X-ray counting experiment

We attempted a pilot study to test whether the characteristic ~ 3.2 keV x-ray emitted during both ground state and excited state electron capture of ^{40}K could be detected. In our experimental set-up, we used a 50 mm by 5 mm KCl disc as a ^{40}K source and a thin Be-window Ge detector (Ortec LoAx). The source and detector were housed in Pb brick containment to limit x-rays from the surrounding environment. Counts were taken over ~ 250000 s (approximately 2.9 days) to test the possibility of detection. We show example spectra of the background, KCl, and KCl with background subtracted below (Figure S1, **A** - **C**).

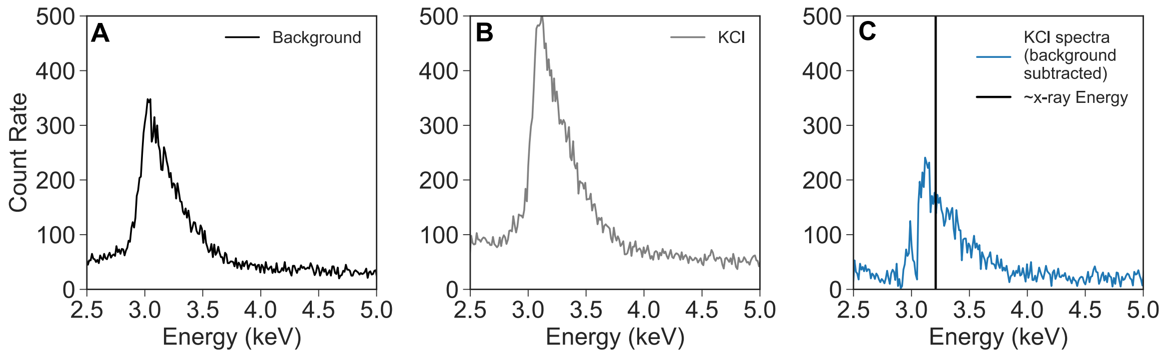

Figure S1. (A) Spectrum measured for the laboratory background, (B) KCl spectrum, and (C) KCl spectrum with background subtracted (C). The detector resolution in the ~3 keV region is approximately 50 eV at full-width half-maximum.

The lower limit of x-ray energy detection is approximately 3 keV, resulting in an exponential noise pile across the energy region we are attempting to observe (Figure S1 A). Unfortunately, this noise pile-up dominates the region of interest during measurement (Figure S1 B). The Ar-K x-ray is detected (Figure S1 C), but is difficult to resolve from the noise pile up. Note that the characteristic x-ray does not appear at exactly 3.209 keV due to what we believe to be a non-linearity in the relationship between energy and channel number in the detector. We use this simple experimental set up to show that there is potential to detect the ^{40}K characteristic x-rays can be detected in our simple experimental configuration. We acknowledge that this set up cannot be used to distinguish between the x-rays of each electron capture decay mode of the ^{40}K decay scheme but use this set up as a pilot study to test the possibility to observe these x-rays and from this, make improvements and additions to move toward the experimental verification of the electron capture to ground state decay mode.

Conclusions and Recommendations

The pilot study here shows the potential of determining the existence of the electron capture to ground state decay through the detection of characteristic ~3 keV x-rays associated with the relaxation of the daughter ^{40}Ar nucleus after decay. However, we acknowledge that this experimental set up cannot distinguish between x-rays that are from the electron capture to excited state and x-rays from the electron capture to ground state that is required for verification. The absolute verification requires the detection of excess x-rays that are not coincident with the γ-ray from the de-excitation of $^{40}Ar^{2+}$ to $^{40}Ar^{0+}$. Further, as illustrated in Di Stefano et al. (2020), it is expected that 50 electron capture to excited state decays (EC*) occur for every 1 electron capture to ground state decay (EC_{ground}); therefore, a detector efficiency of ≥ 98% is required to make sure that there is fewer than one mis-tagged EC* decay for each true EC_{ground} decay. The experiment therefore requires an x-ray spectrometer able to resolve the Ar-K x-ray from other x-rays in the background, and accurately account for the x-ray–γ-ray coincidence efficiency (≥ 98%) to quantify x-ray emission rates in excess of those from the $^{40}Ar^{2+}$ state. In our experiment, a simple KCl source is used pressed to a thin disc to aid in the minimisation of self-absorption. However, this still results in a low count rate at the x-ray energy. Therefore, we recommend the use of a source enriched in ^{40}K, and a thinner sample to limit x-ray self-absorption. We also recommend the use of a NaI detector, with a detector efficiency of ≥ 98%, which offers both greater resolution at low energies and a much lower detection limit. Furthermore, counting over a very long period, on the order of months, is required to accumulate enough measurements to yield a precise result. The low activity of the potassium may also require long counting experiments in extremely low background environments, such as the Boulby Dark Matter Laboratory.

References

Di Stefano, P.C.F., Brewer, N., Fijałkowska, A., Gai, Z., Goetz, K.C., Grzywacz, R., Hamm, D., Lechner, P., Liu, Y., Lukosi, E. and Mancuso, M., The KDK (potassium decay) experiment. J. Phys. Conf. Ser. (Vol. 1342, No. 1, 012062). IOP Publishing, http://dx.doi.org/10.1088/1742-6596/1342/1/012062, 2020.