$I=0$ state lies below that for $I=1$, thus providing the 0−0 transition necessary to explain the well-known pair emission of the lowest excited state in O^{16}, and that the order of magnitude of the splitting is compatible with reasonable assumptions about the interactions. In N^{15} one may have an excited s-nucleon coupled to a p-shell resembling C^{14} or N^{14} having $J=0$ or 1 (or more) and giving rise to single levels and doublets.

Such an interpretation has a simplicity appropriate to the simple doublet pattern observed and to other indications of nuclear shell structure, but in detailed consideration of the lower doublet of O^{16} it unfortunately encounters obstacles which, unless otherwise overcome, make it desirable to seek instead a mechanism capable of pairing states of quite different angular momentum, since the doublets seem too numerous to be fortuitous. Wayne Arnold has recently observed[5] a pronounced alpha-gamma-angular correlation in $F^{19}(p,\alpha)O^{16}$ which seems to indicate $I=3$ rather than $I=1$ for the 6.1_4 Mev state of O^{16}, in striking contrast to $I=0$ for the 6.0_6 Mev state. Furthermore, the odd parity of the configuration p^5s, while consistent[6] with the existence of the three known pair resonances, requires that the two known pair-plus-long-range-alpha-resonances be chance superpositions of states of different parity-angular-momentum in the rather crowded spectrum of Ne^{20}.

[1] R. Malm and W. W. Buechner, Phys. Rev. **78**, 337 (1950) as reported at New York (2.71 Mev is C^{13} contamination), and personal communication through the kindness of D. M. Van Patter, who has also observed a doublet in B^{11}, perhaps significantly at 6.8 Mev; Kinsey, Bartholomew, and Walker, Phys. Rev. **77**, 723 (1950); Guggenheimer, Heitler, and Powell, Proc. Roy. Soc. **190**, 196 (1947); L. D. Wyly, Phys. Rev. **76**, 316 (1949).
[2] Chao, Tollestrup, Fowler and Lauritsen, Phys. Rev. **78**, 88 (1950); Streib, Fowler, and Lauritsen, Phys. Rev. **59**, 253 (1941); Becker, Fowler, and Lauritsen, Phys. Rev. **62**, 186 (1942); R. Walker and B. McDaniel, Phys. Rev. **74**, 617 (1948); Freeman and Baxter, Nature **162**, 696 (1948).
[3] M. G. Mayer, Phys. Rev. **78**, 16 (1950); Haxel, Jensen, and Suess, Naturwiss. **36**, 155 (1949).
[4] W. M. Elsasser, J. de phys. et rad. **4**, 549 (1934); W. Heisenberg, Zeits. f. Physik **96**, 473 (1935); E. Feenberg and E. Wigner, Phys. Rev. **51**, 95 (1937).
[5] Private communication at the suggestion of Arthur Roberts.
[6] J. R. Oppenheimer and J. S. Schwinger, Phys. Rev. **56**, 1066 (1939); D. M. Dennison, Phys. Rev. **57**, 454 (1940).

The Half-Life of Cm^{242}

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April 10, 1950

DURING recent work on the neutron irradiation of americium it was noticed that the Cm^{242} produced decayed at a rate significantly different from that expected from the published half-life of 150 days.[1] Accordingly an attempt was made to measure this half-life with reasonable precision.

Three sources were available whose disintegration rates were known with adequate accuracy at a sufficiently early date to give a good value for the half-life. These were all unseparated sources containing the whole of the parent americium. This is not a serious drawback as the curium α-rays are more energetic and were well resolved from the α-rays from any isotope of americium present. A small correction has to be made, however, for the growth of Cm^{242} from the long-lived ground state of Am^{242} which is present.[2]

The activity of the sources was measured in a low geometry proportional counter using a 30 channel pulse analyzer. The counter, designed in this laboratory by Mr. A. G. Ward several years ago, can be trusted to maintain a constant geometry over an indefinite period of time. It consists essentially of a vertical cylinder with a removable base on which is placed the source to be counted. The lower half of the cylinder contains a collimator defining the geometry. The space above the collimator hole contains a proportional counter. The whole is filled with methane at a suitable pressure. The pulse size is a measure of how far an α-particle has penetrated the counting volume and consequently the several disintegration rates of the components of a mixed source can be measured simultaneously.

Table I. Disintegration data on Am^{241} and Cm^{242}.

Source	Date	Days	Am^{241} disin./min.	Cm^{242} disin./min.	Ratio Cm/Am	Half-life calculated from time zero
			($\times10^{-5}$)	($\times10^{-5}$)		
	16:2:49	0	1.492±0.017	2.550±0.021	1.709±0.022	—
A	1:11:49	257	1.465±0.014	0.832±0.008	0.568±0.008	161.8±2.7
	16:2:50	365	1.481±0.014	0.537±0.005	0.362±0.005	163.1±2.2
			($\times10^{-6}$)	($\times10^{-7}$)		
B	18:7:49	0	5.5±0.2	6.522±0.020	—	—
	25:11:49	130.2	not measured	3.747±0.010	—	162.9±1.5
			($\times10^{-5}$)	($\times10^{-6}$)		
	3:6:49	0	1.5±0.1	21.58±0.14	—	—
C	20:11:49	180	1.6±0.1	9.987±0.020	—	162.0±1.5
	14:2:50	256	1.6±0.1	7.254±0.020	—	162.7±1.0
	16:3:50	286	not measured	6.364±0.015	—	162.3±0.9

The three sources were all prepared by evaporation from solution on mirror-finish platinum disks and ignited to red-heat. *Source A*, produced by a very short irradiation, gave comparable Am^{241} and Cm^{242} disintegration rates. *Sources B and C* were aliquots of much more heavily irradiated sample of americium.

Source A was rather small, requiring very long counting times for good statistical accuracy, but the americium and curium counting rates could be measured with comparable precision. With sources B and C the very intense curium activity was accompanied by a finite low energy tail which precluded a very accurate estimation of the americium. The total activity of these two sources was measured and the result corrected for the presence of americium and the growth of Pu^{238}. The uncertainty in these corrections was not large enough to produce a significant error. The geometry of the counter was checked by counting a standard Pu^{239} source on each occasion. The results are given in Table I.

We are somewhat apprehensive that the sources would be weakened by aggregate recoil and give a spuriously short half-life. The constancy of the americium counting rate of source A suggests that this effect is small since it is likely that americium would accompany any curium removed in this way. However, a more satisfactory check that this effect was not significant was obtained by monitoring the inside of the containers in which the sources had been kept: no activity was detected with an instrument sensitive to a few hundred α-disintegrations per minute.

It is possible that sources B and C contain some Cm^{243} formed by a second neutron capture during irradiation. However, the α-activity from this isotope is not expected to exceed a few tenths of one percent of the Cm^{242} activity. The agreement between the half-lives from B and C and the lightly irradiated source A suggest an upper limit of about $\frac{1}{2}$ percent.

Seaborg, James, and Morgan[2] have shown that in neutron irradiated americium there occurs about one β-disintegration of the long-lived ground state of Am^{242} for every 1000 α-disintegrations of Cm^{242} in a fresh unseparated sample. In our measurements the correction for this growth of curium amounts to −0.2 day in the half-life.

Our "best value" is 162.7−0.2 days=162.5 days. The limits of error are probably ±2 days.

[1] G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 639 (1948).
[2] Seaborg, James, and Morgan, "The new element Americium," AECD 2185.

Measurement of Gamma-Ray Energies with One Crystal*

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THE use of scintillations in a single crystal to measure gamma-ray energies[1] may have important applications in nuclear physics because of the possibility of examining sources of very weak radioactivity. In view of this attractive possibility we have studied the pulse-height distributions in clear NaI(Tl)

crystals of various sizes and with various degrees of collimation of the gamma-rays investigated. The crystal pulses were analyzed by a single-channel discriminator.[2] The photo-multiplier employed has been the *EMI* 5032. The crystals were freshly cleaved from Harshaw supplied material, coated with a thin layer of Nujol and kept in a dry atmosphere. The quality of the surfaces has been of great importance in obtaining the following results.

Figure 1 shows the results observed with a 1° collimated beam of Co^{60} (1.17, 1.33 Mev) gamma-rays in a $\frac{1}{2}$-in. crystal cube of NaI(Tl). Figure 2 shows the results obtained with an 8-microcurie point source of Co^{60} in an uncollimated arrangement with the source 3 cm from the crystal. The two peaks near 60.5 and 68.5 volts in each figure correspond to the full energy of the gamma-rays from Co^{60}, while the third larger peak, near 49 volts, is the maximum of the Compton recoil electron distribution. The reproducible asymmetry lying near 54.0 volts in Fig. 1 is believed to be due to the peak of the Compton recoil electron distribution associated with the higher energy gamma-ray component (1.33 Mev). These assignments, consistent among themselves, are also consistent with the established positions of the Compton recoil lines in Fig. 3 of the accompanying paper.[1]

The peaks at 60.5 and 68.5 volts are interpreted as partially due to the photoelectric effect in the iodine constituent of NaI. Merged with these peaks are some pulses caused by Compton forward recoil electrons and their associated ~200-kev back-scattered gamma-rays, the latter of which are also captured by the crystal. The sum of the electron and photon pulses is again the whole energy of the gamma-ray.

The reproduction in Fig. 2 of the important features of Fig. 1 shows that gamma-energies in extremely weak sources may indeed be studied without the losses involved in collimation. There is however an attendant loss in resolution of detail. Nevertheless, it is easy to miss detection of the detailed structure present by using imperfect crystals and by unfortunate choice of crystal size.[3] This is exemplified by Fig. 3 which shows how the spectrum of Fig. 1 is distorted by employment of a larger crystal ($1\times1\times\frac{11}{16}$ in.). In this case multiply-scattered Compton gamma-rays are partially captured in the crystal, broadening and smearing out

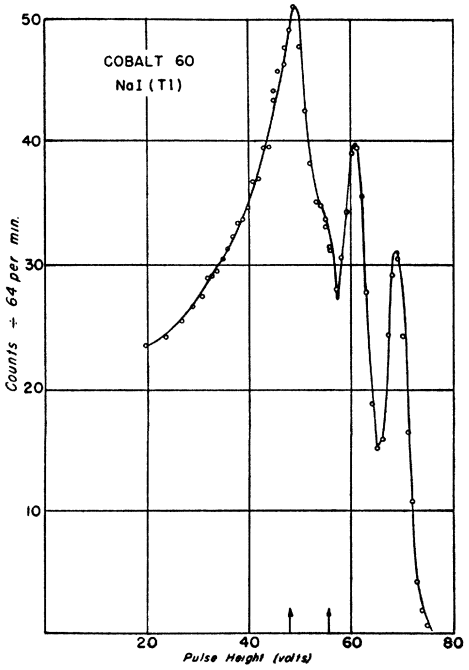

FIG. 1. Pulse-height distribution due to 1° collimated Co^{60} gamma-ray beam in 0.5-in. crystal cube of NaI(Tl).

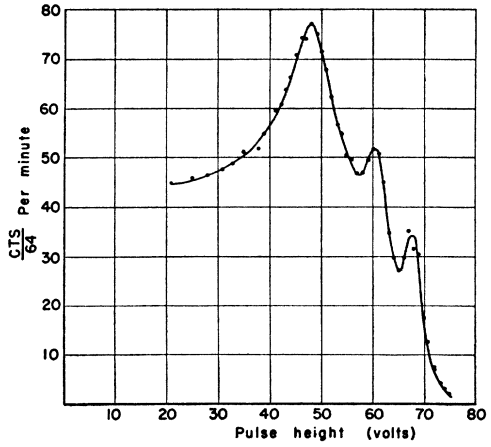

FIG. 2. Pulse-height distribution of uncollimated Co^{60} gamma-rays in NaI(Tl) using 8-microcurie source. Crystal used is identical with the crystal of Fig. 1.

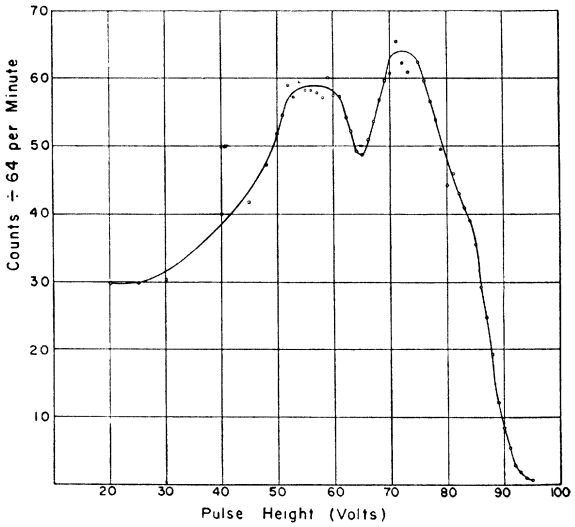

FIG. 3. Pulse-height distribution due to 1° collimated Co^{60} gamma-ray beam in $1\times1\times\frac{11}{16}$ in. crystal of NaI(Tl). Abscissa scale not the same as those in Figs. 1 and 2.

the structure presented by the smaller crystal. Energy measurements would have dubious value if carried out with such large crystals, particularly when the source itself has a complex spectrum. Previously reported Co^{60} curves[4] do not show the structure given in Fig. 1; the lack of collimation, thick diffuse source, and perhaps poor crystal are probably reasons for the differences. On the other hand, a very large crystal (perhaps a 2- or 3-in. cube) might give essentially a line for a single gamma-ray since all the scattered products would be absorbed within the crystal. In organic scintillators this possibility is rather remote because of their small densities. The published curves of Bell and Cassidy[5] on K^{40} and Zn^{65} also show no structure.

Of incidental interest is the fact that the narrow width of the lines in Fig. 1 indicates that approximately 480 photo-electrons per Mev are produced at the photo-cathode of the multiplier tube, if the entire width is assigned to statistical effects. Allowing a five percent photo-efficiency and 50 percent light collection, the resulting luminous efficiency of NaI(Tl) on an energy basis is about six percent.

After this work had been completed it was found that Johann-

son[6] had also observed "photo-electron lines" using NaI(Tl). His results show considerably less detail than those presented here.

* This work received partial support from a U. S. Army Signal Corps Contract and from the joint program of the ONR and AEC.
[1] See also the accompanying paper by R. Hofstadter and J. A. McIntyre, Phys. Rev. **78**, 619 (1950).
[2] Design to be reported by L. W. Hamner.
[3] The double-crystal arrangement of the accompanying paper gives a unique spectrum of gamma-ray lines and avoids the difficulties described in connection with the single crystal.
[4] Pringle, Standil, and Roulston, Phys. Rev. **77**, 841 (1950).
[5] P. R. Bell and J. M. Cassidy, Phys. Rev. **77**, 409 (1950).
[6] S. A. E. Johannson, Nature **165**, 396 (1950).

Measurement of Gamma-Ray Energies with Two Crystals in Coincidence*

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THE known properties of the Compton effect may be used in connection with scintillation counters to measure accurately and without confusion the energies of gamma-rays. A method by which this may be accomplished is shown in Fig. 1.

The line, labeled $h\nu$ in Fig. 1, represents a collimated beam of incident gamma-rays whose energy it is desired to measure. In a

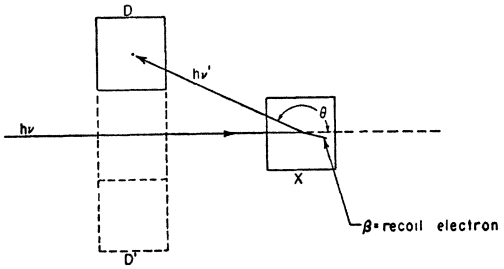

FIG. 1. Schematic of coincidence method for determining gamma-ray energies.

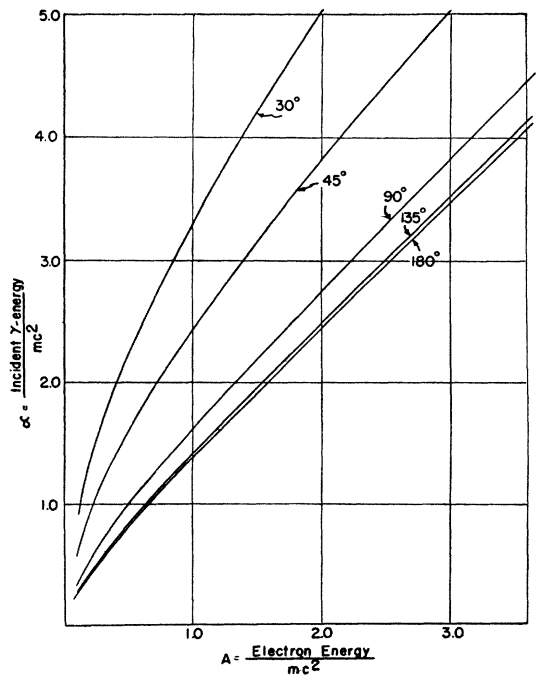

FIG. 2. Energy of incident gamma-ray plotted against electron recoil energy with angle θ as parameter. Energies are expressed in mc^2 units.

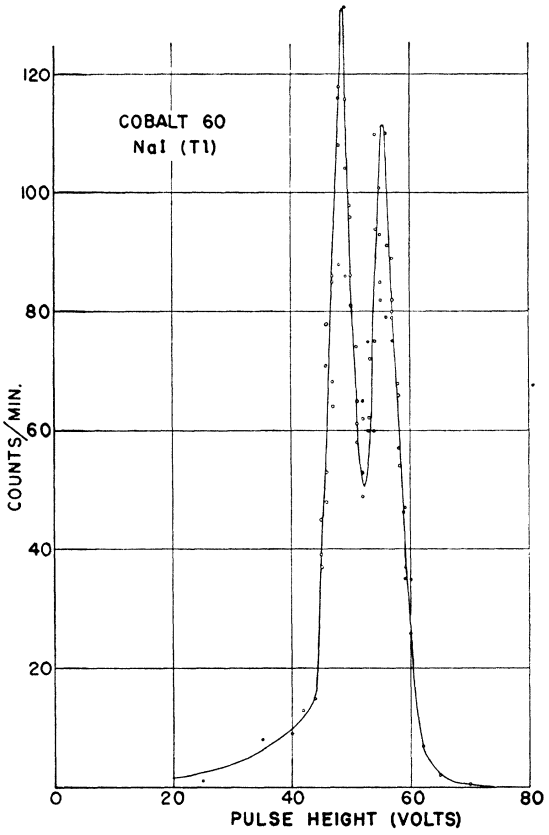

FIG. 3. The spectrum of Co^{60} obtained with the coincidence method.

Compton encounter involving $h\nu$ and crystal X, the scattered gamma-ray $h\nu'$ and recoil electron β appear simultaneously. A fraction of the total number of $h\nu'$ gamma-rays engage in further Compton encounters in "detector" crystal D, or in photoelectric encounters in this crystal. In either case crystal D produces a light flash due to $h\nu'$ while crystal X produces a simultaneous light flash due to β. These coincident light flashes are the ones selected for study. If the pulse in D is used as a gate to trigger a single-channel (or multi-channel) discriminator, the resulting pulse size distribution in X (β-pulses) provides the energy of the incident gamma-ray beam. This follows from the fact that pulse height is proportional to the energy of the recoil electron. If more than one energy is present in the incident beam, each energy provides in X a unique pulse distribution appropriate to this energy.

Using the energy-momentum equations of the Compton effect the energy of the original gamma-ray beam can be calculated from the energy of the recoil electron. Let $h\nu=\alpha(mc^2)$ and β-energy $=A(mc^2)$. Then

$$\alpha=\tfrac{1}{2}A\{1+[1+2/(A\,hav\theta)]^{\frac{1}{2}}\}. \quad (1)$$

Figure 2 shows a set of curves of α *versus* A obtained from Eq. (1) for various values of θ. It may be observed that between 135° and 180° the dependence on θ is extremely small. This corresponds to the well-known fact that a quantum of approximate energy $\frac{1}{2}mc^2$ is scattered in the back hemisphere for a large range of values of $h\nu \geq mc^2$. Hence a large solid angle for detector D may be employed without sacrificing much energy resolution. To gain still higher efficiencies of detection the ring counter DD' may be used. We are now using the single block D shown in Fig. 1 at an approximate angle of 150° at a center-to-center distance of crystals of 1.5 in.

With this arrangement, a single-channel discriminator, and