# Review of: "Relation Between Quantum Jump and Wave Function Collapse"

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Relation between quantum jump and wave function collapse

by Tadashi Nakajima

By adopting the postulate of Microscopic Quantum jump (MIJ) and by discarding the Postulate of Classicality of the Apparatus (PCA), in his paper I [1], the author, in his own words, has constructed "a measurement theory consistent with standard quantum mechanics".

In this second paper, Nakajima, based on the first paper, discusses the question of the wave function collapse as the "major remaining question in the theory of quantum measurement", stating that the difficulty of finding a solution to this question stems from two facts:

a) in the past, "it has been not recognized that single-particle quantum mechanics and many-particle quantum mechanics must be treated separately"

b) "quantum jump (QJ) and wave function collapse (WFC) need clearer definitions". In this context, the author defines "a QJ as a process of selecting a set of system eigenvalues (SEVs) of an observable and a WFC as a process of determining the probability distribution (PD) of SEVs, both from a single measurement. "

In paper I, the author exemplifies his new interpretation of the measurement problem in Quantum Mechanics by discussing two examples of measuring apparatuses, the micro-channel plate (MCP) and the Wilson Cloud Chamber (WCC) to illustrate the case of single-particle quantum mechanics. In the MCP case, a single photon passing through a double slit is detected by an MCP; in the second case, an alpha particle coming from the decay of an atom of U^(238) is detected as a track in a WCC. In both cases, "a single quantum system interacts with only one particle in an apparatus at a time as a quantum jump (QJ)".

In the first case, the QJ (photoelectric effect) generates a microscopic particle (an electron), potentially carrying the information of the system eigenvalues (SEV), which is subsequently amplified or accumulated to obtain the statistics of the SEVs. The author considers that both processes (amplification and accumulation) are outside the domain of single-particle quantum mechanics. Moreover, since to obtain the complete statistics of the SEVs one has to repeat many times the same experiment, it is concluded, according to point b) above, that "for single-particle quantum mechanics, a MIJ does not produce a probability distribution (PD) and the wave function does not collapse". I shall discuss the WCC case later.

Even though the conclusion is correct in the logical frame described by points a) and b) above, it is very hard to believe that the wave function of the photon prepared in the two-slit mode does not collapse at the QJ. After all, in the photoelectric effect, the photon disappears and an electron is created whose wave function bears no direct relation with that of the original photon.

A way out of this bewildering conclusion is to abandon the artificial distinction between single-particle and many-particle quantum mechanics in the measurement process and return to the original view that a single quantum system interacts with the enormously many degrees of freedom of the measuring apparatus. In fact, the apparatus is made up of atoms to which quantum mechanics can be applied. In this context, the statement that the processes of amplification and accumulation in a detector are outside the domain of single-particle quantum mechanics seems to be a tautology without physical justification.

This point is better illustrated by the second case discussed by the author, the Wilson Cloud Chamber. The debate on how to reconcile the observation of tracks, pointing to a particle-like behavior, with the quantum wave nature of the α-particle in the cloud chamber has gone on since the beginning of Quantum Mechanics. Two possible approaches were considered:
1) in the first, the α-particle is the quantum system under consideration (while the gas of the chamber is part of the measuring device)
2) in the second, the quantum system consists of the α-particle and the atoms of the gas.

It is noteworthy that both Born and Heisenberg considered the two points of view completely equivalent in the endeavor to guarantee the consistency of the standard interpretation of quantum theory, ascribing the appearance of the track to a wave packet reduction process at each ionization event.

This latter seems to be the attitude of the present author when he states that the "ionization track is the result of a series of position measurements of the droplets carrying the information of the passage of the α-particle. In a sense, the track is an ensemble of the positions of the α-particle".

The author seems to consider the emergence of the track as a result of a series of independent position measurements of the α-particle. However, his explanation of the linearity of the track is not convincing, if not incorrect.
The fact that sqrt(σ)/x is $10^{-4} \ll 1$ (where σ is the ionization cross section of a $N_2$ molecule by an α-particle and x is the mean free path before one ionization occurs) is not sufficient to ensure not only the linearity of the track but even its emergence. This is easily seen by assuming for example a spherical cross section for the ionization impact. One should supplement this information with the condition that the cross section is strongly peaked in the forward direction with respect to the momentum direction of the α-particle, as shown by Mott [2] in his quantum mechanical treatment of the ionization event of the α-particle with two hydrogen atoms, where it is shown that the probability of consecutive ionization of the two hydrogen atoms is different from zero only if the two atoms are collinear with the position of the emitting source of the spherical wave.

But this is not the whole story. In fact, the presence of another atom along the line connecting the source of the α-particle with the first two scatterers has the effect of reinforcing the forward scattering probability, a phenomenon well known in multiple scattering theory. For example, the emission probability of a photo-electron originated from a localized core state in a solid (and therefore in a definite angular momentum state) is enhanced if there is a collinear configuration of atoms along the direction of observation. Even though in this example one is dealing with elastic electron-atom scattering, the dynamical situation is very similar to the $N_2$-ionization by an α-particle in the WCC, which is quasi-elastic due to the fact that "the ratio of the ionization potential of a $N_2$ molecule (15 eV) and the kinetic energy of the α-particle (5MeV) is $3 \times 10^{-6} \ll 1$".
Indeed, quoting a very interesting paper on the subject [3], "the classical behavior of the α-particle is far from being universal. A completely dissimilar behavior has to be expected if the values of the physical parameters are different". I refer to this article for a comprehensive discussion of the Mott paper regarding the interpretation of the WCC measuring device in the scientific context at the time of its publication.

Therefore, in order to explain convincingly the phenomenology of the Wilson Cloud Chamber, one is

led to consider the interaction of the α-particle with all the N2 molecules in the chamber. In this case, the wave function collapse of the original α-particle is from a spherical wave to an eigenstate of the momentum operator.
This is in contrast with the attitude of the present author, who tends to distinguish between single-particle and many-particle quantum mechanics in the measuring problem.

One might mention other instances where this distinction is clearly not possible, namely in all the cases where the measuring device is a macroscopic quantum system, like a crystal. Bragg diffraction for measuring the wavelength of a photon or its polarization state by a tourmaline crystal are such examples. In these cases, the result is due to a coherent long-range interference of the particle with the measuring apparatus.

Finally, it is difficult to judge the conclusions of the author in the case of many particle QM due to the lack of concrete measurement examples.

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[1] T. Nakajima, “Microscopic quantum jump: An interpretation of the measurement problem,” Int J Theor Phys 62, 67 (2023).

[2] Mott N.F., The wave mechanics of α-ray tracks. Proc. R. Soc. Lond. A, 126, 79-84, 1929.
Reprinted in: Wheeler J.A., Zurek W., Quantum Theory and Measurement, Princeton University Press, 1983.

[3] Figari R. and Teta A., Emergence of classical trajectories in quantum systems: the cloud chamber problem in the analysis of Mott (1929) ArXiv:1209.2665v1 [math-ph] 12 Sep 2012

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