The half-life of ^{198}Au: high-precision measurement shows no temperature dependence

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This experiment was undertaken to investigate whether the half life of the β-decay of ^{198}Au in a metallic environment showed any dependence on temperature as had been claimed in a recent publication [1]. An article describing this experiment has already been published [2].

Previous publications claiming to observe a temperature dependence of β-decay half-lives [1, 3, 4] have invoked the so-called "Debye effect" to explain the phenomenon. Their authors' explanation proceeds as follows: Beta decay involves either the emission of a positron or an electron from the nucleus, or the capture of an electron into the nucleus. Since metals possess large numbers of "conduction" electrons that are basically free to travel within the metal, these electrons are deemed to form a sort of plasma, which is referred to as a "Debye plasma". When a beta-decaying nuclide is placed in a metallic environment, the authors propose that the presence of the Debye plasma alters the phase space available for beta decay. In the case of β^--decay or electron capture decay, they argue that the available phase space is *reduced*, slowing the decay rate and increasing the half-life. For the case of β^+-decay, the available phase space is *increased*, having the opposite effect. According to their formulation of this theory, the change in phase space can be enhanced if the host metal is cooled to very low temperatures (e.g., ~20 K).

With an eye to testing both the claimed experimental observation and the model that it generated, we have repeated one of the experiments that claimed to have observed a temperature-dependent effect [1]: a measurement of ^{198}Au in gold metal. Our experiment was performed to a precision of 0.04%, more precise than the previous work by a factor of 25.

We used gold samples obtained from Goodfellow Corp; these were 10 mm in diameter, 0.1 mm thick, and had a purity of 99.99+%. The foils were activated at a flux of $\sim 10^{10}$ neutrons/cm$^2\cdot$s, each for 10 s, at the Texas A&M Triga reactor. An activated gold sample, now containing ^{198}Au, was placed on the cold head of a CryoTorr 7 cryopump. A 70% HPGe detector was placed directly opposite the sample, and just outside the plate covering the cryopump. A cavity had been bored in the cover-plate such that only 3.5 mm of stainless steel remained between the sample and the face of the detector. We used the same set-up for measurements at both room temp and at 20 K, the distance between the detector face and the sample being 4.5 cm.

Consecutive six-hour-long γ-ray spectra, were acquired and saved consecutively, for a period of about one month for each temperature. All spectra were collected for an identical, pre-set live time. Throughout the experiment, we synchronized the time prior to each day's collection, using the signal broadcast from radio station WWVB. We also kept the system's dead time below about 3% for all but the first few spectra. Since the TRUMP™ card used in our data collection corrects for dead time losses, our results were nearly independent of dead time losses. However, to achieve a precision under 0.1%, we performed an additional procedure to allow us to determine the presence of any residual, rate-dependent effects. This procedure involved measuring the 662 keV γ-ray peak from a ^{137}Cs source, then repeatedly re-measuring this peak in the presence of a ^{133}Ba source, which was moved nearer and nearer the detector. As the barium source moved closer to the detector, the dead time and the number of chance coincidences both increased. By plotting peak areas versus dead time, we found the residual loss to be (5.5 ± 2.5) $\times 10^{-4}$ per 1% increase in dead time; this small correction was applied to all spectra.

We measured the half-life of ^{198}Au via the 411-keV γ-ray in ^{198}Hg, which follows its β-decay. We used the least-squares peak-fitting program GF3 (in the RADware series [5]), to obtain the peak area in each of the ~250 recorded spectra. Use of this program allowed us to make very accurate determinations of spectral backgrounds and areas. Each peak was analyzed and then corrected for residual, rate-dependent effects, as mentioned above. The decay curves resulting from this analysis were then plotted as a function of time. Following this, the resulting curve was analyzed, by a maximum-likelihood fit (single exponential), using a code based on ROOT [6]. We had tested this code previously to a precision of 0.01%, with Monte-Carlo generated data.

From our analysis we obtained the following half-lives: at 20 K, 2.6953 ± 0.0006 d; at room temperature, 2.6949 ± 0.0005 d (statistical uncertainties only). The difference between these results is less than 0.0012 d or 0.04%. This result contradicts the previous claim that there is a 90-times larger difference, 3.6 ± 1.0%, between the half-lives when measured at essentially the same temperatures.

With a provision for systematic error incorporated, our half-lives become 2.6953 ± 0.0009 d (cold), and of 2.6949 ± 0.0008 d (room temperature). These results compare very well with previously published results for room temperature measurements. Their weighted average (see Ref. [2] for a table) is 2.6950 ± 0.0005 d.

Clearly we see no evidence for the effects of a Debye plasma on the β^--decay of ^{198}Au. Whether these negative results will extend to β^+-decay or electron capture remains uncertain. We are currently measuring the half-life of ^{97}Ru, which decays by pure electron capture. It should provide the answer for that class of decay.

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[3] B. Limata *et al*., Eur. Phys. J. A **28**, 251 (2006).

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[6] R. Brun, and F. Rademakers, Nucl. Instrum. Methods Phys. Res. **A389**, 81 (1997).