Investigation of Radioactive Decay Chains

V. S. SHPINEL' AND G. A. KUZNETSOVA
Moscow State University

J. Exptl. Theoret. Phys.(U.S.S.R.)30, 231-242 (February, 1956)
(Submitted to JETP editor October 11, 1954)

Using a β-spectrometer with two magnetic lenses and a γ-spectrometer with NaI (Tl) scintillator, an investigation of the following transitions has been carried out: $Zr^{97} \rightarrow Nb^{97} \rightarrow Mo^{97}$; $Ru^{97} \rightarrow Tc^{97}$; $Ru^{105} \rightarrow Rh^{105} \rightarrow Pd^{105}$; and $Ru^{103} \rightarrow Rh^{103}$. The results obtained are generally in agreement with published decay schemes with the exceptions that a sample of $Zr^{97} + Nb^{97}$ emits a β spectrum with $E_\beta \sim 0.48$ mev (intensity 15%) and low intensity hard γ-rays of 2.2 and 1.6 mev. The decay of Rh^{105} is accompanied by the emission of 0.08 mev γ-rays. The occurrence of corresponding β and γ transitions in odd nuclei differing by two neutrons is noted.

INTRODUCTION

In a previous paper of one of the authors[1] certain regularities were noted in corresponding levels of selected nuclei with odd number of nucleons. To obtain further and more precise data on the excited states of these nuclei, we undertook a spectroscopic investigation of radioactive transitions in nuclei of mass number A=97, A=103 and A=105.

1. Zr^{97} AND Nb^{97}

PUBLISHED DATA

Investigation of the 17 hour Zr^{97} and 75 minute Nb^{97} activities has previously been carried out by absorption methods with the aid of a lens spectrometer, and by the method of β-γ coincidences.[2-4] Zr^{97}-Nb^{97} sources were obtained by slow neutron bombardment of either a natural isotopic mixture, or one enriched in Zr^{96}, or alternatively by chemical separation from the fission fragments of uranium. Measurements were made with a mixture of zirconium and niobium in radioactive equilibrium as well as with separated niobium. Spectrometer measurements[2] showed that Zr^{97} makes a β-transition to an isomeric level of Nb^{97m} with excitation energy E=0.747 ±0.005 mev, and subsequently decays to the ground state of Nb^{97} with a period of 60 seconds. The β-spectrum of Zr^{97} is simple, with an upper energy E_β =1.91 ±0.02 mev. Subsequently Nb^{97} decays by β emission, accompanied by γ-rays of energy $E_\gamma = 0.665 \pm 0.02$ mev. The maximum energy of the niobium β-spectrum is E_β = 1.267 ±0.02 mev.

Measurements of γ-energy by the absorption method (Ref. 3) show the existence of quanta with energy E_γ = 1.42 mev which the authors ascribe to Zr^{97}.

β AND γ SPECTRA OF Zr^{97} AND Nb^{97}

Powdered ZrO_2 was bombarded by slow neutrons; investigation of the induced radioactivity with the two lens β-spectrometer[5] began 9 hours after the end of bombardment. The first spectrum was taken with a disk shaped source, diameter 10mm and thickness 5 mg/cm^2. The source was mounted on a mica sheet of 6.3 mg/cm^2, and the counter window was celluloid of 0.5-0.7 mg/cm^2. Measurements were repeated three times in the course of four days. Intensity reduction of the spectrum has a characteristic half period of 17 hours, which is in good agreement with the known value for Zr^{97}. The observed β-spectrum is shown in Fig. 1. The two K-electron conversion lines give γ-ray energies $E_{\gamma 1} = 0.666 \pm 0.006$ mev and $E_{\gamma 2}$ = 0.750 ±0.005 mev. The straightened β-spectrum (Kurie plot) in Fig. 2, shows the superposition of two spectra with limit energies $E_{\beta 1}$=1.90 ±0.025 mev and $E_{\beta 2}$=1.18 ±0.050 mev. These values are in satisfactory agreement with known values for the limit energies of Zr^{97} and Nb^{97} respectively. The experimental points on the Kurie plot show the presence of another soft β spectrum with limit energy $E_{\beta 3}$=0.48 mev. This value is close to the spectrum limit energy for Zr^{95} which could have been formed during the bombardment. Our measurements show that the intensity of this spectrum, obtained by subtraction of the harder spectra, diminishes with a period of the order of 20 hours. This shows

[1] V. S. Shpinel, J. Exptl. Theoret. Phys.(U.S.S.R.)224, 90 (1953).

[2] W. H. Burgus. Phys. Rev. 79, 104 (1950).

[3] C. E. Mandeville et al., J. Frankl. Inst., 254, 381 (1952).

[4] C. E. Mandeville et al., Phys. Rev. 86, 813 (1952).

[5] V. S. Shpinel, J. Exptl. Theoret. Phys.(U.S.S.R.)22. 225 (1952).

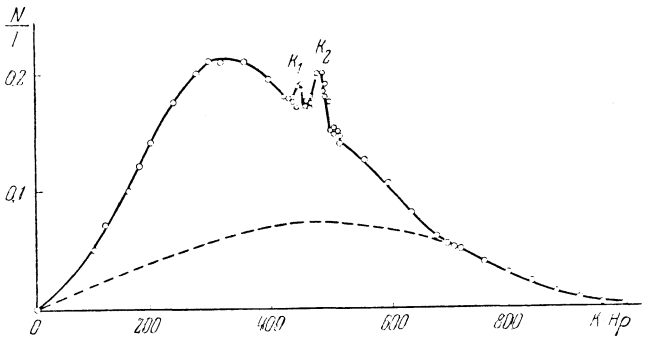

FIG. 1. Primary spectrum of Zr^{97} and Nb^{97} in radioactive equilibrium. K_1 --0.666 ±0.006 mev, K_2--0.750 ± 0.005 mev.

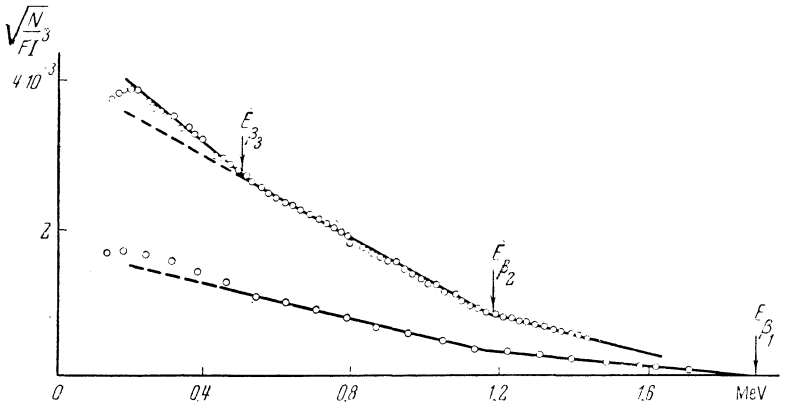

FIG. 2. Kurie plot for Zr^{97} and Nb^{97}. E_{β_1} —1.9±0.025 mev, E_{β_2} —1.18± ± 0.025 mev, E_{β_3} — 0.48 ± 0.05 mev

that it can not depend on Zr^{95}, and we have assigned it to Zr^{97} +Nb^{97}. The areas of the Zr^{97} and Nb^{97} β spectra are equal, within our accuracy, as would be expected for sources in radioactive equilibrium. The area of the $E_{\beta 3}$ = 0.48 mev. β spectrum comprises 15% of the area of each of the above β spectra. From the ratios of the conversion peak areas from 0.666 and 0.75 mev γ-rays to the β-spectrum area, we have obtained the conversion coefficients (2.5 ±0.3) x 10^{-3} and (1.43 ± 0.17) x 10^{-2} respectively.

Control measurements of the initial Zr^{97} +Nb^{97} spectra were made with a source obtained by neutron irradiation of an enriched target, with 48% Zr^{96}. In this case also, a Kurie plot shows a soft β- spectrum, with an upper limit ≈ 0.5 mev. The source thickness in these measurements was 0.6 mg/cm^2.

To obtain the spectrum of secondary electrons (Fig. 3), active ZrO_2 powder was put into a brass container, inside diameter 10mm and height 8mm. The thickness of the front wall of the container, in which the initial β-spectrum was absorbed, was 1.3 mm. The lead converter had a thickness of 49.3 mg/ cm^2 and a diameter of 10 mm. The observed photoelectron lines give the following γ-ray energies (with correction for absorption in the converter) : 0.662 ± 0.006 mev and 0.742 ± 0.007 mev, which are in good agreement with the conversion data.

The γ-spectrum of this source taken with a NaI (Tl) scintillation spectrometer is shown in Fig. 4. Besides the photoelectron peak associated with the 0.664 ± 0.746 mev γ-ray lines, a hard γ-spectrum ending at about 2.2 mev was observed. Detailed examination of the hard γ-spectrum, carried out by N. N. Deliagin, showed two rays of energies 2.2 and 1.6 mev, if the observed maxima on the spectrum are assumed to be caused by photoelectrons.

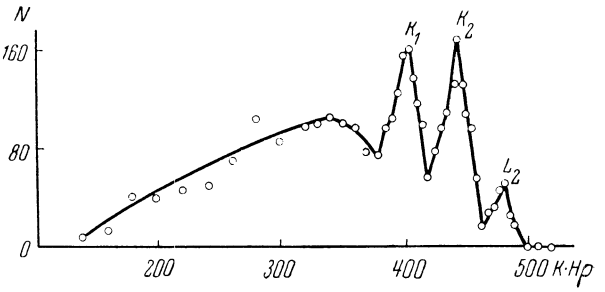

FIG. 3. Photoelectron spectrum Zr^{97} and Nb^{97} K_1 — 0.662, K_2 and L_2 — 0.742 mev

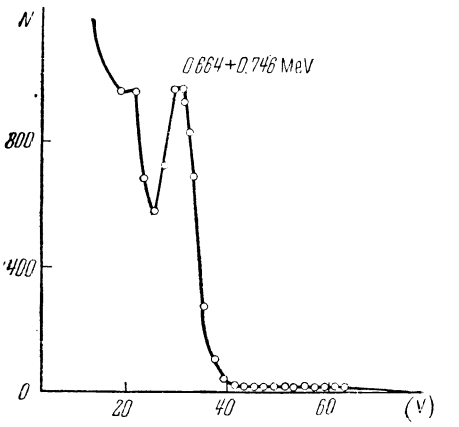

FIG. 4. γ-spectrum of Zr^{97} + Nb^{97} observed with the scintillation spectrometer.

2. Ru^{97}, Ru^{103}, AND Ru^{105}

When a natural isotopic mixture of ruthenium isotopes is irradiated by slow neutrons, the radioactive isotopes Ru^{97}, Ru^{103} and Ru^{105} are produced, In this section we give results of measurements performed with these isotopes.

PUBLISHED DATA

Ru^{97}. The radiation of Ru^{97} was first investigated by the absorption technique in Ref. 6. It was determined that Ru^{97}, obtained by slow neutron bombardment, decays by K-capture with a period of 2.8 days. This decay is accompanied by a γ-ray of energy 0.23 mev. The observed weak electron emission with energy 0.097 mev was assigned to the daughter isotope Tc^{97} with period of 90 days[7]. In Ref. 8 Ru^{97} was obtained by α-bombardment of Mo^{94}, and subsequent electromagnetic enrichment to 75%. In Ref. 9 a Ru^{97} α-ray energy E_γ =0.21 7 mev was found. Photoelectrons were observed in a lens spectrometer, using a slow neutron irradiated ruthenium source. The observed photoelectron line was quite weak compared to the background of γ-radiation due to Ru^{103}.

Ru^{103}. The radiations of 42 day Ru^{103} [10,11] have been investigated by several authors. In a number of cases the results are in poor agreement with each other. The first measurements were made with the absorption technique[12]. Ref. 13 made use of a magnetic lens spectrometer with 4% resolution. The decay scheme of Ru^{103} was first given in Ref. 14, in which absorption and coincidence methods were used. More accurate spectroscopic measurements were carried out in Refs. 15, 16. The most accurate measurements of conversion electron energies were made with a 180° focussing β-spectrometer and photographic detection[17].

The above named papers determine the existence of two β-transitions and two γ-transitions; the energies found by various authors are given in Table 1. Besides these radiations, reference 17 observed γ-rays of 0.0529, 0.295, and 0.61 0 mev. The discovery of the 0.61 0 mev γ-ray allowed the authors to assume the existence of a third β-transition with limit energy E_β = 0.13 7 mev.

---

[6] W. H. Sullivan, N. R. Slight and E. M. Gladrow, Phys. Rev. 70, 778 (1946).

[7] B. N. Cacciopuoti and E. Segre, Phys. Rev. 52, 1252 (1937).

[8] D. T. Eggen and M. L. Pool, Phys. Rev. 74, 57 (1948).

[9] T. Y. Mei, C. M. Huddleston and A.C. G. Mitchell, Phys. Rev. 79, 429 (1950).

[10] T. J. Livingood, Phys. Rev. 50, 425 (1936).

[11] W. H. Sullivan, N. R. Slight and E. M. Gladrow, Phys. Rev. 70,778 (1946).

[12] E. Bohr and N. Hole, Arkiv. f. Mat. Astr. o. Fysik. 32A, No. 15 (1945).

[13] N. Hole, Arkiv f. Mat. Astr. o. Fysik. 36A, No. 2, (1948).

[14] C. Mandeville and E. Shapiro, Phys. Rev. 77, 439 (1950).

[15] F. Kondiah, Arkiv f. Fysik 4, 81 (1952).

[16] T.Y. Mei, C. M. Huddleston and A. C. G. Mitchell, Phys. Rev. 79, 429 (1950).

[17] J. M. Cork, T. Le Blanc, E. Stumpf and W. Nester, Phys. Rev. 86, 575 (1952).

TABLE 1.

Reference	[10]	[11]	[12]	[13]	[14]	[15]	[16]
Half life (days)	42	41	—	—	39.8	43	—
Energy (mev)							
β_1	0.200	—	0.350	0.150	0.217	0.204	—
β_2	0.800	0.750	0.665	0.680	0.698	0.648	—
γ_1	—	—	—	—	0.040	0.0404	0.0396
γ_2	0.530	0.400	0.312	0.520	0.498	0.494	0.4985

Two conversion lines at 0.215 and 0. 290 mev were observed in reference 13. According to the decay schemes proposed in Refs. 15, 16, the soft β-spectrum is accompanied by a cascade of γ-transitions of 0.495 and 0.040 mev, while the hard γ-spectrum corresponds to a transition to the 0.040 mev level. The decay scheme assumed in Ref. 17 differs from the above in that the hard β-spectrum is connected with a transition to a third level at 0. 0529 mev.

Ru^{105}. Early investigations of the chain $Ru^{105} \rightarrow Rh^{105} \rightarrow Pd^{105}$ were carried out by the absorption method [12, 18]. More exact data on the β and γ radiation were obtained by using a lens spectrometer with resolution of 3 and 6%.[19] This work showed that the β-spectrum of Ru^{105} was simple, with a limit energy 1.15 mev. The excited state of Rh^{105} arising from the β-decay of ruthenium decays to a metastable level of energy ~ 0.1 mev (45 sec) through the emission of a 0.726 mev γ-ray of low multipolarity.

Rh^{105} (36 hour.) in its ground state emits electrons with maximum energy 0.570 mev, and goes to the ground state of Pd^{105}. In Ref. 20 Rh^{105} was found to emit a β-spectrum with intensity of 10% and upper limit of energy of 0.26 mev, a 0.322 mev γ-ray, and weak γ-rays of 0.157 and 0.080 mev.

β AND γ SPECTRA

Measurements on ruthenium were made with a lens spectrometer under conditions analogous to those in Sec. 2. The initial measurements were made with neutron irradiated metallic ruthenium powder and showed background radiation originating in an admixture of iridium. Subsequently, chemical separation of the ruthenium was used*. The metallic ruthenium was melted with alkali, became rutanate ($H_2RuO_4 + K_2RuO_3$), and subsequently was made into the salt ($RuCl_3 + RuCl_4$). The mixture obtained was volatilized in the form RuO_4 and absorbed by a weak solution of hydrochloric acid saturated with hydrogen sulfide gas. As a result we obtained a pure powder of $RuCl_3$, which was again irradiated by slow neutrons. The spectroscopic investigation of this sample was repeated several times in the course of more than a month.

The photoelectron spectrum, from a source of the same geometry as in the zirconium measurements, is shown in Fig. 5 (thickness of the lead converter 28 mg/ cm^2). Curves 1, 2, and 3 correspond respectively to measurements made 6 hours, 26 hours, and 8 days after irradiation. A further three measurements, made after 3 days and 40 days, are not shown on Fig. 5.

The energy of γ-lines and their periods, obtained from changes in intensity, are shown in Table 2. From this data it is possible to assign each line to the isotope listed in the 6th column.

This γ-radiation was also investigated with the scintillation spectrometer. Two series of measurements were taken using two ruthenium sources that differed by the length of neutron bombardment. The first series of measurements was made with a source that had been bombarded 4 hours; the second series, with the aim of increasing the 36 hour Rh^{105} intensity, was made with a 10 hour bombarded source. The first measurements were taken 4 hours after the end of bombardment, and in the next 70 hours, the spectrum was taken 8 times. In the second series measurements were begun 5

[18] H. T. Born and W. Sulmann-Eggebert, Naturwissen. 31, 420 (1943).

[19] R. B. Duffield and L. M. Langer, Phys. Rev., 81, 203 (1951).

[20] G. E. Boyd, Phys. Rev. 86 , 578 (1952).

* We would like to take the opportunity to express our thanks to H. P. Rudenko, in whose laboratory the necessary chemical separations were carried out.

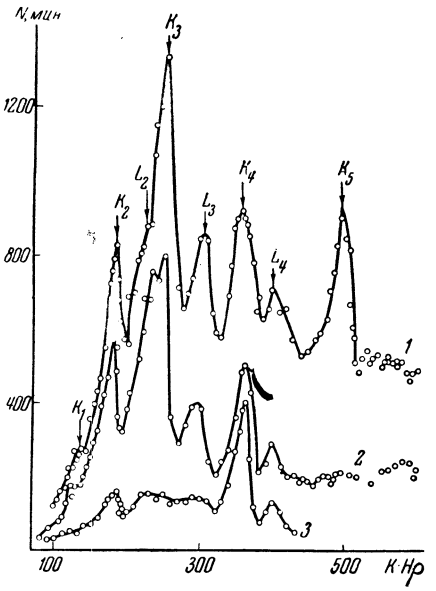

FIG. 5. Photoelectron spectrum taken with a source produced by slow neutron bombardment of ruthenium. Curves *1*, *2*, and *3* correspond to measurements taken 6 hrs., 26 hrs., and 9 days respectively after the end of bombardment. K_2 and L_2 --0.219 mev (Ru^{97}, 68 hrs.); K_3 and L_3 --0.320 mev (Ru^{105}, 36 hrs.); K_4 and L_4 --0. 497 mev (Ru^{103}, 42 days); K_5 --0.728 mev (Ru^{105}, 4.2 hrs.).

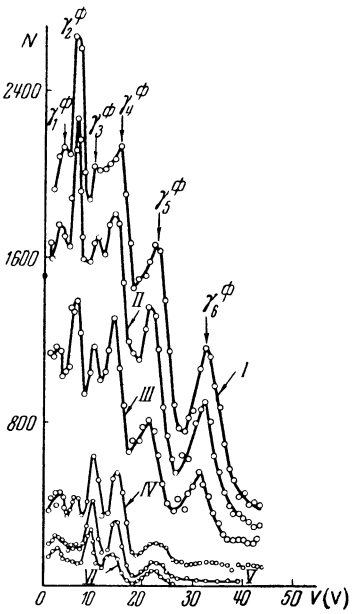

FIG. 6. Spectrum for a ruthenium source bombarded by slow neutrons. Curves *I*, *II*, *III*, *IV*, *V*, and *VI* were taken 4, 7, 9, 27, 36, and 56 hours after the bombardment respectively. $\gamma_1^{\Phi} - 0.08$; $\gamma_2^{\Phi} - 0.133$; $\gamma_3^{\Phi} - 0.22$; $\gamma_4^{\Phi} - 0.33$; $\gamma_5^{\Phi} - 0.5$; $\gamma_6^{\Phi} - 0.74$ mev

TABLE 2.

Line	Photo-electron energy (mev)	Absorption corrections in converter (kev)	γ-ray energy (mev)	Half life	Isotope
K_1	0.067	9	0.164 ?	—	Rh^{105}
K_2	0.124	7	0.219±0,004	68 hrs.	Ru^{97}
L_2	0.187	7	0.220±0,004	68 "	—
K_3	0.226	6	0.320±0,006	36 "	Rh^{105}
L_3	0.298	6	0.320±0,006	36 "	—
K_4	0.403	6	0.497±0,004	—	—
L_4	0.478	6	0.500±0,004	42 days	Ru^{103}
K_5	0.636	6	0.728±0,004	4.2 hrs.	Ru^{105}

hours after bombardment, and the spectrum was taken 8 more times in the course of 140 hours.

The spectra obtained in the first series of measurements are shown in Fig. 6. The γ-ray energies on Fig. 6 as well as the decay period obtained from a decay curve for each line are in good agreement with the results obtained from the magnetic spectrometer measurements. Furthermore, on this spectrum we clearly observe a γ-line at 0.133 mev, as well as a weak line at 0.08 mev; these lines did not appear on the spectrum of Fig. 5. The 0.5 mev γ-line decays with two periods, of $\sim$ 4 hours and of the order of tens of days, which allows us to consider the line as complex. One of these lines must be dependent on photoelectrons from the known 0.496 mev γ-line of 42 day Ru^{103}, while the short period line must be due to Ru^{105}. Since the γ-spectrum of Ru^{105} taken with the magnetic spectrometer does not show a line near 0.5 mev, we may associate the short period component with

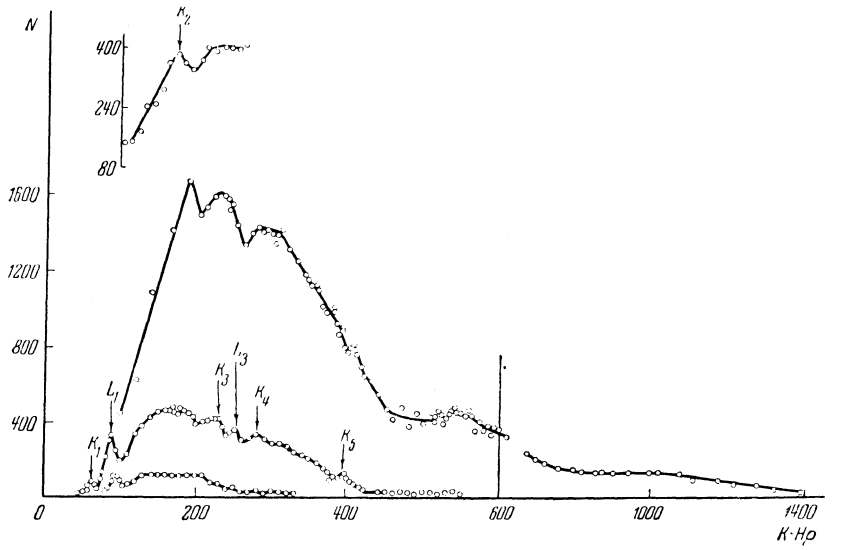

FIG. 7. Primary spectrum of a source obtained by slow neutron bombardment of ruthenium. Each curve was taken at a different time. K_1 and L_1 --0.04 mev (Ru^{103}); K_2--0.133 mev (Ru^{105*}); K_3 and L_3 --0.216 mev (Ru^{97}); K_4--0.311 mev (Ru^{105}); K_5 --0.492 mev (Ru^{103}).

TABLE 3.

Line	electron energy (mev)	γ-ray energy (mev)	Isotope
K_1	0.019	0.041	—
L_1	0.035	0.038±0.002	Ru^{103}
K_2	0.110	0.133±0.010	$Rh^{105}m$
K_3	0.194	0.216±0.011	Ru^{97}
L_3	0.217	0.220	—
K_4	0 288	0 311±0.010	Rh^{105}
K_5	0.470	0.492±0.009	Ru^{103}

Compton electrons from the 0.74 mev Ru^{105} line, which must give a maximum superimposed on the position of the 0.5 mev photoelectron line. Figures 5 and 6 show spectra taken with a source which emitted an additional hard γ-radiation. Repetition after chemical purification showed no hard γ-radiation, which had presumably been caused by an admixture of Na^{24}.

The β-spectrum source was made from activated $RuCl_2$ powder mixed in a weak zapon lacquer solution, and deposited on a cellophane backing (6.3 mg/cm^2). Source thickness was 2 mg/cm^2 with an 8 mm diameter. Figure 7 shows the results of several series of measurements of the primary spectrum carried out at various times. Energies of the observed conversion lines and corresponding γ-rays are given in Table 3. These results agree, within the experimental errors, with those obtained from photoelectrons.

Figure 8 gives a Kurie plot of this data; the upper limit energies and decay periods are shown in Table 4. The third column of this table shows the isotopes to which the observed β-spectra are assigned.

We have assigned the hard β-spectrum E_β= 2.72 mev to a contamination of our source by manganese during the chemical purification. Repetition of purification reduced the intensity of this

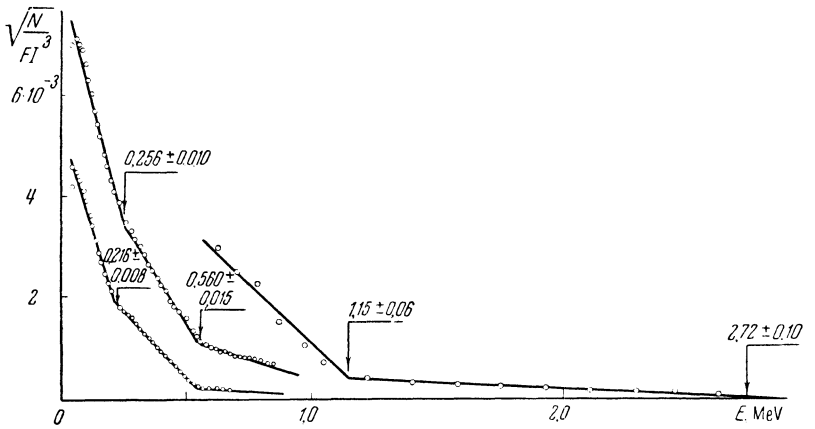

FIG. 8. Kurie plot for the curves shown in Fig. 7.

TABLE 4.

Upper spectrum limit (mev)	Observed period	Isotope
0.216±0.008	—	Ru^{103}
0.256±0.010	—	Rh^{105}
0.560±0.015	33 hrs.	Rh^{105}
1.150±0.020	4.5 hrs.	Ru^{105}

spectrum from a value of 15% to 6% (of the β-spectrum with E_β= 1.15 mev). The decay period of the hard β-spectrum in the vicinity of $E >$ mev is ~ 2.5 hours, which corresponds to the known period of Mn^{56}--2.57 hours. The period of the hard spectrum in the region $E < 2$ mev is ~ 3.5 hours, and may be caused by a Ru^{105} β-spectrum with upper limit $E_\beta \sim 2$ mev, and an intensity not exceeding a few percent. It was, however, impossible to make this assignment definite because of the remaining admixture of manganese.

For the γ-transition at 0.496 mev assigned to Ru^{103}, the conversion coefficient was obtained from the ratio of the conversion peak area to that of the continuous β-spectrum. We obtained $N_e/N_\beta \sim 0.6\%$. Comparison of this result to theory shows that the transition is $E2$, although the possibility of $M1$ cannot definitely be excluded.

3. DECAY SCHEMES

A) THE SELECTED A = 97 FAMILY

The data we have obtained on the radioactive transitions $Zr^{97} \rightarrow Nb^{97} \rightarrow Mo^{97}$ are in agreement with the decay scheme shown in Fig. 9. The data from the $Ru^{97} \rightarrow Tc^{97}$ transition shows that Tc^{97} has a level 0.219 mev above the known 0.097 isomeric level. The isomeric transitions 0.750 mev in Nb^{97} and 0.097 in Tc^{97} are usually considered as $M4$ transitions between $p_{1/2}$ and $g_{9/2}$ states.[21] Such a γ-transition follows in particular from our measured value for the conversion coefficient for 0.75 mev γ-rays. Our value of the conversion coefficient for the 0.666 mev γ-transitions implies an electric quadrupole transition $E2$.

The value of $\lg \tau f$ for the β-transition $Nb^{97} \rightarrow Mo^{97}$ with E_β = 1.18 mev is 5.51; consequently this may be considered a first order forbidden transition. For the β-transition (E_β=1.9 mev) the value of $\lg \tau f$ is 7.4, and apparently this is a 2nd or 3rd order forbidden transition.[22] If we assume that the ground state of Mo^{97} is $d_{5/2}$[22], then the above data on β and γ transitions allows the probable assignment of quantum states as shown in Fig. 9.

Ru^{103}. The results of the present investigation, as well as the observations of H. V. Forafontov on β-γ coincidences, can be arranged in the decay scheme (Fig. 10) proposed in [9,15] and improved in [17]. Reference 15 makes the ground state assignment $7/2^+$ and a $p_{1/2}$ isomeric state for Rh^{103}. However measurements of the spin and magnetic moment show that the ground state of stable Rh^{103} is $p_{1/2}$. It follows that the isomeric state should be assigned $7/2^+$. Since the 0.496 γ-transition is $E2$, the upper excited state of Rh^{103} may be assigned $3/2^+$.

---

[21] M. Goldhaber and A. W. Sunyar, Phys. Rev. 83, 906 (1951).

[22] B. S. Dzhelepov and A.V. Kurdiavtseva, J. Exptl. Theoret. Phys.(U.S.S.R.)19, 761 (1949).

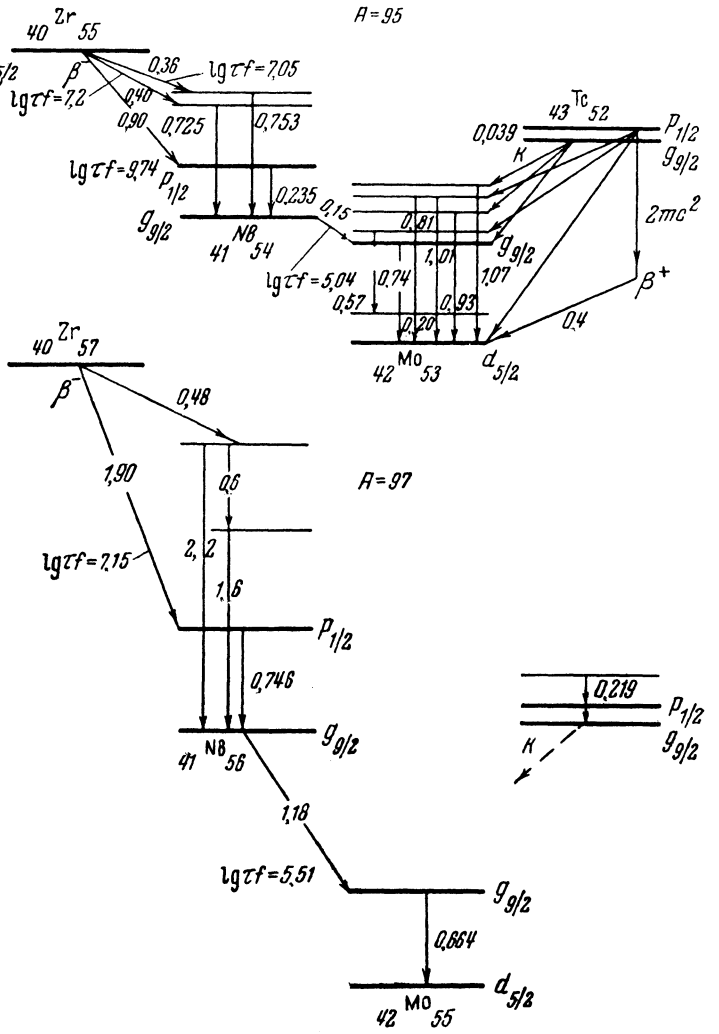

FIG. 9. Decay schemes for the selected families with A=95 and A=97. Corresponding levels for isotopes differing by two neutrons are indicated as thick lines.**

**Note added in proof. After the submission of this article, A. A. Sorokin and N. V. Forafontov carried out measurements on β--γ and γ--γ coincidences for Zr^{97} +Nb^{97}. The measurements of β--γ coincidences were made with out β-spectrometer and scintillation γ-spectrometer connected to a coincidence circuit. This allowed the identification of the partial β-spectrum with E_{β}=0.45 mev and correlated with hard γ-rays. For this β-transition lg τf=5.4. Measurements of γ--γ coincidences were made with two NaI (Tl) γ-spectrometers connected to a coincidence circuit. These showed the existence of a γ-cascade with energies 1.5 mev. and 0.6-0.8 mev, with intensity 7-10% of the total number of Zr^{97} decays. With a Nb^{97} source, chemically separated from Zr^{97} γ--γ coincidences were not observed. The data obtained is in agreement with the decay scheme shown in Fig. 9.

B) THE SELECTED A= 105 FAMILY

Our data on the decay chain $Ru^{105} \rightarrow Rh^{105} \rightarrow Pd^{105}$ show that the decay scheme (Fig. 10) proposed in Ref. 23 is essentially correct. However this scheme does not contain the low intensity γ transitions of 0.08 and $\sim$ 0.160 mev, which were observed both in Ref. 20 and by us. The isomeric 0.133 mev transition in Rh^{105} has been identified as $E3^{21}$.

[23] M. Goldhaber and R. D. Hill, Revs. Mod. Phys. **24**, 179 (1952).

4. DISCUSSION

It is interesting to compare the β and γ transitions observed in the selected A=97 family with the corresponding transitions for the family with A=95.[24-26] The scheme of these transitions is shown in Fig. 9.

We first note that the excited states of 0.664 mev in Mo^{97} and 0.740 mev in Mo^{95} differ little in energy, and that in both cases the corresponding γ-transition is $E2$. The β transitions $Nb^{97} \rightarrow Mo^{97}$ and $Nb^{95} \rightarrow Mo^{95}$ have similar values of $\lg \tau f$, 5.41 and 5.04 respectively. The isomeric transitions in Nb^{97} (0.746 mev) and in Nb^{95} (0.235 mev), although differing in energy, are both $M4$. Similarly the isomeric transitions for Tc^{97} and Tc^{95} are $M4$. The transition from the ground state of Zr^{97} to the isomeric level of Nb^{97} with an upper energy limit 1.90 mev and $\lg \tau f$= 7.4, can be compared to the partial β transition from the ground state of Zr^{95} to the isomeric state of Nb^{95}. The value of $\lg \tau f$ for this β transition with upper energy limit $\sim$ 1 mev is 9.74. This differs significantly from the value given for Zr^{97}.

The above comparison indicates that the addition of two neutrons to a nucleus, in the examined odd nuclei, makes only small changes in some nuclear states and in the correeponding radioactive transitions. This situation is quite natural in the case of single particle states of the same shell. From this point of view it seems probable that the soft β spectrum which we observed with a Zr^{97}+Nb^{97} source is caused by one or two additional β transitions in Zr^{97}, corresponding to the β transitions of Zr^{95}. The existence of a soft β spectrum for Zr^{97} is in agreement with the observation of hard γ-radiation

Let us note that the energies of the analogous transitions are not identical for the two selected families. Furthermore certain energy levels found in Mo^{95} have not yet been seen in Mo^{97}. This may possibly be explained by assuming that in the latter nucleus certain states may not be excited because the energy levels have been shifted, and consequently certain transitions have become impossible. The displacement of energy levels between two isotopes differing by two neutrons must depend, at least partly, on the change of coulomb energy due to the increase of average distance between protons

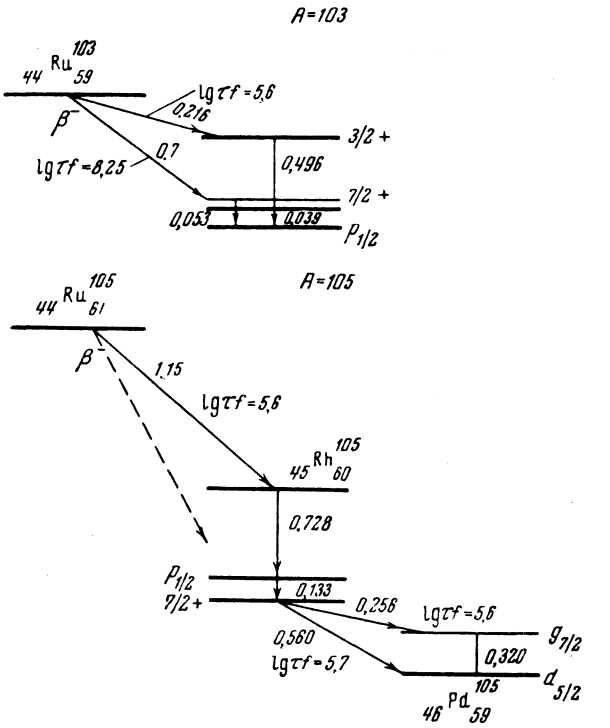

FIG. 10. Decay schemes of Ru^{103} and Ru^{105}; corresponding levels are indicated by thick lines.

From the above considerations, the decay schemes of Ru^{103} and Ru^{105}, shown in Fig. 10, must also be similar. Indeed both cases show transitions with the same $\lg \tau f$= 5.6.

The isomeric transitions of both nuclei (0.039 and 0.133 mev) are $E3$. However, the assumption that the ground and isomeric states of these nuclei have respectively the same configuration does not agree with the nature of the β transition $Rh^{105} \rightarrow Pd^{105}$.

We must therefore assume that the configurations of the isomeric and ground states of Rh^{105} are reversed. i.e., a $p_{1/2}$ isomeric state and a 7/2 + ground state. The existence of a low intensity hard β-spectrum for $\lg \tau f$ = 8.25 in Ru^{103} allows the prediction of a hard β-spectrum for Ru^{105}.

Analogous regularities are observed if two neutrons in a nucleus are replaced by two protons.[1]

In conclusion we would like to thank H. V. Forafontov and Ia. I. Gaziev who carried out a series of control measurements.

[24] V. S. Shpinel, J. Exptl. Theoret. Phys.(U.S.S.R.)21, 1370, (1951).

[25] H. Slätis and L. Zappa, Arkiv f. Fysik 6, 81 (1953).

[26] J. M. Cork, T. Le Blanc et al, Phys. Rev. 90, 579 (1953).

Translated by G. L. Gerstein
44