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Abstract

Full Text

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INVESTIGATION OF NUCLEAR ISOMERISM IN Hf^{180m}

(Presented by Academician I. V. Kurchatov, 17 XI 1956)

The system of levels in Hf^{180} with excitation energies of 93.3 keV, 309.3 keV, 641.7 keV, 1085.3 keV and with spins 0+, 2+, 4+, 6+, 8+ ([1]) is rotational and corresponds to the ideas developed recently concerning the collective motion of nucleons in nuclei ([2]).

Above the energy level with spin 8+ there is a metastable level with a total excitation energy of 1142.9 keV and a half-life of 5.5 hr. The transition from this level to the 8+ level ($E_\gamma = 57.6$ keV), according to the data on the lifetime and the coefficients of internal electron conversion, was identified as a transition of type M3 ([1]). However, there are indications that such an identification is not correct ([3]).

In the present work, in order to establish the multipolarity of the radiation, measurements were made of the coefficient of internal conversion on the L shell of the atoms for the isomeric transition with energy 57.6 keV in Hf^{180m}.

The electron spectra were measured on a β-spectrometer with electron focusing through an angle $\pi\sqrt{2}$.

Fig. 1. Electron spectrum of Hf^{180m}, Hf^{181}, and Ta^{181} in the energy interval from 20 keV to 70 keV. The abscissa axis gives the current in the electromagnet winding.

To obtain radioactive sources, a layer of hafnium oxide 0.22 mg/cm^2 thick was deposited by evaporation in vacuum onto aluminum foil 4 μ thick, and then the deposited oxide was irradiated with neutrons in a reactor for 18 hr. The size of the sources was 17×1 mm^2.

Fig. 2. Spectrum of γ-rays of Hf^{180m} and Ta^{181} in the energy interval from 30 keV to 160 keV

Figure 2: Fig. 2. Spectrum of γ-rays of Hf^{180m} and Ta^{181} in the energy interval from 30 keV to 160 keV

Figure 1 shows the electron spectrum in the energy interval from 20 to 70 keV. Since the decay of Hf^{180m} proceeds according to a cascade scheme, the results of measurements of the electron spectrum shown in Fig. 1 make it possible to determine α_L for the transition with energy 57.6 keV. From the ratio of the areas of the conversion lines corresponding to the transitions of 57.6 keV and 93.3 keV (taking into account corrections for radioactive decay, for the energy interval, for self-absorption of electrons in the source and for absorption in the counter film) and the calculated data for the conversion coefficients on the K and L shells ([3], [4]) for the transition with energy 93.3 keV

($\alpha_K = 1.1$ and $\alpha_L = 1.7$), the internal-conversion coefficient on the L-shell for the transition with energy 57.6 keV can be determined. For α_L a value of 0.19 ± 0.10 was obtained.

This same coefficient α_L was also determined by comparing the numbers of L-electrons of internal conversion and γ-quanta associated with the 57.6-keV transition in Hf^{180m}. Since in these experiments different samples were used for measurements on the β- and γ-spectrometers, the conversion coefficient was determined by using the radiation of Ta^{181}. The number of L-electrons of internal conversion of the 57.6-keV transition in Hf^{180m} was compared with the number of K-electrons of internal conversion of the 133-keV transition in Ta^{181} in one sample ($0.22\,\mathrm{mg/cm^2}$), and the number of 57.6-keV γ-quanta with the number of 133-keV γ-quanta in another ($\sim 2\,\mathrm{mg/cm^2}$). In this procedure the value of α_K already measured for the 133-keV transition in Ta^{181}, equal to 0.48 ± 0.02 ([5]), was used.

Ta^{181} is formed as a result of the β-decay of Hf^{181} ($T_{1/2} = 46$ days); Hf^{181} is obtained together with Hf^{180m} in samples of natural isotopic composition by means of the (n, γ)-reaction. According to our measurements, the formation cross section of Hf^{180m} is ~ 0.6 barn. The internal-conversion coefficient for this transition ($E_\gamma = 133$ keV) was measured by us by comparing the number of conversion electrons on the K-shell with the number of electrons of the β-spectrum. The measurements carried out for α_K gave a value of 0.5, in agreement with work ([5]).

Fig. 2. Spectrum of γ-rays of Hf^{180m} and Ta^{181} in the energy interval from 30 keV to 160 keV

From the internal-conversion electron spectrum shown in Fig. 1, the ratio of the number of conversion electrons from the L-shell of Hf for the transition with energy 57.6 keV to the number of conversion electrons from the K-shell of Ta for the transition with energy 133 keV was determined for several time values.

With the aid of a scintillation spectrometer, the spectrum of γ-rays of Hf^{180m} and Ta^{181} was measured in the energy interval from 30 keV to 160 keV (Fig. 2). Owing to the insufficient resolving power of the γ-spectrometer, characteristic x-radiation associated with all transitions in Hf^{180} and Ta^{181} is superposed on the investigated γ-radiation with energy 57.6 keV of Hf^{180m}; the γ-line with energy 136 keV of Ta^{181} is superposed on the γ-line with energy 133 keV. In addition, γ-rays with energy 93.3 keV of Hf^{180} are also present in the γ-ray spectrum. The number of γ-quanta in the 57.6-keV maximum associated with the decay of Hf^{180m} was determined by subtracting the γ-ray spectrum of Ta^{181} (Fig. 2, curve *b*), measured after the decay of Hf^{180m}, from the total γ-spectrum of Hf^{180m} and Ta^{181} (Fig. 2, curve *a*).

From the γ-ray spectrum shown in Fig. 2, the ratio of the number of γ-quanta with energy 57.6 keV of Hf^{180m} to the number of γ-quanta with energy 133 keV of Ta^{181} was determined. In doing so, the calculated values of the internal-conversion coefficients ([4]) for E2 transitions in

^{180}Hf–$\alpha_K(93.3\text{ keV}) = 1.1$, $\alpha_K(216\text{ keV}) = 0.14$, $\alpha_K(332.4\text{ keV}) = 0.04$, $\alpha_K(443.6\text{ keV}) = 0.02$, the fluorescence yield for the K shell of hafnium ($\omega = 0.94$) ([3]), and also the fraction of γ quanta with energy 136 keV present in the 133-keV γ line ([5]) was taken into account. This determination was made for the same time values as the ratio of the numbers of conversion electrons for these transitions.

As a result of the measurements and calculations carried out, for the internal-conversion coefficient on the L shell for the transition with energy 57.6 keV in Hf^{180m} a value of 0.23 ± 0.15 was obtained. This value agrees, within the measurement errors, with the value of α_L obtained by the first method.

For a more detailed investigation of the decay scheme of Hf^{180m}, experiments were performed to search for a transition from the level with excitation energy 1142.9 keV to the level with excitation energy 641.7 keV (spin 6+). The energy of this transition should be 501.2 keV. The search for this transition was carried out with a scintillation γ spectrometer with a 20-channel amplitude analyzer. The spectrum of γ rays obtained as a result of the measurements is shown in Fig. 3. According to Fig. 4, the number of transitions with energy 443.6 keV is equal to the number of transitions with energy 57.6 keV. Consequently, the ratio of the numbers of γ quanta with energies 443.6 and 501.2 keV, taking into account the small internal-conversion coefficients for these transitions, gives the ratio of the probabilities of transitions with energies 501.2 and 57.6 keV. From comparison of the areas of the γ-spectrum lines shown in Fig. 3, the ratio of the probabilities of these two transitions is obtained as 0.15 ± 0.05.

Fig. 3. Spectrum of γ rays of Hf^{180m} in the energy interval from 400 keV to 550 keV, obtained by subtracting the γ-ray spectrum of Ta^{181} from the summed spectrum of Ta^{181} and Hf^{180m}

Fig. 3. Spectrum of γ rays of Hf^{180m} in the energy interval from 400 keV to 550 keV, obtained by subtracting the γ-ray spectrum of Ta^{181} from the summed spectrum of Ta^{181} and Hf^{180m}

Figure 3: Fig. 3. Spectrum of γ rays of Hf^{180m} in the energy interval from 400 keV to 550 keV, obtained by subtracting the γ-ray spectrum of Ta^{181} from the summed spectrum of Ta^{181} and Hf^{180m}

In calculating the internal-conversion coefficient α_L for the transition with energy 57.6 keV, in connection with the data given above, it is necessary to introduce a correction for the presence of a parallel transition with energy 501.2 keV. The value of the internal-conversion coefficient is obtained as 0.22 ± 0.10.

Comparison of the obtained value of the internal-conversion coefficient with those calculated from tables ([3]), by far extrapolation for the energy 57.6 keV and $Z = 72$ ($\alpha_{1L} = 0.23$, $\alpha_{2L} = 10$, $\alpha_{3L} = 500$; $\beta_{1L} = 3.3$; $\beta_{2L} = 90$, $\beta_{3L} = 1600$), leads to the conclusion that the transition with energy 57.6 keV is of type E1, and the level with total excitation energy 1142.9 keV has spin 9−. Comparison of the preliminary experimental value of the relative conversion coefficients on the L subshells (see Fig. 1) with those calculated from tables ([3]) also indicates an E1 transition.

The lifetime, calculated from formulas for single-particle transitions ([6]), for electric dipole radiation with energy 57.6 keV should be of the order of 10^{-12} sec. It should be noted that this value differs by $\sim 10^{16}$ times from the experimentally observed lifetime for Hf^{180m}. For an electric octupole transition with energy

501.2 keV, the calculated lifetime is of the order of 10^{-4} sec.; the difference from the experimental value is by a factor of $\sim 10^9$.

It might be supposed that such a large discrepancy in the experimental lifetime values is due to insufficient investigation of the decay scheme of Hf^{180m}. For example, above the level with an excitation energy of 1142.9 keV there may be a low-excited level that has a half-life of 5.5 hours, and an E1 transition with an energy of 57.6 keV is in cascade with it.

The transition from the low-excited level should be strongly converted. We carried out preliminary experiments to search for this level in the electron-energy interval from 5 keV to 50 keV, and the corresponding conversion lines could not be detected.

Comparison of $\tau_{\text{exp.}}$ and $\tau_{\text{theor.}}$ for a large number of isomeric nuclei gives, for the ratio $\tau_{\gamma\,\text{exp.}}/\tau_{\gamma\,\text{theor.}}$, a value not exceeding 10^3 (7). In the case of Hf^{180m} there is an anomalously large value of the ratio $\tau_{\text{exp.}}$ to $\tau_{\text{theor.}}$, which indicates an additional hindrance for the probability of isomeric transitions with energies 57.6 and 501.2 keV. The existence of such an additional hindrance (K-hindrance) was indicated in work (3). This additional hindrance is connected with the fact

Fig. 4. Decay scheme of Hf^{180m}

Figure 4: Fig. 4. Decay scheme of Hf^{180m}

that the 9− level with excitation energy 1142.9 keV is apparently the first level of a new system of rotational levels.

The transition from this level ($K = 9$) to levels with spins 8+ and 6+ ($K = 0$) is connected with a large change in the quantum number K, which leads to a long lifetime for the E1 and E3 transitions in Hf^{180m}.

Fig. 4. Decay scheme of Hf^{180m}

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Note: Figure translations are in progress. See original paper for figures.