An Investigation of the Disintegration Schemes of Ru^{103} and Rb^{86}*

C. E. MANDEVILLE AND E. SHAPIRO
Bartol Research Foundation of The Franklin Institute, Swarthmore, Pennsylvania
(Received October 20, 1949)

The disintegration schemes of the 42-day Ru^{103} and the 19-day Rb^{86} have been studied with the use of absorption and coincidence methods. Ninety-two percent of the disintegrations of Ru^{103} proceed by way of an inner beta-ray group at 0.15-Mev coincident in time with a gamma-ray of energy 0.52 Mev, which is (4±1) percent converted. A harder beta-spectrum having a maximum energy of 0.68 Mev leads to the ground state of Rh^{103}.

It is estimated that (12±2) percent of the beta-rays of Rb^{86} are contained in the inner spectrum. Absorption measurements confirm the energy values given by the Indiana group.

INTRODUCTION

THE activities described in the present manuscript were induced in oxides of ruthenium and rubidium which were irradiated by slow neutrons in the Oak Ridge pile. Chemical purification of the irradiated material was carried out in regard to both activities.

The pile irradiated RuO_2 was aged for about two months to allow for decay of the 2.8-day ruthenium (97), after which time RuO_4 was distilled from a suspension of 100 mg of RuO_2 in 5 ml of concentrated H_2SO_4 and 5 ml of sixty percent $HClO_4$. The distillate was collected in 25 ml of 6N NaOH. This solution was boiled with alcohol to precipitate ruthenium metal which was then removed by centrifugation, dissolved in 1N HCl, and reprecipitated with magnesium powder. The excess magnesium was dissolved in HCl, and the ruthenium was removed by filtration, washed with alcohol and ether and dried for use.

Neutron irradiated rubidium carbonate was freed of its principal impurity, cesium, by three precipitations of cesium silicotungstate from a 6N HCl solution, using weights of carrier cesium in each precipitation comparable to the initial weight of rubidium. The third filtrate was treated with 5 ml of $HClO_4$, evaporated to $HClO_4$ fumes, and centrifuged. Five ml of absolute alcohol was added to the supernatant, precipitating $RbClO_4$ which was removed by filtration, washed with alcohol and ether and dried for measurement. The yield of $RbClO_4$ was about 20 percent.

The beta-rays of Ru^{103} have been said to have energies of 0.25 Mev,[1] 0.3 Mev (95 percent), 0.8 Mev (5 percent),[2] and 0.75 Mev.[3] The gamma-radiation is reported as having a quantum energy of 0.56 Mev[2,4] and of 0.4 Mev.[3] All of the above quoted data were obtained by absorption methods.

Spectrometric and coincidence data have been combined by the Indiana group[5] to show that the 19-day Rb^{86} decays with the emission of beta-ray spectra having end points at 1.822 Mev and 0.716 Mev. The gamma-ray energy was measured as 1.081 Mev. It is estimated by the Indiana group that twenty percent of the disintegration proceeds by way of the inner beta-ray group.

The energies of the radiations of Ru^{103} and Rb^{86} reported in the present paper were measured by absorption methods. Beta-gamma, beta-beta, and gamma-gamma-coincidences were observed with the aid of a coincidence circuit having a resolving time of 0.10 microsecond. No attempt was made to study the soft radiations of the well-known metastable state of Rh^{103} having a half-period of about one hour.

Ru^{103}

The beta-rays of Ru^{103} were absorbed as shown in the logarithmic plot of Fig. 1. The end point of the inner

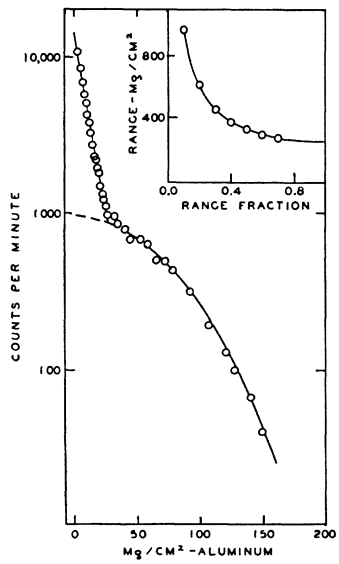

FIG. 1. Absorption in aluminum of the beta-rays of the 42-day Ru^{103}. The end points occur at 0.15 Mev and 0.68 Mev. The softer component constitutes 92 percent of the total beta-radiation.

* Assisted by the Joint Program of the ONR and the AEC.

[1] W. E. Grummitt and G. Wilkinson, Nature **158**, 163 (1946).

[2] Sullivan, Slight, and Gladrow, Plutonium Project Report CC-1493 (March 1944), quoted by Seaborg and Perlman, Rev. Mod. Phys. **20**, 585 (1948).

[3] E. Bohr and N. Hole, Arkiv. f. Mat. Astr. O. Fys. **32A**, No. 15 (1948).

[4] L. E. Glendenin, Plutonium Project Report CC-920, 43 (September 1943), quoted by Seaborg and Perlman.

[5] Zaffarano, Kern, and Mitchell, Phys. Rev. **74**, 682 (1948). E. T. Jurney, Phys. Rev. **74**, 1049 (1948).

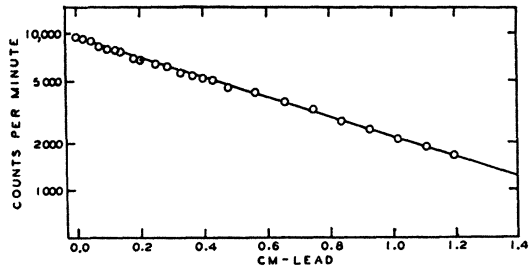

FIG. 2. Absorption in lead of the quantum radiations of Ru^{103}. The energy taken from the slope of the curve is 0.52 Mev.

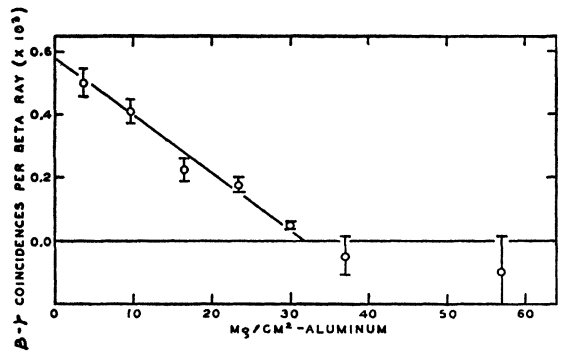

FIG. 3. The beta-gamma-coincidence rate of Ru^{103} as a function of the surface density of aluminum placed before the beta-ray counter. These data show that the softer spectrum is coincident in time with the gamma-ray of energy 0.52 Mev.

group occurs at 28 mg/cm², corresponding to an energy of 150 kev. From the Feather plot also shown in Fig. 1, the harder spectrum appears to have a maximum range of 250 mg/cm², corresponding to an energy of 0.68 Mev. Extrapolation of the two spectra to zero absorber thickness shows that only eight percent of the beta-particles fall in the harder spectrum.

The gamma-rays of Ru^{103} were absorbed in lead as shown in Fig. 2. The slope of the curve corresponds to a quantum energy of 0.52 Mev.

The beta-gamma-coincidence rate of Ru^{103} was measured as a function of the surface density of aluminum placed before the beta-ray counter. These data are

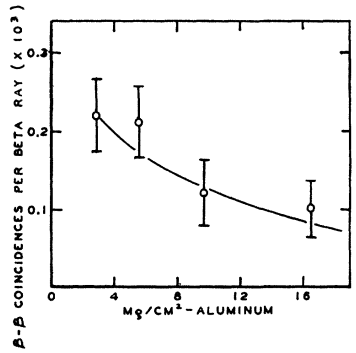

FIG. 4. The beta-beta-coincidence rate of Ru^{103} as a function of the surface density of aluminum placed before both counters. It is estimated that the total conversion coefficient of the gamma-ray at 0.52 Mev is (4±1) percent.

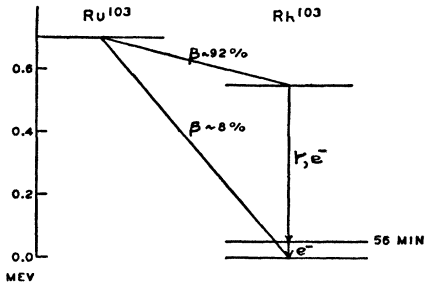

FIG. 5. Proposed disintegration scheme of the 46-day Ru^{103}.

shown in Fig. 3 where the beta-gamma-coincidence rate is seen to decrease from an extrapolated value of 0.58×10^{-3} coincidence per beta-ray at zero absorber thickness to zero at ~30 mg/cm², showing that the intense soft spectrum of Fig. 1 is coincident in time with gamma-radiation and that the weak spectrum at 0.68 Mev goes to the ground state of the residual nucleus. Calibration of the gamma-ray counter showed that the beta-gamma-coincidence rate at zero absorber thickness is consistent with the view that 92 percent of the nuclear beta-rays are followed by a gamma-ray of energy 0.52 Mev.

No gamma-gamma-coincidences were found in the disintegration of Ru^{103}.

Beta-beta-coincidences were measured as a function of the surface density of aluminum absorbers placed before both beta-ray counters. The curve of these data is shown in Fig. 4. From the coincidence rates of the beta-beta-coincidence counting arrangement, it is estimated that the 0.52-Mev gamma-ray is converted to the extent of (4±1) percent.

The absorption and coincidence data are combined in Fig. 5 to give a disintegration scheme.

Rb^{86}

The beta-gamma-coincidence rate of Rb^{86} is shown in Fig. 6 where the coincidence rate is seen to decrease to zero in the vicinity of a kinetic energy of 0.5 Mev.

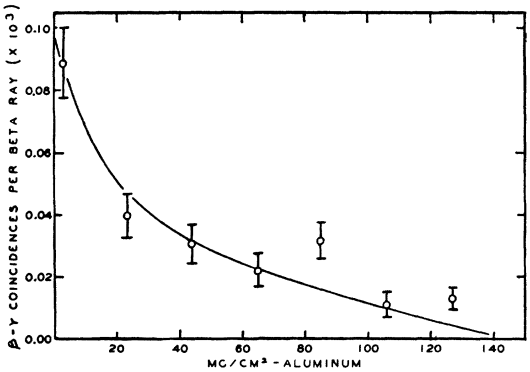

FIG. 6. The beta-gamma-coincidence rate of Rb^{86} as a function of the aluminum absorber thickness placed before the beta-ray counter. It is estimated that (12±2) percent of the total beta-radiation lies in the soft spectrum.

From the calibration of the gamma-ray counter and the coincidence rate at zero absorber thickness it is estimated that (12±2) percent of the total beta-radiation lies in the inner beta-ray group which is coupled with the 1.08-Mev gamma-ray. This is to be compared with previous estimates of 20 percent obtained from spectrometric data and 33 percent as indicated by an absorption method.[5] Absorption of the radiations of Rb^{86} in aluminum and lead confirmed the conclusions of the Indiana group as to the energies.

ACKNOWLEDGMENT

The writers wish to acknowledge the continued interest of Dr. W. F. G. Swann, Director of Bartol.

PHYSICAL REVIEW VOLUME 77, NUMBER 4 FEBRUARY 15, 1950

The Neutron-Proton Interaction

RICHARD S. CHRISTIAN AND EDWARD W. HART
Radiation Laboratory, Department of Physics, University of California, Berkeley, California
(Received October 14, 1949)

An analysis of the high energy (40 and 90 Mev) experimental neutron-proton scattering results is presented. It is shown that there is good agreement with the theoretical predictions based on a potential model having a $\frac{1}{2}(1+P_x)$ exchange dependence and a "long-tailed" radial dependence. There is evidence, furthermore, from the scattering for the inclusion of a tensor force. A comparison of the predictions of square well, exponential, and Yukawa radial dependences is included to illustrate the effect of different shape characteristics.

INTRODUCTION

THE purpose of the present paper is to ascertain if it is possible to determine a phenomenological description of the neutron-proton interaction in terms of a potential. A further aim is to determine with what uniqueness this potential can be determined from the present experiments, particularly those at high energies. The program will be to assume a number of potential models so adjusted that they fit the low energy region and attempt to correlate the high energy scattering with the various features of each model.

It is well known that the experimental results in the low energy region can be described by an interaction potential; however, for sufficiently high energies relativistic corrections may be expected to be of major importance. Detailed scattering calculations, using a field theory, show that the use of relativistic momenta corresponds to calculating the kinematical aspects relativistically, but that the dynamical corrections depend on the specific theory employed. Scattering deduced from a field theory[1] has, in general, relativistic corrections proportional to $(v/c)^2$; for example, at 90 Mev $(v/c)^2$ is 0.05 while approximately 10 percent corrections are found by application of the Møller method to the scalar and vector meson theories.[2] Thus a choice cannot be made between two models both of which agree within 10 percent with the experimental results at 90 Mev.

The experimental results of the low energy region (including some derived quantities) are summarized in Table I. None of these experiments give information concerning the explicit radial dependence of the forces or of the forces in other than S states, and, in fact even the ranges are determined only approximately. In the triplet state there is a further uncertainty in the relative central and tensor ranges. This latter uncertainty would be removed considerably if it were assumed that the magnetic moment gave a measure of the D state admixture due to tensor forces. Unfortunately, because of uncertain relativistic corrections[3] this forms an unreliable restriction. The depths of the various potentials, i.e., singlet and triplet central and triplet tensor, are, however, accurately determined for any specified combination of ranges.

The high energy experimental angular distributions are shown in graphical form in Fig. 1. The expansion (in Legendre polynomials, $P_n(\theta)$) for the 90-Mev distribution is

$$4\pi\cdot\sigma(\theta)=\sigma[1-0.14P_1(\theta)+0.73P_2(\theta)+0.08P_3(\theta)+0.17P_4(\theta)],$$

with an estimated error of ±0.1 for the coefficients of $P_1(\theta)$ through $P_4(\theta)$. The most noteworthy result is the near symmetry about 90°. We have therefore assumed that the 40-Mev angular distribution, which has been determined only in the range 60°–180°, is symmetrical

[1] L. Rosenfeld, *Nuclear Forces* (Interscience Publishers, Inc., New York), Vol. 2, p. 311 ff. It might appear at first sight that corrections due to spin orbit coupling are of order v/c. Actually, in a field theory calculation corrections which introduce this coupling include also a gradient of the potential (e.g., the Thomas term for the hydrogen atom) which in scattering produces an additional factor of v/c.

[2] H. Snyder and R. E. Marshak, Phys. Rev. 72, 1253 (1947).

[3] R. G. Sachs, Phys. Rev. 72, 91 (1947); H. Primakoff, Phys. Rev. 72, 118 (1947); G. Breit and I. Bloch, Phys. Rev. 72, 135 (1947).