We agree with many of the points put by Zeh [1] in response to our Letter [2], in particular the importance of the environment and decoherence for reduction, position localisation and measurement, and the proven advantages of continuous physical theories over discrete ones. We agree that for some practical purposes the “decoherence can be interpreted as the occurrence of dynamical discontinuities”. We also agree that “density matrices are effectively equivalent to ensembles of narrow wave packets”.

But unlike Zeh we have an equation for the wave packets, and it is this to which he appears to object, since the equation is different from the Schrödinger equation.

It is not clear to us why he should object to those who wish to represent his narrow wave packets explicitly. Let us therefore provide a chain of reasoning which leads to our state diffusion picture of open quantum systems, details of which are in ref. [3] (see also ref. [4]), and other stochastic theories using quantum jumps.

It is common ground that quantum mechanics forces us to abandon something of classical physics. In particular the violation of Bell’s inequalities tells us that locality must be abandoned [6]. This violation is a physical property of classical events linked by quantum systems, and is independent of whatever quantum theory one may choose. On the evidence of experiment, nonlocality is a physical fact. To our knowledge there is no such evidence which forces us to abandon other aspects of classical physics, in particular that where waves have negligible effect, they have negligible amplitude. (Try this for water waves or classical electromagnetic waves.) So it is worth seeking a quantum theory which abandons locality, because it has to, but keeps these other aspects impact.

When this is applied to de Broglie waves, the Schrödinger equation has to be modified. For example, when a single photon is diffracted by two slits, and absorbed by a screen on the other side, the effect of the photon is localised in a small region of the screen. Since there is no effect on the screen anywhere else, the amplitude of the de Broglie wave should become negligible everywhere else. This narrowing or spatial localisation of the wave is achieved in the quantum state diffusion theory, and in some other stochastic theories, but it violates Schrödinger’s equation. This is an “observable effect”, in the
sense that the term is used in classical physics, that deviates from the global Schrödinger equation. We realize of course that according to a many-world-components interpretation of quantum mechanics such effects are observed in one world-component, but not in others, and that the waves that have a negligible effect in our world-component do have effects in other world-components \[1,7\]. Thus, in order to explain the unobserved, this position requires the introduction of infinitely many parallel world-components that cannot communicate with one another. But this is too high a price to pay just to save an equation, even the Schrödinger equation. Parallel world-components could be used to justify any theory which makes superfluous predictions, not just quantum mechanical theories. The superfluous predictions just happen in the other world-components, not ours. Physical scientists are helped by removing superfluous predictions, as shown by the advantages of using the state diffusion theory in practice \[3\]. This is a strong reason for preferring additional stochastic terms in the Schrödinger equation to infinitely many parallel world-components, although we acknowledge that neither is perfect. For further arguments see the articles by Gisin \[8\] and Shimony \[9\].

In the state diffusion and quantum jump theories described in refs. \[3,4\], the expectation values of physical quantities computed using the density matrix and those values obtained as averages over samples of an ensemble produced by the stochastic equations are the same. Each sample behaves like a single run of a laboratory experiment, and the expectation values are derived as averages in the same way. This can and has been used as a practical way of computing the evolution of open quantum systems \[3-5,10\]. Thus the state diffusion model of open systems is better for some practical purposes than the usual theory based on the density operator, and this is a direct result of using a representation that dispenses with superfluous predictions. The Schrödinger equation is no longer the best for all practical purposes \[11\].

We would like to thank H.D. Zeh for sending his Letter to us in advance of publication and A. Shimony for his comments on our manuscript.

References

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