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.

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

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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

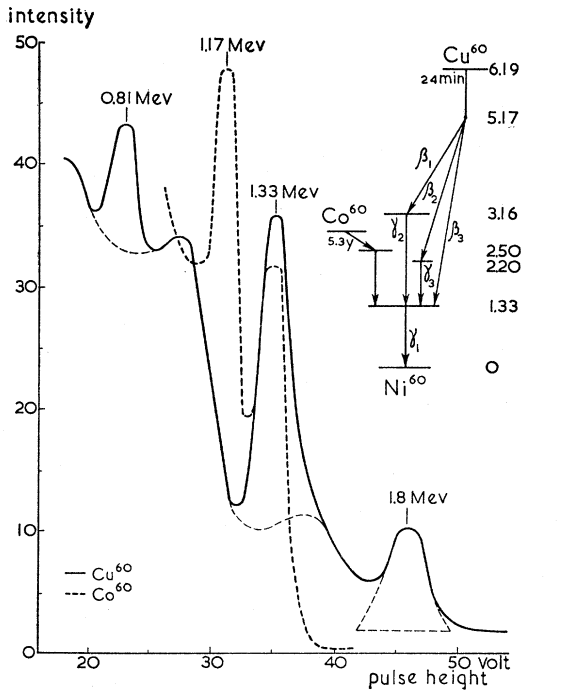

FIG. 1. γ-ray spectra of Cu^{60} and Co^{60}, taken with a 1-in. NaI crystal mounted on a Dumond K-1186 photomultiplier tube. The decay characteristics of the proposed decay scheme are given in Table I.

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

3.16 Mev is not excluded by our work. This decay scheme is also in agreement with the results of $\beta-\gamma$ and $\gamma-\gamma$ coincidence measurements carried out by us with a Geiger counter arrangement described elsewhere.[5]

It should be pointed out that the total decay energy of 6.17 $\pm$0.05 Mev following from this decay scheme disagrees appreciably with the threshold of 5.1$\pm$0.02 Mev in the reaction $Ni^{60}(p,n)Cu^{60}$ found by Leith *et al.*[1] However, our value is more in line with the systematics of β-decay energies for the other Cu isotopes.[3]

A detailed discussion of these results will appear in *Physica*. The Cu^{60} was prepared by irradiation of metallic Ni with 26-Mev deuterons in the Philips synchro-cyclotron. The chemical separation was performed by Miss G. de Feyfer and Miss R. Boelhouwer of our Chemical Department. We thank Dr. C. J. Bakker and Dr. A. H. W. Aten, Jr., for their interest in this work and Mr. L. Th.M. Ornstein for assistance with the experiments.

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The Acceleration of Nitrogen-14 (+ 6) Ions in a 60-Inch Cyclotron*

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A STUDY of the acceleration of heavy ions in the 60-inch cyclotron at the University of California Crocker Laboratory has been in progress for some time. Although this effort has been only part of our over-all program, a continuous improvement in performance has taken place. The original results published by this group[1-5] have recently been augmented by other laboratories,[6-10] where the emphasis, in general, has been on attempts to accelerate ions other than $C^{12}(+6)$. Specific ions include $C^{13}(+6)$, $Ne^{20}(+9)$, $Be^{9}(+4)$, $N^{14}(+6)$, $C^{12}(+5)$, $C^{13}(+5)$, and $O^{16}(+6)$. Developmental work by the Crocker Laboratory group with ion sources, beam monitoring techniques, and other cyclotron parameters has yielded larger $C^{12}(+6)$ beams than previously reported. These larger beams have permitted further experimental work in the fields of biology and nuclear chemistry. Carbon-12 (+6) internal beam intensities of 0.2 microampere have been realized with energies greater than 100 Mev; externally deflected beams of 0.001 microampere with an energy of 120 Mev have been consistent.

The efforts of this group in the acceleration of ions have been rewarding in the cases of those ions with a lower-order ionization state that is a one-third multiple of the ion to be accelerated. In more general terms, a given cyclotron can accelerate any ion for which

$$e/m=K/(2n+1), \qquad (1)$$

where $n=0, 1, 2, \cdots$, and K is a design parameter, i.e, $K=g(\omega,H)$. In the cases where $n=0$, the fundamental ion frequency (ω_i) will prevail; where $n=1$, the ion frequency will be $1/3\omega_i$. This fact was reported earlier[11] and has since been corroborated by the University of Birmingham group[8,9] working with their 60-inch cyclotron.

The techniques used with $C^{12}(+6)$ ion acceleration have been applied to $N^{14}(+6)$ ions by changing the ion source gas from CO_2 to N_2, and increasing the magnetic field to resonance for $K=6/14$, in Eq. (1). This provides that for $n=0$, $N^{14}(+6)$ is accelerated at the fundamental ion frequency (ω_i); $n=1$ indicates an $e/m=2/14$ which allows for acceleration of $N^{14}(+2)$ at $1/3\omega_1$. Under these conditions internal beams of $N^{14}(+2)$ have been measured to a level of 50 microamperes while those of $N^{14}(+6)$ are of the order of 0.1 microampere with energies greater than 100 Mev. This again suggests a mechanism for production of $N^{14}(+6)$ by secondary stripping; namely, that $N^{14}(+2)$ ions produced in the ion source are accelerated at $1/3\omega_i$ and are further ionized to $N^{14}(+6)$ in the region of the ion source. It is not certain whether the further ionization to the $N^{14}(+6)$ state is due either to collisions of the $N^{14}(+2)$ ions with gas molecules within the vacuum system or due to bombardment of the $N^{14}(+2)$ ions by fast electrons which are known to oscillate between the dees[12] at an energy which is a function of the dee voltage. However, experiments with $C^{12}(+2)$, in an effort to increase the $C^{12}(+6)$ beam, indicate that collision stripping is less likely than multiple bombardment by high-energy electrons.

To verify the existence of these high-energy nitrogen ions in the 60-inch cyclotron, several experiments have been performed in which isotopes of elements with atomic number $Z+7$ have been produced from target elements of atomic number Z and isolated by chemical procedures. It is possible to show that the isotopes found could not have been made from target impurities by projectiles of lower Z than nitrogen.

The production of short-lived alpha-emitting isotopes of astatine ($Z=85$) from gold ($Z=79$) targets has always been a convenient method for monitoring the carbon-ion beam of the 60-inch cyclotron; as a first check for the nitrogen beam, astatine isotopes were produced from platinum ($Z=78$). After it was verified experimentally that carbon-ion bombardment of platinum foils produced no detectable astatine alpha-particle activity from possible gold impurity, these same foils were irradiated in the nitrogen beam. The presence of $_{85}At^{205}$ was established by alpha-particle pulse analysis of its 5.9-Mev alpha particles which decay with a 25-minute half-life. Alpha particles of shorter half-life have also been seen which probably belong to the 7-minute $_{85}At^{203}$. Saturation activities of 10^4 to 10^5 alpha counts per minute are observed in bombardments of 0.0025-inch platinum foils. These astatine isotopes cannot be produced by 40-Mev helium ions from possible bismuth or heavy-element impurities in the target foils; nor is it physically reasonable that helium ions could be accelerated at the high magnetic fields employed here.

Analogous to the production of astatine from platinum is the synthesis of iodine ($Z=53$) from palladium ($Z=46$). Because of the simplicity of rapid radio-iodine chemistry, this procedure also lends itself well to an investigation of the nitrogen-ion beam. Short bombardments of palladium foils have yielded the following activities in the radio-iodine fraction:

Half-life	Relative activity
18.0$\pm$1 min	1000
83.5$\pm$2 min	67
5$\pm$1 day	0.5.

The 83.5-minute radio-iodine is probably I^{121}, produced by the reaction $_{46}Pd^{110}(N,3n)_{53}I^{121}$. The 18-minute activity may be the same as the ~30-minute radio-iodine found by Marquez and Perlman[13] from high-energy helium-ion bombardments of antimony, and assigned by them to either I^{119} or I^{120}. The 5-day tail in the decay curve may correspond to 4.5-day Te^{119}, in which case the 18-minute radio-iodine probably is I^{119}. The reaction would be $Pd^{110}(N,5n)I^{119}$ or $Pd^{108}(N,3n)I^{119}$. It should be mentioned that, previous to the nitrogen-ion bombardments, similar palladium targets were subjected to carbon-ion irradiation, and no activity could be detected in the iodine fractions, though normal yields for the corresponding (C,xn) reactions were found in the tellurium fractions.

We wish to acknowledge the assistance of A. Ghiorso for the pulse analysis of the alpha particles from the astatine isotopes,