A Study of the Radiations from Columbium (95), Rhenium (188), Osmium (191), and Osmium (193)*

C. E. MANDEVILLE, M. V. SCHERB,** AND W. B. KEIGHTON***
Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania
(Received June 14, 1948)

The characteristic radiations of Cb^{95}, Re^{188}, Os^{191}, and Os^{193} have been investigated by absorption and coincidence methods. Maximum beta-ray energies were determined by aluminum absorption, and maximum quantum energies were measured by coincidence absorption of the secondary electrons in aluminum.

Beta-beta-, beta-gamma-, and gamma-gamma-coincidence rates were measured when possible. Some remarks concerning Sb^{124} and Au^{198} are also included.

INTRODUCTION

THE characteristic radiations of several radio-isotopes produced by slow neutron bombardment in the Oak Ridge pile have been investigated by coincidence and absorption methods. The general method has been previously described.[1] The beta-ray energies were measured by absorption in aluminum; the gamma-ray energies were measured by coincidence absorption, and whenever possible, beta-beta-, beta-gamma-, and gamma-gamma-coincidences were investigated. A coincidence resolving time of 0.10 microsecond was used throughout the course of the experiments.

COLUMBIUM (95)

The 35-day columbium (95) was separated from the fission fragments of the pile at Oak Ridge. The columbium was further purified for the removal of phosphorous, zirconium, copper, and iron as possible impurities. An absorption curve of the beta-rays of Cb^{95}, shown in Fig. 1, gave a maximum beta-ray energy of 0.14 Mev. This value agrees with earlier measurements and is an indication of the purity of the material. A coincidence absorption experiment gave 0.92 Mev as the maximum energy of the gamma-rays. These data are shown in Fig. 2. The beta-gamma-coincidence rate was found to be 1.3×10^{-3} coincidence per beta-ray as shown in Fig. 3. The gamma-ray counter was constructed of "low Z" materials and was calibrated by the beta-gamma-coincidence rate of Sc^{46}. It was thus concluded that the beta-rays of Cb^{95} are followed by 0.92 Mev of gamma-ray energy.

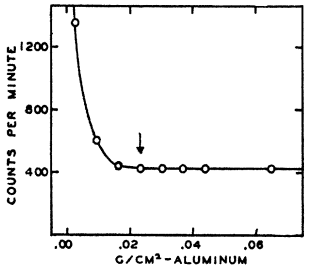

FIG. 1. Absorption in aluminum of the beta-rays of Cb^{95}.

A gamma-gamma-coincidence rate of $(0.28\pm0.02)\times10^{-3}$ coincidence per gamma-ray was also present. This indicates that the Mo^{95} residual nucleus de-excites by emission of the 0.92 Mev gamma-ray or by an alternate mode involving the emission of two or more gamma-rays.

The writers had previously assigned the 0.92 Mev gamma-ray to zirconium (95), the parent element of columbium (95), produced when zirconium is irradiated by slow neutrons.[2] The present data show that the earlier assignment was incorrect, undoubtedly the result of an incomplete chemical separation.

A small number of beta-beta-coincidences were detected in the disintegration of Cb^{95}, confirming that some of the gamma-rays are converted.[3]

* Assisted by the joint program of the Office of Naval Research and the Atomic Energy Commission.
** Now at Princeton University.
*** Also of the Department of Chemistry, Swarthmore College.
[1] C. E. Mandeville and M. V. Scherb, Phys. Rev. **73**, 141 (1948).
[2] C. E. Mandeville and M. V. Scherb, Phys. Rev. **73**, 1434 (1948).
[3] Plutonium Project Report, "Nuclei formed in fission," Rev. Mod. Phys. **18**, 513 (1946).

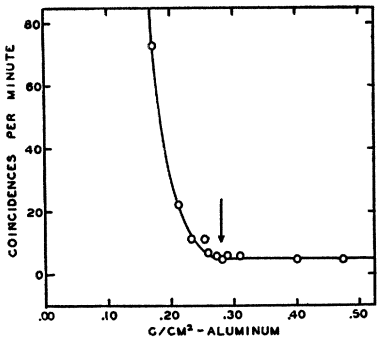

FIG. 2. Coincidence absorption of the secondary electrons of the gamma-rays of Cb^{95}.

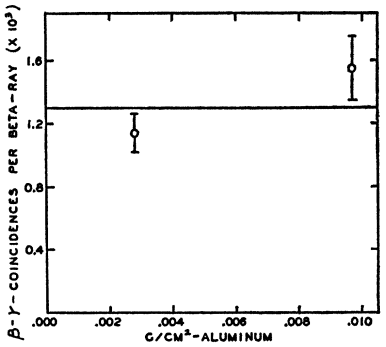

FIG. 3. Beta-gamma-coincidence rate for Cb^{95} as a function of aluminum absorber thickness before the beta-ray counter.

RHENIUM (188)

The eighteen-hour activity was induced in ReO_2, irradiated by slow neutrons for thirty minutes in the pile. Measurements were initiated about twenty hours after removal of the rhenium from the pile. Using the method of coincidence absorption, a calibrated[2] coincidence-counting set gave a maximum quantum energy of 1.39 Mev. This agrees well with 1.43 Mev reported by Miller and Curtiss[4] employing a thin lens spectrometer. The coincidence absorption data are given in Fig. 4.

A very low beta-gamma-coincidence rate, plotted in Fig. 5, was measured in Re^{188}. The beta-gamma-coincidence rate is seen to be constant from 0.5 g/cm² to 0.05 g/cm² where a rise in the curve sets in. The first point of the curve brings the coincidence rate down again. This may have been an unduly large statistical fluctuation or an indication of the presence of conversion electrons of low energy. The break in the curve at 0.05 g/cm² indicates the presence of a beta-ray spectrum having a maximum energy of 0.225 Mev. This spectrum is apparently coupled with the 1.39 Mev gamma-ray and other gamma-rays. From Fig. 5 it is seen that the beta-gamma-coincidence rate of 0.02×10^{-3} coincidence per beta-ray extends beyond a beta-ray energy of 1 Mev. This would indicate that the 2.07 Mev[5] beta-rays of Re^{188} lead to a low-lying excited level of the Os^{188} residual nucleus. Among the gamma-rays reported by Miller and Curtiss[4] is one having an energy of 0.16 Mev which in addition to being to some extent converted, is more intense than the other gamma-rays present. It seems probable that the hard beta-rays of Re^{188} are coupled with this gamma-ray.

Beta-beta-coincidences† were measured in Re^{188}. They drop to zero at 0.018 g/cm² as shown in Fig. 6. This corresponds to a conversion electron energy of 0.12 Mev or a gamma-ray energy of 0.19 Mev. The beta-gamma-coincidence rate in the beta-beta-coincidence counting arrangement was too small to measure with any accuracy so that no estimate of the internal conversion coefficient was obtained.

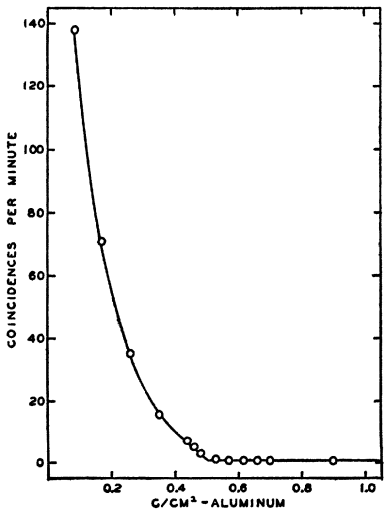

FIG. 4. Coincidence absorption of the secondary electrons of the gamma-rays of Re^{188}.

[4] L. C. Miller and L. F. Curtiss, Phys. Rev. **70**, 983 (1946).
[5] L. J. Goodman and M. L. Pool, Phys. Rev. **71**, 288 (1947).

† All beta-beta coincidence data were obtained by placing aluminum absorbers before both of the beta-ray counters.

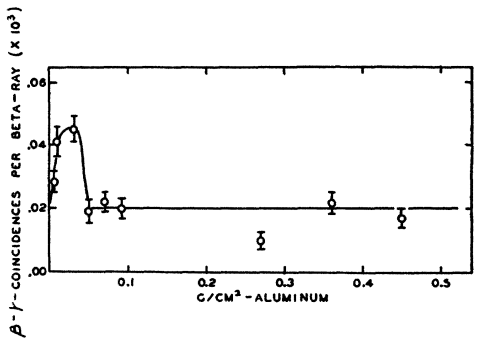

FIG. 5. Beta-gamma-coincidence rate for Re^{188} as a function of the surface density of aluminum placed before the beta-ray counter.

A gamma-gamma-coincidence rate of $(0.096 \pm 0.009) \times 10^{-3}$ coincidence per gamma-ray was observed in the disintegration of Re^{188}, showing that gamma-rays are emitted in cascade.

The absorption and coincidence measurements on Re^{188} are summarized in Fig. 7 where a tentative and incomplete level diagram is given.

It should be remarked that during the time of the measurements, the source appeared to be decaying for the most part with a half-period of 18 hours. It has also been previously shown[6] that the 90-hour Re^{186} emits no gamma-rays so that it would appear that the measurements were hardly affected by its presence.

OSMIUM (191)

The 32-hour activity was induced in osmium irradiated by neutrons for thirty minutes in the pile. The hard beta-rays were absorbed in aluminum as shown in Fig. 8. The end point corresponds to a maximum energy of 1.15 Mev. A small beta-gamma-coincidence rate, 0.03×10^{-3} coincidence per beta-ray, independent of the beta-ray energy, is shown in Fig. 9. As in the case of Re^{188}, this suggests that the hard beta-rays lead to a low-lying excited state of the Ir^{191} residual nucleus.†† This fact is confirmed by the presence of beta-beta-coincidences shown in Fig. 10. This coincidence rate reached zero at 0.024 g/cm², corresponding to a conversion electron energy of 0.14 Mev and a gamma-ray energy of 0.22 Mev. The beta-gamma-coincidence rate in the beta-beta-coincidence counting arrangement was too small to obtain an accurate measure of the conversion coefficient.‡ A coincidence absorp-

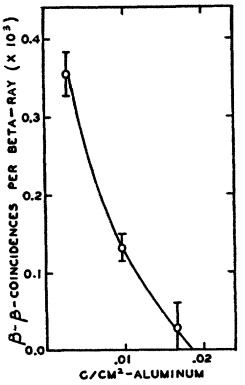

FIG. 6. Beta-beta-coincidence curve for Re^{188}.

[6] E. C. Creutz, Communication to G. T. Seaborg, Rev. Mod. Phys. **16**, 1 (1944).

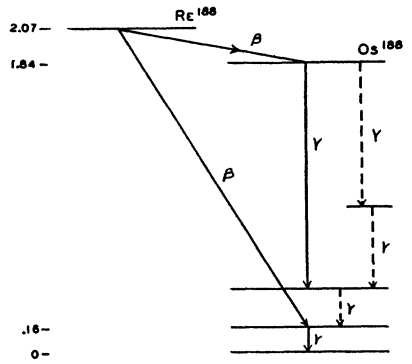

FIG. 7. Tentative disintegration scheme for Re^{188}.

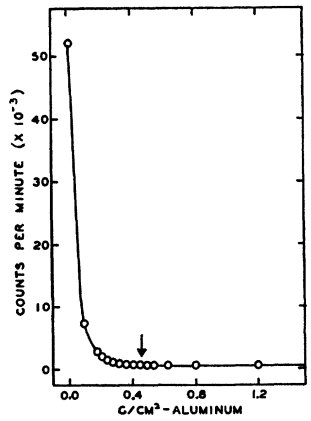

FIG. 8. Absorption in aluminum of the beta-rays of Os^{191}.

†† The gamma-rays from such low-lying levels in Os^{188} and Ir^{191} might be delayed. No search for delayed coincidences was made in the course of the present investigations.

‡ Calculation of conversion coefficients for both Re^{188} and Os^{191} would be difficult because the measurements of this paper give evidence of possible complexity of the beta-ray spectra of both elements.

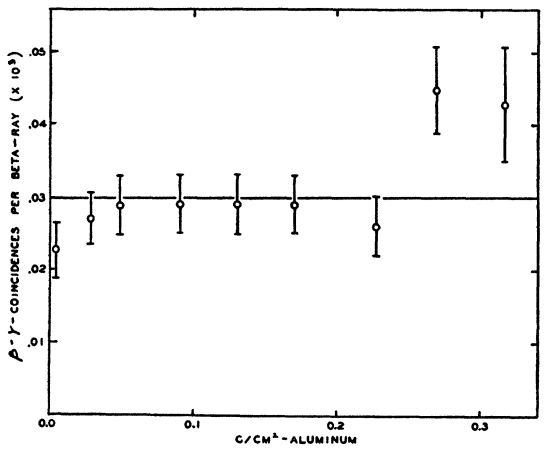

FIG. 9. Beta-gamma-coincidence rate for Os^{191} as a function of the surface density of aluminum placed before the beta-ray counter.

tion curve, shown in Fig. 11, gives a maximum gamma-ray energy of 1.58 Mev. A gamma-gamma-coincidence rate of $(0.13\pm0.03)\times10^{-3}$ coincidence per gamma-ray was also measured.

It appears that the hard gamma-ray must be coupled with a beta-ray spectrum of low energy and low intensity which made no appearance on the beta-gamma-coincidence curve. It is certainly non-coincident with the hard beta-rays.

OSMIUM (193)

After the irradiated osmium had decayed for about forty days, a small residual activity was present, the seventeen-day Os^{193}. Absorption of the beta-rays in aluminum gave a maximum energy of 0.15 Mev. These data are shown in Fig. 12.

Although the source was of low intensity, it was possible to measure beta-gamma-coincidences as shown in Fig. 13. Gamma-gamma-coincidences were also present.‡‡

ANTIMONY (124)

Several authors have recently reported internal conversion in the disintegration of Sb^{124}. Kern, Zaffarano, and Mitchell,[7] and Feister and

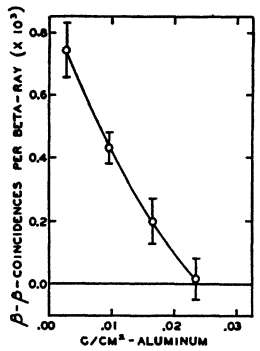

FIG. 10. Beta-beta-coincidence rate for Os^{191}.

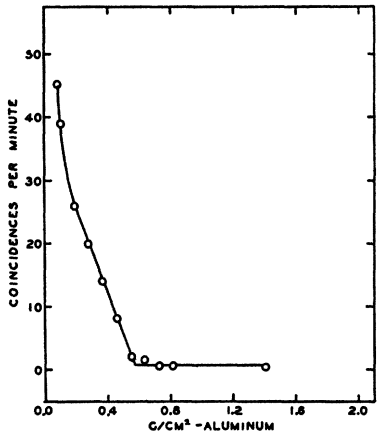

FIG. 11. Coincidence absorption of the secondary electrons of the gamma-rays of Os^{191}.

Curtiss[8] have reported conversion of the 0.6 Mev gamma-ray, and, in addition, Cook and Langer[9] have reported a conversion line corresponding to a quantum energy of 0.12 Mev. Accordingly, beta-beta-coincidences in Sb^{124} were searched for

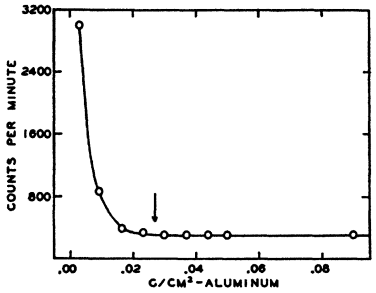

FIG. 12. Absorption in aluminum of the beta-rays of Os^{193}.

‡‡ *Note added in proof:* Saxon, Bull. Am. Phys. Soc. **23**, No. 4, 16 (1948) has reported a spectrometric value of 0.142 Mev for the beta rays of Os^{193}. Katzin and Pobereskin, Phys. Rev. **74**, 264 (1948) give absorption and coincidence data on Os^{193} very similar to those of this paper.

[7] B. D. Kern, D. J. Zaffarano, and A. C. G. Mitchell, Phys. Rev. **73**, 1142 (1948).

[8] I. Feister and L. F. Curtiss, J. Research NBS **40**, No. 4, 315 (1948).

[9] C. S. Cook and L. M. Langer, Phys. Rev. **73**, 1149 (1948).

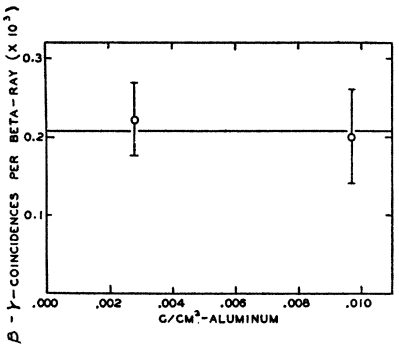

FIG. 13. Beta-gamma-coincidence rate of Os^{193}.

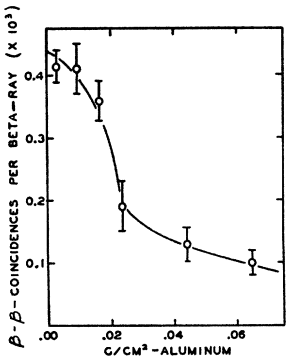

FIG. 14. Beta-beta-coincidence curve for Sb^{124}.

and found by the writers. The coincidence curve is given in Fig. 14. No conclusions have been drawn with regard to a conversion coefficient, because more than one converted gamma-ray is present, and the beta-ray spectrum is very complex.

GOLD (198)

A short time ago, the writers published[10] what they felt constituted conclusive evidence that gamma-gamma-coincidences are present in the disintegration of Au^{198}. Since that time it has been pointed out that the low gamma-gamma-coincidence rate could be explained by the presence of the 23-hour mercury activity. The Au^{198} of the previously performed gamma-gamma-coincidence experiment was chemically purified so that mercury should not have been present. The chemical purification is given in the appendices of this paper.[11]

ACKNOWLEDGMENT

The writers wish to acknowledge the continued interest of Dr. W. F. G. Swann, Director of the Bartol Research Foundation.

APPENDIX I

Chemical Purification of Columbium (95)

One mc of Cb^{95} in solution as the oxalate complex, carrier free, was mixed with a solution of inactive columbium. The solution of inactive columbium was prepared from 0.1 g of Cb_2O_5 fused with $KHSO_4$ and dissolved in ammonium oxalate solution. The combined oxalate solutions were diluted to 60 cc and carefully neutralized with ammonia and hydrochloric acid. Two grams of NH_4Cl were added, and the columbium was precipitated with excess tannin and ignited to Cb_2O_5.

ZrO_2, 0.1 g, was added as a carrier, and the precipitate and carrier were fused with K_2CO_3. The melt, when cold, was leached with cold water to dissolve the columbium, which was then precipitated with SO_2. The precipitate was ignited to Cb_2O_5.

This procedure was intended to separate from the columbium phosphorous, zirconium, copper, and iron.

APPENDIX II

Chemical Purification of Gold (198)

About 15 mg of gold from the pile and an equal quantity of inactive gold were dissolved in boiling aqua regia, and the excess was boiled away. A few milligrams of platinum were added as H_2PtCl_6. 20 ml of water, 1 ml of HCl, and 4 ml of saturated SO_2 solution were then added. After standing on the steam bath for an hour, filter pulp was added; the precipitated gold was washed by decantation with hot dilute HCl (1:99) and collected on a filter. The precipitate was digested for three hours with concentrated ammonia to remove any possible AgCl and was then washed with water.

The gold was again dissolved with dilute aqua regia and washed from the paper pulp with hot, dilute HCl. After adding several milligrams of H_2PtCl_6 the extract was evaporated to dryness, moistened with HCl, and again evaporated. Two

[10] C. E. Mandeville and M. V. Scherb, Phys. Rev. **73**, 634 (1948).

[11] For recent information on the gamma-rays of Au^{198}, see DuMond, Lind, and Watson, Phys. Rev. **73**, 1392 (1948).

repetitions of this process destroyed the HNO_3. The residue, dissolved in 1 ml of HCl, 1 drop of H_2SO_4, and 15 ml of water, was treated with 5 ml of a saturated oxalic acid solution, and boiled for ten to fifteen minutes. After standing for four hours, it was washed with dilute HCl (1:99), filtered with paper pulp, and finally ignited to gold. This procedure was intended to separate the gold from most other metals including platinum, silver, and mercury, calcium, and iron.

PHYSICAL REVIEW VOLUME 74, NUMBER 8 OCTOBER 15, 1948

A Note on the Magnetic Moment of the Electron

J. M. LUTTINGER*
Swiss Federal Institute of Technology, Zurich, Switzerland
(Received May 19, 1948)

Recent experiments seem to require a modification in the g-factor of the electron. It has been suggested that the coupling between the electron and the radiation field is responsible, and Schwinger has calculated the effect on the basis of a general subtraction formalism for the infinities of quantum electrodynamics. It is here shown that the change in magnetic moment may be derived very simply without any reference to an elaborate subtraction formalism.

I.

IT has been suggested recently by Schwinger[1] that the coupling between an electron and the radiation field leads to a change in the g-factor of the electron, as seems to be required by experiment.[2] This result was derived on the basis of his (as yet unpublished) general subtraction formalism for the infinities of quantum electrodynamics. It is the purpose of this note to show that the change in magnetic moment may be derived very simply without any reference to an elaborate subtraction formalism.

We may characterize the problem as follows: Given an electron in a homogeneous magnetic field, what is the energy of this electron as a result of interactions with the zero-point vibrations of the quantized radiation field? It is well known that this energy is infinite, the infinities which arise usually being ascribed to changes in the mass and charge of the electron. What we seek are those parts of the energy which do not correspond to the ordinary mass and charge changes, but those which arise because of the presence of the external magnetic field. The problem of subtracting the original infinities is made very simple in this case by the existence of a state for the electron (in a homogeneous magnetic field) which has as an energy simply $E=m$.[3] This is a direct result of the fact that the (unperturbed) Dirac electron has a g-factor of exactly 2. For this state we have the energy of the orbital magnetic moment exactly canceling the energy of the spin magnetic moment. The change in energy of such a state due to a change in mass ($E_{\text{self}}(0)$) and charge of the electron is simply

$$\Delta E = E_{\text{self}}(0), \tag{1}$$

which is independent of the external field. This means that when we calculate the energy and find terms which depend on the external field strength, these terms must represent the true change in the energy, and they must converge. This expectation is borne out by the calculation of the energy to terms linear in H_0 (the external field strength). The coefficient of this latter term gives immediately the alteration of the g-factor of the electron.

II.

We now proceed to an outline of the calculation. For the electron we must use the quantized formalism of the theory of holes[4] and for the

* Fellow of The Institute for International Education.

[1] J. S. Schwinger, Phys. Rev. **73**, 415 (1948); Bull. Am. Phys. Soc. **23**, 15 (April 1948).

[2] See for example: P. Kusch and H. M. Foley, Phys. Rev. **72**, 256 (1947); **73**, 412 (1948); J. Nafe and E. Nelson, Phys. Rev. **73**, 718 (1948).

[3] We shall use throughout natural units, e.g., $\hbar=c=1$. m is the mass of the electron.

[4] Cf. G. Wentzel, *Ein. in die Quant. Theorie der Wellenfelder* (Franz Deuticke, Wien, 1943), pp. 158–91.