Calibration to a Reference Determines when Schrödinger's Cats Die

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Abstract

In 1935 E. Schrödinger proposed a thought experiment to illustrate his concerns with superpositions in quantum measurements. It appears in his experiment that a cat is both alive and dead. This paradoxical superposition has not been explained before. The following identifies that calibration to a reference, currently assumed to be only empirical in measurement theory, explains the paradox of Schrödinger's cats.

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Background on Schrödinger's cat from Wikipedia[ii]: "Although originally a critique on the Copenhagen interpretation [of quantum mechanics], Schrödinger's seemingly paradoxical thought experiment became part of the foundation of quantum mechanics. The scenario is often featured in theoretical discussions of the interpretations of quantum mechanics, particularly in situations involving the measurement problem.... Fundamentally, the Schrödinger's cat experiment asks how long quantum superpositions last and when (or whether) they collapse. Different interpretations of the mathematics of quantum mechanics have been proposed that give different explanations for this process, but Schrödinger's cat remains an unsolved problem in physics." Here is Schrödinger's thought experiment:[iii]

> *"One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following diabolical device (which must be secured against direct interference by the cat): in a Geiger counter, there is a tiny bit of radioactive substance, so small, that perhaps in the course of one hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The first atomic decay would have poisoned it. The ψ function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts."*

One way to understand this problem uses many experimental runs, destroying one cat in each run. After each run the diabolical device is reset and another unfortunate cat is penned in for the next run. The diabolical device is assumed to cause each cat's death a short fixed time after an atom's decay. An atom in each run has a 0.5 probability of decaying at one hour from the start of a run. The continuous ψ (wave) function of this system is illustrated by the two hat shaped (^) curves in the figures (for drawing simplicity). Any two parallel curves where the mean of all the atom's probability of decay was 0.5 at 1 hour would fit Schrödinger's description. Assuming different parallel curve shapes will not significantly change the following analysis.

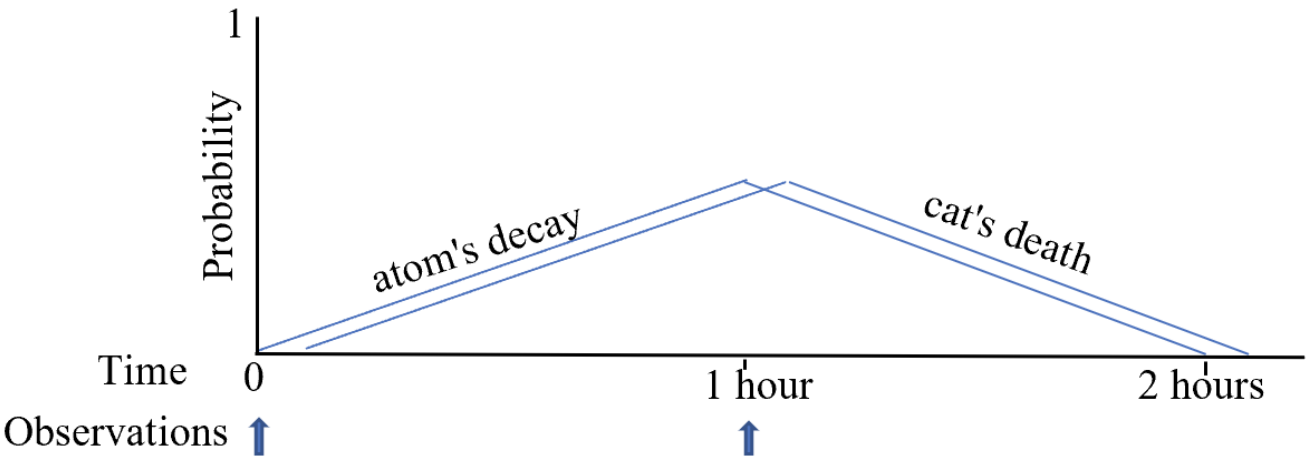

Fig. 1. When Schrödinger's cats die.

Each experimental run establishes one atom's decay time and one cat's time of death. Many experimental runs produce the two parallel, offset and hat shaped curves. Fig. 1 and Fig. 2 assume the maximum distribution of each atom's decay and each cat's time of death is approximately 2 hours which maximizes the paradoxical effect. Again, assuming both the maximum distributions to be longer or shorter does not significantly change the following analysis.

Many experimental runs establish the continuous curves of the two observables and represent the ψ function. At the bottom of Fig. 1 the two bold upward arrows indicate when a human observes each cat in each run. The first time is when a cat is penned into the diabolical device (time 0) and the second time is at 1 hour, near the middle of the approximate 2 hour range of the distribution. These two observations are made using a time reference set to one hour (e.g., a timer which sounds at one hour).

The human's observations are restricted in time. Each cat's actual time of death is shown as a point on the curves in Fig. 1, but is only measured with a precision of ± one hour. Each cat's actual time of death occurs over the two hour range. The two observations identify that in half the runs a cat is still alive when observed at 1 hour, and in half the runs a cat is already dead at 1 hour.

This thought experiment is paradoxical because the time reference unit (one hour) determines the precision (± one hour) of an observation which is similar to the approximate two hour range of the maximum distribution. Half the cats, when observed at one hour, are alive. And half, when observed at one hour, are dead, but not the same cats. What Schrödinger has described is an imprecise measurement process.

Consider Fig. 2, which changes Schrödinger's statement, "If one has left this entire system to itself for an hour,...", to 10 minutes. Now the human's observations occur every 10 minutes (10 minutes = 1/6 factor of the one hour time reference unit) which is more precise relative to the two hour distribution. Then the observed time of death occurs within ±10 minutes (which is the recalibrated precision relative to the reference unit) of the actual time of death. Dividing the one hour reference unit into even smaller states, by further recalibration, increases the precision of the observation of each cat's time of death.

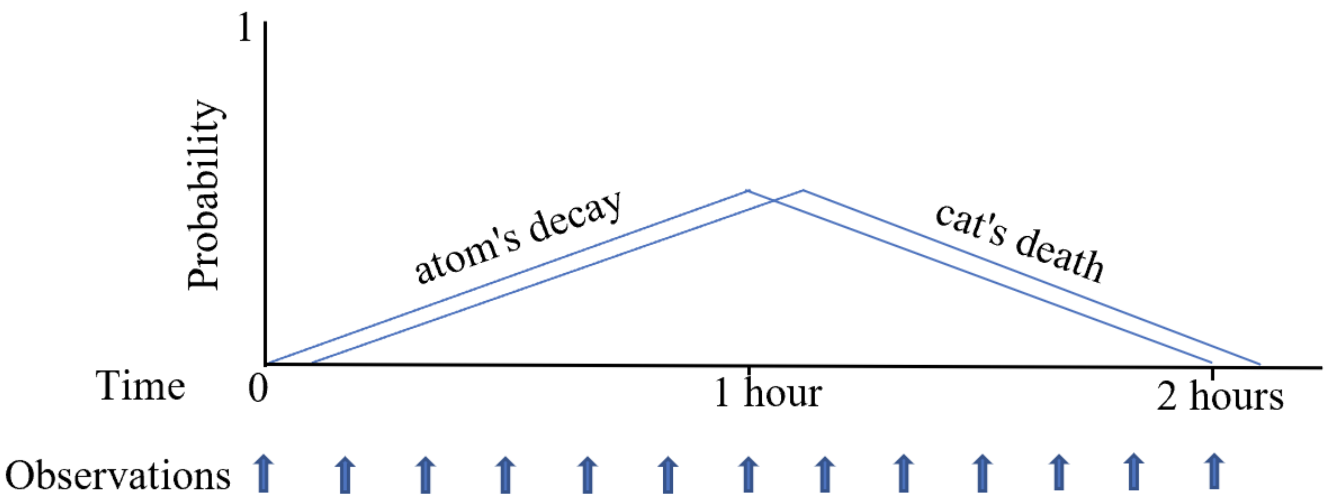

Fig. 2. After recalibration, when Schrödinger's cats die.

The figures illustrate that this measurement result includes both a value (alive or dead) and a unit, the one hour time interval. In metrology, all measurement results include both a numerical value and a unit which is correlated to an interval of a measurement apparatus's scale. As each interval of the scale is divided into smaller calibration states, the precision of the units of the measurement result becomes greater.

In metrology, the precision of a measurement instrument's interval relative to a reference or factor thereof is determined by a calibration process. A calibration process usually divides each measurement instrument's smallest interval, representing (but not always equal to) a reference unit or factor thereof, into smaller equal value states and then correlates the number of calibration states in each interval relative to the reference (which may be a standard unit or factor thereof) to determine the precision of the intervals.

A precise measurement result of an observable (i.e., a precision smaller than the mean measurement apparatus's interval), in theory or experiment, is only produced when a calibration process divides each measurement apparatus interval into smaller calibration states than the mean interval.

Thus, Schrödinger's thought experiment actually identifies that without dividing the human's observation intervals into smaller calibration states relative to the one hour reference (i.e. part of a calibration process), the observation of the cat's time of death is imprecise. However, in the current theory of a measurement in all physics, calibration is treated as an empirical process that adjusts an experimental measurement instrument's intervals (often termed units) precisely enough for the measurement.[iv]

In current measurement theory the scale of a measurement apparatus is assumed to be linear and each interval of the scale equal to a reference/standard or factor thereof. The reference/standard may be perfect in theory, but the intervals of a scale are not linear by assumption (e.g., no linear scale occurs in nature). Each interval must be divided into calibration states, correlated to the reference/standard and statistically summed into a measurement result in both theory and practice.

An example of statistical summing (without noise or distortion): A measurement result is the sum of four contiguous intervals (i = 1 - 4) of a scale: u1+u2+u3+u4 = 4ui.[v] Each ui has a ± precision (is non-linear) due to calibration state quantization, which when all the statistical possibilities of the combinations of the four independent ui are summed produces a Gaussian distribution which occurs in all repetitive experimental measurement results,[vi] verifying statistical summing.

The current measurement theory (which does not require calibration) incorrectly assumes the units of a scale are equal in theory, which incorrectly assumes the correlation between each interval and a reference or factor thereof can be perfect in theory. Both assumptions ignore Heisenberg uncertainty in quantum mechanics and are exacerbated by statistical summing.[vii]

In Schrödinger's experiment, the measurement results (e.g. alive or dead) currently appear to be in a superposition (a sum of states). The metrology interpretation above identifies Schrödinger's measurement results are imprecise measurements without calibration to a reference. This metrology interpretation indicates that a superposition in a linear state space (no reference) would not occur in a calibrated state space with a reference (physical measurement system), which is not linear. This raises the question of the application of such superpositions in quantum computing.

When the statistical sum of each interval's states is treated by calibration in measurement theory, a Gaussian distribution of experimental measurement results appears in all repetitive experimental measurement results. When the number of measurement instrument intervals and their calibration states is small (e.g., many quantum measurement experiments) repetitive experimental measurement results of an unchanged observable likely will not be the same (and do not commute) because the measurement results are imprecise in the same manner as in Schrödinger's thought experiment.

Notes

[i] An earlier version of this paper appeared on the blog ScienceX June 17, 2020.https://sciencex.com/news/2020-06-schrdinger-cat.html?utm_source=nwletter&utm_medium=email&utm_campaign=daily-nwletter. Later versions appear on the preprint site Qeios.com.

[ii] Wikipedia (Nov 29, 2023) https://en.wikipedia.org/wiki/Schr%C3%B6dinger%27s_cat

[iii] E. Schrödinger, "The Present Situation in Quantum Mechanics". First published in German in Naturwissenschaften 23, 1935. This translation (J. D. Trimmer) first appeared in the Proceedings of the American Philosophical Society, 124, 323–38 (1980). This paragraph is the complete information Schrödinger supplied on his thought experiment.

[iv] D. H. Krantz, R. D. Luce, P. Suppes, A. Tversky, Foundations of Measurement, Academic Press, New York, 1971, Vol. 1, page 32. “The construction and calibration of measuring devices is a major activity, but it lies rather far from the sorts of qualitative theories we examine here”.

[v] K. Krechmer, The correlation of classic and experimental measurement results with quantum measurement theory,

preprint on Qeios, https://www.qeios.com/read/AOXTC5.4. This paper includes a formal development of a measurement function.

[vi] A. Lyon, Why are Normal Distributions Normal? British Journal of the Philosophy of Science, 65 (2014), 621–649.

[vii] K. Krechmer, Relative measurement theory (RMT), Measurement, 116 (2018), pp. 77-82. This paper formally develops the relationship between quantization and Heisenberg's uncertainty.