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The ^{198}Au β^--half-life in the metal Au*

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Abstract. For the β^--decay of ^{198}Au in a Au metallic environment the half-life was observed to be longer by $0.4 \pm 0.7\%$ at room temperature ($T = 293\,\mathrm{K}$) and by $4.0 \pm 0.7\%$ when the metal was cooled to $T = 12\,\mathrm{K}$, both compared to the literature value of $T_{1/2} = 2.6943 \pm 0.0008\,\mathrm{d}$.

PACS. 26.20.+f Hydrostatic stellar nucleosynthesis – 27.30.+t $20 \leq A \leq 38$ – 21.10.Tg Lifetimes

Recently, changes in the half-life for the electron capture of ^{7}Be ($0.8 \pm 0.2\%$ longer half-life [1]) and for the β^+-decay of ^{22}Na ($1.2 \pm 0.2\%$ shorter half-life [2]) have been reported, where these nuclides were implanted in the metals Pd and In and cooled to $T = 12\,\mathrm{K}$. For the β^+-decay of ^{22}Na in the metal Al at $T = 90\,\mathrm{K}$ a shorter half-life of $0.7 \pm 0.5\%$ has been found [3]. Earlier reports on a reduced radioactivity for the β^--decay of ^{3}H in the metal Ti [4] (implying an up to 40% longer half-life) and an increased radioactivity for the α-decay of ^{210}Po in the metal Pd [5] (implying a up to 300% shorter half-life) have been published. From a recent theoretical paper [6] one predicts for α-decays no change in half-life. Furthermore, on the basis of low-temperature nuclear orientation data, an absence of appreciable half-life changes in α-emitters and in other radioactive decays has been suggested [7]: the radioactive nuclides have been implanted here at 60 keV (ISOLDE laboratory) and were located thus very close to the surface; the surface may have an oxygen and/or hydrogen content thus representing to a large extent an insulator, for which no appreciable effect on half-lives is indeed expected; it is also not clear under what vacuum conditions the radioactive samples have been cooled.

We report here on the β^--decay of ^{198}Au ($Q = 1370\,\mathrm{keV}$, $T_{1/2} = 2.6943 \pm 0.0008\,\mathrm{d}$ [8], emission of a 412 keV γ-ray). If this decay occurs in a metal cooled to $T = 12\,\mathrm{K}$, one arrives for the Debye potential [1,2] at $U_\mathrm{D} = Z_\mathrm{e} Z_\mathrm{t} U_\mathrm{e}(\mathrm{d} + \mathrm{d})(293/12)^{1/2} \approx 110\,\mathrm{keV}$, where we used a typical value of 300 eV for the d + d fusion reaction at $T = 293\,\mathrm{K}$ and assumed the $U_\mathrm{D} \propto T^{-1/2}$ dependence to be valid for $T < 293\,\mathrm{K}$. Since the decay rate scales approximately with the fifth power of energy, one obtains a decay enhancement of $f_\mathrm{lab} \approx ((Q - U_\mathrm{D})/Q)^5 = 0.66$, *i.e.* a longer half-life by 34%. At room temperature the half-life is longer by 8%. Using the actual phase space factors in the decay rates, one arrives at respective values of 32% and 7%. The present work reports on experimental investigations of these expected lifetime changes of ^{198}Au in the metal Au.

Table 1. Results of ^{198}Au half-lives.

Sample	$T_{1/2}$ (d)
	$T = 293\,\mathrm{K}$
1	2.698 ± 0.022
2	2.669 ± 0.017
3	2.730 ± 0.013
*	2.706 ± 0.019
	$T = 12\,\mathrm{K}$
4	2.817 ± 0.023
5	2.755 ± 0.035
6	2.830 ± 0.050
*	2.802 ± 0.020

* Weighted average.

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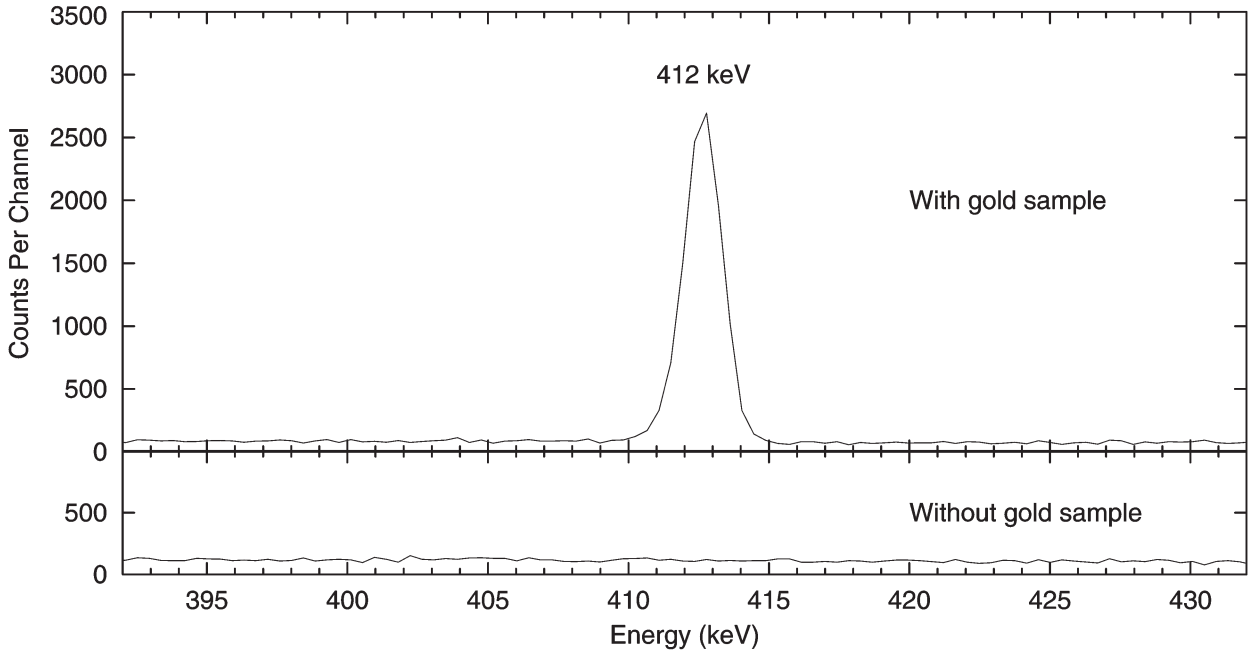

Fig. 1. Spectra near the 412 keV γ-ray of the ^{198}Au decay with and without the activated Au sample in place, obtained both over a running time of 1 h.

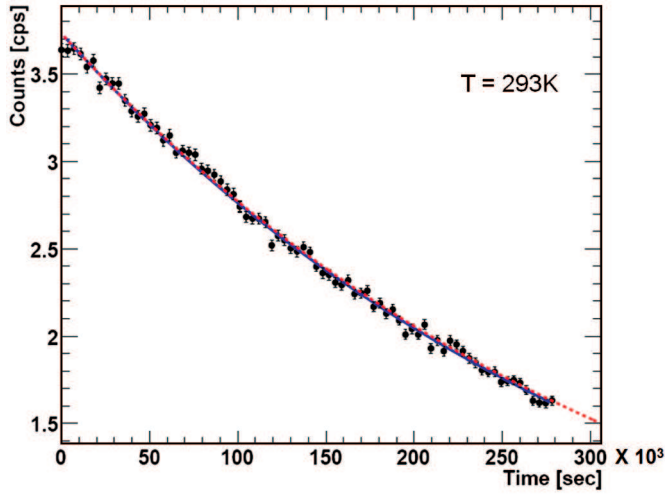

Fig. 2. Decay curve, $A(0)\exp(-t\ln 2/T_{1/2})$, of the 412 keV γ-ray from the ^{198}Au decay in the metal Au at $T = 293$ K; the errors shown are of statistical origin only. The fitted solid curve leads to $A(0) = 3.68\pm0.04$ cps and $T_{1/2} = 2.669\pm0.017$ d, while the dashed curve represents the expected curve for the $T_{1/2}$ literature value [6] assuming the same $A(0)$ value.

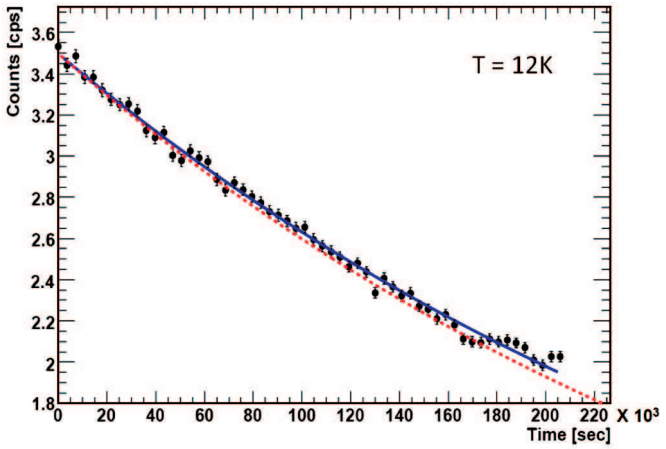

Fig. 3. Decay curve, $A(0)\exp(-t\ln 2/T_{1/2})$, of the 412 keV γ-ray from the ^{198}Au decay in the metal Au at $T = 12$ K; the errors shown are of statistical origin only. The fitted solid curve leads to $A(0) = 3.50\pm0.05$ cps and $T_{1/2} = 2.817\pm0.023$ d, while the dashed curve represents the expected curve for the $T_{1/2}$ literature value [6] assuming the same $A(0)$ value.

The setup [1,2] consisted of a cryopump (Leybold RGD210, minimum fixed temperature $T = 12$ K), where on the head of its Cu rod (length = 24 cm) the sample was installed together with a Si diode (Lake Shore Cryotronics DT-670) for the temperature measurement. The chamber with the cryopump was evacuated by a turbopump, an ion-getter-pump, and another cryopump leading to a base pressure of $p = 1.2\times10^{-9}$ mbar. When this base pressure was reached, the cryopump with the sample was turned on, whereby the pressure improved only slightly: $p = 1.0\times10^{-9}$ mbar; in this way the sample was not polluted significantly by the rest gas in the setup. This setup represents a significant improvement compared to previous studies [1,2,7].

A Ge detector with 120% relative efficiency (at $E_\gamma = 1.3$ MeV) was placed at 0° to the cryopump-axis at a 18 cm distance to the sample, to observe the 412 keV γ-rays from the radioactive decay of ^{198}Au (fig. 1). A linear fit of the background below and above the 412 keV peak was used

in the peak analysis. A 50 Hz pulser was used to measure the data acquisition dead time, which was below 0.1%.

Several Au foils (thickness = 0.5 mm, area = $2\times2\,\mathrm{cm}^2$, with impurities of less than 1 ppm O and H; obtained from Chempur) were activated over 3 weeks via the reaction $^{197}\mathrm{Au}(\mathrm{n},\gamma)^{198}\mathrm{Au}$ in the neutron source at the Isotopenlabor of the Ruhr-Universität Bochum reaching a 412 keV γ-ray activity of about 3 kBq. In this procedure the whole 0.5 mm thick Au foil is activated and its total activation is observed via the 412 keV γ-rays, whereby the ratio of bulk to surface activation is maximized; this represents another significant improvement compared to previous studies [1, 2, 7].

Due to the relatively short half-life of ^{198}Au, we measured its exponential decay curve, $A(0)\exp(-t\ln 2/T_{1/2})$, over a running period of several days in 1 hour steps for $T = 293\,\mathrm{K}$, where $A(0)$ is the initial activity in units of counts per second (cps). The fit of the data (fig. 2) included $A(0)$ and $T_{1/2}$ as free parameters leading to $A(0) = 3.68 \pm 0.04\,\mathrm{cps}$, $T_{1/2} = 2.669 \pm 0.017\,\mathrm{d}$, and $\chi^2 = 1.06$. The weighted average of the results of 3 different activated samples led to a half-life of $T_{1/2} = 2.706\pm0.019\,\mathrm{d}$ (table 1). The cryopump was then turned on ($T = 12\,\mathrm{K}$) and we measured the decay curve over a similar period of time (fig. 3): $A(0) = 3.50\pm0.05\,\mathrm{cps}$, $T_{1/2} = 2.817\pm0.023\,\mathrm{d}$, and $\chi^2 = 1.07$. The weighted average of 3 different activated samples led to a half-life of $T_{1/2} = 2.802 \pm 0.020\,\mathrm{d}$ at $T = 12\,\mathrm{K}$ (table 1). Thus, the half-lives are longer by $0.4\pm0.7\%$ and $4.0 \pm 0.7\%$ at $T = 293$ and 12 K, respectively. The results are consistent qualitatively with the predictions of the Debye model, but the observed effects are significantly smaller (a factor of 8 at $T = 12\,\mathrm{K}$) than expected.

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