**On measurement and quantum nondemolition**

(Letter to PHYSICS TODAY, July 2011, page 10. The paragraph in square brackets was omitted in the publication on request of the editor. As a substitute I added the last sentence of this Letter.)

In his letter, Christopher Monroe recommends that the term “quantum nondemolition” be abandoned (PHYSICS TODAY, January 2011, page 8). I agree, although for somewhat different reasons.

Quantum measurement theory has always used the concept of ideal measurements, or "measurements of the first kind," in which the state of the measured system does not change—that is, it is not "demolished"—if it is already in an eigenstate of the observable. Although an ideal measurement is often a good approximation when dealing with conserved particles, its realization requires special effort in the case of photons, which are usually absorbed while being measured. So while the concept of ideal measurements is certainly meaningful, I do not agree with the suggestion that the repeated preparation of the same photon state should be regarded as being equivalent to its nondemolition during a measurement. The term nondemolition may thus be quite useful in photon experiments or in the construction of gravitational-wave antennae, where it was first used, as far as I know. But in a general context, the traditional terminology would be more to the point, since nonabsorption of the measured photon does not necessarily define an ideal measurement.

Much of the confusion originates in the abridged description of a measurement as a stochastic jump from a superposition $a|0\rangle + b|1\rangle$ of a microscopic system into $|0\rangle$ or $|1\rangle$ with probabilities $|a|^2$ or $|b|^2$, respectively. That description is a relic from the times when quantum theory was expected to apply only to isolated atoms, electrons, and so forth. (It does *not* seem to be a genuine part of the Copenhagen interpretation, which describes measurement outcomes in classical terms and often assumes that the wavefunction loses its meaning thereafter.) In most situations, though, one has to include other interacting systems in the unitary description. In fact, all of the much-discussed weirdness of quantum theory has been *derived* by using entangled quantum states for all involved systems. Therefore, most of the inflationary confusing vocabulary of quantum weirdness—including spooky action, quantum teleportation, quantum eraser, quantum Darwinism, sudden death, quantum information, and even quantum jumps—could be abandoned if one used instead a consistent description in terms of entangled wavefunctions representing reality, at least as far as this entanglement remains relevant.[1] Usually this is so until irreversible decoherence, which was itself derived from unitary interaction with the environment, has occurred in the chain of interactions leading to observation. However, I think it is definitely wrong to say that decoherence theory allows us to "think of *any* measurement as a quantum nondemolition measurement plus a possible interaction with a reservoir."

[Probably the most misleading term ever used in quantum theory is "quantum information". A collapse (as used above) does not merely describe an increase of information, but evidently a *change of the physical state*. It is a shame that physics students are still taught that the wave function represents just probabilities, although we all know it to be wrong: the superposition a|0> + b|1> of two spin states, for example, represents *one* new spin state, while the wave function (a superposition of different classical configurations) defines real and measurable quantities, such as angular momentum or the ground state energy of the helium atom – to mention a well known nontrivial case. Nobody has ever succeeded in constructing a model that might allow us to derive the wave function as an epistemic concept. Physicist talking about quantum theory in this way are just using wishful thinking: the outcome of a measurement is created but not selected, as the states before and after measurement in the above example both represent complete information (with the same vanishing ensemble entropy). Therefore, the phrase that the wave function "is not real but represents information" reminds me of arguments used in homeopathy.]

Although I personally prefer the assumption that unitary dynamics is universal, I agree that some stochastic dynamics has to be *used* somewhere along the chain of interactions that ends at the observer. It does not matter whether you describe this observed indeterminism in terms of a collapse or a branching of a universal wavefunction into dynamically autonomous components (unlike the collapse, this branching does not require any new dynamical postulate; it is a consequence of the Schrödinger equation with local interactions). Such a real or apparent collapse is an important part of the effective dynamics of "our quantum world"—our "branch," if you like—that should be carefully analyzed rather than being used ad hoc in a pragmatic and confusing manner. In neither case would it describe a mere increase of information about an initially incompletely known quantum state of the involved systems; the indeterminism is described by a *change* of a state which is known to be different from an ensemble of potential states.

**Reference**

1. See, for example, H. D. Zeh, *Found. Phys.* **40**, 1476 (2010).

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