from the back of the counter. The tube for evacuating the counter was also inserted in the side. The back of the counter then served as a radiator for Compton electrons, when the source was placed behind it as shown. The Compton electrons which gave coincidences traveled through the window and into a second end window counter placed facing the first as shown. Absorbers were placed between the two counters. Knowing the thickness of the mica windows and the absorber thickness, the energy of the electrons[9] being counted could be determined closely. If W is the maxi-

[1] L. G. Elliot and R. E. Bell, Phys. Rev. **72**, 979 (1947).
[2] K. Siegbahn and M. Deutsch, Phys. Rev. **73**, 410 (1948).
[3] C. L. Peacock and R. G. Wilkinson, Phys. Rev. **75**, 329A (1949) and private communication.
[4] Mandeville, Scherb, and Keighton, Phys. Rev. **74**, 601 (1948).
[5] A. K. Solomon and L. E. Glendenin, Phys. Rev. **73**, 415 (1948).
[6] D. E. Matthews and M. L. Pool, Phys. Rev. **72**, 163 (1947).
[7] E. T. Jurney and A. C. G. Mitchell, Phys. Rev. **73**, 1153 (1948).
[8] A. C. G. Mitchell, Rev. Mod. Phys. **20**, 246 (1948).
[9] L. E. Glendenin, Nucleonics **2**, 12 (1948).

mum energy of the Compton recoil electrons, then $W = h\nu/(1+m_0c^2/2h\nu)$ and the energy of the gamma-ray, $h\nu$, may be calculated.

3. RESULTS

Cs^{134}

The disintegration scheme of Cs^{134} has been investigated by Elliot and Bell[1] and by Siegbahn and Deutsch[2] using spectrometer and coincidence techniques. From a Fermi plot of the beta-ray spectrum Elliot and Bell found two beta-ray groups with end-point energies of 0.658±0.030 Mev and about 0.090 Mev. They estimated that the low energy group represents about 28 percent of the total number of beta-rays. From absorption measurements using a windowless counter Siegbahn and Deutsch estimated the abundance of this group as 32±8 percent. Beta-gamma-coincidences have been measured by Wiedenbeck and Chu.[10] They obtained a constant ratio $N_{\beta\gamma}/N_\beta$, independent of beta-ray energy, but only one point was taken in the very low energy region.

The spectrum of Cs^{134} has been investigated by absorption and beta-gamma-coincidence methods. The source was obtained from Oak Ridge and was purified by an amberlite resin ion exchange column at this university. For absorption measurements an end window counter with a window thickness of 0.8 mg/cm² was used, the counter and source being placed in an evacuated chamber. For very low absorption thicknesses the absolute air pressure in the chamber was used as the absorbing medium, this pressure being varied from 1 cm to 76 cm of Hg. At 1 cm of Hg absolute pressure the air absorption plus the window thickness represented a window cut-off of about 23 kev. Figure 2 shows the beta-ray absorption curve obtained. By visual inspection of the end point, and using the curve of Glendenin[9] showing beta-ray energy *vs.* absorber thickness, a maximum beta-ray energy of 0.60±0.03 Mev was obtained. The insert in Fig. 2 shows an enlargement of the low energy end of the curve. In this region the high energy beta-ray curve is essentially a straight line and the low energy group may be clearly seen rising from it. An end point for the less energetic group may be readily determined and gives an energy of 96±8 kev. By extrapolating the curves back to zero absorber, the abundance of the low energy component was determined as 34±5 percent.

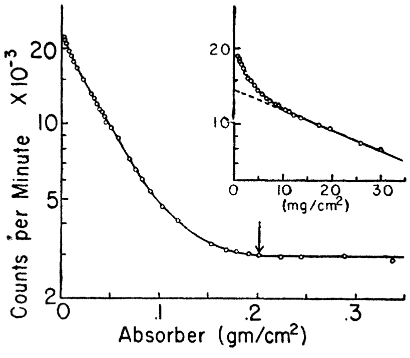

FIG. 2. Absorption of the beta-rays of Cs^{134}. The insert is an enlargement of the low energy region.

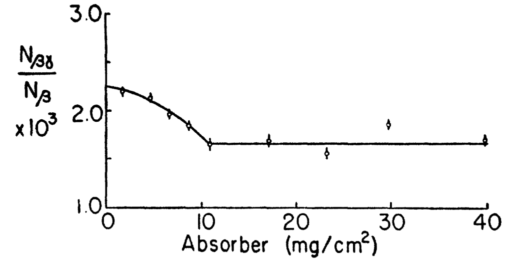

FIG. 3. Low energy beta-gamma-coincidences in Cs^{134}. The ratio $N_{\beta\gamma}/N_\beta$ remained constant for the higher absorber thicknesses not shown.

Using the same thin window beta-counter and a cylindrical lead counter to measure gamma-rays, a beta-gamma coincidence experiment was performed. The source and both counters were placed in the evacuated chamber for low energy determinations. The low energy end of the beta-gamma-coincidence curve is shown in Fig. 3. The curve extended on out to the right in the same straight line showing that except for very low energies the ratio $N_{\beta\gamma}/N_\beta$ was independent of beta-ray energy. However, again the presence of the very low energy beta-group may be clearly seen. The point of intersection of the sloping curve with the straight portion represents an energy of 85±10 kev. Gamma-gamma-coincidences were observed in Cs^{134} and the ratio $N_{\gamma\gamma}/N_\gamma$ had a value of $0.25\pm0.05\times10^{-3}$.

These results are in complete agreement with the disintegration scheme proposed by Elliot and Bell.

I^{124}

Nothing is to be found in the literature on the radiations from I^{124} other than that it is a positron emitter and has a half-life of 4 days.[11] I^{124} was made by bombarding antimony with 23-Mev alpha-particles in the Indiana University cyclotron. The irradiated material was dissolved in nitric acid and potassium iodide carrier added. The iodide was immediately oxidized to iodine and the mixture was boiled using a reflux condenser. The iodine sublimed and collected on the walls of the condenser in solid form. This was washed out with carbon tetrachloride, the iodine reduced to iodide ion, and then precipitated as silver iodide.

Since I^{126} (13.0 days) may also be produced by bombarding antimony with alpha-particles, the half-life was watched closely and when an appreciable amount of I^{126} began to appear, experiments on I^{124} were stopped. Figure 4 shows the half-life for one of the sources. All

[10] M. L. Wiedenbeck and K. Y. Chu, Phys. Rev. **72**, 1164 (1947).

[11] J. J. Livingood and G. T. Seaborg, Phys. Rev. **54**, 775 (1938).

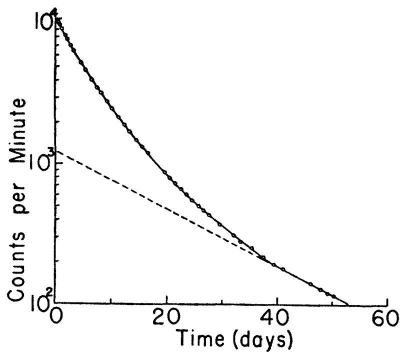

FIG. 4. Decay of I[124]. Experiments were conducted for only the first four days.

measurements using this source were made during the first four days when the slope of the curve corresponded very closely to the reported half-life of I^{124}. The same procedure was followed with a second source. It was estimated that less than 15 percent of the total activity could be ascribed to I^{126} while measurements on I^{124} were being taken.

Figure 5 shows the results of absorbing the beta-rays in aluminum. The gamma-ray background was subtracted, and the resultant pure beta-ray curve analyzed by the method of Bleuler and Zunti.[12] The maximum energy of the beta-rays was found to be 2.30±0.15 Mev. The analysis gave no indication of the presence of a lower energy beta-ray group.

The maximum energy of the gamma-rays was measured by the coincidence absorption in aluminum of Compton recoil electrons using the counter arrangement shown in Fig. 1. The results are given in Fig. 6. The endpoint corresponds to an energy of 2.01 Mev for the electrons, or 2.24±0.15 Mev as the maximum gamma-ray energy. The curve shows several decided breaks at energies below the maximum indicating the presence of at least two lower energy gamma-rays.

Beta-gamma-coincidences are shown in Fig. 7. The ratio $N_{\beta\gamma}/N_\beta$ was found to be independent of beta-ray energy down to an energy of less than 0.1 Mev, again indicating the presence of only a single beta-ray group.

Gamma-gamma-coincidences were measured using two lead counters, first with the source located midway between the counters (the 180° position) and then with one counter at an angle of 90° with respect to its first location but at the same distance from the source. The source was contained in a copper tube so that all positrons would be stopped and the subsequent annihilation radiation emitted from the geometrical center of the arrangement. The value of $N_{\gamma\gamma}/N_\gamma \times 10^3$ in the 180° position was 0.975±0.027 and at 90° this ratio was 0.370±0.017, the two values being related to each other by a factor of 2.6. This is to be compared with results from Cu^{64} (a known positron emitter with no gamma-gamma-coincidences) which gave 2.83±0.14 in the 180° position and 0.25±0.05 in the 90° position, a factor of 11.3. Accordingly the observations on I^{124} showed that while annihilation radiation was present, it did not account for all of the coincidences. Gamma-gamma-coincidences were also present.

An attempt was made to measure coincidences between beta-particles and internal conversion electrons. No such coincidences were observed down to an energy of about 23 kev. It was concluded that if internal conversion electrons are present in I^{124} they do not arise from a gamma-ray which is in coincidence with the beta-ray, or that if the gamma-ray in coincidence with the beta-ray is internally converted, the conversion coefficient is quite small.

If a disintegration scheme is drawn for I^{124} and the 2.30-Mev positron is considered as in coincidence with the 2.24-Mev gamma-ray, the excited state of I^{124} would have to lie at least as high as 4.5 Mev plus $2m_0c^2$. It appears more logical to assume that the positron is in coincidence with a lower energy gamma-ray, and that the high energy gamma-ray results after *K*-capture. If *K*-capture were present, the characteristic x-rays of tellurium would be observed. By critical absorption in Ag, Cd, In, and Sn the characteristic x-rays of tellurium were found to be present. Since the number of internal-conversion beta-particle coincidences seems to be negligible, it would appear that the critical absorption experiments establish the presence of *K*-capture in I^{124}.

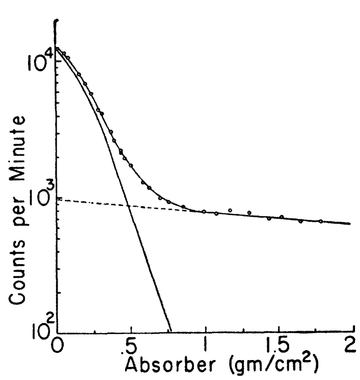

FIG. 5. Beta-ray absorption for I[124]. The curve was analyzed by the method of Bleuler and Zunti.

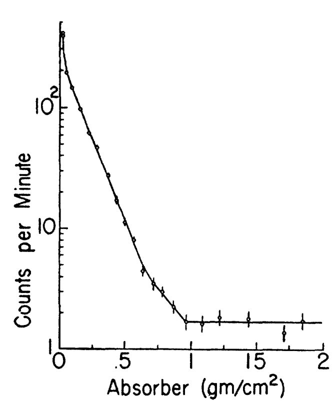

FIG. 6. Coincidence absorption of Compton recoil electrons in I[124]. The breaks in the curve indicate the presence of lower energy gamma-rays.

[12] E. Bleuler and W. Zunti, Helv. Phys. Acta **XIX**, 375 (1946).

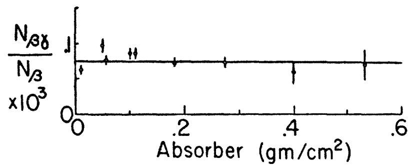

FIG. 7. Beta-gamma-coincidences in I^{124}.

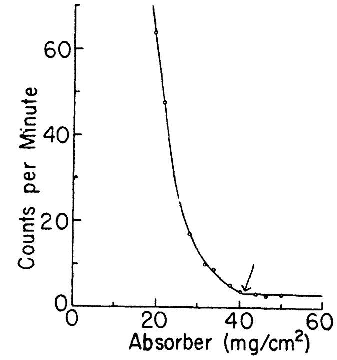

FIG. 9. Coincidence absorption of recoil electrons in Au^{199}.

Au^{199}

The radiations from Au^{199} have been studied recently by Peacock and Wilkinson[3] using a spectrometer and by Mandeville, Scherb, and Keighton[4] using coincidence and absorption methods. Peacock and Wilkinson observed several gamma-rays, one of approximately 0.22 Mev and others of lower energy, some of which were internally converted. In addition the beta-ray endpoint was 0.32 Mev. Mandeville, Scherb, and Keighton determined the beta-ray as 0.38 Mev but detected only one gamma-ray, by absorption in lead.

The source here investigated was obtained from Oak Ridge in the form of platinum which had been irradiated with neutrons. Au^{199} is formed from Pt^{199} which decays with a thirty minute half-life. The platinum was dissolved in aqua regia and gold carrier added. The gold was extracted from the platinum with ethyl acetate and the acetate solution washed with ammonium chloride solution to remove any mercury which might have been present. There is a 43-minute isomeric state of Hg which has been attributed[13] to either Hg^{199} or Hg^{201}. Since Au^{199} decays to Hg^{199}, one would expect to find this metastable state, if Hg^{199} is the correct assignment. The purified gold, which was dissolved in ethyl acetate, was allowed to stand for several hours to permit the supposed 43-min. Hg^{199} to form. The ethyl acetate solution was then washed with ammonium chloride to take out any mercury formed and the resultant mercury checked for activity. This procedure was repeated several times. No 43-minute activity was found.

The absorption of the beta-rays of Au^{199} in aluminum is shown in Fig. 8. An end point of 0.32 ± 0.01 Mev was obtained in agreement with Peacock and Wilkinson.

The gamma-radiation was first investigated by absorption in lead. This indicated the presence of at least two gamma-ray energies of around 0.24 Mev and 0.14 Mev. A more exact determination of the maximum gamma-ray energy was obtained by measuring the coincidence absorption of recoil electrons in aluminum using the counter arrangement shown in Fig. 1. The results are given in Fig. 9, which shows the maximum energy of the recoil electrons to be 0.205 ± 0.015 Mev. If these recoils were Compton electrons, the gamma-ray energy would be 0.34 Mev, but if the recoils were photoelectrons ejected from the wall of the brass counter, 9 kev should be added giving 0.214 ± 0.015 Mev as the maximum gamma-ray energy. This value is approximately the same as that obtained by Peacock and Wilkinson. It may appear that the number of photoelectrons produced would be too small to give an absorption endpoint. However, for a 0.214-Mev gamma-ray the Compton recoil electrons would have a maximum energy of 0.095 Mev which energy would have been completely cut out by the thickness of the counter windows plus the air between the counters, a total of 14.2 mg/cm². With these Compton electrons cut out, the endpoint would have been that due to photoelectrons.

Absorption of the coincidences between beta-particles and internal conversion electrons, Fig. 10, gave an endpoint of 0.120 ± 0.015 Mev. Adding to this the binding energy of the K-electrons of mercury, 0.083

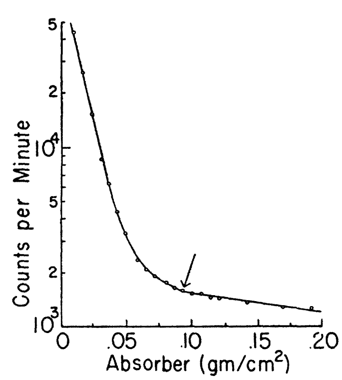

FIG. 8. Beta-ray absorption for Au^{199}.

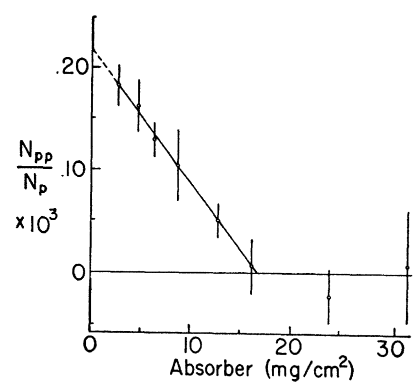

FIG. 10. Beta-beta-coincidences in Au^{199}. The absorber was either air or aluminum placed before both counters.

[13] M. Friedlander and C. Wu, Phys. Rev. **63**, 227 (1943). Sherr, Bainbridge, and Anderson, Phys. Rev. **60**, 473 (1941).

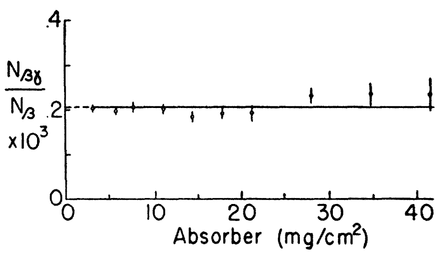

FIG. 11. Beta-gamma-coincidences in Au[199].

Mev, gives the energy of the most energetic gamma-ray, which is internally converted as 0.203±0.015 Mev, in agreement with the value obtained for the maximum gamma-ray energy from absorption of photoelectron coincidences.

A beta-gamma-coincidence rate per recorded beta-ray was obtained which was independent of beta-ray energy, as shown in Fig. 11. This indicated the presence of only a single beta-ray or that any lower energy beta-ray groups are of low abundance. Gamma-gamma coincidences were observed using two silver cathode glass counters and enough aluminum absorber to cut out all the beta-rays. The ratio $N_{\gamma\gamma}/N_\gamma$ was $0.19\pm0.01\times10^{-3}$.

Ca^{45}

Measurements by Solomon and Glendenin[5] and by Matthews and Pool[6] have shown Ca^{45} to be a simple beta-ray emitter unaccompanied by gamma-rays. Solomon and Glendenin obtained a beta-ray endpoint of 0.26 Mev and Matthews and Pool obtained 0.21 Mev. In the present experiment, a source of Ca^{45} obtained from Oak Ridge, was chemically purified and an absorption curve taken. This absorption curve is shown in Fig. 12. The beta-ray endpoint is found to be 0.22±0.01 Mev, and in addition there were no gamma-rays present.

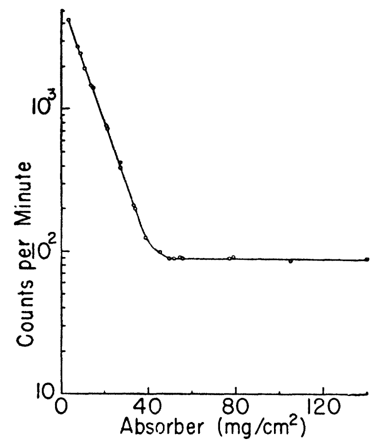

FIG. 12. Beta-ray absorption for Ca^{45}.

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