18. Problems with probability in linear quantum mechanics. The many-worlds interpretation is not valid.

As we have observed (Ch. 6), the wave function (state vector) of quantum mechanics often contains several versions of reality. We know experientially that we perceive only one of those versions, but we also know from Ch. 11 that quantum mechanics predicts more than one version will never be *perceived* so there is no conflict on that account. On the other hand, we know that if an experiment is repeated many times, there will be a *probability* of perceiving one result or another. Our aim in this chapter is to show that the standard mathematics of quantum mechanics cannot account for the experimentally observed probabilistic results.

No probability implied by the standard, linear quantum mechanical mathematics.

The half-silvered mirror experiment of Ch. 6 will be used to illustrate the ideas, with the mirror more than half-silvered. After the mirror, the state of the photon is, say,

$$.316\ |H\rangle + .949\ |V\rangle, \quad (.316)^2 + (.949)^2 = .1 + .9 = 1 \tag{1}$$

where $|H\rangle$ is the part of the photon wave function traveling on the horizontal path and $|V\rangle$ is the part traveling on the vertical path. We put a detector on each path and add an observer. Then after the two parts of the photon state vector hit the detectors and annihilate, the state vector of the system is

$$\begin{aligned} &.316\ |DH, \text{yes}\rangle\ |DV,\text{no}\rangle\ |\text{ver. 1 of the observer perceives yes,no}\rangle\ + \\ &.949\ |DH, \text{no}\rangle\ |DV,\text{yes}\rangle |\text{ver. 2 of the observer perceives no, yes}\rangle \end{aligned} \tag{2}$$

Standard quantum mechanics—in which the time translation operator is linear and unitary, and there are no hidden variables or collapse—was used to obtain this state. We see it has no obvious probabilistic nature; essentially the same two-version state will be produced on each run of the experiment; and each of the versions of the observer is equally valid, equally 'aware.' There is no indication that 'my' perceptions will more often correspond to one state of the observer than to a different state because **there is no singular 'me'** in the theory.

To avoid the possibility that we are consciously or unconsciously assuming the observer is quantum mechanically special, we could replace the observer by a robot. Then there is no way I can imagine of convincingly showing the robot perceives the no,yes version 90% of the time (where the 90% comes from the $|a(i)|^2$ law). In fact, the statement "the robot perceives the no,yes version 90% of the time" doesn't even make sense, because there is no 'the' robot.

Argument against probability from many runs of an experiment.

This reasoning by itself—that there is no element of chance in the state vector—would seem to be sufficient to show that the standard mathematics does not lead to probability. But since probability has to do with what happens when the die is rolled many times, it is prudent to examine N runs of the experiment, with N equal, say, to 10,000. Suppose the observer perceives the outcome of each run. Then in the end, since there are two possibilities per run, there will be $2^{10,000}$ different possible outcomes and therefore $2^{10,000}$ different versions of the observer. 10,000!/[*n*!(10,000-*n*)!] of those versions will perceive *n* H′s and (10,000-*n*) V′s. This has a maximum at *n*=5,000. But the $|a(i)|^2$ probability law says we will only see about *n*=1,000 H′s. Now the ratio of the number of states with *n* near 5,000 to the number of states with *n* near 1,000 is approximately 10^{1600}; that is, for every version that sees 1,000 H′s, there are 10^{1600} versions (a number somewhat larger than the national debt) that see 5,000 H′s.

The question is whether the mathematics of standard quantum mechanics can account for our perception of about 1,000 H′s. It cannot.

> **There is no reasoning within the basic, linear mathematics that would explain why the overwhelmingly many versions of the observer who perceive *n* near 5,000 essentially never correspond to our perceptions.**

An observer-ensemble interpretation.

One might propose a simple observer-ensemble interpretation to get probability. The ensemble consists of all the 2^N different versions of the observer at the end of N runs. And the ‘actual’ observer is presumed to correspond to a typical one of these. In this case, because of the
N!/[*n*!(N-*n*)!] number of versions that perceive *n* H outcomes, a typical version of the observer will perceive *n* very near N/2, independent of the coefficients. So this ‘interpretation’ doesn’t work.

An actual observer?

One possible way out might be the following: Assume that in addition to the *versions* of the observers, there is an *actual* observer. The probability would then be put in by supposing there is a probabilistic link between versions of the observer and the ‘actual’ observer. On each run, the actual observer has a probability of .1 of her perceptions corresponding to the H version of the observer and a probability of .9 of her perceptions corresponding to the V version.

But of course the trouble is, there is no *actual* observer in the mathematics; there are only *versions* of the observer. In addition, there is no mechanism in the standard mathematics for randomly apportioning the actual observer’s awareness to H or V. And so this scheme doesn’t work. See Part V for a more in-depth exploration of this type of interpretation.

The failure of the Everett many-worlds interpretation.

One must conclude that the origin of the probability law does not lie within the mathematics of the standard theory. That is, the many-worlds interpretation, which attempts to explain all observations from the consequences of the standard mathematics alone, fails. This is an important result. When combined with the results of A18.1 —a linear, non-unitary theory also cannot account for probability—it says that **a linear theory of quantum mechanics, plus the idea that the state vectors are all that exist, is not sufficient for describing the physical universe.**

The work of others.

Others—Vaidman [1,2], Deutsch [3,4], Saunders [5-7], Wallace [8,9], Zurek [10,11]—have attempted to show that the probability law does indeed follow from the standard mathematics. My analysis of their attempts is given in the arXiv paper *Problems with probability in Everett's many-worlds interpretation of quantum mechanics,* arXiv:0901.0952v3 They use various methods and assumptions to derive the coefficient squared ($|a(i)|^2$) form of the law. But in their derivations of the specific $|a(i)|^2$ law, they do not first satisfactorily show that standard quantum mechanics implies (coefficient-dependent) probability *at all*. That is, they do not show that the arguments given in this chapter, showing that probability cannot follow from the premises of standard quantum mechanics, are wrong.

What next?

What is usually done is either (1) assume there is probability-obeying collapse, so there is only one version of the observer; or (2) assume there are probability-obeying hidden variables which single out one version of the observer as the only 'conscious' one, the only one allowed to correspond to 'me.' The rest of Part III will be devoted to showing the problems associated with both of these possibilities. And then, because one has no confidence either collapse or hidden variables can be made to work, a different sort of proposal for explaining probability is made in Part V.

Evaluation.

The same as Ch. 8. Almost all physicists agree there is no probability hidden in basic quantum mechanics.

References.

[1] Lev Vaidman, *On schizophrenic experiences of the neutron or why we should believe in the many-worlds interpretation of quantum theory.* International Studies in the Philosophy of Science, Vol. 12, No. 3, 245-261 (1998).

[2] Lev Vaidman, *Many-Worlds Interpretation of Quantum Mechanics.* Stanford Encyclopedia of Philosophy. (http://plato.stanford.edu/entries/qm-manyworlds/) (2002).

[3] David Deutsch, *Quantum Theory of Probability and Decisions*, Proceedings of the Royal Society of London **A455** 3129-3137 (1999).

[4] David Deutsch, *Quantum theory of probability and decisions,* arXiv:quantph/ 9906015 (1999).

[5] Simon Saunders, *Derivation of the Born rule from operational assumptions*, arXiv:quant-ph/0211138v2 (2002).

[6] Simon Saunders, *What is probability?* arXiv:quant-ph/0412194v1 (2004).

[7] Simon Saunders and David Wallace, *Branching and uncertainty,* British Journal for the Philosophy of Science, **59**(3):293-305 (2008).

[8] David Wallace, *Quantum probability from subjective likelihood: improving on Deutsch's proof of the probability rule,* arXiv:quant-ph/0312157v2 (2005).

[9] David Wallace, *The quantum measurement problem: state of play,* arXiv:quant-ph/0712.0149v1 (2007).

[10] Wojciech Hubert Zurek, *Relative states and the environment: einselection, envariance, quantum Darwinism, and the existential interpretation,* arXiv:quantph/0707.2832v1 (2008).
[11] Wojciech Hubert Zurek, *Probabilities from entanglement, Born's rule from envariance,* arXiv:quant-ph/0405161v2 (2005).