Logical explanation of wave vector collapse

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In his most recent reply to the present author's attempts to defend an objectivist interpretation of quantum measurements which does not involve attributing any special role to the observer's consciousness (Villars, 1982, 1983), D.F. Lawden appears to accept that the proposed interpretation is logically consistent but re-emphasises his criticism that it provides "no scientific explanation" of the phenomenon of state vector collapse (Lawden, 1983b). In particular, he considers the postulated unique behaviour of observing instruments during observations to be "completely unexplained" and to constitute "a wholly mysterious or occult element" of the interpretation.

It is true that the proposed interpretation offers no physical explanation, in the sense of a derivation from more general physical laws, of the reduction of state vectors during observations. These events are simply postulated in special axioms of the theory. However, it does not follow that these events are "wholly mysterious". Quantum theory has other axioms, for example, the Schrödinger equation itself (axiom IV in M. Jammer's simplified presentation of the quantum formalism (Jammer, 1974)), which are similarly incapable of physical explanation, but which, presumably, Lawden does not find particularly mysterious. Why does the phenomenon of state vector collapse seem so mysterious?

That a special class of physical interactions (observation interactions) should obey special laws not derivable from the general laws governing all other physical interactions is clearly contrary to Lawden's statement that he expects "any fundamental physical theory to treat all physical entities impartially" (Lawden, 1983a). According to this view, observation interactions ought to be just ordinary physical interactions. The proposed interpretation says that they are not, and hence, must appear strange. However, it will be argued below that quantum theory is a fundamental physical theory which simply does not support Lawden's general expectation. Quantum theory does not treat all physical systems impartially, but makes a fundamental distinction between observing instruments and all other physical systems. The fundamental concepts in terms of which the theory is formulated make essential reference to observing instruments which consequently have a special role in the theory. If this fact is taken into account, it is possible to give a logical, or intuitive, explanation of state vector collapse which may perhaps dispel the apparent mysteriousness of these events. To show this, it is necessary to consider briefly the meaning of observables and states in quantum physics.

Classical physics described physical systems in terms of intrinsic properties, i.e. properties they possessed in themselves independently of our means of observing them. The possibility of this mode of description depended on our ability to make observations of, in principle, unlimited precision. In classical physics, the effect of the observation interaction on the observed object could always be made negligibly small, and consequently, the results of observation could be interpreted as representing properties of the observed object alone.

The discovery of the quantum of action, h, i.e. a very small, but nevertheless finite, and indivisible, lower limit to the magnitude of all physical actions, has forced quantum physics to abandon the classical mode of description. In quantum physics, an observation always involves an irreducible and unanalysable interaction with the observed object which, due to the very low masses of the objects observed, will generally be significant, i.e. non-negligible, in comparison with the quantity being measured. As Bohr, in particular, has repeatedly emphasised, in quantum physics, the observation interaction forms an inseparable part of what is observed (Bohr, 1963). Results of observation must be interpreted as representing properties of the observation interaction as a whole, not properties of the observed object alone.

Thus, whereas in classical physics what was observed of a physical system was its intrinsic properties, in quantum physics what is observed is the interactions between the system and our observing instruments. This change in the meaning of observables is reflected in a change in the meaning of states. A classical state was the totality of the actual values of the intrinsic properties of a system at a given time. A quantum state is the potentiality of a system, at a given time, for interacting with our observing instruments to produce particular observational results. This potentiality has two components; a range of possible interactions, each corresponding to a particular observational result, and a weight, or probability, associated with each possibility.

Consider an experiment to observe the position of a photon using a fixed photographic plate. Before the observation interaction, the photon may be represented by a wave extending over the whole surface of the plate. This wave, not an actual wave spreading in 3-dimensional space, but a probability wave evolving in a complex vector space called Hilbert space, represents the potentiality of the photon for interacting with the plate to produce marks at definite positions. It represents all the possible interactions of the photon and their respective probabilities. The wave extending over the whole surface of the plate indicates that it is possible for the photon to interact anywhere on that surface, and the intensity of the wave at any point gives the probability of the interaction occurring there. During the observation interaction, the photon actualises one of these possibilities, ionising a particular atom and giving rise to a mark at a particular point. As a result, its potentiality changes abruptly. In particular, it will in general no longer be possible for it to interact at all other points of the surface; in actualising one possibility, it excludes the others. This abrupt change in the range of potential interactions open to the photon due to its actualisation of one of them is what is referred to as the collapse, or reduction, of the state vector.

Why do reductions of state vectors only occur during observation interactions and not during all physical interactions generally? According to the preceding explanations, a state vector represents the potentiality of a physical system for interacting with observing apparatus to produce particular results and the reduction of a state vector represents the actual occurrence of one of these potential interactions. Given this interpretation of the terms, the question becomes, Why do physical systems only actualise their potential interactions with observing apparatus when they interact with observing apparatus? Now the answer is obvious, for it is only when interacting with observing apparatus that a physical system *can* actualise one of its potential interactions with apparatus. Understood in this way, the reductions of state vectors seem obvious and logical and not "wholly mysterious or occult".

It must be emphasised that the above considerations are not intended as a physical explanation of state vector collapse, but merely as an intuitive explanation which, hopefully, indicates why the present author at least does not find these events, interpreted objectively, to be "wholly mysterious" or "crying out for explanation". Though no physical explanation of how state vector collapse occurs can be given, these events do not seem mysterious if we take into account what state vectors, and their reductions, represent.

References

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