Measurement problem and emerging tachyons (very brief synopsis of a very brief talk)

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The infamous so called measurement problem in quantum mechanics doesn't need any introduction to. Everybody knows about the miserable fate of the Schrödinger's cat and about the somewhat contradictory nature of the standard description of quantum mechanics, that tries to combine unitary evolution with the Von Neumann's reduction postulate.

There are several ways to deal with this problem, from which the most widespread one is to ignore it. The modern version of this ignoring usually appeals to the decoherence processes, claiming that the reduction postulate can nowadays be forgotten in favour of rapid and inevitable decoherence. That is unfortunately (or maybe luckily) not the case: the careful analysis shows that decoherence alone doesn't provide enough explanation to the problem, and there still remains a need of Born's rule in some form, which returns us to the beginning.

The more or less reasonable attempts to solve the problem are the following: (1) many-worlds interpretations, (2) rather mysterious modal interpretations, (3) elaborate philosophical arguments that the problem is ill-formulated and there actually is none, (4) theories of hidden variables, and finally (5) the brute force inserting of the wave-function reduction in the evolution law. There are many subcases of these approaches, but one can calmly admit that none of them is satisfactory.

The last method of attack differs from all the others in the way it affects the predictions of the theory: that is, it does actually affect them, though very slightly. The first consistent collapse theory is known as GRW [Ghirardi, Rimini, Weber, 1986]; the struggle of avoiding some of its bad behaviour leads to the CSL (Continuous Spontaneous Localisation) model [Pearle, 1989], that does its work of describing quantum world quite well. The "only" problem is to formulate its relativistic version, which remains at least partially open until today.

What is bad about the direct relativistic analogue of CSL is that it leads to such absurdities, as the almost immediate creation of infinite number of particles from vacuum state – the effect known as vacuum instability. The rather recent idea of Pearle is to consider the tachyon excitations of the collapse field and it surpisingly seems to be a nice way of dealing with the mentioned difficulties. It's interesting that the tachyonic structure naturally appears in this model, taking in the account that we are trying to deal with nonlocal theory of quantum mechanics.

What is also interesting and absolutely unknown (as far as the author is concerned) is the emerging of tachyons from the much more simple and naive toy model (V. A. Franke, 1976). One can consider the well-known Lindblad equation

$$\dot{\rho} = -i[H, \rho] + \sum_n \left(2A_n \rho A_n^+ - A_n^+ A_n \rho - \rho A_n^+ A_n\right)$$

not as describing the decoherence, but as a fundamental one describing the evolution instead of the Heisenberg (Schrödinger) one

$$\dot{\rho} = -i[H, \rho].$$

Such modified theory will not escape the measurement problem (because of the same reasons as in the case of usual decoherence only), but will at least have the “incorporated” decoherence inside. Then the natural thing to do is to look at the relativistic modification of the equation, taking it for example in the Tomonaga-Schwinger form:

$$\frac{\delta \rho^{(int)}}{\delta \sigma(x)} = -i[\mathcal{H}_{int}(x), \rho^{(int)}].$$

If we let collapse field be scalar one $\varphi(x)$, the resulting equation will have this form:

$$\frac{\delta \rho^{(int)}}{\delta \sigma(x)} = -i[\mathcal{H}_{int}(x), \rho^{(int)}] + \lambda \left(2\varphi(x)\rho\varphi^+(x) - \varphi^+(x)\varphi(x)\rho - \rho\varphi^+(x)\varphi(x)\right).$$

Here $\rho^{(int)}$ is taken in the interaction picture, $\mathcal{H}_{int}(x)$ is the interaction hamiltonian density, $\sigma(x)$ is any space-like hyperspace and λ is the (very small) coupling constant. The condition of integrability is the locality of all field operators (i.e. they have to commute if taken in two space-like separated points).

Now it’s easy to see that this equation leads to the immediate creation of particles from the vacuum state $\rho_0 = |0\rangle\langle 0|$ thanks to the members of the form $\lambda\varphi(x)\rho\varphi^+(x)$. The core of the problem is that the local operators $\varphi(x)$ can not annihilate the vacuum state ($\varphi(x)|0\rangle \neq 0$), which is prohibited by the theorem of the axiomatic QFT. However the proof of this theorem relies also on the positive mass of the field, and if we let the mass be imaginary then it appears to fail.

There can of course be also some interaction between the “real” (say, fermionic) and the tachyonic fields. Such hamiltonian will allow spontaneous creation of the fermion-tachyonic pairs with the rate controlled by the coupling constant, which is presumed to be sufficiently small. The interesting observation is that these tachyons can be destroyed by the “Lindblad” items of the equation, whereas fermions survive. Effectively it looks like the very slow creation of matter — which can appear useful in some cosmology models concerning for example the inflation of the Universe right after the Big Bang.

Nowadays tachyons are also often mentioned in the context of string theory, where people are usually trying to eliminate them as soon as possible. If we also recall the vague hypotheses [Penrose etc] that the spontaneous collapse of wave-functions may have something to do with gravity fluctuations, the whole matter becomes really intriguing.

> There was a young lady named Bright,
> Whose speed was far faster than light.
> She went out one day,
> In a relative way,
> And returned the previous night!
>
> — *Reginald Buller, researcher of fungi*