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The Internally Converted Gamma-Rays of Several Radioactive Elements

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The conversion electron spectra of a number of radioactive elements produced by proton and deuteron bombardment in the cyclotron have been investigated. The beta-ray spectrograph was designed to allow rapid replacement of the source and photographic film so that successive fresh samples of short period activities could be used for a single exposure. The results may be summarized as follows: Br^{80} (4.4 hr.) three conversion lines observed corresponding to two gamma-rays, one of 48.9±0.4 kev and a second of either 37.1 or 25.3 kev, both arising in the isomeric transition to the 18-min. state. Br^{78} (6.3 min., e^+) K and L_1 conversions in Se of two gamma-rays of 45.8±0.4 and 107.7±0.9 kev; $Cd^{107\text{ or }109}$ (6.4 hr., K capture) K, L_1 and M_1 conversions of a gamma-ray of 92.6±0.8 kev. In this case there is an anomalously high L_1 conversion since the K and L_1 lines have nearly equal intensity. Also a 530-kev gamma-ray, possibly annihilation radiation, although no positrons are observed. Ga^{67} (78 hr., K capture) K and L_1 conversions of a gamma-ray of 92.5±0.8 kev; Ga^{70} (18.5 min., e^- and possible K capture) K and L_1 conversions of a gamma-ray of 53.8±0.5 kev and probably a second line of about 117 kev.

INTRODUCTION

THE low energy line spectra of electrons emitted by radioactive isotopes are of interest in giving information about the mode of decay, the gamma-ray spectra and the process of internal conversion. Studies of such spectra for the radioactive isotopes Br^{80}, Br^{78}, Cd^{107} (or Cd^{109}), Ga^{67} and Ga^{70} are reported in this paper. The results are summarized in Table I.[1]

PROCEDURE

The beta-ray spectrograph used is shown in Fig. 1. It was developed after observations of the behavior of two previous instruments which indicated, that insofar as the sharpness of the line spectra were concerned, electron scattering could be neglected in such an arrangement. Accordingly the simplest design which would allow quick and accurate replacement of both source and photographic plate or film was sought.

TABLE I. *Conversion electron and gamma-ray energies.*

Radio-active Nucleus	Half-life	$H\rho$ (gauss-cm)	Electron Energy (kev)	Conversion Shell	Gamma-ray Energy (kev)
Br^{80}	4.4 hr.	524	23.6	Br K or L_1	37.1 or 25.3
		646	35.5	Br K	48.9±0.4
		749	47.2	Br L_1	
Br^{78}	6.7 min.	619	32.7	Se K	45.8±0.4
		725	44.3	Se L_1	
		1090	95.5	Se K	107.7±0.9
		1150	105.4	Se L_1	
Cd^{107} (or Cd^{109})	6.4 hr.	897	66.4	Ag K	92.6±0.8
		1053	89.6	Ag L_1	
		1065	91.5	Ag M_1	
Ga^{67}	78 hr.	1006	82.4	Zn K	92.5±0.8
		1066	91.7	Zn L_1	
Ga^{70}	18.5 min.	721	43.8	Zn K	53.8±0.5
		794	52.7	Zn L_1	
		1160	107.1	Zn K (?)	117.0±1.0

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[1] The values of the natural constants used in computation were those appearing in the publication of J. W. M. DuMond, Phys. Rev. **56**, 153 (1939); namely, $e_0=4.80290\times10^{-10}$ e.s.u.; $m_0=9.11096\times10^{-28}$ gram; $h_0=6.62602\times10^{-27}$ erg sec.

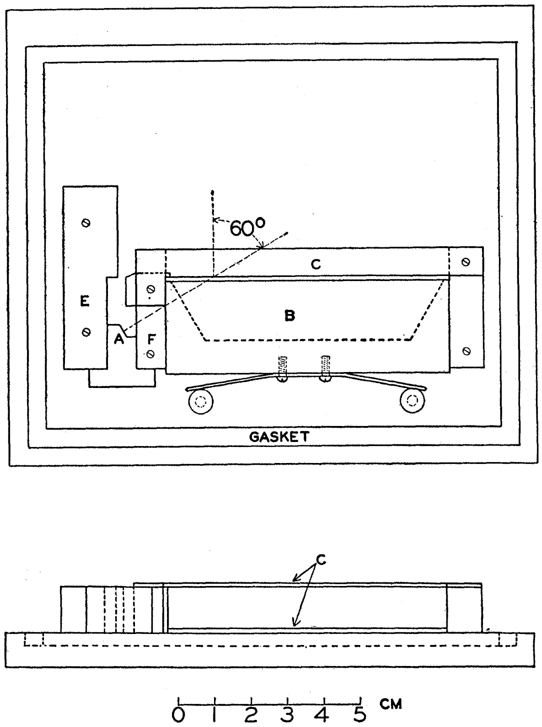

FIG. 1. Magnetic spectrograph. The radioactive source is placed on the inclined face of the removable block, *A*. The film or plate is clamped between the stationary members *C* and the sliding block, *B*. The elevation is drawn without *B*.

The first condition was met by mounting the radioactive source on the inclined face of the removable block *A*, which fits between the slit jaws consisting of two aluminum blocks *E* and *F*. The sources themselves were thin foils from 1 to 3 mm wide and 11 mm long. Several blocks similar to *A* were available. When high resolution was desired to determine line energies, the inclined face of *A* was tilted at 60 degrees as shown in Fig. 1. In this case, the sources were 1 mm wide and fastened to *A* so that the source edge nearest the photographic plate lay on a line through the center of the slit and normal to its plane. If this is not the case, the high energy side of the lines is not formed by exactly semi-circular trajectories and a small error results. For higher intensity with lower resolution, the source was tilted at an angle of 45 degrees and made 2 to 3 mm wide.

The photographic film or plate is clamped between the longitudinal members, *C* and the block *B*. *B* is pushed against the back of the film by the flat spring shown.

All of the parts shown in Fig. 1, including the base plates, are of aluminum except the block *B* which is a brass case filled with lead. A loosely hinged cover of brass, the beveled edges of whose sides fit the gasket shown, is held tight by atmospheric pressure. A sufficiently good vacuum was produced by a Megavac pump.

The magnet was constructed of Armco Ingot iron with pole face dimensions of eight by fourteen inches. The field produced was sufficiently uniform to make corrections unnecessary over the area occupied by the instrument of Fig. 1. The precision of our results is limited only by the constancy of the direct-current supply. The field was observed to vary over a maximum range ± 0.5 percent during a run of 24 hours. Unless otherwise indicated, our measurements of $H\rho$ represent the mean values from several plates. No deviations from the mean greater than 0.5 percent were observed.

The field meter was a small direct-current generator driven by a synchronous motor. It is quite similar to the design published by Cole,[2] except that the part of the rotating shaft inserted between the magnet poles is made of lucite instead of brass. The average voltage produced by such a device is proportional to the magnetic field. This voltage was measured by a potentiometer. The generator and potentiometer was checked for linearity over the range of fields used with a pair of Helmholtz coils excited by storage batteries. No departure from linearity greater than 0.1 percent in the range of 100 to 500 gauss was observed.

To calibrate this field meter, the prominent *F* line from the thorium B·C transition was used for which line Ellis[3] gives the value 1385.8 gauss-cm.[4]

Both Eastman and Agfa "No Screen" x-ray films were used and developed for 8 minutes in Eastman D-19 developer at 66 degrees F. No significant difference between these two films was found in the range of opacities covered. These films are emulsion coated on both sides, a feature which served only to raise the background fog in the present work, since none of

[2] R. H. Cole, Rev. Sci. Inst. **9**, 215 (1938).
[3] C. D. Ellis, Proc. Roy. Soc. **A138**, 318 (1932).
[4] We wish to thank Professor T. R. Wilkins for preparing the thorium B sources for us.

the electron groups had sufficient energy to penetrate the film base.

The films were photometered at 0.2-mm intervals in the region of the lines. Wherever these measurements are significant they are plotted here as opacity *vs.* distance along the plate, with a superimposed $H\rho$ scale. The opacity of the plates is used instead of the density since with proper choice of development time this quantity is a linear function of the exposure.[5] To check this, a plot of line intensity *vs.* exposure was obtained from seven plates exposed to the same source of Ga^{67} for various periods of time. It was found that the intensity of the K line, measured either as the opacity of the peak of the line or as the area under the line, was a linear function of the exposure, provided the peak opacity was less than five. We have accordingly worked in this region.

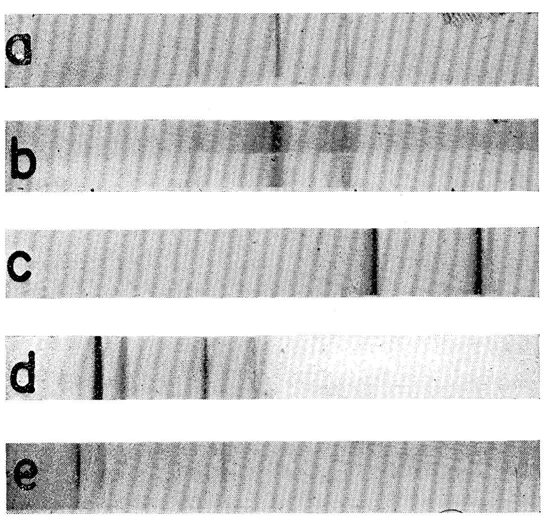

FIG. 2. (a) and (b) Plates of the 4.4-hour Br^{80}. (a) Plate from which energy measurements were taken. Source 1 mm inclined at 60 degrees. (b) Shielded plate. Source 2 mm inclined at 45 degrees. Upper section exposed 48 min. beginning immediately after bombardment; lower section exposed 55 min. beginning 48 min. after bombardment. (c) Plate of 6.4-hour $Cd^{107 \text{ or } 109}$. Thin silver films evaporated on aluminum foil and bombarded with protons used as sources. Sources 1 mm and inclined at 60 degrees. (d) and (e) Plates of 18-min. Ga^{70} and 78-hour Ga^{67} from bombardment of zinc with deuterons. (d) Plate from which energy measurements were taken. Plate was exposed for 75 min. to each of four sources of thin zinc foils 1 mm inclined at 60 degrees. (e) Shielded plate. Upper section exposed continually; lower section exposed for 26 min. beginning 21 min. after bombardment. Sources 2 mm inclined at 45 degrees.

[5] Cf. C. D. Ellis and W. A. Wooster, Proc. Roy. Soc. **A114**, 266 (1927).

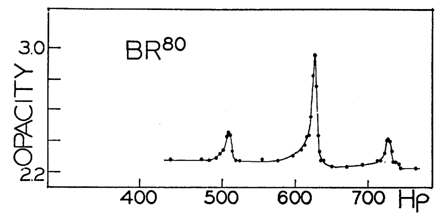

FIG. 3. Photometer record of plate shown in Fig. 2(a).

Br^{80}, Br^{78}

Since our previous communication[6] on the spectrum of Br^{80}, we have so improved our technique as to make desirable a more careful repetition of these experiments. The measurements were all made with sources produced by the deposition of thin films of selenium on aluminum foil by evaporation in a vacuum. The selenium-coated foils were cut to the correct size for the spectrograph, placed in an evacuated bombarding cup, which was cooled with dry ice in butyl-alcohol, and mounted on the exit port of the cyclotron chamber behind a 0.0005-inch aluminum window. During the bombardment the beam was sufficiently focused so that about 75 percent of the total current was intercepted by a foil 3 by 11 mm in size.

Figure 2(a) and (b) show two of the many spectra taken with selenium targets bombarded for various lengths of time and for different exposure times. Figure 2(a) is a spectrum such as was used to determine accurately the energies of the lines previously reported. Here the source was 1 mm wide and inclined at an angle of 60 degrees. The photometer measurements of this plate are shown in Fig. 3. Three lines at $H\rho$ values of 524, 646, 749 gauss-cm are clearly evident. The corresponding energies are 23.6, 35.5, 47.2 kev. These values supplant those previously given. The difference between the energies of the two highest lines is 11.7 kev agreeing within limits of error with the energy difference of 11.8 kev between the K and L_1 absorption edges of Br. The difference between the two lowest lines is 11.9 kev. It seems safe to ascribe the lines at 646 and 749 $H\rho$ to the K and L_1 conversion of a gamma-ray of 48.9 ± 0.4 kev. The line at 524 $H\rho$ may be the result either of a K conversion of a gamma-ray of about

[6] G. E. Valley and R. L. McCreary, Phys. Rev. **55**, 666 (1939).

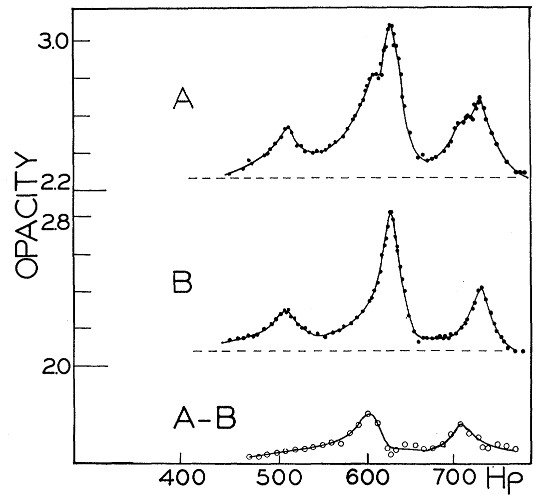

FIG. 4. Photometer records of plate shown in Fig. 2(b). *A*, record of the upper section; *B*, record of the lower section; *A–B*, difference curve.

37 kev (the L_1 conversion group being hidden in the large peak at 646 $H\rho$ [7]), or the L_1 conversion of a gamma-ray of about 25 kev. In the latter case there should be a K conversion line at 12 kev, but we shall show some evidence below in support of the supposition of Ellis[3] that the sensitivity of photographic emulsions decreases sharply with decrease in energy in this region so that such a line would not be registered. For this reason also, no good estimate of the relative intensities of these lines can be given.

It remains to establish that these lines all come from 4.4-hour period of Br^{80}. Buck[8] has shown that Se when activated by protons of 6.5 Mev exhibits the following radioactive periods: 6.3 min. (Br^{78}, e^+), 18 min., and 4.4 hours (Br^{80}) and 33 hours (Br^{82}, e^-). We have excluded the 33-hour period by exposing another plate to a source which had already produced the lines previously. This second exposure of twenty hours beginning twenty hours after bombardment should have revealed the same spectrum with 0.65 times the intensity of Fig. 3 if Br^{82} were responsible. Actually, two exposures of this type showed no evidence for any lines whatever.

It was next of great importance to determine whether this spectrum was due entirely or in part to the 18-minute isomer of Br^{80}. The procedure was to bombard a selenium covered foil for 90 minutes with a beam of 1.5 microamp. of 6.5-Mev protons. This target was placed in the spectrograph within 90 seconds after the end of bombardment and an exposure of 48 minutes taken with the lower section of the photographic plate shielded longitudinally with 0.5-mm aluminum strip. The exposure was then interrupted for one minute while the lower section of the plate was uncovered and the upper section shielded. The exposure then continued for 55 minutes. Meanwhile a second source was being bombarded, to which the same plate was exposed in turn with the same procedure. This was repeated with six sources in order to get the lines sufficiently dark for reliable photometry. Since it was found necessary to use sources about 2 mm wide inclined at only 45 degrees in order to increase the intensity, the resolution is not as good as that obtained previously. This plate is shown in Fig. 2(b) and the photometry measurements of both longitudinal sections in Fig. 4. Here A is the section exposed for the first period of 48 minutes and B is the section exposed for the second period of 55 minutes. If any of these lines occur only in the 18-minute period they should be about seven times as strong in A as in B, while if they come from the 4.4-hour period their opacities should be the same for the two sections. There remains the possibility that one or more of these lines accompany both the isomeric periods, 18 min. and 4.4 hr. However, from Buck's[8] measurements of the cross section of the two periods under similar conditions, it is found that at the end of this bombardment there would be about 35 times as many 18-minute atoms as there are 4.4-hour atoms. Hence a line common to both periods would give relative intensities in sections A and B about the same as if they came from the 18-minute period alone.

After subtracting out the backgrounds, indicated by the dashed lines in Fig. 4, it is found that the peak opacities of the lines on the two sections are equal to within 4 percent, which is satisfactory proof that the lines at 525, 646 and 749 $H\rho$ come from the 4.4-hour half-life only.

The situation is complicated, however, by the doublet structure which appears on the low

[7] Cf. also C. D. Ellis, reference 3, who gives two instances of this curious phenomenon in thorium.

[8] J. H. Buck, Phys. Rev. **54**, 1025 (1938).

energy side of the lines at 646 and 749 $H\rho$. That this is a new pair of lines was revealed by making the ordinates of A exactly equal to those of B at the peak of the 646 $H\rho$ line and subtracting B from A. This reveals a pair of lines at 620 and 725 $H\rho$. It was obvious that these do not come from the 4.4-hour half-life alone. The possibilities were then that they came from (1) the 6.3-minute Br^{78}, or (2) the 18-minute period, or (3) the 18-minute and the 4.4-hour half-lives. Accordingly, the above experiment was repeated in faster tempo to settle this point.

A source was bombarded for 12 minutes and exposed to the upper section for 7 minutes with the lower section shielded, immediately after which the lower section was exposed for 8 minutes with the upper section shielded. This procedure, as in the previous experiment, was repeated for 8 sources with the same conditions prevailing for each source. Under these conditions, lines from the 6.3-minute period should be twice as strong in the upper as in the lower section, whereas lines from the 18-minute, (or the 18-minute and 4.4-hour) period should appear equally strong. The photometer tracings of this plate appear in Fig. 5. This shows that these lines as well as two more of higher energy come from the 6.3-minute period of Br^{78}. Because of the low intensity and resolution (2-mm sources inclined at 45 degrees) the $H\rho$ values of the new lines could not be determined accurately. However, the following are approximate values for the four lines of the 6.3-minute period: 619, 725, 1090 and 1150 gauss-cm, corresponding to energies of 32.7, 44.3, 95.5 and 105.4 kev, respectively. These can be interpreted as the K and L_1 conversions, in the product nucleus Se, of gamma-rays of 45.8±0.4 and 107.7±0.9 kev.

Significance of the $Br^{78,\,80}$ lines

Segrè *et al.*[9] have shown that the 4.4-hour Br^{80} isomer decays into the 18-minute isomer with the emission of internally converted gamma-rays. These are the gamma-rays which have been detected. The absence of any others from the 18-minute period alone confirms this view since these would be impossible if there is such a genetic relationship. If some of these lines appeared in both periods, it would mean merely that they came from an excited state of the product nucleus, Kr^{80}. This is, however, not the case with these gamma-rays. The much harder gamma-rays detected by Buck[8] in both periods are probably from the excited Kr^{80}.

The existence of the two gamma-ray lines associated with the 4.4-hour Br^{80} requires that there be an additional level in this nucleus between the 4.4-hour and the 18-minute levels. Transitions between the latter two levels give rise to the 48.9-kev gamma-ray while transitions from the 4.4-hour level to an intermediate level give rise to the 37.1 (or 25.3) kev line. The succeeding transition from the intermediate to the lower (18-minute) level either is not internally converted to any appreciable extent or (in case 25.3 kev is the correct value), gives lines nearly coinciding with the first transition. It is also possible, but less probable in view of the necessary spin differences, that the two gamma-rays are emitted in cascade, the total energy difference between the upper and lower states being 86.0 (or 74.2) kev. In this case direct transitions might be expected, but are not observed.

The group of conversion electron lines from the positron emitting Br^{78} (6.3 minute) is of interest. They might be ascribed to transitions from a hitherto unobserved isomeric state of this nucleus of much shorter period, or more probably to excited levels in the product nucleus Se^{78}. (The accuracy is not sufficiently great to distinguish between the $K-L_1$ differences for Br and Se.) In the latter case this would suggest a fine structure in the upper limit of the positron

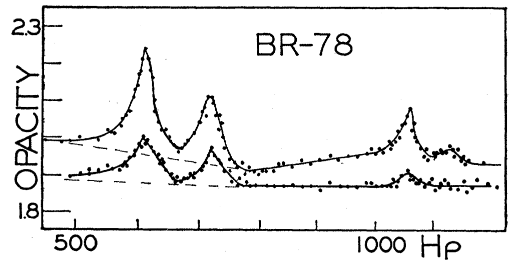

FIG. 5. Photometer records of both upper and lower sections of the 6.3-min. Br^{78} plate. Top curve shows section exposed for 7 min. beginning immediately after bombardment; bottom curve shows section exposed for 8 min. beginning 7 min. after bombardment.

[9] E. Segrè, R. S. Halford and G. T. Seaborg, Phys. Rev. **55**, 321 (1939).

spectrum which is at 2.3 Mev.[10] This fine structure would not be directly observed by present methods, but might be of interest in connection with the theory of beta-decay.

6.4-hour Cd

Figure 2(c) shows the spectrum obtained after bombarding silver deposited on 0.0005-in. aluminum foil to a thickness of 0.48 mg/cm². Fig. 6 shows the photometer measurements of this plate. There are three lines whose $H\rho$ values are: 897, 1053 and 1065 gauss-cm, corresponding to energies of 66.4, 89.6 and 91.5 kev, respectively. These correspond within experimental error to the K, L_1 and M_1 conversions of a gamma-ray of 92.6±0.8 kev. The lines corresponding to the K and L_1 conversions are seen to have equal opacities. It is highly improbable that any corrections for the decreased sensitivity of the plate at lower energies, can possibly make the line at 897 $H\rho$ more than twice the intensity of that at 1053 $H\rho$. This is still a fourfold discrepancy from the usual ratio of 8 to 1 for K and L_1 conversions. W. T. Harris[11] of Princeton University has also measured these lines and confirms the fact that the two lowest energy lines appear equally strong. Further, as will be shown below, the K and L_1 lines from Ga^{67}, at about the same energy, appear to have about the correct relative opacities (8 to 1) which rules out any large correction for the change in sensitivity of the plate with $H\rho$.

It is difficult to understand the large difference in the ratio K to L_1 conversion between this Cd activity (ratio approximately one) and Ga^{67} (ratio approximately eight), the gamma-rays being about the same energy. One might assume that these two lines are both K conversions of two different gamma-rays. One has then to explain why there is no line corresponding to the L_1 conversion of the second gamma-ray. Attempts to observe this have been made without success. In making the choice between anomalously high and anomalously low L_1 conversion, the former has been chosen because of the presence of the low intensity (M_1) line at 1065 gauss-cm.

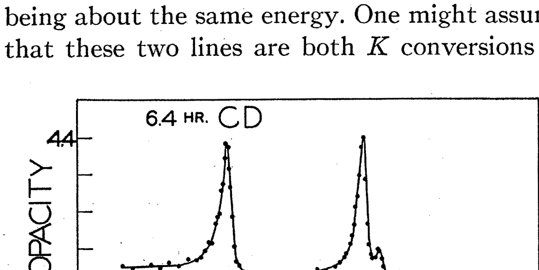

FIG. 6. Photometer record of plate shown in Fig. 2(c).

Since this nucleus gives off large quantities of x-rays which arise from K capture as well as from the high internal conversion of the 92.6-kev gamma-ray and since the fluorescent yield in silver is about 0.75, the Auger electrons should be of sufficient number to be observed. From Ilford Q2 plates[12] as well as the usual x-ray emulsions, no evidence was found for these electrons. It is concluded that electrons of energy less than 20 kev have very little effect upon these photographic emulsions as compared to those of two or three times that energy. It is for this reason that no statement can be made concerning the relative intensities of the conversion groups from the Br^{80}.

Delsasso *et al.*[13] also report a hard gamma-ray accompanying this decay. A thick piece of silver was bombarded for two hours with 1.5 microamp of 6.7-Mev protons. This gave a source sufficiently intense so that the decay was followed over a half-life with the radiation filtered by 1.89 g/cm² of lead. This decay is shown in Fig. 7. At the same time the absorption curve in lead, which is also shown in Fig. 7 was taken. From this the mass absorption coefficient was found to be 0.146 g/cm², corresponding to a gamma-ray of 0.53 Mev, according to Gentner's[14] compilation. This immediately suggests the annihilation of positrons. Positrons were looked for by placing a specimen, several hours after bombardment, in a cloud chamber. No positrons were seen in 250 pictures although several thousand short range tracks of the conversion electrons were noted. However, a few positrons with an energy of 100 kev or less might have escaped observation because at this energy

[10] A. H. Snell, Phys. Rev. **52**, 1007 (1937).
[11] W. T. Harris, private communication.
[12] We wish to thank Professor K. T. Bainbridge for the gift of these plates.
[13] L. A. Delsasso, L. N. Ridenour, R. Sherr and M. G. White, Phys. Rev. **55**, 113 (1939).
[14] W. Gentner, Physik. Zeits. **38**, 836 (1937).

scattering has more to do with track direction than the magnetic field.

Silver, 0.01 in. thick has been bombarded as an internal target in the cyclotron chamber[15] for approximately six hours at 20 microamp. With this source possible annihilation radiation was searched for by measuring the coincidence counting rate when the source was placed alternately between and above two Geiger counters. No conclusive evidence for annihilation radiation was found. The experiment is made difficult, however, by the very low intensity of this 530-kev gamma-ray compared to the other very intense radiations which accompany this decay.

The 32-minute half-life which appears in Fig. 7, was shown not to be cadmium by chemical separation. Less than one percent of sulphur impurity would produce sufficient Cl^{34} to appear here. There is, therefore, no evidence sufficient to fix the assignment of the 6.4-hour period to either Cd^{107} or Cd^{109}.

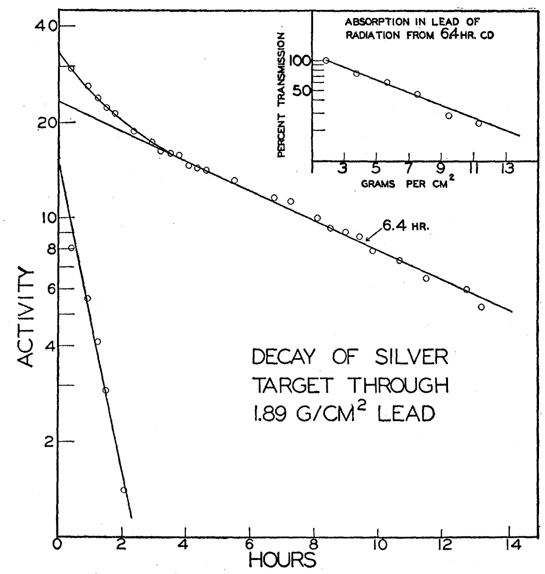

FIG. 7. Decay and absorption in lead of $Cd^{107 \text{ or } 109}$.

Ga^{67}, Ga^{70}

The zinc radioactivities with half-lives of 57 minutes and 13.8 hours have been shown by Livingood and Seaborg[16] to be isomers of Zn^{69}. These have about the same beta-ray upper limits. Since this is a necessary condition for the isomers to be related genetically, zinc has been bombarded with 4.3-Mev deuterons and observed for internal conversion spectra arising from the isomeric transitions. Several lines were found, but none can be attributed to either period of Zn^{69}. This confirms the result of the absorption measurements of Livingood and Seaborg.[16]

Figures 8 and 9 show the decay of gallium and zinc, the two elements having been chemically separated after bombardment of zinc with 4.3-Mev deuterons. The gallium periods are 18.5 minutes, 69.5 minutes and 78 hours corresponding to the isotopes, previously reported by Buck,[8] or Ga^{70}, Ga^{68} and Ga^{67}, respectively. The zinc separation (which included any other elements which may have been present) shows only the periods of Zn^{69} plus a trace of the long-lived Zn^{65} (245 days) which has been subtracted out from Fig. 9.

To determine the source of the observed lines, zinc foils were bombarded for 75 minutes with 0.8 microamp. of 4.3-Mev deuterons. These foils were obtained by rolling out spectroscopically pure zinc crystals (from the New Jersey Zinc Co.) to the thickness of 0.0006 inches. Four such sources were exposed in the spectrograph, each for 75 minutes, in order to attain sufficient density on the plate. The plate is shown in Fig. 2(d) and the accompanying photometer curves in Fig. 10, curve A. Another piece of this zinc was bombarded for 6 hours at 1.2 microamp. of 4.3-Mev deuterons and two successive two-hour exposures, Fig. 10, curves B and C, were taken. These three plates taken together show five lines, three at $H\rho$ values of 721, 794 and 1160 gauss-cm accompanying a half-life of less than two hours, the other two at $H\rho$ values of 1006 and 1057 gauss-cm accompanying a much longer half-life.

Commercial zinc was bombarded as an internal target in the cyclotron for six hours at about 20 microamp. of 4.3-Mev deuterons. From this source thirteen exposures of various lengths of time were made during the course of ten days. Two of these, the first exposed for two hours beginning four hours after the end of bombardment, the second exposed for six hours beginning

[15] R. R. Wilson and M. D. Kamen, Phys. Rev. **54**, 1031 (1938).

[16] J. J. Livingood and G. T. Seaborg, Phys. Rev. **55**, 457 (1939).

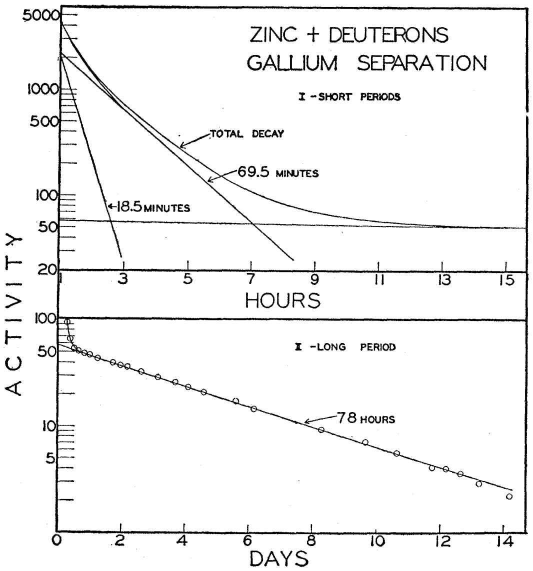

FIG. 8. Decay curves of gallium separation from zinc bombarded with deuterons.

224 hours after bombardment, exhibit the line at 1006 gauss-cm with the peak opacities above background of 0.9 and 0.36, respectively. It was assumed that the plate responded linearly between these values the decay period of this line was computed giving a value of about 75 hours. This indicates that this is the K line accompanying the decay of Ga^{67}. Having ascertained this, it was felt justifiable to calculate the exposures to the other plates using the known period of Ga^{67} and thus obtaining the exposure *vs.* intensity data previously mentioned.

The lines at $H\rho$ values of 1006 and 1066 gauss-cm, corresponding to electron energies of 82.4 and 91.7 kev, respectively, accompany the decay of the long life Ga^{67}. Since this is a well-known case of decay by K-electron capture previously reported by Alvarez,[17] these energies correspond to the internal conversion in the Zn K and L_1 shells, respectively, of a gamma-ray of 92.5 ± 0.8 kev. This is in fair agreement with the gamma-ray reported by him.

The lines at $H\rho$ values of 721 and 794 gauss-cm, corresponding to electron energies of 43.8 and 52.7 kev, respectively, were shown definitely to be associated with Ga^{70} in a manner similar to that employed in investigating Br^{80}. Zinc was

[17] L. W. Alvarez, Phys. Rev. **54**, 486 (1938).

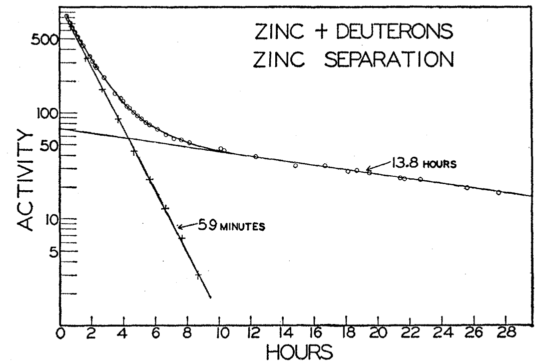

FIG. 9. Decay curve of zinc separation from zinc bombarded with deuterons.

bombarded with deuterons for 40 minutes and the upper section of the plate exposed for a period of 47 minutes; the lower section was shielded for the first 21 minutes after bombardment. The shield was then removed and this section was then exposed for a period of 26 minutes. This schedule was repeated with five sources. This plate is shown as Fig. 2(e). Fig. 11, curve A, shows the photometer record of the upper section of this plate. Here since the plate shows a large background increasing toward the low energy end, an interpolated background was subtracted and these relative opacities above background were plotted for the upper and lower sections as Fig. 11, curves B_1 and B_2, respectively. The curve B_1 shows the lines at $H\rho$

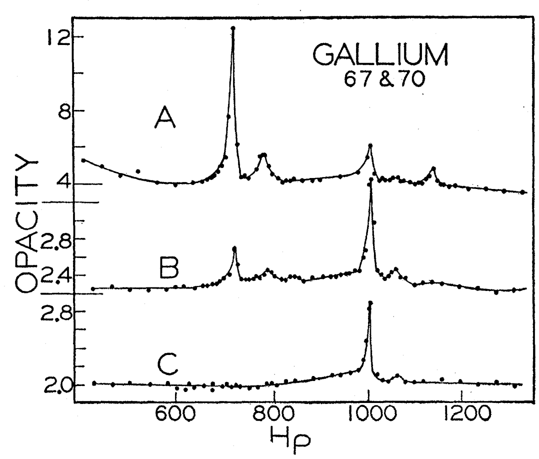

FIG. 10. Photometer records of Ga^{67} and Ga^{70} plates. A, record of the plate shown in Fig. 2(d); B and C, records of plates of successive two-hour exposures to a strongly activated zinc source by deuterons. Plates for B and C are not shown.

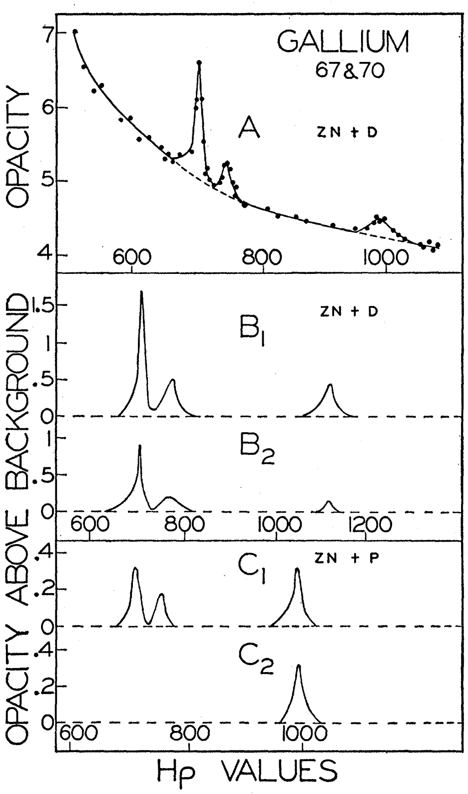

FIG. 11. Photometer records of Ga^{67} and Ga^{70} plates. *A*, record of the upper section of the plate shown in Fig. 2(e); B_1 and B_2, records from which the background has been subtracted out of the plate shown in Fig. 2(e). C_1 and C_2, records of plate exposed to zinc bombarded with protons. C_1 is upper section exposed for 46 min. beginning immediately after bombardment; C_2 is lower section exposed for 48 min. beginning 46 min. after bombardment.

values of 721 and 794 gauss-cm twice as strong as does curve B_2. This is about what one would expect for an 18-minute decay. The line at 1160 also seems to come from a half-life shorter than 20 minutes.

Since the only activity of the required short half-life which we have detected was the 18-minute Ga^{70}, we tried the experiment of bombarding 0.0002-inch zinc foil with 6.7-Mev protons. Buck[8] has previously established the reaction $Zn^{70}(p, n)Ga^{70}$. The sample was bombarded for a period of 90 minutes; the upper section of the plate was exposed for a period of 46 minutes after bombardment and subsequently the lower section for a period of 48 minutes. Several sources were exposed. This plate is not shown, but the photometer records, from which the background has been subtracted out, are shown as Fig. 11, curves C_1 and C_2. Curve C_1, which is the upper section, shows the lines at $H\rho$ values of 721, 794 and 1006 gauss-cm. Curve C_2 shows only the line at 1006 gauss-cm, which is the Ga^{67} K line. This is conclusive evidence for the existence of the lines at 721 and 794 gauss-cm in Ga^{70}. However, the failure to observe the line at 1160 gauss-cm by bombardment of zinc with protons, renders the assignment of it doubtful.

Mann[18] reports the existence of 4.9-Mev negative electrons accompanying the decay of Ga^{70} to stable Ge^{70}. Since Buck found the threshold for the formation of Ga^{70} by bombardment of zinc with protons to be below 1.6 Mev, this would indicate a surprisingly high mass difference between Ga^{70} and Ge^{70}. Zinc was bombarded with protons for a period of 9 minutes behind sufficient aluminum to reduce the beam energy to 2 to 3 Mev which is above the threshold for Ga^{70}, but below that of the short period positron emitting isotopes of Ga. With such a bombardment the 18-minute Ga^{70} should be much more intense than any other gallium periods formed. Such a source, however, showed no high energy electron tracks in the cloud chamber, although there were a number of positrons from other weak activities. This suggests that Ga^{70} decays mainly by K capture to Zn^{70}, though the emission of a few beta-rays is not excluded. The electron lines at $H\rho$ values of 721 and 794 gauss-cm are then interpreted as arising from the internal conversion in the Zn K and L_1 shells of a gamma-ray of 53.8 ± 0.5 kev.

In conclusion we wish to thank Professor L. A. DuBridge and Dr. S. W. Barnes for suggesting some of these investigations, and Dr. S. N. VanVoorhis who has most graciously given us his assistance. We are indebted to Dr. C. V. Strain for the use of his Geiger counters and ionization chamber, and to the Institute of Optics for the use of their photometer. This work was supported in part by a grant from the Research Corporation.

[18] W. B. Mann, Phys. Rev. **54**, 649 (1938).

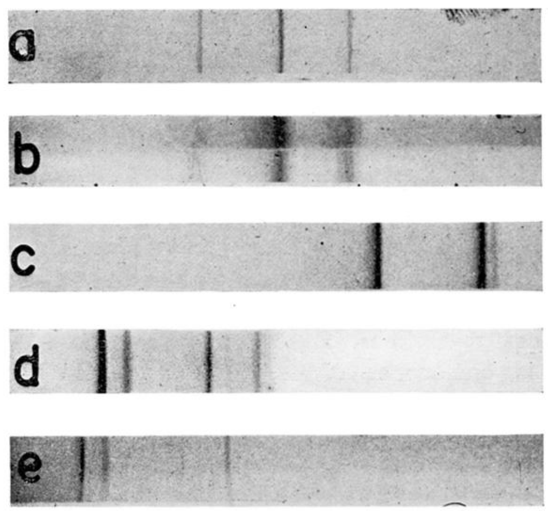

FIG. 2. (a) and (b) Plates of the 4.4-hour Br^{80}. (a) Plate from which energy measurements were taken. Source 1 mm inclined at 60 degrees. (b) Shielded plate. Source 2 mm inclined at 45 degrees. Upper section exposed 48 min. beginning immediately after bombardment; lower section exposed 55 min. beginning 48 min. after bombardment. (c) Plate of 6.4-hour $Cd^{107 \text{ or } 109}$. Thin silver films evaporated on aluminum foil and bombarded with protons used as sources. Sources 1 mm and inclined at 60 degrees. (d) and (e) Plates of 18-min. Ga^{70} and 78-hour Ga^{67} from bombardment of zinc with deuterons. (d) Plate from which energy measurements were taken. Plate was exposed for 75 min. to each of four sources of thin zinc foils 1 mm inclined at 60 degrees. (e) Shielded plate. Upper section exposed continually; lower section exposed for 26 min. beginning 21 min. after bombardment. Sources 2 mm inclined at 45 degrees.