Comment on "Hidden assumptions in decoherence theory"

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It is shown that the conclusion of the paper "Hidden assumptions in decoherence theory" [1] is the result of a misunderstanding of the concept of pointer states. It is argued that pointer states are *selected* by the interaction of quantum systems with the environment, and are not based on any *measurement* by a conscious observer.

Italo Vecchi has very recently written an article which apparently points out some "hidden assumptions" in the formulation of the idea of decoherence [1]. The author claims that there is an ambiguity in the formulation of decoherence in that any vector can be chosen as a pointer basis. We show here that it is not so, and the claim is born out of a misunderstanding of the idea of pointer states.

The author starts his argument by considering a system S which is in a superposition of certain eigenstates $|n\rangle$ and its environment W which is in a state $|\Phi_0\rangle$. The evolution can then be described as

$$\sum_n c_n|n\rangle|\Phi_0\rangle \rightarrow exp(iHt)\sum_n c_n|n\rangle|\Phi_0\rangle \rightarrow \sum_n c_n|n\rangle|\Phi_n(t)\rangle$$

Now, the author of [1] claims that $|\Phi_n(t)\rangle$ are pointer states. He further goes on to say that "any act of measurement on W induces a collapse of its vectors into one of the pointer vectors". As we started from the assumption that W is the environment with which S is interacting, it is ridiculous to talk of a measurement on the environment. Environment is not something which can be controlled or measured. The source of confusion can probably be traced back to the article by Joos where he uses the states of the apparatus-environment combined [2].

Pointer states are emergent states of a quantum system, the *pointer*, or the *apparatus*, because of interaction with the environment. These states of the apparatus emerge as stable states as a result of environment induced super-selection. Superposition of these states would be destroyed by the environment.

In fact, in the above example, if S is assumed to be the *apparatus* interacting with the rest of the world, that is, an environment W, it can be used to understand the concept of pointer states. Of course, for a rigorous calculation, one has to consider a specific model of the environment. In this case, clearly, the pointer states are $|n\rangle$ because S was in some arbitrary state, which was represented as a superposition of the states $|n\rangle$, and after interacting with the environment, these states get entangled with certain environment states $|\Phi_n(t)\rangle$, which will eventually lead to a loss of coherence between the different $|n\rangle$ states. The states $|n\rangle$ are not arbitrarily *chosen* by any external measurement, but*emerge* because of the nature of the interaction and nature of S itself.

There are several examples available in the literature where pointer states are shown to emerge from an interaction with the environment [3,4]. For a harmonic oscillator interacting with the environment, coherent states emerge as pointer states [4]. In [4], a harmonic oscillator is assumed to be acting as a pointer for measuring a spin-1/2. This calculation doesn't rely on any concept of predictability sieve. The superpositions between the coherent states are destroyed because of interaction with a model environment which has an infinite number of degrees of freedom.

The author's other statement, "...it is based on the unphysical no-recoil assumption on th scattering process...", is also baseless, because the whole argument is not based on the no-recoil assumption, which is just an approximation to derive a simplified result. Apparent diagonalization of a system's density matrix can be demonstrated using exact quantum dynamics of a model system coupled to a model environment [3].

The author's example of Planck's radiation law can be easily understood in the light of the recent results of Paz and Zurek [5] which show that for quantum systems very weakly coupled to the environment, energy eigenstates are the pointer states. Thus one knows that the right thing to do is to apply the entropy maximization to the discreet energy spectra, and not to any other basis. Thus one doesn't need any observer for Planck's law, as claimed in [1]. Rayleigh-Jean's law is just the long wavelength limit of Planck's law. In other words, in the appropriate limit, Planck's law *appears to be* Rayleigh-Jeans law, and one does not need to invoke an *observer* associated with continuous spectra.

In conclusion, we emphasize that the pointer states are the emergent stable states of a quantum system because of its interaction with the environment, and are *not* an outcome of any measurement by an observer. Thus there is no hidden assumption in the decoherence theory in this regard, as claimed in [1].

[1] *Hidden assumptions in decoherence theory*, I. Vecchi, quant-ph/0001021.

[2] *Decoherence through interaction with environment*, A. Joos in *Decoherence and the appearance of a classical world in quantum theory*, eds. Guilini et al. (Springer) (1996)

[3] Environment-induced decoherence: The Stern-Gerlach measurement, A. Venugopalan, D. Kumar, R. Ghosh, Physica **220** (1995) 563.

[4] *Pointer states via Decoherence in a Quantum Measurement*, A. Venugopalan, quant-ph/9909005 (To appear in Phys. Rev. A)

[5] *Quantum limits of decoherence: environment induced super-selection of energy eigenstates*, J. P. Paz and W. H. Zurek, Phys. Rev. Lett. **82** (1999) 5181