The $^{198}$Au $\beta^-$-half-life in the metal Au revisited

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Abstract. The half-life of the $\beta^-$-decay of $^{198}$Au has been measured for room temperature and 12 K. The resulting values of $T_{1/2}^{(\text{RT})} = 2.684 \pm 0.004 \text{d}$ and $T_{1/2}^{(12 \text{K})} = 2.687 \pm 0.005 \text{d}$ agree well within statistical uncertainties. An evidence for a temperature dependence of the half-life was not observed.

In a recent experiment an increase in the half-life $T_{1/2}$ for the $\beta^-$-decay of $^{198}$Au from $2.706 \pm 0.019 \text{d}$ to $2.802 \pm 0.020 \text{d}$ has been observed cooling the sample to $T = 12 \text{K}$ [1]. This observation triggered a number of half-life measurements on various isotopes, which could not confirm the results [2,3,4,5,6,7].

Further measurements have been undertaken to resolve this discrepancy, using a similar setup as described by Spillane et al. [1].

The experimental setup consisted of a vacuum chamber equipped with a turbomolecular pump and two cryopumps. The gold sample was installed on top of the cooling rod of one of the cryopumps. The pressure reached within the chamber was lower than $10^{-5} \text{mbar}$. The temperature at the sample was measured using a Silicon diode (Lake Shore Cryotronics DT-670).

A high-purity germanium detector (relative efficiency 120% at $E_{\gamma} = 1.33 \text{MeV}$) was placed at $90^\circ$ with respect to the cryopump-axis as in Spillane et al. [1]. The distance between the detector and the Au-Foil was about 2 cm to improve statistics compared to the previous experiment.

In the present experiment the same Au-foils as in [1] were used (thickness = 0.5 mm, area = $2 \times 2 \text{cm}^2$, impurities less than 1 ppm O and H, obtained from Chempur). They were activated via the reaction $^{197}$Au (n, $\gamma$)$^{198}$Au using the AmBe neutron source at the Isotopenlabor of Ruhr-Universität Bochum. Saturation is achieved approximately within one week. In total three runs have been performed at room temperature, and at $T = 12 \text{K}$, respectively.

To measure the decay curve the 412 keV $\gamma$-rays were observed, that are emitted by $^{198}$Hg after the $\beta^-$-decay of $^{198}$Au. The runtime for each spectrum was one hour.

Additional background spectra with one hour runtime each were taken over several days before and after the measurements with the sample. The resulting background spectrum has been determined by summing up all background spectra from one series. This sum spectrum has been subtracted from each Au-spectrum after normalization. Two examples for this procedure are shown in fig. 1 for the relevant region around $E_{\gamma} = 412 \text{keV}$. In the background, a small peak at 409.5 keV is visible due to a $\gamma$-transition in $^{228}$Th following the $\beta^-$-decay of $^{228}$Ac, belonging to the natural Thorium series. This $\gamma$-ray line can only be clearly identified in very high statistics background runs, i.e. here a 142 hour run. However, this line may have an effect on the $^{198}$Au $\gamma$-ray line analysis at low counting rate and, hence, on the extracted half-life.

After mounting the Au-sample at the cooling rod of the cryopump, the turbopump was started first to reach a vacuum of less than $10^{-7} \text{mbar}$. During the room temperature measurements, only the turbopump was used. For the measurements at 12 K, both cryopumps were started consecutively, to avoid any contamination of the sample by deposition of rest gas atoms.

The $40 \text{K}$ line at $E_{\gamma} = 1461 \text{keV}$ has been used to normalize all spectra and to correct for deadtime effects. An additional 50 Hz pulser has been used in selected runs to obtain the counting rate in the $40 \text{K}$ line.

The peak area of the 412 keV $\gamma$-ray line has been determined by integration of the natural background subtracted spectrum. The remaining background around the peak has been interpolated with a linear function and has been subtracted. One should note that without prior background subtraction the evaluation of the half-life has proven to be very sensitive to the choice of the background area around the peak.

The resulting activities have been fitted using the usual decay formula

$$A(t) = A_0 \exp(-\lambda t)$$  \hspace{1cm} (1)
where

$$\lambda = \frac{\ln 2}{T_{1/2}} \quad (2)$$

is the decay constant and $A_0$ is the initial activity for $t = 0$.

Due to the relatively short half-life, normally eq. (1) has to be integrated over the time $\Delta t$ of a single run starting at $t_0$. In the present experiment $\Delta t$ varies only due to negligible differences in the dead time and eq. (1) can be used except for a modified initial activity. The half-life is independent of the absolute activity, hence, the final result is not influenced by this modification.

Finally, each decay curve has been fitted using the initial activity $A_0$ and the decay constant $\lambda$ as free parameters. Additional fits have been performed fixing $\lambda$ at the literature value $\lambda_{\text{lit}}$, only varying $A_0$, to test the consistency of the experiment with the literature value of $\lambda$. The resulting parameters with their statistical uncertainties are shown in table 1 along with the reduced chi-square $\chi^2_{\text{red}}$. Fig. 2 shows decay curves for room temperature and 12 K respectively.

As shown in table 1 all fits are compatible when the decay constant has been fixed at the literature value; using it as a free parameter gives only a slight improvement in $\chi^2_{\text{red}}$, if any. An overview of the half-life results is shown in table 2 and fig. 3 together with the mean values of $T_{1/2}$ for room temperature and $T_{1/2}^{(12\text{K})} = 2.687 \pm 0.005 \text{d}$ at 12 K show no effect of a change within the statistical uncertainties.

Thus, the present experiment excludes the large effect observed previously [1]. A possible explanation for the assumed change in half-lifes can be given by the difficulty analyzing the spectra without subtraction of a high statistic background spectrum. In the present analysis the obtained half-life was affected strongly by the choice of the region around the $412 \text{keV}$ $\gamma$-ray line used for the background determination. This effect vanished when the background spectrum was subtracted before the peak was evaluated. Particularly a proper background measurement and subtraction of the $409.5 \text{keV}$ $\gamma$-ray line is important before the peak is integrated.

In summary we confirm the conclusion of recent works [2,3,4,5] that no temperature effect on the half-life of $^{198}\text{Au}$ is present within the statistical uncertainties of this experiment.

References

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Table 1. List of all measurements and the resulting fit parameters with their statistical uncertainties and the reduced chi-square. RT denotes room temperature, $\Delta T$ is the total run time of the measurement. In the right part the decay constant was fixed to the literature value $\lambda_{\text{lit}} = \ln 2 / T_{1/2,\text{lit}} = 0.25714 \text{ d}^{-1}$, which also gives excellent fits.

| Run | $T$ | $\Delta T$ (h) | $A_0$ (s$^{-1}$) | $\lambda$ (d$^{-1}$) | $T_{1/2}$ (d) | $\chi^2_{\text{red}}$ | $A_0$ (s$^{-1}$) | $\lambda_{\text{lit}}$ fixed | $\chi^2_{\text{red}}$ |
|-----|-----|---------------|----------------|----------------|--------------|---------------|----------------|------------------|---------------|
| 1   | RT  | 266          | 11.14 ± 0.04  | 0.2581 ± 0.0007 | 2.686 ± 0.007 | 0.9400        | 11.087 ± 0.021 | 0.9456           |
| 2   | RT  | 119          | 5.180 ± 0.022 | 0.2576 ± 0.0016 | 2.691 ± 0.016 | 1.0351        | 5.174 ± 0.012  | 1.0273           |
| 3   | 12 K| 286          | 1.070 ± 0.006 | 0.2559 ± 0.0016 | 2.709 ± 0.017 | 0.9181        | 1.074 ± 0.004  | 0.9172           |
| 4   | 12 K| 307          | 1.005 ± 0.006 | 0.2576 ± 0.0017 | 2.691 ± 0.017 | 0.9494        | 1.004 ± 0.004  | 0.9465           |
| 5   | RT  | 313          | 8.235 ± 0.023 | 0.2584 ± 0.0005 | 2.683 ± 0.006 | 0.9692        | 8.187 ± 0.013  | 0.9874           |
| 6   | 12 K| 502          | 6.376 ± 0.018 | 0.2581 ± 0.0005 | 2.685 ± 0.006 | 0.9171        | 6.347 ± 0.011  | 0.9239           |

Fig. 2. Decay curves at room temperature ("RT") and for $T = 12$ K. (a) shows the decay curve where the peak area is evaluated by integrating the region of the gamma-peak after subtracting in a first step the corresponding environmental background spectrum and in a second step the remaining background determined in areas left and right of the peak (width normalized to the width of the peak region). The data points (b) show this remaining normalized background.

Fig. 3. Comparison of all obtained half-lifes in the order of measurements. Experiments at room temperature are represented by dots, experiments at $T = 12$ K with triangles. The two rightmost points represent the average values. The error bars only include statistical uncertainties. The horizontal bar indicates the literature value, $T_{1/2,\text{lit}} = 2.6956 \pm 0.0003 \text{ d}$, with its uncertainty.

Table 2. Half-lifes for all runs, ordered by temperature. The resulting average values for room temperature and $T = 12$ K are in good agreement. The values for the single runs are given with higher accuracy than required by the errors, because reducing this accuracy leads to a change in the average values in the last significant digit by 1. As usual, uncertainties have been rounded up.

| Room temperature | $T = 12$ K |
|------------------|------------|
| Run $T_{1/2}$ (d) | Run $T_{1/2}$ (d) |
|------------------|------------|
| 1 2.6855 ± 0.0065 | 3 2.7092 ± 0.0167 |
| 2 2.6906 ± 0.0160 | 4 2.6913 ± 0.0169 |
| 5 2.6825 ± 0.0051 | 6 2.6851 ± 0.0051 |
| average 2.684 ± 0.004 | average 2.687 ± 0.005 |