A possible experimental test to decide if quantum mechanical randomness is due to deterministic chaos in the underlying dynamics

Johan Hansson
Department of Physics
University of Gävle
SE-801 76 Gävle, Sweden

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Abstract

A simple experiment using radioactive decay is proposed to test the possibility of a deterministic, but chaotic, origin of quantum mechanical randomness.

In a recently proposed mechanism for understanding the “measurement problem” in quantum mechanics [1], i.e., the transition from quantum to classical behaviour, the possibility arise that the quantum mechanical randomness actually can derive from deterministic chaos in the fundamental non-abelian interactions. An experiment to test this possibility could in principle be devised in analogy to the confirmation of deterministic chaos in a dripping water tap by Shaw and collaborators [2],[3].

If we replace the dripping tap with a suitable radioactive substance (presumably a fairly small sample with simple decay and low activity), the time-series, i.e., the string of time intervals between observed decays, can be used to try to observe a chaotic attractor by applying a method [4],[5] of converting a single time series into a phase space portrait via “delay coordinate embedding”. This can be accomplished, assuming a suitably low-dimensional attractor, by defining the coordinates as follows

\[ x = t_i, \quad y = t_{i+1}, \quad z = t_{i+2}, \quad (1) \]
where \( t_i \) is the time interval between decay \( i \) and \( i + 1 \) in the time series, and so on. A given \( i \) then gives a point, \((x, y, z)\), in phase space. To give an example, the seemingly random data in Fig.1 is actually due to the very simple "logistic mapping", \( x_{n+1} = k x_n (1 - x_n) \), in its highly chaotic regime with \( k = 4 \). The reconstructed attractor, using the method described above, is seen in Fig.2 (2-D) and in Fig.3 (3-D). We do not, however, expect that an eventual attractor in quantum mechanical data will be so simple and low-dimensional.

\[
x = \ldots
\]

Figure 1: Seemingly random data, actually generated by the very simple and deterministic "logistic mapping" in its chaotic region, see text.

If the seemingly random decay of radioactive nuclei, obeying quantum mechanics, give rise to a distinct attractor (or possibly several attractors) with non-integer fractal dimension, onto which the phase space points are concentrated, it would be a clear indication that the decay is actually the consequence of dynamical deterministic chaos, in direct analogy to how the experiment [3] revealed deterministic chaos in the dynamics of the dripping water tap. For examples of qualitatively typical chaotic attractors see, e.g., the figures in [3]. The exact shape, dimension and complexity of the attractor is governed by the detailed underlying dynamics. The rest of the analysis carries through just like in [3]. In fact, in the present case it is in principle even easier to obtain a result as any observed structure indicates a deviation from the usual assumption of total stochasticity of quantum mechanics, as it is normally assumed that, e.g., the decay of an individual nucleus is an independent and truly random process. A practical problem is of course that
there exist no perfect detectors, which results in missing part of the time series and also in the introduction of noise in the data. The more of the time series one misses, the harder it becomes to reconstruct an (eventual) attractor.

If, however, no attractor is found in the experimental data, i.e., if the points are scattered randomly in phase space and no structure whatsoever is seen, as in Fig. 4, where every $t_i$ has been generated at random, then quantum mechanical “measurements” (e.g., decays) probably cannot be described by deterministic equations, and some truly stochastic effect(s) must instead be at work, as assumed in orthodox quantum mechanics.

Hence, it should be possible to falsify the hypothesis that quantum randomness is due to underlying deterministic dynamics, without having to penetrate the details of the very complicated equations of non-abelian gauge fields [1].

Not being an experimentalist, and due to the very crude experimental setup used, the data in Fig. 5 is included for illustrative purposes only. This trial setup consisted of samples of Cs-137 and Am-241 at 5 cm distance from a GM-counter (Passco SN-7927) with accompanying computer software. It is included only as an incentive for hopefully initiating more elaborate, controlled and detailed investigations by experimental physicists. The data in Fig. 5 is from Am-241, but the data from Cs-137 gave a similar picture. It seemingly differs from the random distribution in Fig. 4, and also from a
normal (Gaussian) distribution around a given mean, Fig.6.

The lognormal distribution in Fig.7 somewhat resembles the data. No simple attractor in phase space is visible in the obtained data points, Fig.5. However, as the experimental setup due to its geometry and crudeness misses most part of the time series, one cannot draw the conclusion that no attractor is present. Therefore, a sensitive 4π-detector would be very helpful for further investigations. Also, if a relatively small number of unstable particles (cold neutrons?) could be isolated, repeating the experiment several times, more controlled time series could be obtained.

References

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Figure 4: When no dynamical relation between the $t_i$s exist, no structure is obtained by the reconstruction mechanism.

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Figure 5: The reconstructed phase space in 3-D from experimental data on radioactive decay, see text.
Figure 6: Phase space in 3-D arising from normal (Gaussian) distribution around a given mean.
Figure 7: Phase space in 3-D arising from lognormal distribution around a given mean.