Half-life of the electron-capture decay of ^{97}Ru: Precision measurement shows no temperature dependence

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This experiment was undertaken to investigate whether the half life of the electron-capture decay of ^{97}Ru atoms located in a metallic environment shows any temperature dependence, as has been claimed for the electron-capture decay of ^{7}Be in a recent publication [1].

Previous publications claiming to observe a temperature dependence of β^-, β^+ and electron-capture-decay half-lives [1-3] have used the so-called "Debye effect" to explain the phenomenon. The authors claim that the conduction electrons, present in a metal, comprise a sort of plasma, which they refer to as a Debye plasma. They argue that this plasma changes the phase space available for the decay and thus increases (for β^- or electron-capture decay) or decreases (for β^+-decay) the nuclide's half life. The change in phase space would be enhanced, they argue, if the source is cooled to very low temperatures. Although the half-life changes, which were reported at low temperature (~12K), were less than their proposed theory indicated, they were in the same direction.

We set out by repeating one of the reported experiments: the measurement of the half-life of ^{198}Au in gold at room temperature and at 19K [4]. Spillane *et al*. [3] had claimed a 3.6(10)% effect but we found no effect and set an upper limit of 0.04%, two orders of magnitude lower than their claims. Having shown no effect to exist for the β^--decay of ^{198}Au, we have now turned to a case of electron-capture: the decay of ^{97}Ru.

We used a natural ruthenium sample obtained from Goodfellow Corporation. This was in the form of a single crystal, 8 mm in diameter, 1 mm thick, and with a purity of 99.999%. The crystal was activated twice – once for the low-temperature measurement, and then again later for the measurement at room temperature – in a flux of ~10^{10} neutrons/cm^2·s for 10 s at the Texas A&M Triga reactor.

We used the same experimental set-up as we used for the ^{198}Au experiment [4]; as in that experiment, the set-up was unchanged for both the cold (19K) and room-temperature measurements. The activated sample, containing ^{97}Ru among other activities, was placed upon 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. The distance between the detector and cryopump remained constant throughout the measurement.

Six-hour γ-ray spectra were acquired and saved consecutively over a period of 29 days for each measurement. All these 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. The system dead time was always below 4%; so, since the TRUMP^{TM} card used in our data collection corrects for dead-time losses, our results were nearly independent of dead-time losses. However, to bring our precision down to about 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. Moving the barium source closer to the detector increased both the dead time and the number of chance coincidences. By plotting peak areas versus dead time, we found the residual loss to be 5.5(25) x 10^{-4} per 1% increase in dead time. This correction was then applied to all spectra.

We used the least-square peak-fitting program gf3 in the RADware series [5], to analyze the 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 plotted as a function of time and fitted by a single exponential with a code based on ROOT [6]. This code uses the maximum likelihood method and has been tested previously by us to a precision of 0.01%, with Monte Carlo generated data.

From our analysis of the 216-keV delayed γ-ray in ^{97}Tc, the daughter of ^{97}Ru, we obtained a half-life of 2.8382 ± 0.0013 d for the cold-temperature measurement, and of 2.8370 ± 0.0013 d for the room temperature measurement. These results demonstrate that the half-life of ^{97}Ru is the same within 0.1% at room temperature and at 19K.

Since their delayed γ-rays were present in the spectra as well, we have also obtained data at both temperatures for two other isotopes, ^{103}Ru and ^{105}Rh, which both decay by β^- emission. We were able to show that neither of these isotopes undergoes a change in half-life, as would be predicted by the "Debye theory":

- For ^{103}Ru, our measurements yield a half-life of 39.210 ± 0.016 d at room temperature and 39.219 ± 0.025 d at 19K. These results are also the same within 0.1%.
- For ^{105}Rh, our measurements obtain a half-life of 35.347 ± 0.036 h at room temperature, and a half-life of 35.314 ± 0.023 h at 19K. These results are the same within 0.2%

In conclusion, so far our measurements neither confirm the claimed observation of the temperature dependence of half-lives nor corroborate the so-called Debye theory, which was devised to explain the effect. Our measurements so far have included ^{198}Au, ^{97}Ru, ^{103}Ru, and ^{105}Rh, cases which include both β^--decay (^{198}Au, ^{103}Ru, and ^{105}Rh) and electron-capture-decay (^{97}Ru) processes.

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