Absence of a self-induced decay effect in $^{198}$Au

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Abstract

We report the results of an improved experiment aimed at determining whether the half-life ($T_{1/2}$) of $^{198}$Au depends on the shape of the source. In this experiment, the half-lives of a gold sphere and a thin gold wire were measured after each had been irradiated in the NIST Center for Neutron Research. In comparison to an earlier version of this experiment, both the specific activities of the samples and their relative surface/volume ratios have been increased, leading to an improved test for the hypothesized self-induced decay (SID) effect. We find $T_{1/2(\text{sphere})}/T_{1/2(\text{wire})} = (0.9993 \pm 0.0002)$, which is compatible with no SID effect.

Keywords: Beta decays, Neutrinos, Nuclear decay lifetimes

1. Introduction

In the first 35 years after Becquerel’s discovery of radioactivity, more than eighty attempts were made to alter the rate of decay of a radioactive source by artificial means. Temperatures from -255 to 1350°C (18 to 1600 K), pressures up to 200 MPa (2000 atm), accelerations up to nearly $10^7$ m/s$^2$ (970,000 g), and magnetic fields as high as 8.3 T have all been found to be ineffectual [1]. External gamma radiation also had no effect [2], and recent suggestions of a change at very low temperature in metals have not been confirmed [3, 4]. The sole verified exception to constant decay rates is the influence of chemical state upon decay modes involving atomic electrons, such as electron capture and internal conversion, the physics of which is well understood [5, 6].

It has recently been suggested [7, 8, 9, 10, 11, 12, 13, 14] that short-duration and annual periodic anomalies, of order ±0.3%, that have been observed in several cases of decay of radioactive sources may be related to the Sun, specifically to solar neutrinos. Although neutrinos have been suggested to exhibit remarkable physics [15], correlations of radioactive decay with the Earth-Sun distance have not been found in other data sets [16] at the 0.3% level, although they do appear to be present in these data at a lower level [17]. Constraints on electron antineutrinos as a source of the periodic signals observed in various data sets have been derived by de Meijer et al., from a recent experiment using a research reactor as a source of neutrinos [18].

Previous work in this laboratory [19] compared the decay constants of spherical and foil sources of $^{198}$Au, with very different surface/volume ratios and hence very different internal neutrino density, and found no detectable difference in the half-life.

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In the present work, we have extended these measurements by doubling both the specific activity and the surface/volume ratio difference of the earlier work.

2. Experimental

A 1.004 mg sphere, prepared by melting gold foil, was compared with a 33 µm diameter gold wire 6.0 cm long, weighing 1.02 mg. Each sample was irradiated for six hours (the maximum permissible time) in the RT1 rabbit facility of the NIST Center for Neutron Research, at a neutron flux of $1.05 \times 10^{14}$ n/cm$^2$/s. Beginning a few hours after the irradiation ended, the source was counted repeatedly for 2 h live time through about 2.5 cm of lead absorber at 40 cm from a well-characterized Ge gamma detector (relative efficiency 37.3%, resolution 1.70 keV), collecting ~200 spectra during seven half-lives. A precision pulser [20, 21] monitored the rate-related spectrometer losses. At the beginning of the measurement, each source had an activity of 62 mCi (2.3 GBq), emitting $2.3 \times 10^{12}$ neutrinos/s/g.

The 412-keV gamma ray peak in each spectrum was integrated with a fixed-boundary summation routine [22]. Each datum was corrected for decay during the dead-time-extended counting interval, and for pulse pileup using the reference pulser. The data set was then fitted to an exponential function by a nonlinear reduced gradient method for $\chi^2$ minimization, using the Solver function [23] in Microsoft Excel to determine the half-life ($T_{1/2}$) and the initial activity ($A_0$). The weight of each data point was taken as the inverse Poisson variance of the net peak areas plus that of the missing pulser counts. Fits were performed over the entire data sets, as well as subsets comprising the first and last half-lives.
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results are given in Table 1. The uncertainty \(d f\) was inflated by a
factor of \(\chi^2/df\). Perhaps because this experiment was carried
out under more extreme conditions, the absolute values of the
half-life are about 0.5% lower than our previous work and the
consensus of a recent evaluation \[25\].

Since the activity of the two sources at the end of irradiation differed by 14% and the initial decay times were different, the comparison for the first half-life used spectra with comparable
counting rates. A second model was fitted to the data, employ-
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deading times \[26, 27\]. This function is less facile to implement and gave slightly inferior \(\chi^2\) values, but the conclusions are the same as with the simpler model.

The mean solar neutrino flux at earth is 6.5\(\times\)10\(^{-9}\)/cm\(^2\)s \[28\],
varying according the \(r^2\)-law by 6.9% from perihelion to aphe-
ilon. The number of solar neutrinos passing through the surface (twice the projected area) of the gold sphere is then 1.1\(\times\)10\(^9\)/s, and through the wire 2.6\(\times\)10\(^9\)/s. By comparison, the number of internally generated neutrinos from \(^{198}\)Au passing through the surface of the sphere is 3.4\(\times\)10\(^7\)/s and through the surface of the wire 3.7\(\times\)10\(^7\)/s at the beginning of the measurements. The 20-MW NIST research reactor, located 49 m from the detector, contributed 1.3\(\times\)10\(^8\) antineutrinos/cm\(^2\)s continuously during the experiment \[29\].

In the formalism of Ref. \[19\], the postulated effect of an internal flux of neutrinos is to modify the usual decay formula such that

\[
\frac{dN(t)}{dt} = -\lambda_o N(t) \left[ 1 + \xi \frac{N(t)}{N_o} \right],
\]

where \(\lambda_o = \ln(2)/T_{1/2}\) is the conventional \(^{198}\)Au decay constant. The constant \(\xi\) is a phenomenological parameter that depends on the shape of the sample \[30\].

3. Results and Discussion

The results are given in Table 1. The uncertainty \(s\) is the increment in \(T_{1/2}\) that increases the value of \(\chi^2/df\) by unity, where \(df\) is the number of data points minus 2. It is evident that not all sources of uncertainty are accounted for. Since approximately 4\(\times\)10\(^8\) net counts were accumulated in the first spectrum, the very small Poisson uncertainty in this number is likely to be overshadowed by small, incompletely understood non-linearities in high-rate gamma spectrometry, and thus the value of \(\chi^2\) is higher than in our previous measurements. As with other published half-life measurements, it is arguable that the formal uncertainties are underestimated, and following the practice of the Particle Data Group \[24\] the uncertainties are inflated by a factor of \(\sqrt{\chi^2/df}\). Perhaps because this experiment was carried out under more extreme conditions, the absolute values of the half-life are about 0.5% lower than our previous work and the consensus of a recent evaluation \[25\].

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where \(\lambda_o = \ln(2)/T_{1/2}\) is the conventional \(^{198}\)Au decay constant. The constant \(\xi\) is a phenomenological parameter that depends on the shape of the sample \[30\].
In conclusion, our results imply that the periodic signals reported in Refs. [7, 8, 9, 10, 11, 12, 13, 14] were probably not caused by the $\bar{\nu}_e$ component of solar neutrino flux. This conclusion thus supports, and is supported by, the previously cited reactor experiment of de Meijer et al. [18]. However, this does not exclude the possibility that other components of solar neutrino flux ($\nu_e, \nu_\mu, \nu_\tau$), or some other unknown particles, could be responsible for the effects reported in Refs. [7, 8, 9, 10, 11, 12, 13, 14]. Additionally, it may be that $^{198}$Au is simply less sensitive than other nuclides to whatever influences are responsible for the time-varying effects observed to date. As we have noted elsewhere, [9] the sensitivity of radioactive nuclides to an external influence is likely to depend on decay energy and other kinematic effects, as well as on details of nuclear structure, and hence could vary from nuclide to nuclide.

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