POSITRON DECAY OF Re^{182}

N. B. BADALOV, S. S. VASILENKO, M. G. KAGANSKIĬ, D. L. KAMINSKIĬ, and M. K. NIKITIN

A. F. Ioffe Physico-technical Institute, Academy of Sciences, U.S.S.R.

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Positron emission has been detected in the decay of the two Re^{182} isomers. For $Re^{182} \rightarrow W^{182}$ decay with the half-life $T_{1/2} = 13$ hours the intensity is $\sim 3 \times 10^{-3}$ positron per decay. An analysis of the spectrum of this isotope indicates the presence of two β^+-decay branches with end-point energies 550 and 1740 keV and intensities 0.6×10^{-3} and 1.8×10^{-3} positron per decay, respectively. The total transition energy was found to be 2860 ± 20 keV. For Re^{182m} decay ($T_{1/2} = 64$ hours) the intensity is 5×10^{-6} positron per decay. The positrons result mainly from internal conversion with pair production in the electromagnetic transitions accompanying electron capture in Re^{182}. It is shown that the absence of β^+ decay of Re^{182m} can be accounted for by K-forbiddenness.

1. INTRODUCTION

THE two known Re^{182} isomers have half-lives of 13 hours and 64 hours, respectively [1)] and decay mainly by electron capture, which has recently been investigated in [1-3]. Positron decay of the rhenium isomers has not been reported hitherto although this process is energetically feasible. According to [1] the total energy of the $Re^{182} \rightarrow W^{182}$ transition is ~ 2.5 MeV. We shall here describe an investigation of the positron spectrum in Re^{182} decay.

2. EXPERIMENTAL PROCEDURE

Re^{182} was produced by bombarding a tantalum target with 40-MeV α particles. This choice of α-particle energy was based on the fact that the maximum cross section for the $Ta^{181}(\alpha, 3n)Re^{182}$ reaction is found at $E_\alpha = 38$ MeV. When tantalum is bombarded the competing $(\alpha, 2n)$ and (α, n) reactions produce the additional isotopes Re^{183} and Re^{184}. However, these isotopes have half-lives of 70 and 38 days, respectively, and the Re^{182} spectra can be identified from their much shorter half-lives.

The targets contained 1—3% niobium impurity, so that isotopes of tungsten, molybdenum, and technetium were produced by the α-particle bombardment in addition to the rhenium isotopes. The procedure used to separate and purify the rhenium was chosen because of the possible presence of these radioactive impurities.

The irradiated (~ 0.5 g) tantalum target was dissolved in a minimum quantity of HNO_3 + HF. The tantalum was then precipitated by centrifuging with potassium hydroxide in a test tube. A few drops of 30% H_2O_2 were added to the hydroxide to prevent coprecipitation of rhenium. The combined centrifugate contained 97—99% rhenium, plus tungsten, molybdenum, and technetium impurities. The rhenium was extracted from 10—15 ml 5N KOH by two 5-ml portions of methyl ethyl ketone. [5] The organic layer for tungsten and molybdenum removal was washed twice with 5N KOH and was evaporated in a teflon cup.

Further purification and concentration of rhenium was performed by ion-exchange chromatography using AB-17×14 anionite. The distribution coefficients for rhenium and technetium in HF showed that in low HF concentrations both elements are strongly adsorbed by the anionite, whereas in high HF concentrations technetium is adsorbed considerably more weakly than rhenium. This difference in adsorption was used to purify and concentrate rhenium. The salts remaining after the evaporation of methyl ethyl ketone were dissolved in 1M HF. The solution was transferred to a polyethylene chromatographic column filled with AB-17×14 (F^-) anionite of 20—30-μ grain size. The column was washed successively with 1, 10, and 15M HF (10 drops of each concentration). Technetium and rhenium were washed out with 28M HF. Figure 1 is the chromatogram of rhenium purification. The radioactive material was collected on teflon plates and the drops were dried; the rhenium was removed from the plates by distilled ammonia and was transferred to alu-

[1)] The relative heights of the isomer energy levels are still unknown. We shall denote the 64-hour isomer by Re^{182m}.

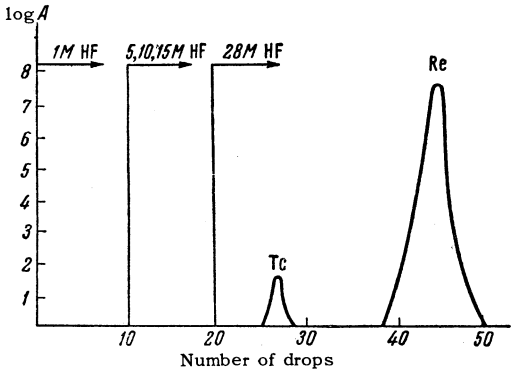

FIG. 1. Chromatogram of rhenium purification in a column filled with anionite AB – 17 × 14. A is given in pulses/min.

minum foil, which served as a backing for the β source.

The spectra were measured with a double-focusing spectrometer described in [5]. The area of the β sources was 1 × 20 mm. The spectrometer resolution was ~ 1%.

3. POSITRON SPECTRUM

The positron spectrum shown in Fig. 2 was measured about 24 hours after target irradiation and is seen to be complex. All portions of the spectrum are found to have an identical half-life of 12.5 ± 0.5 hours. This half-life, which was measured over a period of several days, proves that the observed spectrum resulted from the decay of the short-lived Re^{182} isotope for which a half-life 12.7 ± 0.2 hours is given in the literature.

A Fermi plot was used to analyze the spectrum, which was found to consist mainly of two β^+-decay branches with end-point energies 1740 ± 20 and 550 ± 20 keV (Fig. 2, curves a and b), which were separated by means of the Fermi plot. The results agree with the data in [1] for the level scheme of W^{182} (Fig. 3), according to which the positron decay of Re^{182} (spin and parity 2^-) of highest prob-

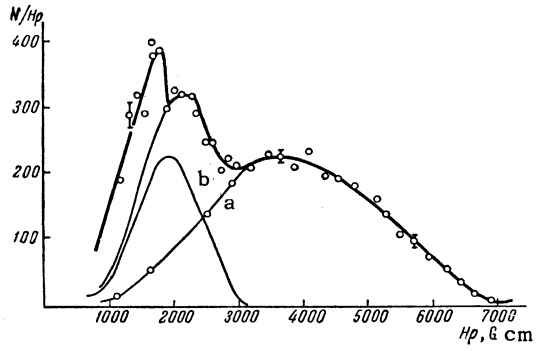

FIG. 2. Positron spectrum of Re^{182} ($T_{1/2}$ = 13 hours). a – Branch with 1740-keV end-point energy; b – Branch with 550-keV end-point energy.

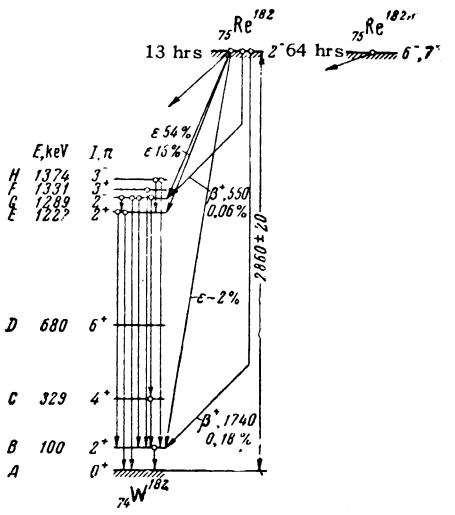

FIG. 3. Part of Re^{182} decay scheme, including the most intense transitions and supplemented by data obtained in the present work.

ability goes to levels G and B. The corresponding difference between the β^+ end-point energies would be 1189 keV, in good agreement with our data.

Figure 2 shows that the soft portion of the positron spectrum considerably exceeds the sum of the two β branches. This excess probably resulted from β scattering in the source. We computed the thickness of the sources to be a few milligrams per cm^2. In addition, we cannot exclude the possible presence of β^+ branches having low end-point energies.

The Re^{182} β^+-decay intensity was determined by comparing the area of the positron spectrum and of the internal-conversion electron spectrum from the 1122-keV EB transition. This transition was selected for analysis because its K-conversion coefficient has been measured [6] and because its intensity in Re^{182} decay can be determined from available data. [1] This makes it possible to compute the number of K electrons per Re^{182} decay and therefore to determine the positron decay intensity I_{β^+}. We thus have

$$I_{\beta+} = (S_{\beta+}/S_{eK})\,\eta\alpha_K, \qquad (1)$$

where S_{β^+} and S_{eK} are the areas of the positron spectrum and K-conversion line obtained under identical conditions; η is the fraction of 1122-keV transitions per single Re^{182} decay event; $\alpha_K = 5 \times 10^{-3}$ is the K-conversion coefficient. [6] From the data in [1] we calculated $\eta = 0.23$ quantum per decay. In determining S_{eK} we took into account the fact that EB transitions accompany the decay of both Re^{182} ($T_{1/2}$ = 13 hours) and Re^{182m}. In order to discriminate the fraction due to Re^{182m}

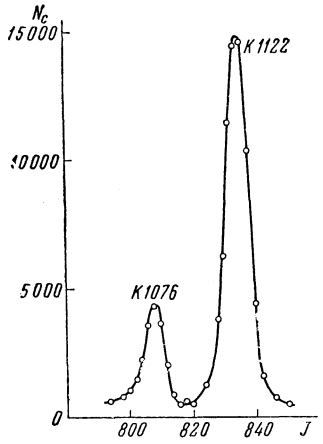

FIG. 4. Re^{182} and Re^{182m} conversion lines used to calculate Re^{182} positron decay intensity. N_c – number of coincidences per min; J – current in scale divisions.

decay we measured simultaneously the 1122-keV and 1076-keV K lines (Fig. 4).

It has been established [1,2] that the 1076-keV transition is associated only with Re^{182m} decay. Therefore the two K lines were measured after a period of time which was long enough so that the 13-hour isomer in the source could be neglected. From the intensity ratio of these conversion lines we were able to calculate the fraction of the EB conversion line, shown in Fig. 4, that resulted from Re^{182m} decay; the remainder of the K line was due to the decay of the 13-hour isomer. It was found that for a source investigated 24 hours after irradiation about 60% of the 1122-keV K line resulted from decay of the 13-hour isomer and 40% from decay of the 64-hour isomer.

The intensity measurements yielded the following results. The probability of β^+-decay with 1740-keV end-point energy is 1.8×10^{-3} positron per decay. For the 550-keV endpoint the probability is 0.6×10^{-3} positron per decay. The total emission in Re^{182} decay is $(2.8 \pm 0.8) \times 10^{-3}$ positron per decay.

On the basis of the foregoing intensities we obtained $\log \tau f = 8.3$ for $E_0 = 1740$ keV and $\log \tau f = 6.5$ for $E_0 = 550$ keV. These values represent first-forbidden and allowed β transitions and are consistent with the spin and parity change in Re^{182} decay (Fig. 3). We note that in [1] 54% probability was obtained for electron capture in Re^{182} with a transition to the G level. When we determine the probability of K capture from our data on the intensity of positron decay to this level we obtain $\epsilon_K \approx 40\%$, in agreement with Feenberg and Trigg.[7] Very good agreement is thus seen with [1]. Using the computations in [7] to calculate the probability of K-capture leading to level B (a first-forbidden β process), we obtain ~ 2% for the relative intensity of this process.

In accordance with the proposed scheme of Re^{182} β^+ decay the total $Re^{182} \rightarrow W^{182}$ transition energy was determined to be 2860 ± 20 keV. We note for comparison that a very rough estimate of this energy from the probability of electron capture leading to high-lying levels has indicated 2000 keV [2] or 2500 keV. [1]

The very first measurements showed that the intensity of positron emission in Re^{182m} decay ($T_{1/2}$ = 64 hours) is many times smaller than in Re^{182} decay ($T_{1/2}$ = 13 hours). In order to reduce to insignificance the contribution of positrons from Re^{182} decay, measurements were obtained 7–12 days after irradiation of the source. Figure 5 shows the positron spectrum measured 10 days after the bombardment of the tantalum target. The analysis shows that the spectrum having a 60 ± 10-hr half-live is accompanied by another positron spectrum having a half-life of several times ten days (curve 2). It is our hypothesis that the latter spectrum represents the positron decay of the Re^{184} present in the source.

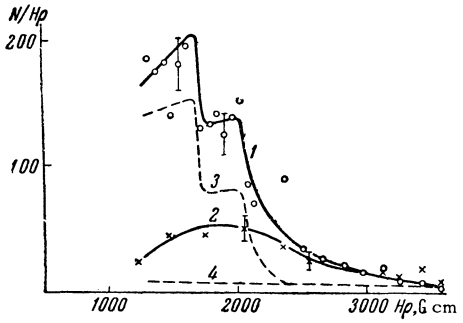

FIG. 5. Positron spectrum measured following the decay of 13-hour Re^{182}. Curve 1 – 10 days after irradiation; curve 2 – 20 days after irradiation; curve 3 – Re^{182m} positron spectrum; curve 4 – spectrometer background.

Subtracting the latter spectrum from the total spectrum (curve 1), we obtained the pure positron spectrum of Re^{182m} (curve 3), whose intensity was determined by the procedure used for Re^{182}. It was found that 5×10^{-6} positron is produced per Re^{182m} decay event, which is three orders of magnitude smaller than in Re^{182} decay. The shape of the positron spectrum shows that in Re^{182m} decay positrons are formed mainly as a result of the internal conversion of γ rays with pair production.

It is interesting to compare the Re^{182m} positron spectrum with the positron spectrum accompanying $Ta^{182} \rightarrow W^{182}$ decay. [8] In this case the positrons also result from internal conversion with pair pro-

duction. Since the most intense γ quanta having energies greater than $2mc^2$ are identical in both cases, the positron spectra should have some common features. Indeed, the steep decline at $H\rho \approx 1700$ G-cm is common to both spectra. The total numbers of positrons from Ta^{182} and Re^{182m} decays are comparable: 3×10^{-6} and 5×10^{-6} positron per decay, respectively. A somewhat higher positron intensity in Re^{182m} decay (and the existence of a steep decline at $H\rho > 2000$ G-cm) evidently can be attributed to the fact that γ rays with $E_\gamma > 1.3$ MeV in Re^{182m} decay are much more intense than in Ta^{182} decay.

It is interesting to note the absence of Re^{182m} β^+ decay leading to the D level of W^{182} (Fig. 3). The end-point energy of this positron spectrum would be ~ 1 MeV. Taking 2×10^{-6} positron per decay as the upper intensity limit of this process, we obtain $\log \tau f > 11.5$, which is extremely large for a first-forbidden process (ordinarily $\log \tau f = 7-8$). Additional forbiddenness appears to be involved. An analysis of the Re^{182m} decay scheme [1] shows that electron capture occurs mainly at the level of rotational bands corresponding to $K = 3, 4$, and 5. Thus, if it is assumed that the 6^- (or 7^-) state of Re^{182m} corresponds to $K = 3$ or 4, the absence of β^+ decay to the D level is due to K-forbiddenness. (The D level belongs to the ground-state rotational band, $K = 0$). We note that electron capture leading to the D level has also not been observed up to the present time.

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