

# QSS48 - Eric Hudson - Questions & Answers

*Eric Hudson*

There are many different experiments trying to get at the Thorium nuclear transition. Can you say a bit more about the differences in trapping Thorium in an ion trap, in a crystal matrix, or other ways?

**ERIC:** The ion trapping experiments appear to be the best way forward to building a system that can really exploit the properties of the system for building a clock or doing something 'quantumy'. The crystal, if it works, is probably the second best since a crystal is essentially Nature's ion trap. At present, to my knowledge, ion traps aren't being used to search for the transition but rather are preparing for once it's measured. There is really no reason you couldn't search for the transition in an ion trap, but it 'feels' a little harder and more expensive than doing it with the other means. The other ways of searching for the transition, using e.g. crystals, metal targets, illuminating with x-rays, are being pursued around the world. These would appear to be the most efficient ways of measuring the transition, but they all involve an 'unproven' step that could keep them from working. So, it's a bit of a gamble, however, they are generally much cheaper to try first and thus that's where the research has been directed.

Why do you need "large" crystals? Would a powder not also work?

**ERIC:** The largeness of our crystals (a few mm<sup>3</sup>) is driven by getting as high a number of thorium nuclei as possible near our detectors. A PMT photocathode is typically on the order of a 1 cm across and so that set our scale. A powder would very likely have a large non-radiative decay. Even if the molecule the powder is composed of, e.g. ThF<sub>4</sub>, does not experience internal conversion decay, you expect that there are organics and such attached to the powder that will likely induce non-radiative decay.

How about getting a LOT more thorium from a nuclear facility and getting an even more thorium-dense target? Would this just be too expensive?

**ERIC:** Now that the field has turned its attention to thorium-229, it is getting easier to get larger quantities. However, we have made some crystals with larger thorium density and they seem to show radiation damage after a year or so. Also, their optical quality never really 'seemed' as good as the lower density crystals.

To what uncertainty interval do you hope to measure the energy of the photon with the superconducting nanowires?

**ERIC:** We guess that 0.1 eV should be possible statistically, but the systematics could be much larger. This is one of the things we're working on now. A potential advantage of the nanowire approach is that it is really a direct measurement of the energy and requires no other corrections other than a calibration with e.g. VUV light.

Once you have found the transition, you still need to divide down its frequency to make a clock. Can you say something about the status of vuv frequency combs?

**ERIC:** VUV frequency combs exist. I am aware of the work of Jason Jones at Arizona and Jun Ye at Colorado, and I'm sure other groups are also pursuing them as well. However, since the VUV clock laser will be produced by some non-linear frequency mixing, it is likely better to just compare the fundamental of the laser to a visible or IR frequency comb.

Is anything known about possible broadening mechanisms? E.g. Is there no coupling between the nuclear excitation and the electronic dofs?

**ERIC:** In the crystal, the broadening mechanisms should be the same ones that are routinely seen in NMR and Mossbauer spectroscopy. We estimate that the largest broadening will be due to magnetic dipole interactions between nuclei and of order 10 kHz. There are other shifts, such as an electric quadrupole shift, which are much larger but these should be identical for the same lattice site. In the ion trap, the broadening depends on the ion charge state. At present experiments are aiming to use  $\text{Th}^{3+}$ , which will have broadening by the electron bridge mechanism – essentially a Raman-like transition where the nucleus can relax by exciting the electron to a bound state and emitting a photon. It's really impossible to accurately estimate this broadening at this stage since it depends sensitively on the exact location of the energy level. However, I believe it can be constrained to be less than a kHz since the measurements in Munich wouldn't work if this decay was at the ms level.