Brief Reports

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Half-life and decay scheme of ^{138}La

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The half-life and decay scheme of ^{138}La have been reinvestigated using a large-volume Ge(Li) detector. The partial half-lives for electron-capture decay and β^- decay have been determined to be $(1.58 \pm 0.02) \times 10^{11}$ yr and $(3.19 \pm 0.22) \times 10^{11}$ yr, respectively. The resulting total ^{138}La half-life is $(1.06 \pm 0.03) \times 10^{11}$ yr. The results of the present work are compared with those of previous investigations.

[RADIOACTIVITY ^{138}La: Measured I_γ, $T_{1/2}$, logft. Ge(Li) detector.]

^{138}La is one of the long-lived naturally occurring radioisotopes that survive from the era of nucleosynthesis. Its production in nature is attributed to the still poorly understood p process.[1] During the past thirty years, the half-life and decay scheme of ^{138}La have been studied a number of times with widely scattered results.[2–8] Most of these investigations have involved the use of NaI detectors. The relatively poor energy resolution of such detectors may have been a major reason for the large discrepancies in the previous measurements. With the availability of large-volume Ge(Li) detectors, low-level γ-ray counting can now be performed with very high energy resolution and reasonable detection efficiency. In an attempt to clarify the situation regarding the decay of ^{138}La, a large Ge(Li) detector was used in two separate experiments designed to determine the half-life and decay scheme of ^{138}La.

Previous decay studies[2–9] have shown that ^{138}La electron-capture decays to the 2^+ 1435.9-keV first excited state of ^{138}Ba and β^- decays to the 2^+ 788.7-keV first excited state of ^{138}Ce. These two levels subsequently decay electromagnetically emitting 1435.9- and 788.7-keV γ rays, respectively. Thus, measurements of the yields of these two γ rays from a known amount of ^{138}La during a specified time interval enable both the partial and total ^{138}La half-lives to be determined. In the present work, two types of measurements of these γ-ray yields were made. The first set of measurements was designed to enable the determination of the ^{138}La half-lives relative to the well-known ^{40}K half-life. In the second type of measurement, the ^{138}La half-lives were determined in an absolute sense.

For the first set of measurements, a "mixed" sample of natural La_2O_3 (0.089% ^{138}La) (Ref. 10) and natural KCl (0.0117% ^{40}K) (Ref. 10) was prepared. 40.02 g of 99.999% pure La_2O_3 and 21.40 g of 99.995% pure KCl were thoroughly mixed together in a 65-ml plastic vial. The vial containing this La_2O_3 and KCl mixture was then positioned against the front face of a well-shielded 135-cm^3 coaxial Ge(Li) detector. γ-ray energy spectra were accumulated in 1024 channels with the use of a multichannel analyzer. The sample was counted in three separate 10^5 sec runs. Following each "sample-in" run, the sample was removed, and a 10^5 sec background run was performed.

The second method employed in the study of ^{138}La decay involved the use of a "point" source. 235 mg of 99.999% pure La_2O_3 were pressed into a 1 cm diam pellet, sealed in a 0.3 cm thick plastic planchet, and mounted directly on the face of the same well-shielded Ge(Li) detector used in the measurements of the mixed source. This sample was then counted for 4×10^5 sec.

The high-energy portion of the background-corrected γ-ray spectrum observed in one 10^5 sec counting period from the mixed La_2O_3 and KCl sample is shown in Fig. 1. The 788.7- and 1435.9-keV γ rays produced by the decay of ^{138}La are clearly seen along with the 1460.8-keV γ ray from the decay of the ^{40}K contained in the vial. Also seen are several peaks attributable to the decay of ^{211}Pb. The same

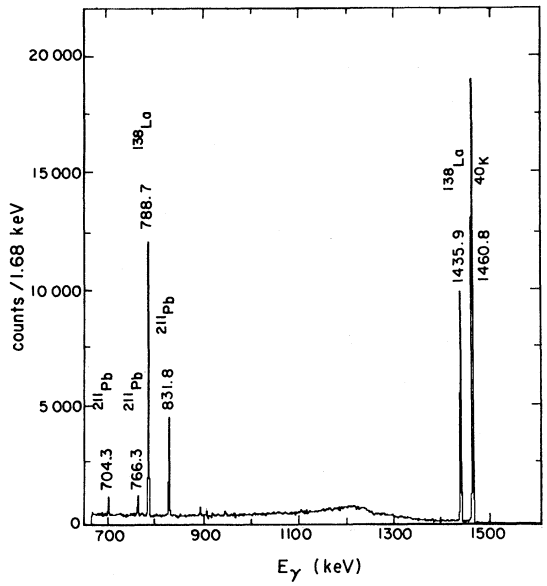

FIG. 1. High energy portion of the background-corrected γ-ray spectrum observed in one 10^5 sec counting period from the mixed La_2O_3 and KCl sample. All γ-ray energies are taken from Ref. 10.

^{211}Pb γ rays were also observed in the point source spectrum.

The presence of ^{211}Pb contaminant lines in the γ-ray spectrum from a La sample is not unexpected. These lines were observed by Ellis and Hall[7] in their study of ^{138}La. Furthermore, in a study of radioactivities found in rare earth compounds, Grench and Buchanan[11] found that ^{211}Pb is one of thirteen ^{235}U decay daughters that occur naturally even in highly purified La compounds. These authors pointed out that uranium and thorium are commonly found in lanthanum-bearing ores. One of the ^{235}U daughters that therefore also would be present in the ore is ^{227}Ac. Lanthanum and actinium, which are located in the same column of the periodic table of the elements, have extremely similar chemistry, and thus their separation from one another is very difficult. The alpha and beta decays from ^{227}Ac lead to ^{211}Pb (and, ultimately, to the stable isotope ^{207}Pb). The presence of the 704.3-, 766.4-, and 831.8-keV ^{211}Pb decay γ rays very near the 788.7-keV ^{138}La γ ray may explain why earlier investigators using NaI detectors not only obtained too high an energy for the 788.7-keV ^{138}La γ ray, but also an incorrect value for the partial half-life for β^- decay.

The background-corrected yields of the 788.7- and 1435.9-keV γ rays were extracted from our data. In addition, for the mixed source runs, the background-corrected yield of the 1460.8-keV ^{40}K γ ray was also determined. Photopeak detector efficiencies were determined using accurately calibrated (5% uncertainties) standard γ-ray sources. These sources were also used to determine the relative attenuation by self-absorption of the 788.7-keV γ ray compared to that of the 1460.8-keV γ ray in the large-volume mixed source. This was done by measuring the relative transmissions of γ rays of several different energies through an empty vial and through the vial containing the mixed source. The results of these measurements were then corrected for the finite size of the mixed sample to obtain the self-absorption factor.

For the mixed source data, the ^{138}La half-lives were determined by comparing the yields of the 788.7- and 1435.9-keV ^{138}La γ rays to the yield of the 1460.8-keV ^{40}K γ ray. Efficiency measurements indicated that the photopeak detection efficiencies at 788.7 and 1435.9 keV were, respectively, 2.071 and 1.019 times that at 1460.8 keV. Also, the attenuation measurements showed that the 788.7-keV yield should be multiplied by a factor of 1.085 to correct for the differential self-absorption of this line compared to the 1460.8-keV ^{40}K line. The 1435.9-keV ^{138}La γ ray is so close in energy to the ^{40}K γ ray that no such attenuation correction was required. The efficiency-and attenuation-corrected yields of the ^{138}La γ rays were then divided by the number of ^{138}La atoms in the sample. Similarly, the observed yield of the 1460.8-keV γ ray was divided by the number of ^{40}K atoms in the sample. The ratios of the normalized 1460.8-keV γ-ray yield to the normalized 788.7- and 1435.9-keV γ-ray yields were then multiplied by the well-known EC + β^+ half-life of ^{40}K [$(1.204 \pm 0.011) \times 10^{10}$ yr] (Ref. 10) to obtain the ^{138}La β^- and EC partial half-lives, respectively. The results of this procedure as applied to the three mixed source runs are shown in Table I. All uncertainties listed in the table are one standard deviation.

For the point source data, the efficiency-corrected yields of the 788.7- and 1435.9-keV γ rays were combined with the number of ^{138}La atoms in the sample to obtain the ^{138}La half-lives. No differential attenuation correction was required because the source was very thin. The point source results are also shown in Table I. The uncertainties on the half-lives determined from the point source run are significantly larger than those from the mixed source runs because of the relatively large statistical uncertainties. However, within these uncertainties, the results obtained from the point source and mixed source agree with one another.

In Table II, the weighted mean values for the partial and total ^{138}La half-lives determined in the present work are compared with those of previous investigations. It should be noted that the uncertainties assigned to the present results include both statistical uncertainties and systematic uncertainties in detector efficiencies, in differential attenuation in the mixed source, in sample masses, and in the ^{40}K half-

TABLE I. Results of the present experiments for the partial and total half-lives of ^{138}La.

Sample		EC Partial $t_{1/2}$ (10^{11} yr)	β^- Partial $t_{1/2}$ (10^{11} yr)	Total $t_{1/2}$ (10^{11} yr)
Mixed La_2O_3 + KCl source		1.62 ± 0.04	3.40 ± 0.28	1.10 ± 0.03
		1.56 ± 0.04	3.28 ± 0.27	1.06 ± 0.03
		1.56 ± 0.04	3.24 ± 0.27	1.06 ± 0.03
	Weighted mean[a]	1.58 ± 0.02	3.29 ± 0.27	1.07 ± 0.03
Point La_2O_3 source		1.46 ± 0.26	2.95 ± 0.39	0.97 ± 0.12
	Weighted mean[a]	1.58 ± 0.02	3.19 ± 0.22	1.06 ± 0.03

[a]Uncertainties in the mean values include both statistical and systematic errors.

life. As in all previous investigations of this type, however, it has been assumed throughout the present work that ^{40}K and ^{138}La are present in their natural abundances[10] in our samples, and no abundance uncertainties have been included in our results. The present result for the EC partial half-life of ^{138}La agrees within the uncertainties with the relatively high precision value obtained by Glover and Watt,[5] and lies within two standard deviations of the result obtained by Marsol *et al.*[8] The present result for the β^- decay partial half-life agrees within the uncertainties with those obtained in the two previous investigations in which Ge(Li) detectors were used.[7,8] However, the present result disagrees by more than one standard deviation with all but one of those obtained in NaI experiments.[3–6]

The decay scheme of ^{138}La deduced from the present investigation is shown in Fig. 2. Logft values for the electron-capture and β^- decay modes were estimated using the present half-life results, the known decay energies,[10] and the logft nomogram of Verrall *et al.*[12] The resulting logft values for electron cap-

TABLE II. Comparison of present and previous measurements of the partial and total half-lives of ^{138}La.

Author	EC Partial $t_{1/2}$ (10^{11} yr)	β^- Partial $t_{1/2}$ (10^{11} yr)	Total $t_{1/2}$ (10^{11} yr)
Pringle *et al.*, Ref. 2			2.0
Mulholland and Kohman, Ref. 3	0.7	12	0.7
Turchinetz and Pringle, Ref. 4	2.1 ± 0.1	2.4 ± 0.2	1.0 ± 0.1
Glover and Watt, Ref. 5	1.64 ± 0.06	3.5 ± 0.3 4.1 ± 0.7	1.13 ± 0.04
De Ruyter *et al.*, Ref. 6	1.66 ± 0.02	2.83 ± 0.04	1.04 ± 0.014
Ellis and Hall, Ref. 7	2.34 ± 0.37	4.7 ± 1.5	1.56 ± 0.3
Marsol *et al.*, Ref. 8	1.87 ± 0.21	3.95 ± 0.63	1.27 ± 0.18
Present work	1.58 ± 0.02	3.19 ± 0.22	1.06 ± 0.03

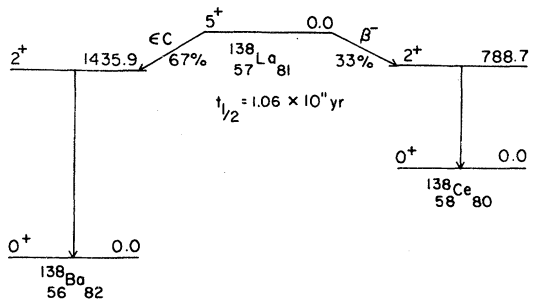

FIG. 2. Decay scheme of ^{138}La deduced from the present work. All energies, spins, and parities are taken from Ref. 10.

ture and β^- decay are 18.3 and 18.7, respectively. The very large logft values found also by early investigators led them to conclude that these decays were third-forbidden transitions and thus, that the spin and parity of the ^{138}La ground state are 5^-. However, DuBard *et al.*[13] have shown that the ^{138}La ground state has $J^\pi = 5^+$. Thus the EC and β^- decays of ^{138}La are second-forbidden unique transitions, and the large logft values are due to nuclear structure effects associated with ^{138}La and its decay daughters.[13]

Note added in proof. We have learned of three other recent studies of ^{138}La decay.[14–16] Cesana and Terrani[14] obtained β^- decay and EC decay partial half-lives of $(3.68 \pm 0.14) \times 10^{11}$ yr and $(1.99 \pm 0.03) \times 10^{11}$ yr, respectively. Taylor and Bauer[15] found a total half-life of $(1.28 \pm 0.12) \times 10^{11}$ yr and an EC decay/β^- decay half-life ratio of 0.51 ± 0.04. Sato and Hirose[16] obtained β^- decay, EC decay, and total half-lives of $(3.02 \pm 0.04) \times 10^{11}$ yr, $(1.56 \pm 0.05) \times 10^{11}$ yr, and $(1.03 \pm 0.02) \times 10^{11}$ yr, respectively. Thus, the results of the present investigation do not agree with those of Cesana and Terrani[14] nor with those of Taylor and Bauer,[15] but do agree very well with those of Sato and Hirose.[16]

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