Retro-Causation in the Quantum World – Do Quantum Objects Change Because of Future Events?

Sofia D. Wechsler

Abstract
An Afshar-type experiment is presented, using two entangled photons, A and B, tested by the experimenters Alice and Bob, respectively. The photon A is tested later than the photon B.
The problem posed is how many components (wave-packets) has the photon B. It is proved that their number depends on the type of test that Alice chooses to do on photon A. Despite the fact that by the time Alice tests her photon, the photon B doesn't exist anymore, it is shown that either the photon B *imposes to Alice* what type of test to perform, or photon B knows in advance what will be Alice's choice on the test-type, and adjusts its number of wave-packets accordingly. Moreover, contrary to the opinion of some physicists that accepting the existence of a preferred frame would solve the problem, it is shown here that even judging according with an absolute time, the backward-in-time effect persists.

Abbreviations

B-I-T = backwards-in-time
GRW = Ghirardi, Rimini, Weber
HWP = half-wave plate
PBS = polarization beam-splitter
QM = quantum mechanics
w-f = wave-function

I. Introduction

In trying to find out whether a quantum object feels in some way the detector before actually touching, and adopting, according to the type of test, the behavior of a particle or of a wave, J. A. Wheeler proposed a series of experiments known under the name "delayed choice experiments" [1]. The idea in these experiments was that it may be that in the microscopic world exists *backward-in-time influence* on the behavior of objects. Different experiments were done with the purpose to elucidate this issue, e.g. [2 – 8]. But no evidence was found on pre-measurement definite behavior as a particle, or as a wave. To the contrary, the Afshar experiments [6 – 8] showed that the quantum object has the special property of combining the two types of behavior.
L. de Broglie and later on D. Bohm actually suggested a formalism combining the wave behavior – a guide-wave – and the particle behavior [9 – 11]. Though, this formalism was proved by the present author as not compatible with the experiment [12].

Though, some physicists, mainly, the supporters of the GRW interpretation of the quantum mechanics (QM) [13], have another view on what makes the quantum object shrink to a small volume in space, as a particle

> "Our experience in the use of quantum theory tells us that the state reduction postulate should not be applied to a microscopic system consisting of a few elementary particles until it interacts with a macroscopic object such as a measuring device." [14]

In support of this view comes the fact that as long as no macroscopic detector is encountered, the quantum formalism treats the quantum object like a wave – the wave-function (w-f). In case of a multi-particle system, it is treated as a multi-wave. The results of this procedure were never contradicted by the experiment.

On the other hand, the question whether the quantum world allows *influence backwards-in-time* (B-I-T), was never solved. Examples raising this problem are offered by entanglements if the two or more entangled systems are tested *non*-simultaneously. Many experiments were done which illustrate this (at least apparent) influence. A notorious experiment is the one performed by Pan et al. [15], with two pairs of entangled photons, 1 and 2, and 3 and 4 – figure 1. Obviously the photons 1 and 4, as well as 2 and 3, are independent of one another. However, 1 and 4 may be rendered entangled by the test of 2 and 3. This effect is not related to the time at which are tested 2 and 3, i.e. they may be tested later than 1 and 4, and even *in the future light-cone* of the test of 1 and 4. Thus, it seems that the state of 1 and 4, i.e. entangled or not, is established B-I-T from the future.

In the present text, the problem of the B-I-T influence is posed in a harder way. A quantum system is considered a *really exiting object* which travels in our apparatus. About the w-f, this text does not take the part of those who consider the w-f ontic, or epistemic. This issue was, and is, widely debated, see for instance [16 – 21]. Only a minimal property is assumed: *there where the w-f is non-zero, the quantum object is present, and vice-versa*. Thus, if the quantum object has two or more parts, the w-f contains accordingly two or more wave-packets, and vice-versa. That contrasts with the view of some researchers who consider the wave-function as a mere utility of calculating probabilities, e.g. [21].

However, the view adopted here has drastic consequences, as it will appear in the next sections. If the retroactive influence exists, it may entail that parts of one quantum object can be *physical destroyed* because of a test done *later in time* on another quantum object. For illustrating the problem, an experiment is presented in which two entangled quantum objects A and B are tested, A being tested later than B. Before any measurement, the w-f indicates that the system B occupies two regions in space. However, for a particular result produced by A, the part of the object B in one of the regions should not have existed as a *retro-consequence*.

The above issue invites a comparison with the major NO-GO rules of the macroscopic physics. In the macroscopic world, a major restriction is the impossibility to surpass the light velocity, which, in particular, makes impossible faster-than-light communication. As a consequence, the retro-causation is also impossible in that world. The impossibility of retro-causation has its deep root in the fact that time-loops, i.e. re-writing the past, would mean an unstable universe in which it is not clear which event happens at a given time, i.e. how the universe looks like at a given time.

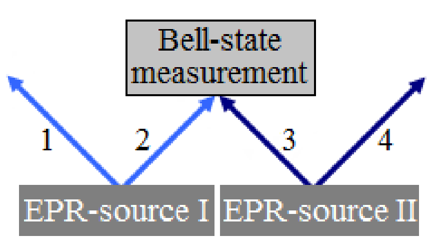

Figure 1. Entanglement swapping (see explanations in the text)

Faster-than-light communication is impossible in the quantum world too, as well-known from the *non-signaling theorem* [22]. However, the retro-causation seems to be allowed. This feature is encrypted in a visible way in the w-f of entanglements, when this is symmetrical in the quantum objects involved, and time-independent.

The next sections have the following content: section II presents three thought-experiments on two particles, in two of the experiments the particles being tested non-simultaneously. Section III discusses what can be inferred from these experiments, pointing to the fact that retro-causation cannot be denied. Section IV contains discussions and conclusions.

II. Three thought-experiments with two photons

Experiment 1.

Consider two down-conversion photons, A and B, prepared in the state

$$|\phi\rangle = |\mathbf{D}\rangle_A |\mathbf{D}\rangle_B, \quad (1)$$

where **D** is the polarization along the first diagonal $|\mathbf{D}\rangle = (1/\sqrt{2})(|\mathbf{H}\rangle + |\mathbf{V}\rangle)$. The photon A (B) flies to the station of the experimenter Alice (Bob) – figure 2. The delay on the path of the photon A is removed in this experiment s.t. the detection of the photon A heralds the presence of the photon B in Bob's apparatus.
On the way of the photon A are introduced three polarization beam-splitters, $PBS_{A'}$, $PBS_{A''}$, and PBS_A, the first one and the latter separating spatially the polarizations as shown in the figure, and $PBS_{A''}$ rejoining the wave-packets polarized **H** and **V**. On the way of the photon B is introduced only one polarization beam-splitter, PBS_B, which separates spatially the polarizations **H** and **V**. The polarization **V** is rotated in continuation by a half-wave plate (HWP) onto –**H**. Ignoring the jumps in phase at the phase shifters and at the mirrors, which are identical for both outputs of PBS_B, the photon B undergoes the transformation

$$|\mathbf{D}\rangle_B \rightarrow 2^{-1/2}(-|\mathbf{H};\text{up}\rangle_B + |\mathbf{H};\text{down}\rangle_B). \quad (2)$$

This relation shows the following: *a*) if a photographic plate would be placed in a **x-y** plane close to PBS_B,

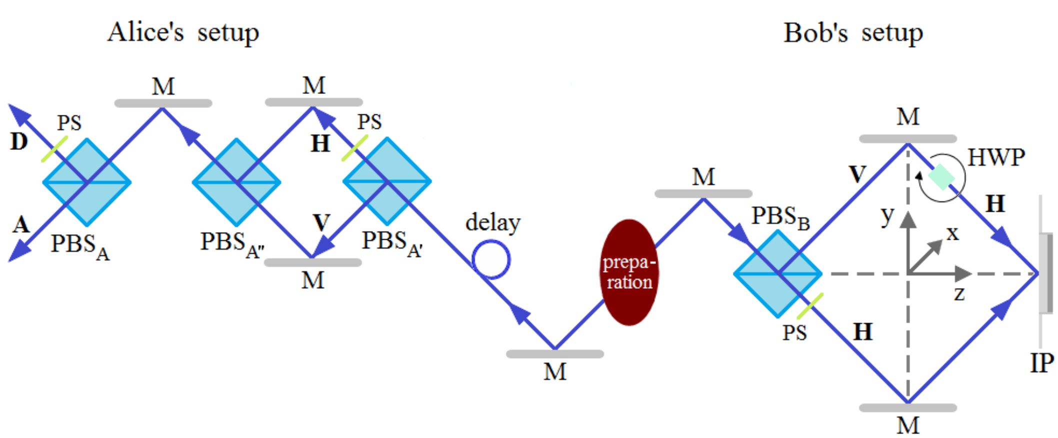

Figure 2. A configuration for two-photon interference experiments.
The delay in Alice's setup is optional, it is introduced only if Alice's test is meant to occur later than Bob's test. M symbolizes a mirror. PBS_A, $PBS_{A'}$, $PBS_{A''}$, and PBS_B, are polarization beam-splitters. The phase shifts PS on the wave-packets transmitted by the splitters, introduce the same change in phase, as the change caused to the reflected wave-packets at the reflection on the glue layer between the two prisms of the splitter. Alice may choose freely to place detectors on the outputs of PBS_A, in which case the phase-shifter on the output **H** of $PBS_{A'}$ is not necessary, or to place the detectors on the outputs of $PBS_{A'}$, in which case the phase-shifter on the output **H** remains in place. PBS_B separates between the polarizations **H** and **V**. The polarization **V** is rotated in continuation onto –**H** by a half-wave plate, HWP. IP is a **x-y** plane passing through the center of the interference region of the output beams of PBS_B.

– such a position is not shown in the figure – in each particular detection obtained by Bob the plate would be impressed either in the upper part, touched by the upper wave-packet, or in the lower part, touched by the lower wave-packet; *b*) if the plate is displaced to the plane IP, which crosses the middle of the overlapping region of the wave-packets, there appears an interference tableau with a dark fringe at $y = 0$.

Alternatively, the experiment can be done with an initial wave-function

$$|\phi\rangle = |\mathbf{A}\rangle_{\mathrm{A}} |\mathbf{A}\rangle_{\mathrm{B}}, \tag{3}$$

where **A** is the polarization along the second diagonal $|\mathbf{A}\rangle = (1/\sqrt{2})\,(|\mathbf{H}\rangle - |\mathbf{V}\rangle)$. Ignoring again phase changes which are identical for both outputs of $\mathrm{PBS_B}$, the photon B undergoes the transformation

$$|\mathbf{A}\rangle_{\mathrm{B}} \to 2^{-½}\{|\mathbf{H};\mathrm{up}\rangle_{\mathrm{B}} + |\mathbf{H};\mathrm{down}\rangle_{\mathrm{B}}\}. \tag{4}$$

On the photographic plate in the plane IP, would appear an interference tableau with a bright fringe at $y = 0$.

Experiment 2.

The setup is the same as in figure 2, however the down-conversion pair is prepared as a polarization singlet. The delay is present on the path of photon A and entails a retardation of the test of this photon by an interval Δt after the test of the photon B. On both sides the detection times are recorded for each photon. To the difference from experiment 1, at Alice's site is recorded the polarization of each photon A, and at Bob's site the photographic plate is replaced by a high-resolution 2D array of detectors, that allows recording the (*x*, *y*) position in the IP plane for each photon B.

Alice is free to place the detectors on the outputs on the outputs of $\mathrm{PBS_A}$, or on the outputs of $\mathrm{PBS_{A'}}$.

For the former case it is convenient to write the w-f as

$$|\mathrm{S}\rangle = 2^{-½}(|\mathbf{D}\rangle_{\mathrm{A}} |\mathbf{D}\rangle_{\mathrm{B}} + |\mathbf{A}\rangle_{\mathrm{A}} |\mathbf{A}\rangle_{\mathrm{B}}), \tag{5}$$

while for the latter case it is convenient to write the w-f as

$$|\mathrm{S}\rangle = 2^{-½}(|\mathbf{H}\rangle_{\mathrm{A}} |\mathbf{H}\rangle_{\mathrm{B}} + |\mathbf{V}\rangle_{\mathrm{A}} |\mathbf{V}\rangle_{\mathrm{B}}). \tag{6}$$

Alice and Bob are instructed to compare their results at the end of the experiment. Given that the time-difference between the detection of the photon B and its pair-photon A is fixed, Δt, it is possible to identify for each photon B, its pair-photon A. Thus the results of the experiment can be arranged in pairs ($\mathbf{P}_{\mathrm{A}}$, $\mathbf{r}_{\mathrm{B}}$) where $\mathbf{P}_{\mathrm{A}}$ is the polarization of the photon A, and $\mathbf{r}_{\mathrm{B}}$ the position of the photon B in the plane IP. After that, the pairs are separated in four sets, one with $\mathbf{P}_{\mathrm{A}} = \mathbf{D}$, one with $\mathbf{P}_{\mathrm{A}} = \mathbf{A}$, one with $\mathbf{P}_{\mathrm{A}} = \mathbf{H}$, and one with $\mathbf{P}_{\mathrm{A}} = \mathbf{V}$. All the positions $\mathbf{r}_{\mathrm{B}}$ in a set are drawn on a plane, separate for each set.

In the plane with the positions $\mathbf{r}_{\mathrm{B}}$ of the set with $\mathbf{P}_{\mathrm{A}} = \mathbf{D}$, there appears an interference tableau with a dark fringe at $y = 0$, as in the first part of the experiment *1*. Similarly, in the plane with the $\mathbf{r}_{\mathrm{B}}$s of the set with $\mathbf{P}_{\mathrm{A}} = \mathbf{A}$, an interference tableau appears with a bright fringe at $y = 0$, as in the second part of the experiment *1*.

However, in the plane of the each one of the sets with $\mathbf{P}_A = \mathbf{H}$ and $\mathbf{P}_A = \mathbf{V}$, there appears a uniform tableau with no structure.

Let's notice that unless this separation of patterns according to Alice's result, the positions recorded by Bob form a uniform tableau. Indeed, for the interference patterns, the bright fringes of one pattern cover the dark fringes of the other, and on top of this come the uniform patterns.

Experiment 3.

This experiment proceeds as the experiment *2*, with a couple of differences – figure 3. In the interference plane IP, instead of detectors are introduced thin horizontal wire absorbers. Bob may choose the altitudes *y* of the wires in two ways: *a*) at the altitudes of the maxima of the interference pattern produced by (2); *b*) at the altitudes of the maxima of the interference pattern produced by (4).
After the interference region, the wave-packets $|\mathbf{H}; \text{up}\rangle_B$ and $|\mathbf{H}; \text{down}\rangle_B$ meet a convergent lens which sends them to a net of detectors. $|\mathbf{H}; \text{up}\rangle_B$ meets the detectors in the region R_1, and $|\mathbf{H}; \text{down}\rangle_B$ in the region R_2.

At the end of the experiment, the pairs of photons are identified and separated into four sets as in the experiment *2*.

Obviously, with the wires at the heights defined by the option *a*, for the set $\mathbf{P}_A = \mathbf{D}$ the number of detections will decrease in both regions R_1 and R_2, while for the set $\mathbf{P}_A = \mathbf{A}$ the number of detections will be only weakly affected in each region. With the option *b* the two sets will be affected vice-versa.

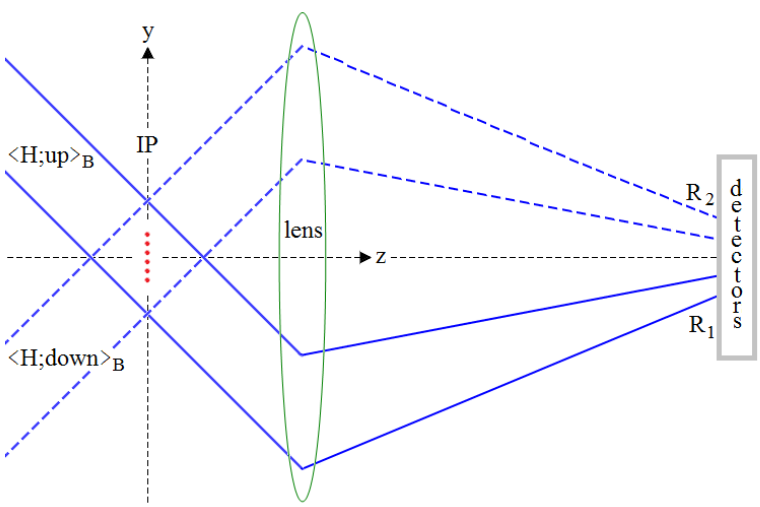

Figure 3. An Afshar-type experiment for testing retro-causation.
(Not to scale.) In the interference plane IP are introduced thin absorbing wires (red) perpendicularly on the plane z-y. The convergent lens redirects the photon beams to the net of detectors. The wave-packet $|\mathbf{H}; \text{up}\rangle_B$ meets the detectors in the region R_1, and the wave-packet $|\mathbf{H}; \text{down}\rangle_B$ in the region R_2.

For the sets $\mathbf{P}_A = \mathbf{H}$ and $\mathbf{P}_A = \mathbf{V}$, the total number of detections will decrease equally. Also, there won't be a difference between the decrease in the option *a*, and that in the option *b*. Differences will be between the number of detections obtained in the two regions: for $\mathbf{P}_A = \mathbf{H}$ ($\mathbf{P}_A = \mathbf{V}$) the detections in the region R_2 (R_1) will be significantly reduced while those in R_1 (R_2) will be less affected.

III. Can a future event erase a present part of a quantum object?

The experiment *1* reveals a major fact: *which-way tests do not tell us all the truth*. If the photographic plate is placed close to PBS_B, in each trial of the experiment a dark point appears, either on the upper part of the plate, on which impinges the wave-packet $|\mathbf{H};\mathbf{up}\rangle_B$, or on the lower part of the plate, on which impinges the wave-packet $|\mathbf{H};\mathbf{down}\rangle_B$. That produces the impression that in each given trial of the experiment only one of the two wave-packets exists.[1] Or, said accordingly to the view adopted in this work, the photon B as a physical object travels only on one of the paths. However, with the photographic plate in the plane IP one can see that the photon travels on both paths at once, because interference is produced.

The experiment *2* invites the question of B-I-T influence.
It's important to notice that whatever is the way we write the singlet state, (5) or (6), it implies that both wave-packets $|\mathbf{H};\text{up}\rangle_B$ and $|\mathbf{H};\text{down}\rangle_B$ are present in Bob's apparatus before any measurement is done.
For the pairs that responded $\mathbf{P}_A = \mathbf{D}$ or $\mathbf{P}_A = \mathbf{A}$ this fact is evident, though later on, *after getting Alice's results*. The interference that appeared in the plane IP confirms that the photon B had two parts.
But for the pairs that responded $\mathbf{P}_A = \mathbf{H}$ or $\mathbf{P}_A = \mathbf{V}$, there is no evidence that there had been interference. Could it be that the later measurement of Alice erased, backwards-in-time, one of the photon B wave-packets? It's hard to answer, because in the state

$$|\text{S}\rangle = 2^{-½}(|\mathbf{H}\rangle_A |\mathbf{H};\text{down}\rangle_B - |\mathbf{V}\rangle_A |\mathbf{H};\text{up}\rangle_B) \quad (7)$$

these wave-packets don't have as coefficients scalar phase-factors, but two mutually orthogonal states of the photon A. Thus, even if both wave-packets of B were present they couldn't produce an interference tableau.

Thus, so far, there remains a question mark upon how many wave-packets were in Bob's setup in each trial, and with it, the issue of the B-I-T influence.

The experiment *3* brings new facts. As said in the previous section, the number of detections got by Bob for Alice's results $\mathbf{P}_A = \mathbf{D}$ ($\mathbf{P}_A = \mathbf{A}$) when he places wires according to the option *a* (*b*), decreases significantly, though in equal proportion for the two regions R_1 and R_2. That speaks in favor of the existence of both $|\mathbf{H};\text{up}\rangle_B$ and $|\mathbf{H};\text{down}\rangle_B$, and of their interference, in these trials.
On the other hand, the fact that for Alice's tests in the base {**H**, **V**} the position of the wires in the plane IP is irrelevant, and for the result $\mathbf{P}_A = \mathbf{H}$ ($\mathbf{P}_A = \mathbf{V}$) only the number of detections in the region R_2 (R_1) decreases

---

[1] Alternatively, one can adopt the de Broglie-Bohm hypothesis [9 – 11] that a quantum system consists in two items, wave and particle, and since the photographic plate is impressed by the particle, the spot on the plate will appear in the region touched by that wave-packet that carried the particle. However, as said in the Introduction, the present author proved that if there exists indeed a particle, it cannot follow a continuous trajectory, [12]. Neither is it possible that the particle jump all the time from one wave-packet to the other, because it would be incompatible with the special relativity: as the particle is never found in the region between the wave-packets, where the w-f is null, the jump should be with *infinite velocity*.

strongly, supports the inference that in each trial there was only one wave-packet in the interference region; namely, $|\mathbf{H};\mathbf{up}\rangle_B$ if Alice got **V**, and $|\mathbf{H};\mathbf{down}\rangle_B$ if Alice got **H**.

Let's though repeat that Alice tests her photon an interval of time Δt after the photon B is absorbed by the detectors. If, as shown above, when Alice measures in the base {**D**, **A**} there is evidence that had in each trial two wave-packets, then this should have been the structure of the Bob's photon also before Alice measured in the base {**H**, **V**}. Yet, the experimental data don't support this idea.

IV. Discussions and conclusions

According to the analysis done above, the retro-causal influence cannot be denied.

A way to avoid this conclusion was suggested, namely, the existence of a preferred frame of coordinates [23]. If such a frame would exist, one could say that by the preferred time axis one of the experimenters measures first, entailing certain modifications of the w-f of the remaining quantum systems involved in the w-f. Then, another quantum system is measured entailing other modifications, and so on until all the systems described by the w-f are measured.

The theory of relativity offers no support to such an assumption, more exactly, such an assumption has no experimental support because all the laws of the nature transform covariantly under the Lorentz transformation.

Though, even if a preferred frame existed, it could not solve the problems discussed in the former section in relation with the experiment *3*. Assuming that by the preferred time axis Bob indeed measures first and Alice measures after an interval of time, there is no reason to admit that in some trials of the experiment Bob's photon contains two wave-packets and in other experiments it contains only one wave-packet.

Moreover, Bob's photon cannot impose to Alice which type of experiment to perform. Therefore, it is strange that exactly in the cases in which the photon B has one single wave-packet, Alice measures in the base {**H**, **V**}. If Alice would choose to measure in the base {**D**, **A**} no interference pattern could be obtained in the plane IP with one single wave-packet.

References

[1] J. A. Wheeler, "The 'Past' and the 'Delayed-Choice' Double-Slit Experiment", Mathematical Foundations of Quantum Theory, A. R. Marlow (ed.), Academic Press, page 9 (1978).

[2] S. P. Walborn, M. O . Terra Cunha, S. Pádua, C. H. Monken, "*Double-slit quantum eraser*", Phys. Rev. A. **65**, 033818 (2002); arXiv:quant-ph/0106078.

[3] V. Jacques, E. Wu, F. Grosshans, F. Treussart, P. Grangier, A. Aspect, and J-F. Roch, "*Experimental Realization of Wheeler's Delayed-Choice Gedanken Experiment*", Science **315** issue 5814, page 966 (2007); arXiv:quant-ph/0610241v1; DOI 10.1126/science.1136303 .

[4] X-S. Ma, J. Kofler, A. Qarry, N. Tetik, T. Scheidl, R. Ursin, S. Ramelow, T. Herbst, L. Ratschbacher, A. Fedrizzi, T. Jennewein, and A. Zeilinger, "*Quantum erasure with causally disconnected choice*", Proc. of National Acad. of Sciences, Jan. 22, **110**, p. 1221 (2013); https://doi.org/10.1073/pnas.1213201110 .

[5] A. G. Manning, R. I. Khakimov, R. G. Dall, and A. G. Truscott, "*Wheeler's delayed-choice gedanken experiment with a single atom*", Nature Phys. **11** issue 7, page 539 (2015); Bibcode 2015NatPh..11..539M .

[6] S. S. Afshar, "*Violation of Bohr's Complementarity, and its implications*", SPIE conference on "THE NATURE OF LIGHT: WHAT IS A PHOTON?", Aug. 2005, SPIE Conf. Proc. 5866, page 229 (2005), arXiv:quant-ph/0701027v1.

[7] S. S. Afshar, "*Violation of Bohr's Complementarity: One Slit or Both?*", Vaxjo University Conf. on "QUANTUM THEORY: Reconsideration of Foundations", Jan. 2006, AIP Conf. Proc. 810, page 294 (2006), arXiv:quant-ph/0701039v1.

[8] S. S. Afshar, E. Flores, K. McDonald, and E. Knoesel, "*Paradox in Wave-Particle Duality*", Found. Phys. **37**, page 295 (2007), arXiv:quant-ph/0702188v1.

[9] L. de Broglie, "*Ondes et mouvements*", publisher Gauthier-Villars, (1926).

[10] L. de Broglie, "*An introduction to the study of the wave mechanics*", translation from French by H. T. Flint, D.Sc, Ph.D., first edition 1930.

[11] D. Bohm, "*A suggested interpretation of the quantum theory in terms of "hidden" variables, I*", Phys. Rev. **85**, page 166 (1952).

[12] S. Wechsler, "*Are particles possessing rest-mass, STRICTLY waves?*", DOI: 10.13140/RG.2.2.19264.99844, Section 5, (2018).

[13] A. Bassi, G-C. Ghirardi, "*Dynamical Reduction Models*", Phys. Rept. **379**, page 257 (2003).

[14] D. J. Bedingham, "Relativistic State Reduction Dynamics", Foundations of Physics **41**, page 686 (2011), arXiv:quant-ph/1003.2774v2.

[15] J-W. Pan, D. Bouwmeester, H. Weinfurter, and A. Zeilinger, "*Experimental Entanglement Swapping: Entangling Photons That Never Interacted*", Phys. Rev. Lett. **80**, page 3891 (1998).

[16] Lorentz & Schrodinger, in "*Letters on Wave Mechanics*", K. Przibram (ed.), Philosophical Library, page 43, (1967).

[17] A. Fine, "*The Shaky Game: Einstein Realism and the Quantum Theory*", University of Chicago, see page 77 and page 82, (1996).

[18] J. S. Bell, "*Quantum Mechanics for Cosmologists*", in "*Speakable and Unspeakable in Quantum Mechanics*", Cambridge: Cambridge University Press, (1987), 2nd edition, page 117, print publication year 2004.

[19] D. Z. Albert, "*Elementary Quantum Metaphysics*", in "*Bohmian Mechanics and Quantum Theory: An Appraisal*", J. T. Cushing, A. Fine, and S. Goldstein (eds.), Kluwer Academic Publishers, page 277 (1996).

[20] P. J. Lewis, "*Life in Configuration Space*", *British J. for the Philosophy of Science* **55**, page 713 (2004).

[21] J. Bub, "*Quantum Probabilities: An Information-Theoretic Interpretation*", arXiv:quant-ph/1005.2448v1.

[22] A. Shymony, "*Controllable and Uncontrollable Non-Locality*", Proc. Int. Symp. Foundations of Quantum Mechanics, Tokyo, page 225 (1983).

[23] I. Schmelzer, "About an ether interpretation for the Einstein equations of general relativity", section I, in: A. Reimer, (ed.), "*Horizons in World Physics*" **294**, Nova Science Publishers, ISBN: 978-1-53612-515-3. https://ilja-schmelzer.de/papers/ether_interpretation_paper.pdf