determined position of the ground state and suggests that the short-lived level (presumably $T=1$) responsible for the observed positrons lies roughly 200 kev above the ground state. The position of the $T=1$ level relative to the ground state of Mg^{26} may be estimated, using a calculated Coulomb energy difference and the p-n mass difference. The expected position is shown in Fig. 1 and is seen to agree with this suggestion.

Kluyver *et al.*[4] have measured energies of gamma rays from $Mg^{25}(p,\gamma)Al^{26}$. These agree with the ground state and the 0.418-Mev level shown. The conclusion of Kluyver *et al.* that the 0.418-Mev level has $T=1$ is inconsistent with the fact that it is seen here in the $Si^{28}(d,\alpha)$ reaction with intensity comparable to the ground state. The lack of a gamma ray to the $T=1$ level may be the result of a high spin difference between this state and the capturing state.[5]

It would be desirable to study a reaction not involving isobaric spin-selection rules to see both the $T=0$ and $T=1$ levels. Resolution of better than 100 kev may be required, however. Possible reactions are $Si^{29}(p,\alpha)Al^{26}$ and $Mg^{24}(He^3,p)Al^{26}$. The first requires higher bombarding energies than are available at present with the MIT-ONR machine. The second of course entails operation of an ion source with He^3.

† This work has been supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

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Coulomb Excitation of Energy Levels in Rhodium and Silver

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(Received June 10, 1954)

Coulomb excitation has revealed two hitherto unknown energy levels in each of the nuclei Rh^{103}, Ag^{107}, and Ag^{109}; their energies and excitation cross sections (transition probabilities) are quite similar and seen to continue the striking similarity of nuclear properties which have been known to exist in these three nuclei, namely: spin $\frac{1}{2}$ and negative parity ($p_{\frac{1}{2}}$ configuration) in their ground states, and a low-lying isomeric transition of the $E3$ type, coming from a level of spin $7/2^+$ (Rh^{103}: $E=40$ kev, $t_{\frac{1}{2}}=57$ min; Ag^{107}: $E=94$ kev, $t_{\frac{1}{2}}=44$ sec; Ag^{109}: $E=87$ kev, $t_{\frac{1}{2}}=39$ sec).

We have reported the levels in rhodium as lying at 305 and 370 kev;[1] these values are now slightly revised to 295 and 357 kev, respectively. We reported that silver showed no gamma radiation under 3-Mev alpha particle bombardment.[2] A reexamination with 2-Mev protons revealed two lines at around 310 and 410 kev in ordinary silver.

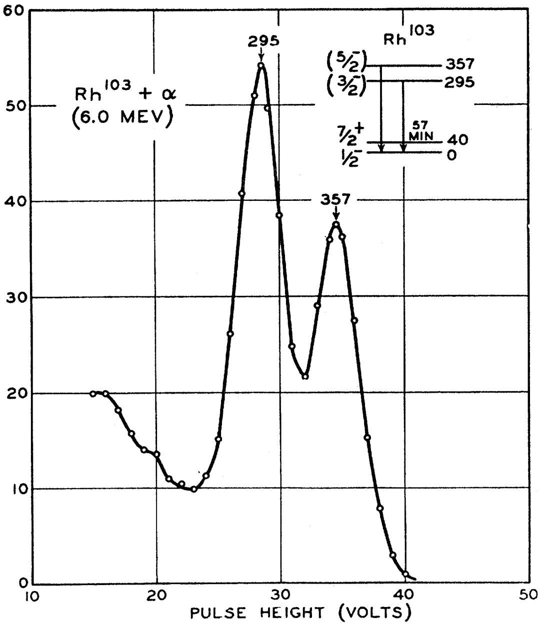

Fig. 1. Pulse-height distribution of gamma radiation from rhodium bombarded with 6-Mev alpha particles.

In the meantime we found that the doubly charged helium-ion current from our rf ion source (~0.3 μa) at *twice* the generator voltage was a very effective tool for

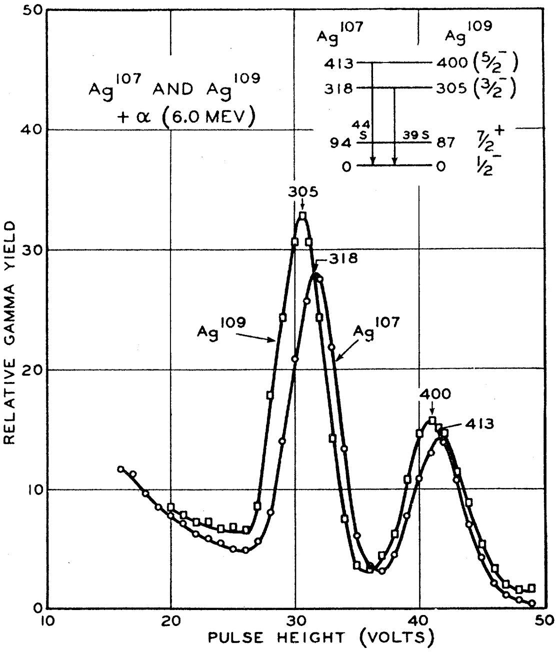

Fig. 2. Pulse-height distributions from silver isotopes bombarded with 6-Mev alpha particles. Circles refer to Ag^{107} (enriched to 90.26 percent, metallic target); squares refer to Ag^{109} (enriched to 99.54 percent, AgCl target corrected for Cl). Relative intensities of all three curves are meaningful.

exciting higher-lying energy levels, having all the advantages characteristic of alpha particles[1–3] plus considerably greater effectiveness in reaching higher excited states. Although the He^{++}-beam current is only about 2 percent of our He^{+}-beam current, the thick-target gamma-ray yield is up by a factor of about 200 at 6 Mev over the 3-Mev value, if the ~310-kev levels in silver are taken as an example. First excited states of even-even nuclei down to $A \sim 60$ ($E \sim 800$ kev) have now become accessible to us.

The pulse-height distribution obtained at 6-Mev bombarding energy with a rhodium target 0.010 in. thick is shown in Fig. 1. The experimental arrangement used is the one described previously.[4] A copper absorber $\frac{1}{16}$ in. thick was used with both Rh and Ag to eliminate the characteristic K x-radiation. Figure 2 shows the pulse-height distributions obtained with thick targets of separated isotopes of Ag^{107} (enriched to 90.26 percent) and Ag^{109} (enriched to 99.54 percent) obtained from the Oak Ridge National Laboratory. Ag^{107} was in metallic form, whereas Ag^{109} was in the form of AgCl; the latter curve has been appropriately corrected by comparison of ordinary silver with ordinary AgCl. This correction consists merely in multiplying by the constant factor 1.39, since negligible radiation is observed from Cl.[1] Gamma rays of 318 kev and 413 kev are seen to occur with Ag^{107}, whereas lines at 305 kev and 400 kev are observed with Ag^{109}. We assign about ±5 kev uncertainty to their energy values. The relative intensity scales are correct for intercomparison of the three nuclei. The separation in energy between the two lines in both isotopes is temptingly close to the energy of the isomeric states; however, the relative peak height of the ~400-kev levels compared to the ~310-kev levels is down by a factor of about 5 at 3-Mev bombarding energy, proving that the two gamma rays cannot come from the same excited state, in which case the ratio would be independent of incident energy.

The excitation curve of the 318-kev gamma-ray yield from Ag^{107} between 2.5 and 3.3 Mev is in good agreement with the theoretical $E2$ curve[5] for $\Delta E = 318$ kev, indicating that the transition takes place between the *ground state* and a state at 318 kev. These curves are very sensitive to ΔE and can certainly reveal at 10 percent change in ΔE.[6] We shall extend these excitation curves up to 7-Mev alpha-particle energy after the completion of an electrostatic analyzer. At the present time, using only gross magnetic separation of the beam, the "mass 2" spot contains, in addition to the He^{++} beam, an energy-dependent admixture of other ions (presumably H_2^{+} and low-energy He). This component is ineffectual in exciting gamma radiation but affects the absolute current determinations at present.

TABLE I. Absolute cross sections (in millibarns) for gamma radiations from rhodium and silver bombarded with 6-Mev alpha particles; decoupling parameter a and rotational constant $\hbar^2/2\mathcal{J}$; derived transition probabilities $B_e(2)$ and intrinsic quadrupole moments Q_0.

Nucleus	E_γ (kev)	σ (mb)	a	$\frac{\hbar^2}{2\mathcal{J}}$ (kev)	$B_e(2)$ (10^{-49} cm^4)	Q_0 (10^{-24} cm^2)
Rh^{103}	295	4.1	+0.77	55	1.8	2.1
	357	5.8			3.2	2.3
Ag^{107}	318	2.6	+0.69	62	1.2	1.7
	413	3.1			2.1	1.9
Ag^{109}	305	2.9	+0.68	60	1.3	1.8
	400	3.6			2.3	2.0

Our attempts to detect the gamma radiation from the isomeric states after shutting off the beam were not successful. The direct Coulomb excitation of these levels is of course out of the question because of the $E3$ character of the transition and its long lifetime (small excitation cross section), but formation of the state is possible by cascade from a higher level. The two gamma rays we observe cannot represent cascades to the isomeric state because of our failure to detect the isomeric transition. Huus and Lundén[7] have observed this transition by counting the conversion electrons, after shutting off their 1.75-Mev proton beam. Since the total internal conversion coefficient of the isomeric transitions is of the order of 15, their method was thus much more sensitive to this transition. From a rough excitation function for the yield of conversion electrons they conclude that a level of around 400 kev is responsible for the formation of the isomer. Combining this information with our results they conclude that in about 0.5 percent of the excitations of the (400+413)-kev level an $E1$ cascade occurs to the isomeric state. It is now clear why we were unable to detect gamma radiation from this state. We do not observe the 0.5 percent of 313 (319)-kev cascade radiation because it is buried under the strong 305 (318)-kev line.[8]

The level schemes shown as inserts in Figs. 1 and 2 summarize these results. The spin assignments are made on the basis of the rotational interpretation of these levels, for the anomalous case where $\Omega = \frac{1}{2}$ (component of the odd-proton angular momentum along the nuclear symmetry axis). The expression for the energy levels in this case is given by[9]

$$E_I = \frac{\hbar^2}{2\mathcal{J}}\left[I(I+1) + a(-1)^{I+\frac{1}{2}}\left(I+\tfrac{1}{2}\right)\right];$$

the decoupling parameter a which obtains in these cases turns out to be ~2/3, so that the normal level sequence (1/2, 3/2, 5/2) is maintained ($|a| < 1$). The $7/2^{+}$ isomeric level belongs to a different value of Ω.

The absolute (thin-target) cross sections, calculated from the thick-target yields, for the Coulomb excitation with 6-Mev alphas of the various gamma rays are listed in Table I,[10] together with approximate values for the reduced transition probabilities $B_e(2)$ and intrinsic nuclear quadrupole moments Q_0 derived from the former in the rotational interpretation.[9] No corrections have been made for internal conversion or cascade radiation from the upper level (expected to be small). The large values obtained for the matrix elements are indicative of $E2$ rotational transitions. It is noteworthy how close the ratios of the quantities $B_e(2)$ for the $(1/2\rightarrow 5/2)$ and $(1/2\rightarrow 3/2)$ transitions come to the value 1.50 predicted from the rotational scheme.

We are indebted to Dr. T. Huus and Dr. A. Lundén for communication of their results prior to publication, and to Dr. A. Bohr and Dr. B. R. Mottelson for informative correspondence.

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[8] T. Huus and A. Lundén see evidence of conversion lines at 306 kev and 321 kev with 1.75-Mev protons on ordinary Ag, in excellent agreement with our values for Ag^{109} and Ag^{107}, respectively.

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[10] The over-all detection efficiency of our system was determined for the 411-kev gamma ray from a Au^{198} source. We are grateful to Miss L. Cavallo and Mr. H. H. Seliger of the National Bureau of Standards for the absolute beta calibration.

Positron Spectrum from the Decay of the μ Meson*

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(Received June 14, 1954)

THE positron spectrum (Fig. 1) produced by the decay of the μ meson has been studied in detail, and also with much improved accuracy, with a 40-in. (pole base diameter) spiral-orbit spectrometer.

The experimental method that was adopted is similar to the one reported by one of us in 1951.[1] The 340-Mev deflected proton beam was used to produce π^+ mesons in the target. Some of the created π^+ mesons decayed inside the target into μ mesons that in turn disintegrated into positrons. Thus the target mounted coaxially with the symmetric magnetic field was the source of positrons. The energy spectrum of these created positrons was analyzed by means of the spiral-orbit spectrometer.[2]

Positrons were measured with momentum resolutions of $\pm 0.6 \sim \pm 1.8$ percent at half intensity. They were detected as quadruple coincidences of signals from four plastic crystals (two of these crystals were $\frac{1}{4}$ by 1.5 by 2.5 in., and the other two $\frac{1}{4}$ by 3 by 3 in.). The counts were taken following a 2-μsec delay relative to the proton pulses and with four consecutive gates each having a 2-μsec width. This enabled us not only to check the half-life but also to reduce background, which usually came in as accidentals.

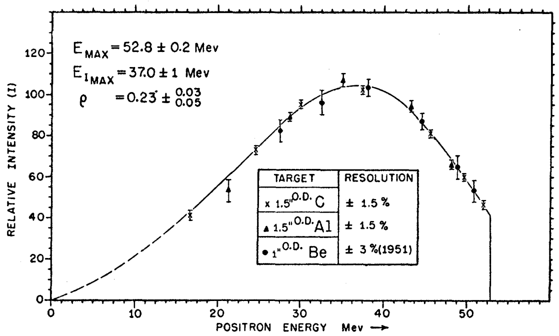

FIG. 1. Positron spectrum from "thick"-target data.

Measurements were made on four thin Be targets of different diameters and thicknesses, as the resolution is directly related to the effective diameter of the cylindrical or tubular targets, and also as the energy absorption of the positrons through the target itself is the other major correction to be applied. In addition to these, two thick targets (C and Al, each $1\frac{1}{2}$ in. outside diameter by 4 in. long) were studied. Each experiment was repeated from 4 to 10 times, and reproducibility of the results was checked.

The accuracy of each magnetic field setting was kept better than 0.1 percent by means of a proton nuclear resonance method during each measurement. As a result, the accuracy of the absolute $H\rho$ value of each measured point is considered to be better than 0.2 percent.

The results are summarized as follows:

(*A*) All the data (most of which have a reasonably small statistical error) can be fitted best to the theoretical curve with $\rho = 0.23_{-0.05}^{+0.03}$ (the constant introduced by Michel[3]), if proper corrections for absorption and resolution are applied, as is shown in Fig. 1.

(*B*) As illustrated in Fig. 2, all thin-target experiments show a definite sharp cutoff at the energy maximum.

(*C*) The absolute value of this maximum energy has been calculated as 52.8 ± 0.2 Mev.

(*D*) This corresponds to a μ-meson mass value of $m_\mu = 207 \pm 0.8 m_e$.

(*E*) With the aid of the fundamental mass ratio,[4] $\pi^+/\mu^+ = 1.321 \pm 0.002$, the mass of the π^+ meson can be established. This value is

$$m_{\pi^+} = 273.4 \pm 1.1 m_e.$$

(*F*) The data obtained in 1951[1] were found to be in good agreement with the present data. (Unfortunately the mass value of the μ meson at that time was too high, and the results were therefore interpreted to show $\rho = 0$.)

(*G*) Since we have measured directly the cutoff at $E_{\max}$ from our experiment, our present results are not dependent on some other mass measurements.