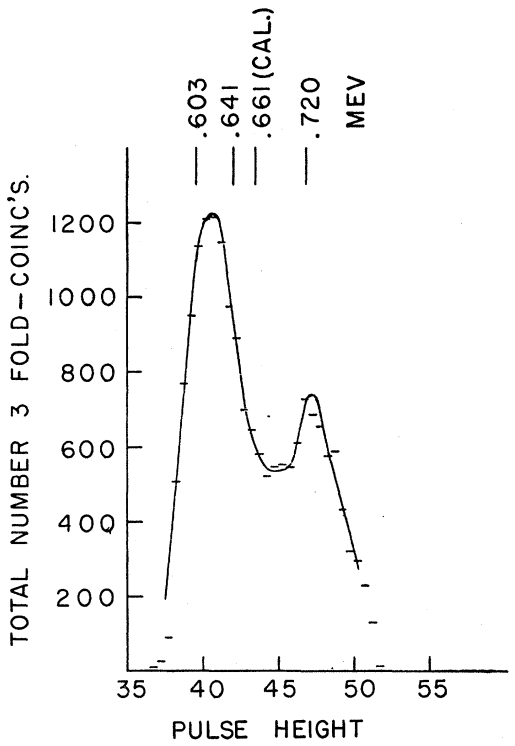

FIG. 1. Triple coincidence gamma-ray spectrum of Sb^{124}.

the same. Background and chance coincidences were found to be completely negligible. Figure 1 shows the combined data of a 17-hr and a 22-hr run obtained with the 100-channel equipment. A Cs^{137} calibration, taken before and after each run, indicated that the drift of the electronic equipment was negligible.

It is clear from Fig. 1 that the double-intensity peak appears at about 0.62 Mev (*viz.*, between 0.64 and 0.60 Mev). This is consistent with the proposal of a 0.64-, 0.72-, and 0.603-Mev cascade.

The authors are pleased to acknowledge the cooperation of Mr. J. Balagna.

† Work performed under auspices of the U. S. Atomic Energy Commission.

* Indiana University, Bloomington, Indiana.

[1] Langer, Lazar, and Moffat, Phys. Rev. **91**, 338 (1953).
[2] E. P. Tomlinson, Indiana Conference on Nuclear Spectroscopy and the Shell Model, Technical Report, p. 31, 1953 (unpublished).

Resonant Scattering of Recoil-Broadened Gamma Rays

K. ILAKOVAC AND P. B. MOON
Department of Physics, The University, Birmingham, England
(Received November 10, 1953)

THE emission and resonant-scattering energies of gamma rays differ, often by a few ev, because of the energy taken by nuclear recoils,[1] and it has long been recognized that the Doppler effect of a preceding beta-ray recoil might sometimes broaden the emission line enough to overlap the scattering resonance.[2] In order that the beta recoil shall be free and shall persist for a time long compared with the gamma-ray lifetime, a gaseous source will usually be preferred. When this is impracticable, a worth-while advantage may be gained by using a liquid rather than a solid source.

The 0.98-Mev gamma rays from a copper cyclotron target containing Zn^{63} showed no measurable selective scattering by copper, but the effect was clearly observed when a nitric acid solution of the target material was used as the source. The difference is, no doubt, mainly due to the 8:1 ratio of densities, but crystal lattice effects may also be involved.

These experiments will be reported in more detail elsewhere, but the above qualitative result may be of use to others working in this field.

[1] W. Kuhn, Phil. Mag. **8**, 625 (1925); P. B. Moon, Proc. Phys. Soc. (London) **63**, 1189 (1950).
[2] E. Pollard and D. E. Alburger, Phys. Rev. **74**, 926 (1948); F. R. Metzger, Phys. Rev. **83**, 842 (1951); F. R. Metzger and W. B. Todd, Phys. Rev. **91**, 1286 (1953).

Natural Alpha Activity of Neodymium*

ESTHER C. WALDRON, VIRGINIA A. SCHULTZ, AND TRUMAN P. KOHMAN
Department of Chemistry, Carnegie Institute of Technology, Pittsburgh, Pennsylvania
(Received November 6, 1953)

IT has been suggested[1] that the lighter naturally-occurring isotopes of a number of even-Z elements in the region from the rare earths to lead might possess detectable alpha activity. The two lightest beta-stable isotopes of neodymium, Nd^{142} and Nd^{143}, are stabilized by the 82-neutron shell, but Nd^{144}, possessing a closed-shell+2 neutron configuration, should possess an alpha instability greater than average for the region.[2] From mass spectrographic data Duckworth *et al.*[3] and others[4] concluded that 58 protons form a closed sub-shell configuration, and this should also contribute to the alpha lability of $_{60}Nd$ isotopes. The data[3] indicate that the reaction $Nd^{144} \rightarrow Ce^{140} + He^4$ is exoergic by 3.0 ± 1.1 Mev.

Early studies[5] showed that any natural alpha activity of neodymium must be considerably weaker than that of samarium. Bestenreiner and Broda,[6] using nuclear emulsions, set an upper limit to the specific activity of $\sim 1\alpha$ $sec^{-1}(g\ Nd)^{-1}$. Mulholland and Kohman,[7] using a large proportional counter, lowered this to 0.02α $sec^{-1}(g\ Nd)^{-1}$. We have made a more intensive search by the nuclear-emulsion technique.

Our starting material was the neodymium sample which had been purified twice by passage through a cation-exchange column in the search for natural beta activity;[7] this we designate Nd_{II}. A portion of this was again fractionated in a smaller column, a central cut being designated Nd_{III}. Another fractionation of a

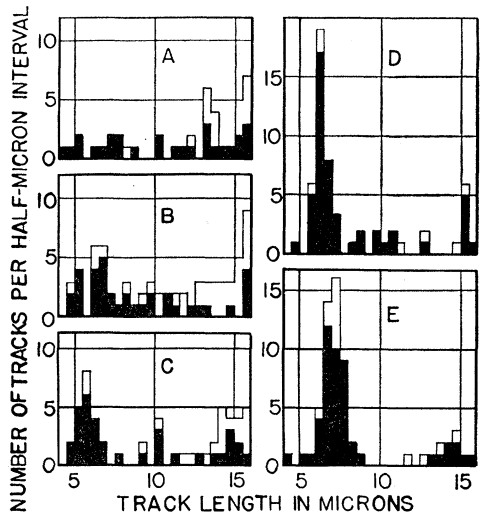

FIG. 1. Representative histograms of short alpha tracks in nuclear emulsions impregnated with neodymium and samarium. "Shallow" tracks are dark, "steep" tracks are light. (*A*) Blank plate, 2.11 cm^2, 75 days old; (*B*) Nd_{II}, 1.63 cm^2, exposed 166 days; (*C*) Nd_{III}, 0.77 cm^2, 153 days; (*D*) Nd_{IV}, 1.25 cm^2, 91 days; (*E*) Nd containing 1 percent Sm, 0.05 cm^2, 162 days.

portion of this yielded Nd_{IV}. All samples were further purified by precipitation as oxalate from acid solution.

Each plate (Ilford C2, 1 in.×3 in.×200μ) was soaked in 10-percent glycerine solution (to prevent stripping during drying), and impregnated by spreading and evaporating upon it 1 ml of aqueous neodymium acetate containing about 20 mg of the element. After exposure at dry-ice temperature and development, portions were scanned at 400× for single alpha tracks lying entirely within the emulsion, and those shorter than ~20μ were measured at 1600×. Lengths were computed assuming a shrinkage factor 2.0. Because of uncertainty in this factor, we distinguish between "shallow" tracks, with original dip $\leqslant 30°$ (black in Fig. 1), and "steep" tracks, with $>30°$ dip (white in Fig. 1), and consider mainly the former group, whose lengths are affected only slightly by shrinkage. Neodymium containing small amounts of samarium was used for calibration and resolution studies. A histogram of Sm^{147} is shown in Fig. 1, the mean range being 7.1μ.

The histogram of Nd_{II} in Fig. 1 shows a peak somewhat broader, and centered somewhat lower, than the samarium peak, suggesting a mixture of Sm^{147} alphas and a group of lower energy. The Nd_{III} peak is sharper and centered still lower. The Nd_{IV} peak is similar to that of Nd_{III}, indicating that a group of alpha particles specific to neodymium has been isolated. The mean range is 6.0μ. The Sm−Nd difference of 1.1±0.3μ corresponds to an energy difference of 0.3±0.1 Mev. Taking the Sm^{147} energy as 2.21 Mev[2,8] yields 1.9±0.1 Mev as the energy of the new group.

Accurate determination of the specific activity was prevented by concentration of solute during loading near the surface of the emulsion, where many tracks are lost.[9] Fewer "steep" than "shallow" tracks were found, indicating that short, steep tracks are easily missed in our scanning technique. The highest specific activity observed, obtained by doubling the number of shallow tracks, is 0.009α $sec^{-1}(g\ Nd)^{-1}$; this is a lower limit. Considering the upper limit given previously,[7] we estimate the specific activity to be 0.015α $sec^{-1}(g\ Nd)^{-1}$, corresponding to a half-life of Nd^{144} of 1.5×10^{15} years. These figures are uncertain by a factor of at least 2.

Although we cannot claim to have purified natural neodymium to a constant specific activity, we have purified it to a constant and unique radiation spectrum. This we regard as an equally good criterion for the identification of a new natural radioactivity. Experiments are in progress to determine more precisely the specific activity, energy, and mass assignment.

* This work has been supported by the U. S. Atomic Energy Commission. The assistance of Henry Selig is gratefully acknowledged.

[1] T. P. Kohman, Phys. Rev. **74**, 1259 (1948); **76**, 448 (1949).
[2] Rasmussen, Thompson, and Ghiorso, Phys. Rev. **89**, 33 (1953).
[3] Duckworth, Kegley, Olson, and Stanford, Phys. Rev. **83**, 1114 (1951).
[4] G. P. Dube and S. Jha, Phys. Rev. **85**, 1042 (1952).
[5] Hevesy, Pahl, and Hosemann, Z. Physik **83**, 43 (1933); G. v. Hevesy and M. Pahl, Z. Phys. Chem. **A169**, 147 (1934); W. F. Libby, Phys. Rev. **45**, 845 (1934); **46**, 196 (1934).
[6] F. Bestenreiner and E. Broda, Nature **164**, 658 (1949).
[7] G. I. Mulholland and T. P. Kohman, Phys. Rev. **85**, 144 (1952).
[8] W. P. Jesse and J. Sadauskis, Phys. Rev. **75**, 1110 (1949); **78**, 1 (1950).
[9] E. Picciotto, Compt. rend. **228**, 2020 (1949).

Decay of Cu^{60} and Nuclear Levels in Ni^{60}†

R. VAN LIESHOUT, R. H. NUSSBAUM, G. J. NIJGH, AND A. H. WAPSTRA
Institute for Nuclear Research, Amsterdam, Holland
(Received November 13, 1953)

COPPER-60, a 24-min β^+ emitter decaying to Ni^{60}, was investigated by Leith *et al.*[1] By absorption techniques they found β rays of 3.3±0.2 Mev (<5 percent) and 1.8±0.2 Mev accompanied by a γ ray of 1.50±0.05 Mev. Inelastic proton scattering experiments[2] on natural nickel yielded levels at 1.34, 1.48, 2.19, 2.33, 2.50, 2.66, 2.81, 2.95, 3.08, 3.16, 3.23 Mev, etc. From the decay of Co^{60},[3] the levels at 1.33 Mev and 2.50 Mev could be assigned unambiguously to Ni^{60}, whereas the 1.48-Mev level was tentatively ascribed to this isotope from the decay data of Cu^{60}.[1]

We have investigated Cu^{60} with a single-channel scintillation spectrometer, built by Dr. N. F. Verster at our Institute using a Dumond K-1186 photomultiplier tube (9.3 percent half-width for the Cs^{137} photoline). The scintillation spectrum (Fig. 1) showed

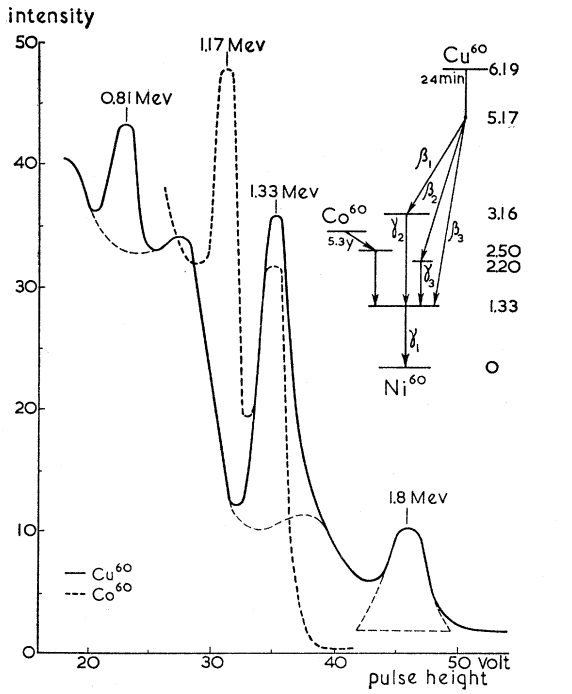

FIG. 1. γ-ray spectra of Cu^{60} and Co^{60}, taken with a 1-in. NaI crystal mounted on a Dumond K-1186 photomultiplier tube. The decay characteristics of the proposed decay scheme are given in Table I.

photolines of three γ rays together with the annihilation radiation from the total positron spectrum. Energies and relative intensities are listed in Table I.

The intensity of a 1.17-Mev γ line, if present, should be less than 10 percent relative to the 1.33-Mev line. The 0.81-Mev γ ray may be complex, as its half-width is larger than should be expected from comparison with the 0.835-Mev γ line of Mn^{54}. The contribution of the pair peak due to the 1.8-Mev γ ray to the area of the 0.81-Mev photoline is about 15 percent of this area.

As these results indicated a more complex decay scheme than that given by Leith *et al.*,[1] we investigated the β spectrum with a magnetic-lens type β-ray spectrometer.[4] The spectrum showed

TABLE I. β and γ rays in Cu^{60} decay.

	Energy (Mev)	Rel. intensity (%)	Log *ft*		Energy (Mev)	Rel. intensity
β_1	3.84±0.05	7±1	7.3	γ_1	1.33	100
β_2	2.96±0.03	19±1	6.3	γ_2	1.8±0.1	80±15
β_3	2.01±0.02	73±1	5.0	γ_3	0.81±0.03	15+5[a]
				β_{tot}^+	0.511	112±15

[a] Corrected for the contribution of the 1.8-Mev pair peak.

three components mentioned in Table I. Our best value for the half-life of Cu^{60} from these measurements is 23.4×0.2 min.

From a combination of the results mentioned above, the decay scheme of Fig. 1 is proposed, which is supported by the fact that levels at 2.19 Mev and 3.16 Mev were also found in the $p-p$ scattering experiments.[2] The existence of γ rays of 2.19 Mev and