The Ontic Probability Interpretation of Quantum Theory – Part II

Einstein's Incompleteness/Nonlocality Dilemma

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ABSTRACT

After identifying in Part I [1] a conceptual confusion (TCC), a Reality preconception (TRP1), and a fallacious dichotomy (TFD), the famous EPR/EPRB [2] [3] [4] [5] [6] argument for correlated 'particles' is now studied in the light of the Ontic Probability Interpretation of Quantum Theory (QT/TOPI). Another Reality preconception (TRP2) is found, showing that EPR used and ignored QT predictions in a single paralogism. Employing TFD and TRP2, EPR unveiled a contradiction veiled in its premises. By removing nonlocality from QT's Ontology [1] by fiat, EPR preordained its incompleteness. The Petitio Principii fallacy was at work from the outset. Einstein surmised the proper solution to his incompleteness/nonlocality dilemma in 1949 [7], but never abandoned his philosophical stance [8]. It is concluded that there are no definitions of Reality: we have to accept that Reality may not conform to our prejudices and, if an otherwise successful theory predicts what we do not believe in, no gedankenexperiment will help because our biases may slither through. Only actual experiments could assist in solving Einstein's dilemma, as has been proven in the last 50 years. Notwithstanding, EPR is one of the most influential papers in history and has immensely sparked both conceptual and technological progress. Part III of this series further develops QT/TOPI, while scrutinizing the mythical 'Schrödinger's Cat', as well as the 'Basis' and 'Measurement' pseudo-problems [9]. Part IV introduces QR/TOPI: a new theory that solves the century-old problem of integrating Special Relativity with Quantum Theory [10].

List of Acronyms

QT	Quantum Theory	EPR	The Einstein/Podolsky/Rosen Paper
TOPI	The Ontic Probability Interpretation	PD	Probability Distribution
PI	Physical Interaction	GI	Gauge Interaction
TM	True Measurement	TRC	The Reality Criterion (EPR)
TCC	The Conceptual Confusion	SD	Standard Deviation of a *PD*
TRP1	The Reality Preconception 1	TFD	The Fallacious Dichotomy
EPRB	EPR-Bohm Gedankenexperiment	TRP2	The Reality Preconception 2

1. Introduction

In Part I [1] we saw that, because -in most cases- a ‘measurement’ (GI) disturbs the state and TRC was mute regarding the property’s ‘reality’, EPR [2] needed to conceive how to predict the result of any ‘measurement’ “with certainty” and “without in any way disturbing the system”. In TOPI language: how to make a GI work as a TM. Directly interacting with the local one of two *entangled* spacelike-separated systems, EPR claimed QT predicts the property value for the remote one “with certainty” and, per the *Principle of Locality*, “without being disturbed”. EPR further argued that the remote property must have existed all along, not somehow created by the ‘measurement’, as many QT pioneers had avowed would have been the case had the remote system been directly ‘measured’. Ergo, it had to be an “element of reality” [2].

2. The Iconic EPR Gedankenexperiment

EPR describes its iconic thought experiment:

EPR8: *For this purpose let us suppose that we have two systems, I and II, which we permit to interact from the time t=0 to t=T, after which time we suppose that there is no longer any interaction between the two parts. We suppose further that the states of the two systems before t=0 were known. We can then calculate with the help of Schrödinger's equation the state of the combined system I+II at any subsequent time; in particular, for any t>T. Let us designate the corresponding wave function by ψ. We cannot, however, calculate the state in which either one of the two systems is left after the interaction. This, according to quantum mechanics, can be done only with the help of further measurements, by a process known as the* ***reduction of the wave packet****.*

We will refer to subsystems I and II as SSI and SSII. Knowing their states prior to interaction, Schrodinger’s Equation predicts the future *composite* state ψ but ***not*** their *individual* states. This is because the equation governs the temporal evolution of the *composite* system in its state-space (a tensor product), not of the subsystems in their own state-spaces [11]. However, EPR believes the subsystems’ states must have definite values that can be determined “only with the help of further measurements”.

EPR imaginarily ‘measures’ *momentum* P_I or *position* Q_I of SSI. To predict the ‘measurement’ of P_I, the wavefunction of the *composite* system is expanded in terms of the *momentum* eigenfunctions of SSI. But because SSI is entangled with SSII due to *momentum* conservation, the coefficients of the expansion are functions of the *momentum* eigenfunctions of SSII. Thus, after the ‘measurement’, SSI adopts one of its *momentum* eigenstates and SSII (despite being spacelike-afar) adopts one of its own *momentum* eigenstates. Mutatis mutandis for ‘measuring’ Q_I. Obviously, the system imagined by EPR is not the dull aggregate of SSI and SSII: QT predicts that, even if they are spacelike-separated, a ‘measurement’ in SSI not only may affect its state but may also affect the state of SSII. The ‘spooky action at a distance’ between two ‘particles’, so despised by Einstein, was obviously at work. A decade before, and specifically at the Solvay 1927, he had denounced the ‘one-particle nonlocality’ as a sign of QT’s ***in****completeness* [12].

2.1 EPRB Gedankenexperiment vis à vis TOPI

In 1951, David Bohm reconceived the EPR gedankenexperiment via two spin-½ qubits in the *singlet* state [5] [6]. There is a homology between EPR and Bohm (EPRB) setups. The philosophical problem is easier to clutch for the latter, so we will reinterpret EPR's assertions per EPRB. The homology is set with two bijections: a) $P \leftrightarrow \mathcal{S}/\hat{n}$ (Spin along $\hat{n}$); and b) $Q \leftrightarrow \mathcal{S}/\hat{n}'$ (Spin along $\hat{n}'$). For the spin operators to be noncommutative, $\hat{n}$ and $\hat{n}'$ are to be ***not*** anti-collinear. The same is valid for both sites: SSI↔Qubit-I and SSII↔Qubit-II. Figure 1 sketches EPRB setup.

Created in a composite (entangled) state, the two qubits travel in spacetime and, if the system stays isolated as a whole, its state is unaffected by their spatial separation. The composite state is:

$$
\begin{gathered}
|s\rangle = \sqrt{2}/2\, sin(\theta/2)\{|s_{I1}s_{II1}\rangle - |s_{I2}s_{II2}\rangle\} + \sqrt{2}/2\, cos(\theta/2)\{|s_{I1}s_{II2}\rangle - |s_{I2}s_{II1}\rangle\} \\
\theta = 0 \;\Rightarrow\; |s\rangle = |singlet\rangle = \left(\sqrt{2}/2\right)|s_{I1}s_{II2}\rangle - \left(\sqrt{2}/2\right)|s_{I2}s_{II1}\rangle
\end{gathered}
\tag{1}
$$

Where θ is the angle between the fields of two Stern-Gerlach magnets for potential GIs with the qubits. The other four ket-symbols stand for the four eigenvectors spanning the composite State-Space. Neither space nor time appears in the expansion for the state, so any interaction between the qubits is not of the dynamic type.

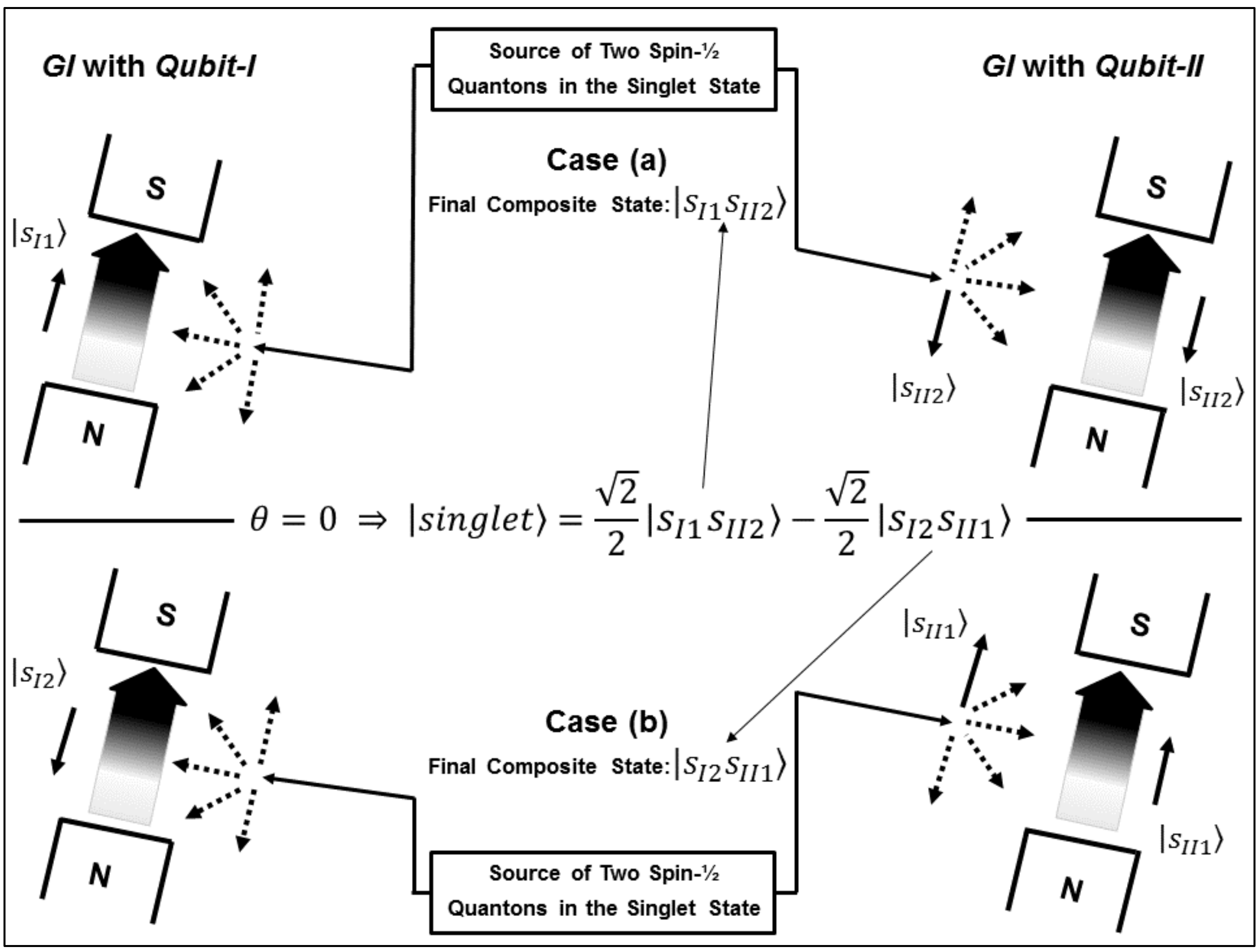

Figure 1: Two Spin-1/2 Qubits in the Singlet State – A GI with Qubit-I occurs First.

Despite the apparent dependence on θ, the ***real*** state is unique; it is the basis (eigenvectors) used to express the state, which changes with the *milieu* (setting a value for θ). From Equations 1 (top), the probability for Qubit-I or Qubit-II to transition (upon a GI) to any one of two eigenstates is 50% irrespective of θ, i.e. the *local* spins are perfectly *random* for any magnet orientation. Yet, their product shows rich probabilistic patterns, e.g. *deterministic* for $\theta = 0$, and perfectly *random* for $\theta = 90°$ [12]. Per QT/TOPI, it is false to say (as EPR8 does) that SSI and SSII states can only be determined with "the help of further measurements". The fact that a single GI delivers a single pure state does not mean it was predetermined; and, even if it was, it may not have been the same state because a GI may or may not be a TM [1]. We will see in Part III that the states of the sub-quantons comprising a composite quanton are not pure but co-states [9].

Figure 1 assumes (in the lab's Inertial Frame) a GI occurs first to Qubit-I depicting the two cases: (a) GI-I delivers a spin aligned to the magnetic field ($|s_{I1}\rangle$); or (b) GI-I delivers a spin anti-collinear to the field ($|s_{I2}\rangle$). All arrows at the field's entrance are dotted conveying that the pre-GI Qubit-I state is (as a pure state) undetermined. However, as soon as GI-I occurs, Qubit-II detangles from Qubit-I and (from Equation 1) its probability to transition (upon any GI-II) to one of its eigenstates ($|s_{II1}\rangle$ or $|s_{II2}\rangle$) is not 50% anymore but given by:

$$Pr(|s_{II1}\rangle/|s_{I1}\rangle) = Pr(|s_{II2}\rangle/|s_{I2}\rangle) = sin^2(\theta/2)$$
$$Pr(|s_{II2}\rangle/|s_{I1}\rangle) = Pr(|s_{II1}\rangle/|s_{I2}\rangle) = cos^2(\theta/2) \quad (2)$$

But a glimpse at Equations 2 shows they correspond to the behavior of an *isolated* qubit when the angle between its direction and the magnetic field is $\theta + \pi$. This proves that Qubit-II, while detangling, adopted a spin anti-collinear to that of Qubit-I, namely $|s_{II2}\rangle$ for (a) and $|s_{II1}\rangle$ for (b). And this state adoption by Qubit-II occurred whether it will ever undergo a GI or not, as indicated in Figure 1 by the only solid arrow before reaching Site-II. It also follows that the angle between the two spin states adopted by Qubit-II upon two GIs on Qubit-I is the same as the angle formed by the respective magnetic fields on Site-I. Hence, if -remaining isolated after detangling- Qubit-II ever interacted with a field collinear to the one on Site-I ($\theta = 0$), its pre-GI state for cases (a) and (b) would be an eigenstate, and its post-GI state would be the same: GI-II would be a TM [1]. It is crucial to realize that Qubit-II is undisturbed by GI-II not because both qubits are spacelike-separated but because its pre-GI state is an eigenstate whenever Magnet-II is aligned to the direction Magnet-I ***had*** when GI-I occurred. The 'spooky' effect occurs (per QT/TOPI) as a result of GI-I happening; GI-II may or may not ever occur. Mutatis mutandis when it is GI-II the one occurring first in the lab's frame.

Going back to the homologous EPR setup, $\theta = 0$ means that the same property (P or Q) is 'measured' on sites I and II, with their homologous spins on each site being not anti-collinear and forming the same angle in both sites. With TCC proviso [1], this is what EPR needed: pre-GI-II and post-GI-II results for P or Q agree and are predicted "with certainty" from the respective results of GI-I. The GIs on Site-I are not TMs, so TRC does not apply; the GIs on Site-II are TMs, so TRC applies [1]. It is also vital to understand that the state adopted by SSII when 'measuring' P on Site-I is different from that adopted when 'measuring' Q on Site-I.

3. The Reality Preconception 2

Firmly believing in the *Principle of Locality,* EPR affirms:

EPR9: *We see therefore that, as a consequence of two different measurements performed upon the first system, the second system may be left in states with two different wave functions. On the other hand, since at the time of measurement the two systems no longer interact, no real change can take place in the second system in consequence of anything that may be done to the first system. This is, of course, merely a statement of what is meant by the absence of an interaction between the two systems. Thus, it is possible to assign two different wave functions to the same reality (the second system after the interaction with the first).*

Intriguingly, instead of relying on Relativity Theory (RT), EPR enforces *locality* by the very assumption of 'no interaction'. Per RT, the only way for two spacelike events to be correlated is through a common cause in their past [13]. This is valid, of course, if RT itself is *complete*, i.e. if every possible "Element of Reality" has been included in its *Ontology* and represented in its *Foundation/Structure* [1], a topic to be argued and resolved in Part IV [10].

Despite the distinct states predicted by QT, EPR9 decrees that SSII is in the same ***real*** state. I call this 'The Reality Preconception 2' (TRP2), which violates the EPR4 dictum [1]. Kemble [14] quickly argued that the EPR argument was not sound, but his counterargument was not sound either. Furry [15] pointed out the incompatibility of EPR premises with QT. Bohm [5] [6] suggested TRP2. Jammer [8] recounts in detail all early criticisms to the EPR argument.

This is the logical trap behind TRP2: if it is true that SSI and SSII do ***not*** interact: (a) the composite state must be a *product-state* [12] [1]; (b) the expansion coefficients for SSI ***cannot*** depend on SSII eigenfunctions; and c) EPR9's first sentence is ***not*** true, rendering its last sentence invalid. EPR9 relies on a cross-influence among wavefunctions that ***contradicts*** its own 'no interaction' assumption. It might not be the type of interaction EPR would philosophically approve, but the mere existence of cross-relations implies an interaction. EPR used and ignored QT's controversial prediction in the same paralogism.

Furthermore, TRP2 uncovers an ***in****completeness* nuance: first, 'incomplete' meant that the same abstract state represented more than one ***real*** state ('real' by virtue of TRP1) so that a "counterpart in the physical theory" for many a 'real' state was missing [1]. Now EPR asserts: the same ***real*** state ('real' by virtue of TRP2) corresponds to more than one *abstract* state. EPR9 dogmatically removes *nonlocality* from the *Ontology* and, inevitably, preordains not only QT's ***in****completeness* but also its ***in****correctness*.

4. Misusing 'The Fallacious Dichotomy'

Before resorting to TFD [1] as the coup de grâce, EPR states:

EPR10: *Thus, by measuring either A [P_I] or B [Q_I] we are in a position to predict with certainty, and without in any way disturbing the second system, either the value of the quantity P [P_{II}] or the value of the quantity Q [Q_{II}]. In accordance with our criterion of reality, in the first case we must consider the quantity P as being an element of reality, in the second case the quantity Q is an element of reality. But, as we have seen, both wavefunctions belong to the same reality.*

Based on TCC [1], TRP1 [1], and TRC [1], EPR concludes: in one case, it is P_{II} the one which is real (single value); in the other, it is Q_{II} the real one. But in both cases, because what happened to SSI did not (by virtue of TRP2) affect SSII at all, P_{II} and Q_{II} must have existed all along, i.e. they had, in EPR's language, a "simultaneous reality". Finally, using TFD [1], via a reductio ad absurdum argument, EPR reaches a contradiction that, alas, already existed in its premises:

EPR11: *Previously we proved that either (1) the quantum-mechanical description of reality given by the wave function is not complete or (2) when the operators corresponding to two physical quantities do not commute the two quantities cannot have simultaneous reality. Starting then with the assumption that the wave function does give a complete description of the physical reality, we arrived at the conclusion that two physical quantities, with non-commuting operators, can have simultaneous reality. Thus the negation of (1) leads to the negation of the only other alternative (2). We are thus forced to conclude that the quantum-mechanical description of physical reality given by wave functions is not complete.*

Despite QT predicting the opposite, EPR insists the 'real' state of SSII has not changed and applies the 'Uncertainty Principle' incorrectly [1]. The purpose is to assert that P_{II} and Q_{II} do not have "simultaneous reality" (one of them has a PD), while they must have it because QT predicts them "with certainty" and "without disturbance". EPR contends that such a logical contradiction (both alternatives false) can only imply that QT is *incomplete*. Instead of contrasting QT predictions with TRP2, EPR could have humbly admitted that perhaps QT was revealing something new about Nature's modus operandi and, ergo, a shift from thought experiments to ***real*** ones was mandatory to confirm/refute those predictions. Such refutation would prove that QT was ***in****correct* (untrue), not merely *incomplete*. Technology was not ready for such a feat – not even in 1964, when John Bell [16] started his seminal work (Part IV [10]).

The truth is that EPR did not start "with the assumption that the wave function does give a complete description of the physical reality". Otherwise, EPR would have accepted that the *predicted* physical reality did change in SSII when the 'measurement' in SSI took place. Had EPR fully accepted QT predictions, no "simultaneous reality" of P_{II} and Q_{II} could have been claimed and no contradiction had occurred. The contradiction EPR claimed to have unveiled was already veiled in their premises. The Petitio Principii fallacy was at work from the very outset.

EPR admitted that had a stricter 'criterion of reality' been adopted, concluding "simultaneous reality" would have been a non sequitur. But, after proposing a new "definition" of reality, EPR immediately labeled it as "unreasonable". There are simply ***no*** definitions of Reality: the only reasonable attitude is to accept that Reality may not conform to our prejudices and, if an otherwise very successful theory seems to predict something we do not believe in (*nonlocality*), no thought experiment will help because our prejudices may creep in. Only actual experiments could do the trick (as proven in the last 50 years). EPR finishes, stating:

EPR12: *While we have thus shown that the wave function does not provide a complete description of the physical reality, we left open the question of whether or not such a description exists. We believe, however, that such a theory is possible.*

I hope I have convincingly argued against EPR having shown that QT "does not provide a complete description of the physical reality".

5. Einstein's Incompleteness/Nonlocality Dilemma

Despite EPR's logical flaws, I am determined to be fair to Einstein, so let me reproduce what he said 13 years later [17]:

> *... when I consider the physical phenomena known to me, and especially those which are being so successfully encompassed by quantum mechanics, I still cannot find any fact anywhere which would make it appear likely that requirement [locality] will have to be abandoned. I am*

therefore inclined to believe that the description of quantum mechanics ... has to be regarded as an incomplete and indirect description of reality, to be replaced at some later date by a more complete and direct one.

Evidently, in 1948, Einstein was open to change his mind upon learning of "any fact anywhere which would make it appear likely that…" it made sense for him to accept *nonlocality*. A year later, in 'Reply to Criticisms' [7], he reformulated The Fallacious Dichotomy (TFD [1]), now endowing it with synthetic value:

By this way of looking at the matter, it becomes evident that the paradox [EPR] forces us to relinquish one of the following two assertions: (1) the description by means of the ψ–function is complete; (2) the real states of spatially separated objects are independent of each other.

His relinquishing option (2) shows that, in 1949, he surmised the solution to his dilemma: if QT was *complete* then the *Principle of Locality* (or at least its universal supremacy) had to go. Nonetheless, Jammer [8] interviewed Einstein in 1953 confirming he never abandoned his view that QT was an *incomplete* description of physical reality. As it is well known (though still highly debated), in 1964, John Bell [16] proved that behind the apparent Lorentz-Invariance of quantum phenomena, there was a deeper level that was not Lorentz-Invariant, namely that *nonlocality* was a ***real*** feature of Nature. He also proved that (barred retrocausality and super-determinism) no hidden-variable theory could avoid *nonlocality*. Copious experimental data followed suit; I am sure that Einstein (dismayingly) would have changed his mind had he seen the evidence we have today. Even so… 23 years into the 21st century, the struggle about Reality continues. Part IV [10] shows that Special Relativity is **in**complete, how to complete it, and how to unite it with QT.

Conclusions

QT/TOPI clearly shows that SSI and SSII detangle upon the first GI occurring to any of them, leaving both (now independent) systems in correlated pure states – irrespective of whether a GI ever happens to the other system. This will help to understand the infamous 'measurement problem' in Part III [9]. A second 'Reality Preconception' (TRP2) was identified, showing that EPR used and ignored QT's prediction of *nonlocality* in a single paralogism. Employing TFD [1] and TRP2, EPR unveiled a contradiction already veiled in its premises. The Petitio Principii fallacy had been at work from the very outset. By 1949, Einstein lucidly surmised the solution to his incompleteness vs. nonlocality dilemma but never changed his mind. The lesson is that there are no *definitions* of Reality: we have to accept that Reality may not conform to our prejudices and, if an otherwise successful theory predicts what we do not believe in, no gedankenexperiment will help because our biases may slither through. Only actual scientifically conducted experiments could help solve Einstein's dilemma, as has been proven in the last 50 years. Notwithstanding, EPR is one of the most influential papers in history and has greatly sparked both conceptual and technological progress. Part III of this series further develops QT/TOPI, while scrutinizing the mythical 'Schrödinger's Cat', as well as the 'Basis' and 'Measurement' pseudo-problems [9]. Part IV introduces QR/TOPI: a new theory that solves the century-old problem of integrating Special Relativity with Quantum Theory [10].

References

[01] F. Alba-Juez, "The Ontic Probability Interpretation of Quantum Theory - Part I: The Meaning of Einstein's Incompleteness Claim," 5 February 2020. [Online]. Available: https://philpapers.org/rec/ALBTOP-2.

[02] A. Einstein, B. Podolsky and N. Rosen, "Can Quantum-Mechanical Description of Physical Reality be Considered Complete?," *Physical Review,* vol. 47, pp. 777-780, 1935.

[03] N. Bohr, "Can Quantum-Mechanical Description of Physical Reality be Considered Complete?," *Physical Review,* vol. 48, pp. 696-702, 15 October 1935.

[04] N. Bohr, "Quantum mechanics and physical reality," *Nature,* vol. 136, p. 65, 1935.

[05] D. Bohm, Quantum Theory, Englewood Cliffs, NJ: Prentice-Hall, 1951.

[06] D. Bohm and Y. Aharonov, "Discussion of Experimental Proof for the Paradox of Einstein, Rosen, and Podolsky," *Physical Review,* vol. 108, no. 4, p. 1070, 1957.

[07] P. A. Schilpp, Albert Einstein: Philosopher - Scientist, London: Cambridge University Press, 1949.

[08] M. Jammer, The Philosophy of Quantum Mechanics, New York: John Wiley & Sons, 1974.

[09] F. Alba-Juez, "The Ontic Probability Interpretation of Quantum Theory - Part III: Schrödinger’s Cat and the ‘Basis’ and ‘Measurement’ Pseudo-Problems," 4 April 2021. [Online]. Available: https://philpapers.org/rec/ALBTOP-3.

[10] F. Alba-Juez, "The Ontic Probability Interpretation of Quantum Theory - Part IV - QR/TOPI: How to Complete Special Relativity and Merge it with Quantum Theory," 2024. [Online]. Available: TBD.

[11] E. Schrödinger, "Discussion of probability relations between separated systems," *Proceedings of the Cambridge Philosophical Society,* vol. 31, pp. 555-562, 1935.

[12] F. Alba-Juez, Elements of REALITY - 1925-1935: The Onset of an Unfinished Philosophical Struggle, Saint George, Utah: Felix Alba-Juez, Publisher, 2019.

[13] F. Alba-Juez, Records of the Future - Classical Entropy, Memory, and the 'Arrow of Time', Salt Lake City: Felix Alba-Juez, Publisher, 2013.

[14] E. C. Kemble, "The Correlation of wave functions with the states of physical systems," *Physical Review*, vol. 47, pp. 973-974, 1935.

[15] W. H. Furry, "Note on the quantum mechanical theory of measurement," *Physical Review*, vol. 49, pp. 393-399, 1936.

[16] J. S. Bell, "On the Einstein Podolsky Rosen Paradox," *Physics*, vol. 1, pp. 195-200, 1964.

[17] A. Einstein, "Quantum Mechanics and Reality," *Dialectica,* vol. 2, pp. 320-324, 1948.