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PH407H

The Weird World of Quantum Mechanics: Paper 1

The paper I read for my first assignment was “Experimental verification of the Heisenberg uncertainty principle-An advanced undergraduate laboratory”. This paper proposes two experiments which can be performed by high-level undergraduate students that are capable of providing students with an empirical means of testing the Heisenberg uncertainty principle, as it pertains to the relationship between energy and time. The experimental design is such that it seeks to expand on Gedanken experiments, and provide a direct means of observing the uncertainty principle with enough technological sophistication so that the results cannot be attributed to errors in instrumental recordings. Of central importance to both experimental designs is the decay of Co57 to Fe57, in which for a brief temporal window, the decay state manifests itself at a particular energy level, the 3/2- state. This is an ideal decay process, as the photon it emits is sufficiently low energy, and the timescale over which it occurs is long enough to be measured by a coincidence counter. This particular experiment focuses on the quantum system of only the nuclear decay, and ignores the uncertainty with regard to the detection of the photons, in order to simplify the experiment in a way that does not detract from the overall takeaway. According to the wave function that governs the 3/2- state, there exists a particular constraint on the relationship between energy and time. In experimental terms, this signifies a trade-off between the ability to measure the energy level of the decay with exactitude, and the ability to obtain precise measurements of the other variable namely time. This can be shown by the collection of two pieces of data: one that is representative of the energy, and one that is representative of time. This is easier said than done, and each piece of data requires its own experimental design. First, a Mossbauer spectroscopy experiment is employed, in which a low energy gamma particle is emitted from the decaying Fe57 nucleus, and captured by a natural iron absorber. If a Co57 source is set to oscillate towards and away from the iron absorbed, the gamma rays Doppler shift in such a way that an absorption spectrums can be obtained. The critical piece of information for this absorption spectrum is the width of the absorption peaks, which can be extracted and various statistical weightings and corrections can be made to counterbalance imperfections in the design and data. After the corrections are made, a value that is representative of the energy can be obtained.

The second experiment seeks to determine the lifetime of the same 3/2- state of the Fe57 that was obtained in the first experiment. To this end, fast NIM timing modules are employed in order to model the formation and decay of the 3/2- state of the Fe57. The goal is to measure the 122.1 keV gamma ray and the 144.4 keV gamma ray through the use of NaI and Si detectors respectively, and use these two data points to fit an exponential curve that can be used to determine the mean lifetime of the 14.4 keV state. It was found that while a 5 mCI Co57 was used for the experimental design of the Mossbauer portion of the experiment, a 10 microCi source was necessary for this portion of the experiment, in order to lower the gamma ray emission rate. I am not sure why using a different Co57 source between the two portions of the experiment would still allow the lifetime of the 3/2- state measurement and the energy reading to be combined, but the authors of the paper did not see this as a problem. In any event, these two data points are combined into a version of an equation describing the uncertainty principle restraints on energy and time. The experimental result provided in the paper is larger than the accepted value even with the range of error given, which the authors seem to believe is a triumph of the uncertainty principle. My question regarding this would be: If the uncertainty principle leads to an inherent variability in the final experimental result, what is the accepted value they are comparing their result to, and why does it not suffer from the uncertainty principle? In closing, this paper appears to have successfully demonstrated the trade-off between a precise energy measurement and a precise time measurement, through a well-designed experiment that due to inherent uncertainty of the measurements taken, could not reproduce an accepted value. The fact that experimental evidence can be collected in support of the uncertainty principle is very significant, albeit confounding. This is because the uncertainty principle is a point of contention between classical physics and quantum mechanics. Classical physics believes that any observable quantity should be quantifiable as a product of a set of fundamental laws, but this result seems to suggest that either: 1) This is the case, but for our purposes the act of observing one complimentary observable obscures measurement for the other, or 2) The nature of reality is such that there is no exact simultaneous solution, and the closest we can get is a range of values of probabilities for each complimentary observable. Either way, experimental evidence that supports the Heisenberg uncertainty principle challenges much of our preconceptions and world views regarding how physical laws govern the universe.