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Abstract

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R. A. Demirkhanov, V. V. Dorokhov, M. I. Dzkuya

Masses of the Isotopes of Lutetium, Ytterbium, and Thulium

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There are few data in the literature on precise measurements of the masses of isotopes of the rare-earth elements. In work (^{3}) for the region $169 \leq A \leq 176$, only one value is given, with a very large error, namely for Lu^{176}, $M = 175.997370 \pm 460$.

The most complete work for this mass range is (^{1}), in which a large number of "isotopic" doublets from gadolinium to gold were measured. The "binding" to the masses of substandard elements was carried out by measuring one or two doublets formed by ions of the element being measured and of an organic compound consisting of atoms H, C, N, and O. Consequently, in each pleiad of isotopes of any element an independently measured substandard was introduced, relative to which all masses of the given pleiad were calculated. The mass spectrometer used for measuring the masses did not resolve a fragment containing the isotope C^{13} from the principal fragments of the organic compound. Therefore the authors had to select such organic compounds whose fragments would not contain a C^{13} satellite. The presence of a small amount of an impurity fragment with C^{13} was corrected by applying a correction to the final result. As the authors state, hydrocarbon ions having small concentrations of C^{13} were found, at least for one mass number of almost every element in the region considered. However, in practice the correction was introduced where the mass-spectrometric data "did not agree" with results from other sources (nuclear reactions, α- and β-decay, etc.), and the magnitude of the correction was quite arbitrary and was introduced "in the manner of introducing the minimum number of arbitrary adjustments."

Thus, of 23 reference doublets, 12 were corrected by amounts equal to or exceeding the experimental error, and 3 doublets from this number were rejected. As a result of such agreements, the authors recommend as the mean error over the entire range of measured masses a value of $150\text{–}200 \cdot 10^{-6}$ m.u. The authors indicate that "the errors may be regarded as standard. It is determined that the error limit is three times the indicated error. It is considered that errors greater than $1 \cdot 10^{-3}$ m.u. should not occur." Taking into account the possible magnitude of the error, as well as the fact that 3 reference doublets were rejected by the authors as incompatible with nuclear data, one may conclude that the authors are not certain of the magnitude and accuracy of the correction which they introduce for the presence of a small amount of C^{13} in the organic fragment.

The aim of the present work was to obtain more accurate mass values for isotopes in the region of the rare-earth elements. The mass measurements were carried out on a mass spectrograph with double focusing (^{2}). As the basic data we used doublets formed by ions of the element being measured and by an organic compound consisting of atoms H^1, C^{12}, C^{13}, N^{14}, and O^{16}. In the measurements, chlorides of rare-earth elements obtained from oxides were used. The amount of impurities in the materials used did not exceed 0.1%. In our case the impurity of a fragment containing the isotope C^{13} was resolved; therefore no corrections for the content of any amounts of C^{13} had to be made. Moreover, where the fragment containing C^{13} had sufficient intensity, it was used as one of the doublets for measuring the mass of the unknown isotope. In the present ...

in this work the isotope mass was in all cases calculated from several independent doublets of different organic composition. Where possible, doublets were measured that connected the unknown mass with the masses of previously measured isotopes. In addition, the quality of the measurements was checked by measuring so-called "isotopic" doublets, i.e., doublets formed by two neighboring isotopes of the given element with a mass difference of approximately 1 mass unit. The isotope-mass values were calculated taking into account the "weight" of the measurement. The mass value of any isotope depends neither directly nor indirectly on the measurement of the masses of other isotopes, except for the substandards. In all cases the instrumental dispersion was calculated by using fragments of organic compounds differing by 1 hydrogen mass. This ensured a relative accuracy of the dispersion calculation over the entire measured mass range of $\sim 10^{-5}$. The mean relative accuracy obtained in the present work, taking into account the "internal" consistency of the results, was $\Delta M/M = (2 \div 5) \cdot 10^{-7}$, which amounts to 30-80 keV.

As substandards we used the masses of H^1, C^{12}, C^{13}, N^{14}, and O^{16}*, given in (^{3}). In all, in the present work 24 doublets were measured, and with their aid 10 masses of stable isotopes of lutetium, ytterbium, and thulium were calculated. The doublet values and the mass values are given in Table 1.

Table 1

Mass A	Doublet	ΔM, 10^{-3} m.u.	Isotope mass, m.u.	Mean mass value, m.u.*(for O^{16}, $M = 16$)	Mass-spectrometric data, m.u. (^{1})	Mean mass value, m.u.*(for C^{12}, $M = 12$)
169	$C_{12}H_{11}N - Tu^{169}$ $Hg^{204} - Tu^{169}Cl^{35}$	154, 972 ± 0, 061 70, 446 ± 0, 098	168, 987936 ± 62 168, 987911 ± 100	168, 987929 ± 30	168, 988056 ± 50 168, 988059 ± 150 *	168, 934220 ± 30
168	$C_{12}H_{10}N - Ib^{168}$ $Ib^{170} - Ib^{168}$	147, 055 ± 0, 103 2001, 543 ± 0, 200	167, 987707 ± 133 167, 987635 ± 202	167, 987692 ± 30	167, 987299 ± 150 ***	167, 934300 ± 30
170	$C_{12}H_{12}N - Ib^{170}$ $C_{11}H_8ON - Ib^{170}$ $C_{11}C^{13}H_{11}N - Ib^{170}$	161, 882 ± 0, 043 125, 406 ± 0, 150 157, 374 ± 0, 210	169, 989171 ± 63 169, 989250 ± 150 169, 989207 ± 210	169, 989178 ± 30	169, 988816 ± 70 169, 988926 ± 130 *	169, 935150 ± 30
171	$C_{10}H_7ON_2 - Ib^{171}$ $C_{11}C^{13}H_{12}N - Ib^{171}$ $Ib^{171} - Ib^{170}$	119, 676 ± 0, 270 164, 195 ± 0, 080 1001, 533 ± 0, 060	170, 990546 ± 270 170, 990533 ± 80 170, 990711 ± 65	170, 990637 ± 40	170, 990800 ± 120 ***	170, 936290 ± 40
172	$C_{10}H_6O_2N - Ib^{172}$ $Ib^{172} - Ib^{171}$ $Ib^{173} - Ib^{172}$	103, 591 ± 0, 060 1000, 265 ± 0, 226 1002, 293 ± 0, 118	171, 990960 ± 65 171, 990902 ± 230 171, 990647 ± 127	171, 990903 ± 70	171, 991187 ± 120 ***	171, 936265 ± 40
173	$C_{14}H_5 - Ib^{173}$ $C_{10}H_7O_2N - Ib^{173}$ $Ib^{174} - Ib^{173}$	101, 062 ± 0, 067 109, 842 ± 0, 063 1001, 022 ± 0, 050	172, 993076 ± 67 172, 992848 ± 63 172, 992922 ± 51	172, 992940 ± 50	172, 993354 ± 110 ***	172, 937960 ± 50
174	$C_{14}H_6 - Ib^{174}$ $Ib^{176} - Ib^{174}$	108, 342 ± 0, 038 2004, 634 ± 0, 050	173, 993942 ± 38 173, 993956 ± 100	173, 993944 ± 30	173, 994378 ± 40 173, 994320 ± 100 *	173, 938645 ± 30
176	$C_{14}H_8 - Ib^{176}$ $C_{13}H_6N - Ib^{176}$	120, 018 ± 0, 046 107, 223 ± 0, 109	175, 998557 ± 46 175, 998772 ± 109	175, 998590 ± 90	175, 998710 ± 70 175, 998662 ± 130 *	175, 942655 ± 90
175	$C_{14}H_7 - Lu^{175}$ $C_{13}C^{13}H_6 - Lu^{175}$	114, 157 ± 0, 037 109, 798 ± 0, 036	174, 996272 ± 37 174, 996159 ± 36	174, 996214 ± 40	174, 997151 ± 160 174, 996534 ± 160 *	174, 940600 ± 40

176	$C_{14}H_8-Lu^{176}$ $Lu^{176}-Lu^{175}$	120,000± 0,049 1002,301± 0,060	175,998575± 50 175,998515± 70	175,998556± 30	175,998790± 150 ***	175,942620± 30

* The errors in the mass values refer to the last significant digits.
** Value obtained from a doublet using an organic compound.
*** Accepted agreed values.

Lutetium. In measuring the masses of lutetium isotopes, the reference standards used were anthracene fragments ($C_{14}H_{10}, M = 178$) with masses 175 ($C_{14}H_7$) and 176 ($C_{14}H_8$). At mass 175 a triplet was obtained, formed by Lu^{175} ions and anthracene fragments $C_{14}H_7$ and $C_{13}C^{13}H_6$. The obtained lutetium mass values were checked by measuring an "isotopic" doublet.

Ytterbium. The masses of ytterbium isotopes were measured both from doublets with standards of different organic composition and from "isotopic"doublets with a difference of one or two mass units. For forming doublets at the masses of Yb isotopes ($M = 176–168$) and calculating the dispersion coefficient— organic compounds were used: anthracene ($C_{14}H_{10}$, $M = 178$), α-nitroso-β-naphthol ($C_{10}H_7O_2N$, $M = 173$), hydrazobenzene ($C_{12}H_{12}N_2$, $M = 184$), and their fragments.

Thulium. In measuring the mass of the thulium isotope, diphenylamine ($C_{12}H_{11}N$, $M = 169$) was used as the standard. This organic compound gives the fragments needed for an accurate calculation of the dispersion. The value of the mass of the isotope Tu^{169} was checked by measuring the doublet formed by $Tu^{169}Cl^{35}$ and Hg^{204}. In this case the dispersion was calculated with the aid of the ions $Hg^{204}H$ and $Hg^{202}H$. Using the most accurate of the presently available values of the masses Hg^{204} (4) and Cl^{35} (5), one can obtain the mass of Tu^{169}.

Fig. 1. Mass differences according to the data of work (1) (M_1) and according to our data (M)

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Comparison of the mass values measured in the present work with the "adjusted" analogous data of work (1) shows that there are no significant discrepancies in the values of the measured masses. The largest discrepancies ($\sim 0.4 \cdot 10^{-3}$ mass units) are covered by the maximum measurement error recommended by the authors of work (1). In most cases the difference between the data of these works is within, or only slightly exceeds, the total statistical error of the measurements.

* Throughout the work the indices H, C, N, and O correspond to the isotopes of maximum abundance, i.e., H^1, C^{12}, N^{14}, and O^{16}.

Figure 1 shows the differences of the absolute values of isotope masses given in work (1) and obtained in the present work, in those cases where direct measurements and "adjusted" values are available. The results of the present work, with the corresponding error, are taken as the baseline. The horizontal dashed lines correspond to the mass values obtained from doublets with organic compounds, and the solid lines to the adopted "adjusted" values. The vertical lines show the total error of the difference under consideration. As can be seen, all corrections introduced by the authors of work (1) into the experimental data obtained by them improve the agreement between the data of the present work and their data (see, for example, Ib^{170}, Lu^{175}, etc.). However, in a number of cases (Ib^{174}, Lu^{175}), the correction, in our opinion, should be more substantial. Taking into account the different methods of measuring isotope masses in work (1) and in the present work, such agreement of the results may be considered entirely satisfactory, and the values of the measured doublets and the isotope masses calculated from them sufficiently reliable.

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