

A Continuum Universe Interpretation of quantum mechanics

Vijay Shankar¹, Narayanankutty Karuppath²

¹ Centre for Computational Engineering & Networking, Amrita Vishwa Vidyapeetham, Coimbatore, India.

² Department of Physics, Amrita Vishwa Vidyapeetham, Amritapuri, India.

E-mail: narayanankuttyk@am.amrita.edu

Abstract. The measurement problem in quantum mechanics has been a cause of much puzzlement over the years. The very idea of having two different versions of reality for the same system has been a cause for much debate. Often quantum mechanics textbooks follow the ‘shut up and calculate’ paradigm. This denies the opportunity for the common student to understand the consequence of one of the most elegant and beautiful aspects of science. The state of the art textbooks give a purely algebraic, perfunctory and monotonous approach where the real consequence of the system is not fully appreciated. A good reason for this is the considerable deviation of the quantum mechanical process from the commonsensical idea of truth, reality and reason. We tend to look at the world in a materialistic, deterministic, causal and objectivistic way. We tend not to accept a world of contradictions. A quantum measurement is essentially an amalgamation of contradictions, mystery and duality. It encompasses an implicit dependence on subjectivity and contradicts with causality as we know it. We look at the world as in the present. But a quantum mechanical measurement is a prediction of the future influenced by the observer or the measurer. This offers a philosophical and pedagogical conundrum. It poses a challenge on not just how our perception of the world might change in addition to providing a big challenge on how to make it compatible with the other successful theories of physics. The most common text book interpretation of quantum mechanics has been the Copenhagen Interpretation suggests the ‘collapse of the wave function’ as a mechanism of transition between duality. But a more bizarre yet elegant theory, extending quantum formalism to the classical domain, called the Many Worlds Interpretation has been catching up very quickly; it stands for the split of the universe when we make a quantum mechanical measurement. Consequently, reality as we is redefined as a universal wave function which is a superposition of several outcomes, which is incompatible with many of the successful concepts of physics and has several problems like the correct idea about probability or basis. We adapt the idea of the universal wave function, but instead suggest a continuum interpretation of quantum mechanics where the universal wave function represents the entire singular universe and the concept of atoms or electrons as conceptually a continuous part of it rather than a distinct separate entity. Such an interpretation could be compatible with other continuum theories like the Superfluid vacuum theory or the Higgs Field.

1. Introduction

The very basic idea of education or knowledge is to imbibe into the student, the idea of a imaginative outlook on life (or nature) to be imparted into the mind of the students, rather than the mere perfunctory transmission of a set of instructions to the students [1]. On the other hand science is about solving problems which are apparently unsolvable directly by using indirect

relevance to other problems or using the historic roots of such a problem and in a way that the resulting theory is falsifiable [2]. This perception of education is more relevant to a subject like quantum mechanics, where students have often struggled because of their difficulty to relate the physical reality with the concepts defining quantum mechanics, thereby following a ‘shut up and calculate’ paradigm [3]. A direct offshoot of this mindset is the popularity of the Copenhagen Interpretation of quantum mechanics [4]. The concept of the Copenhagen Interpretation seems quite out of the ordinary to the average student. When you make the measurement of an atomic constituent, you measure an attribute of that electron, say position x , you get a probability to find that electron at that given position. Now the electron will evolve in time in that position, in a deterministic way. But once again, if you measure the electron in a different position, say y , you will get a probability for the electron to be in that position. This is a result of a barrier imposed by the uncertainty principle [5], you can not measure the position and momentum of a subatomic particle simultaneously. There is a duality between a deterministic measurement (wave) and a probabilistic measurement (particle), also known as the wave-particle duality. In this way we fail to understand the nature of the electron prior to the measurement, in addition to the fact that the system evolves according to our measurement. If you take away the role of the measurer, you know nothing about the state of the electron prior to the measurement. Propounding practicality to the system, it has been suggested that the incertitude is due to the limitations of the measuring apparatus but quantum mechanical wave function is still complete [6]. This is nothing like what a student would encounter in his deterministic world of classical physics. The fact that the observer creates reality and that is what we know about it is hard to reconcile with the practical world around him. The student will find it extremely difficult to understand the fact that one might not be ever able to find out the current state of the atom without the measurement itself influencing it. Upon measurement the same entity can be seen as either a particle or a wave and in order to ‘completely’ understand the microphysics of the system under consideration, we must take into consideration, both the wave and the particle nature of it, known as the complementarity principle [7]. Reality to the average student is singular and is not self-contradicting in any manner. But Quantum mechanics violates it, making it a very difficult concept to imbibe.

The Copenhagen Interpretation suggests the wave as a superposition of several other waves or particles and the probabilities a measure of the proportion of the amount of each observable (say corresponding to position) in the ‘complete’ wave. When you measure a particular attribute, the entire wave function collapses to what you have just measured (it gives a probabilistic result of course). But the collapse of the wave function seems to be an ad-hoc narrative. Another interpretation of the multiple realities is the Many Worlds Interpretation which argues that upon every quantum mechanical measurement a new world is created, every outcome, along with the measurer has a separate world for itself [8]. The Many worlds interpretation is a paradigm shift in taking quantum superpositions to the classical realm. The idea is this, reality or the present is the world in which we exist, but the future is full of options(superpositions) and every step we take takes us to a distinct world [9]. Although the Many Worlds Interpretation has not reached the level of text book acceptance, the theory is quickly catching up. Quantum mechanics is a theory replete with several paradoxes and interpretations [10], we will not attempt to go into the details of such an elaborate subject. But there are considerable proponents of the Many Worlds Interpretation who argue that such paradoxes are dealt with in a better way in the Many Worlds Interpretation, which include quantum entanglement, quantum computing and interaction free measurement etc [11, 12, 13, 14]. In this paper we detail the logical and practical issues with the Many Worlds Interpretation and some of its supporting arguments and attempt to develop a novel interpretation of quantum mechanics ‘A continuum universe interpretation of quantum mechanics’, where we take full cognizance of the universal wave function associated with the Many Worlds Interpretation without the conundrum of branching universes or super complex

superpositions .

2. Classical And Quantum probabilities

The idea of probabilities in quantum mechanics is very strange to the student. Quantum mechanical probabilities can not be seen without juxtaposition with wave particle duality. In a typical probability exercise as the average student would see it, would be a typical question: Consider a bag with 10 blue balls and 10 red balls, ‘what is the probability of getting a blue ball?’ would be the typical question, as is the usual norm of probability in academia. But a quantum mechanical analog of this would be that the bag is a wave function in which there is a definite proportion of blue and red balls, initially. If you measure a red ball you will get a probability of getting a red ball. Now if you let the system as it is, without disturbing it, it would give a bag (wave function) which entirely contains red balls. Instead if you had measured blue balls, you would have received a probability for the bag having a probability of being in a ‘blue ball’ state. And do not disturb, it will evolve in such a way that all its balls are blue. If you, once again ‘disturb’ this (completely red or blue) wave function and measure the state red or blue, you will get a probability (or proportionality) for the completely red or blue wave function to be in either red or blue. This is a direct result of the superposition principle of the Copenhagen Interpretation. This student is not ready for any such thing as the Copenhagen Interpretation, not according to his usual training. Up until high school there is no training attributed to handling this kind of a methodology. The ‘shut up and calculate’ norm in quantum mechanics, which may have resulted in our lack of full fledged understanding of the ‘quantum world’ may very well be a direct result of the difference in the very idea of probability in quantum mechanics and classical physics or the mathematics associated with it.

In the Many Worlds Interpretation, the right version of probability is under much discussion, but the most intuitive and precise probability of the outcome is the number of worlds with that particular outcome or state [15, 16]. Let us retake the previous example, if a bag contains 10 red balls and 10 blue balls, the probability of getting a red ball will be 0.5. That is the proportion of worlds which contain red balls. Instead of the collapsing wave function we have a branching of the worlds. The Copenhagen interpretation doesn’t allow applying probability to objects above the atomic scale, unlike the Many Worlds Interpretation. Thus the probability in the Copenhagen Interpretation is epistemological (knowledge), the probability in the Many Worlds Interpretation is an attempt to make it representing an ontological (existence) phenomenon. In either case, merely saying that quantum mechanics is probabilistic may not show the full complexity of the science, the probabilities are in fact fundamentally different from what the student will usually encounter.

3. The Multiplicity Of The Universe

The universe is ontologically a singular ubiquitous entity that comprises all of the known existence. The idea of the Universe, its unitary existence and expansion has been a very fundamental aspect of physics and education. The idea of either the universe splitting or all of us living in a superposition of several universes is not a concept which may be easily assimilated by the student. The human mind often tends to accept and assimilate the the world around them and try to connect whatever they learn academically with the world or life they are a part of [1]. In that case the acceptability or understanding of multiple universes is going to be difficult. The idea of multiple universes in Everett’s thesis is different from that of the parallel worlds, here the idea of a single universe is a superposition of multiple worlds. This is a paradigm shift in the idea of space and time, multiple worlds are a manifestation of multiple versions of space and time.

The big problem with the Many Worlds Interpretation is the very empirical emptiness of the theory. It does violate the very idea of scientific empiricism, of experimentally proven facts.

Modern science does emphasize a very big importance on experimentally accepted facts. The proponents of the Many Worlds Interpretation have or perhaps can never come forward with a practical solution to experimentally prove the existence of many worlds. If there are indeed multiple or parallel worlds is quantum mechanical measurement a portal to open into a new world? If it is a portal, can we go into that 'distinct' world?. These are natural questions which will arise, when we live in a world of experimentally accepted facts. But this issue is not limited to the Many Worlds Interpretation alone. Even in the collapsible wave function model of the Copenhagen Interpretation there is no experimental proof or a noteworthy nature or mechanism of a collapse happening. If some curious student may ask, why should it be a collapse, why not something else?, the answer is still an open to debate. Open questions in physics are usually at a higher level, it is unusual that a foundational or fundamental subject like quantum mechanics, has open or unanswered questions in its first principles itself.

4. Basic Philosophical Contradictions

The modern norm of education, which has its sound foundations on scientific empiricism, a subject like quantum mechanics, whichever interpretation which one may choose, leads to a challenge of making it acceptable to highly materialistically trained students. In a poll conducted among students of quantum mechanics, it has been shown that the 'realist' and 'agnostic' interpretations were quite popular among the students [3]. The realist interpretation is the argument in favor of incompleteness of quantum mechanics [17]. But the Copenhagen Interpretation regards the quantum mechanical wave function to be complete which is the state of the art interpretation. The agnostic interpretation is also popular which suggests that understanding these open questions are beyond our ability. This can be justified in a scientific way when we go with the fact that measurement or state of the art experimental set up prevents us from understanding the exact mechanism of quantum mechanics [6]. But if one suggests that they will forever remain beyond human ability and quantum mechanics only does not serves the purpose for the need of experimental validity [18], that would be an opportunity missed to learn more about the atomic world. After all, isn't science a quest for the truth?. The current mindset among many students verging on the 'shut up and calculate' paradigm might not lead to scientific progress when they do not have a desire to pursue the truth or the unknown. One good reason why students may have a proclivity towards the realist interpretation of quantum mechanics, even going against the typical classical physics dogma, could be the principle of reductionism which has deep roots in classical physics or our everyday lives. Reductionism is an idea that every phenomenon in the universe can be deduced to a set of fundamental laws of physics [19]. But quantum mechanics can not be treated explicitly as a set of laws, but rather a statistical and observational result which has resulted in a great but still, limited understanding of the atomic world. This is primarily a contradiction with the usual world of physics and common sense, on which the entire pedagogic curriculum may be based on.

The basis for accepting a theory or idea as scientifically correct is experimental proof and falsifiability [20]. The collapsibility of the wave function, the exact process and mechanism is not dealt with in the Copenhagen Interpretation. The uncertainty principle provides a barrier which may hinder us in the falsifiability of such a proposition. The same non-falsifiability exists about the Many Worlds Interpretation as well. If there are multiple worlds, 'can we access them?' or 'will there be any tangible proof for the existence of such multiple worlds?'. There must also be an option of falsifiability. The absence of falsifiability raises an important question on the ontological acceptability of such arguments, both in the case of Copenhagen Interpretation and the Many Worlds Interpretation. Pedagogically, most of the things which we call as science are the ones we accept on the basis of experiments and falsifiability. Quantum mechanics thus becomes a 'weird' science for the students. While quantum mechanics strongly bases it on the basis of experimental results, the interpretations of the results may not be necessarily complete. Quantum mechanics

is a purely statistical result or a consequence of the inability of experiments or perhaps human perception to understand what goes behind the scenes. In Spite of this, the subject forms one of the main pillars of physics, and may have resulted in considerable productivity in recent times. It is strange to note that it has so many philosophical or conceptual contradictions, which make the subject at loggerheads with the largely classical physics.

5. Consciousness In Quantum Mechanics

What the Copenhagen and Many Worlds Interpretation fail to do is keep the ‘consciousness’ of the observer away from the result of the measurement. Consciousness has been in general unacceptable in physics yet has found its way into quantum mechanics [21, 22]. In both the interpretations that we have considered, there is an implicit element of subjectivity. Science is an objective paradigm as the usual classical physics narrative goes. Measurement by the observer influencing the result of the observation is counter intuitive and brings subjectivity into physics. For the Copenhagen Interpretation the change in the quantum state is marked by the change registered in the consciousness of the observer [23, 24]. While in the Many Worlds Interpretation the consciousness has an equally big role to play, because the consciousness of the observer along with his observation of a quantum mechanical system results in the branching of the universe. That is, every decision we make takes us into one version of reality, if we had taken a different decision, that would have embodied a completely different reality. In any case metaphysics or consciousness is not a subject which is a part of a typical physics student’s curriculum. The idea of consciousness can have two major consequences, it may either prompt the learner to seek refuge in realism or materialism or one may develop an impression that, since consciousness plays a role, it may be that there may be limitations in understanding what one can understand fully about the quantum or atomic world. Such a dogmatic approach could be counterproductive to science in general and quantum mechanics in specific. As a spin-off, consider the study of the intricacies of the nervous system which may provide clues to our capabilities or perhaps even limitations towards better understanding of quantum mechanics [25]. In order to critically analyze the role of consciousness in quantum mechanics it is important that an interdisciplinary approach inclusive of metaphysics or even neuroscience be made a part of the physics curriculum. This it will always be better to consider an interpretation where there is minimal role for consciousness.

6. Special Relativity and the Many Worlds Interpretation

One of the biggest paradoxes in quantum mechanics is entanglement. A pair of photons or electrons can become entangled under certain conditions and their anti-correlation continues even if there is a large distance between them(see for example [26]). For simplicity let us take a pair of entangled electrons and measure them at two different ends, at one end if one measures the spin as ‘up’, the measurement at the other the result must be ‘down’ and vice versa. The phenomenon is a paradigm shift, which many believe violates the very idea of locality. Quantum entanglement has always had a tough coexistence with special relativity, where the possibility of superluminal signalling between entangled states as a medium for the anticorrelation has made special relativity at logger heads with quantum entanglement [27]. This incompatibility between special relativity and quantum mechanics with respect to entanglement, in addition to its non-local nature, has been a nagging worry for academia.

A narrative for quantum entanglement using the Many Worlds Interpretation, where the measurement of each entangled state constitutes a separate world [13]. It is further claimed that there is subluminal signalling between the entangled States which are local in their respective worlds [13]. But the idea of slower than light travel between the entangled states seems to be an ad-hoc inclusion in his argument. The Many Worlds Interpretation and special relativity have a considerable number of compatibility issues [9]. If there is signalling between entangled states in different worlds, this concept does not reconcile with special relativity as we know it.

There will be separate space and times in each of those worlds and there is nothing in special relativity to suggest such an inter-world travel of light. Then there is a serious doubtfulness in the argument that the communication between the entangled states is subluminal. So even the Many Worlds Interpretation does not offer a respite from the tension between special relativity and entanglement, although it proposes a local model for entanglement.

7. The Continuum Interpretation of Quantum Mechanics

The issues raised by the Many Worlds Interpretation especially its incompatibility with special relativity in an attempt to explain quantum entanglement requires a single universe definition of the universal wave function. One can not stand outside the Universe and observe the nature of the universe [24]. The same problem may apply to the Many Worlds Interpretation as well, if quantum entanglement causes split [13] then how can one posit the transmission of signalling between the correlated quantum states?.

The measurement problem always evinces a duality between continuous and discrete measurements. Every continuous state can be resolved into discrete system upon measurement. And those discrete states can evolve continuously as well representing a complete picture by themselves. Then the question is what really is the complete picture?. On the other hand even those discrete systems can be resolved into further superpositions in many cases. The linear algebra formulation of quantum mechanics facilitates this. The problem with the Many Worlds Interpretation is its probability picture and the question of the right basis [16]. We posit that the entire universe constitutes a universal wave function, same as that of the Many Worlds Interpretation but without the paradox of multitude or superposition of other universes.. Everett suggests that only the continuous wave function constitutes a true picture in quantum mechanics [24]. When we make a measurement we only measure a constituent part of it. When we let it evolve, then that wave function becomes a component of the Universal wave function. Thus, no matter how many experimenters anywhere in the world make measurements, once the system starts evolving, it is only a part of the single Universal wave function. There is no branching or multiple universes and all the logical conundrums that arise out of such a hypothesis.

The expansion of the universe only evinces that it is a continuously evolving analogous to a quantum mechanical wave function. In any case, what we understand as the universe is a continuously changing entity. The Universe began in a big bang, which can be considered analogous to a discrete measurement phenomenon. There was only one big bang and hence scope for only one universe and not many. If the Universe originated in a big bang that is the evidence of the Many Worlds Interpretation [13], then in that case, there is only one big bang, and if each time when you make a measurement the universe branches out into new universes, it is ad absurdum to consider that there will be one big bang for every quantum mechanical experiment. If big bang is the premise the argument [13], then that evinces a single universe and not multiple, undermining the argument that quantum entanglement is an evidence to the Many Worlds Interpretation.

In the continuum universe interpretation quantum entanglement becomes analogous to a phenomenon like gravity. One will not attach the phrase 'spooky action at a distance' to gravity, although gravitational effects are far and wide and we do not need a signal transmission between masses to accept that. The anti correlation between entangled quantum states may be an effect like gravity. This interpretation departs from the subjective nature of the Many worlds Interpretation or the Copenhagen Interpretation and it agrees with the widely held belief that measurement is the cause for quantum probability [6] and not consciousness. This in turn agrees with the widely accepted fact about probability, being a measure of human ignorance [28], unlike the argument that conditional probability in sequential measurements is a result of changes in consciousness or memory [24]. In comparison with the Copenhagen Interpretation there is no duality here, the time evolving wave function is an entity contiguous with that of the entire

universe. There is an inherent inter connection between all the wave functions which arise out of a quantum mechanical measurement and the universe itself, composing the single universal wave function.

In addition it becomes interesting to consider quantum decoherence: a phenomenon due to which the quantum system reacts with the external world and as a result the superpositioned states of a quantum system which are in coherence with each other, lose their coherence and emerge as a single or discrete wave function [29]. The assumption that there is interaction of the quantum system with the environment world, which has traditionally been disassociated with quantum mechanics sees a change, the environment is given a quantum mechanical attribute to facilitate interaction with the quantum system. The idea of attributing quantum mechanical nature to the environment and the world is a big advent of the Many Worlds Interpretation [8]. But if we consider the continuum universe interpretation, then we do away with the multiple universes, world branching etc and suggest a single universal wave function, which may still encompass decoherence without the unverifiable complexity of the Many Worlds argument.

8. Discussion and Conclusion

There is an essential need to take into consideration contradictions in the picture of studying quantum mechanics. The education system does not focus on studying other interpretations of quantum mechanics other than the Copenhagen Interpretation. From the study in [3], it is clear that the primary focus of academia is on the Copenhagen Interpretation in spite of all its issues. The alternate Many Worlds Interpretation or other interpretations of quantum mechanics are not taught to the students. While there is active research in considering alternative interpretations of quantum mechanics, one must acknowledge the need for including other interpretations in the understanding of quantum mechanics. There is no importance given to understanding how our minds or the brain has an effect in understanding the limitations or capabilities of quantum mechanics. We believe the student must be exposed to all possible considerations in the study of quantum mechanics rather than the 'shut up and calculate' methodology, where the Copenhagen Interpretation is considered sacrosanct. Alternate philosophical viewpoints are also not provided to the students. This evinces a bottle neck in the systemic methodology of education in nurturing potential researchers towards a better understanding the microphysics of the atomic world. Historically quantum mechanics is replete with criticism, arguments and controversies, and hence an argumentative discussion of quantum mechanics in the classroom has been suggested [30]. The training of students in thought experiments may play a significant role in understanding and developing the subject much better. Both the Copenhagen Interpretation and the Many Worlds interpretations among a plethora of other ground breaking concepts in physics are a result of such thought experiments. The natural tendency of the student or any learner per say will be the natural commonsensical intuitive attempt at connection with the real world.

Why should reality be different at the atomic level contradicting the world we live in?. This tendency can lead to a lack of connection on part of the student with the subject. To understand this better let us consider a simple thought experiment. Imagine you are a quantum particle, under the Copenhagen Interpretation, you will live in a superposition of several states and depending upon the observer's measurement, one of your states will be noted and associated with a probability (after the collapse of 'your' complete wave function). On the other hand in the Many Worlds Interpretation, you will have multiple versions of yourself living in multiple universes, and the measurer will measure you in any one of all those possible worlds. The probability here will be a measure of the number of worlds in which you have carried out one particular action (that can be seen as a 'state' in quantum mechanical terms). In a very naive view this can seem very intuitive to the student, much more than the Copenhagen Interpretation. The Many Worlds Interpretation has not yet made its way into textbooks, but it is quickly catching up. However, it has a lot of practical issues.

The Many Worlds Interpretation is a very elegant ontological model for quantum mechanics giving a universal wave function which branches into multiverses, based on the measurement of an individual, making it aggressively subjective. If you take away the multiple universe concept and consider the universal wave function as a continuous entity, you maintain the ontology and deal away with the practical issues including subjectivity. This interpretation of the quantum mechanical state in its continuous form always being a part of a physically realizable universal wave function makes a lot of sense in terms of possibly solving the duality in the measurement problem and offers a basement for a narrative of quantum entanglement in a way similar to gravity, there by avoiding the need for non locality. This paradigm is possibly compatible with the emerging developments in modern physics, all which propose a continuum in the universe like Higgs field [31], superfluid vacuum theory [32], dark matter [33] etc and the ever elusive quest for quantum gravity. But this might not give a last word in the removal of consciousness from quantum mechanics, after all even our consciousness is very well a part of the unitary universal wave function.

Acknowledgments

The authors wish to express their gratitude to the Chancellor of Amrita Vishwa Vidyapeetham, H.H. Mata Amritanandamayi Devi(Amma) for her inspiration to do the work. We would also like to thank Dr.E.A. Goopalakrishnan the chairman of the project committee of the Center for Computational Engineering and Networking (CEN), Amrita Vishwa Vidyapeetham, Coimbatore for having supported this work by understanding its interdisciplinary nature.

References

- [1] Ozoliņš J J T 2013 *Educational Philosophy and Theory* **45** 153–170 ISSN 0013-1857, 1469-5812 URL <https://www.tandfonline.com/doi/full/10.1080/00131857.2012.752990>
- [2] Thornton S 2021 *The Stanford Encyclopedia of Philosophy* ed Zalta E N (Metaphysics Research Lab, Stanford University) Spring 2021 ed
- [3] Baily C and Finkelstein N D 2010 *Physical Review Special Topics - Physics Education Research* **6** 010101 ISSN 1554-9178 URL <https://link.aps.org/doi/10.1103/PhysRevSTPER.6.010101>
- [4] Stapp H P 1972 *American Journal of Physics* **40** 1098–1116 ISSN 0002-9505, 1943-2909 URL <http://aapt.scitation.org/doi/10.1119/1.1986768>
- [5] Busch P, Heinonen T and Lahti P 2007 *Physics Reports* **452** 155–176 ISSN 03701573 URL <https://linkinghub.elsevier.com/retrieve/pii/S0370157307003481>
- [6] Bohr N 1935 *Nature* **136** 65–65 ISSN 0028-0836, 1476-4687 URL <http://www.nature.com/articles/136065a0>
- [7] Wootters W K and Zurek W H 1979 *Physical Review D* **19** 473–484 ISSN 0556-2821 URL <https://link.aps.org/doi/10.1103/PhysRevD.19.473>
- [8] Dewitt B S and Graham N (eds) 2015 *The Many Worlds Interpretation of Quantum Mechanics*: (Princeton University Press) ISBN 9781400868056 URL <https://www.degruyter.com/document/doi/10.1515/9781400868056/html>
- [9] Wallace D 2002 *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* **33** 637–661 ISSN 13552198 URL <https://linkinghub.elsevier.com/retrieve/pii/S1355219802000321>
- [10] Karuppath N 2010 *Critical studies in aspects of quantum reality, time and some applications* Ph.D. thesis Amrita Vishwa Vidyapeetham (University) URL <http://hdl.handle.net/10603/2360>
- [11] David D and Jozsa R 1992 *Proceedings of the Royal Society of London. Series A: Mathematical and Physical Sciences* **439** 553–558 ISSN 0962-8444, 2053-9177 URL <https://royalsocietypublishing.org/doi/10.1098/rspa.1992.0167>
- [12] Santanam R, Sethumadhavan M, Virendra M and Piekarz A (eds) 2011 *Cyber Security, Cyber Crime and Cyber Forensics: Applications and Perspectives* Advances in Digital Crime, Forensics, and Cyber Terrorism (IGI Global) ISBN 9781609601232 9781609601256 URL <http://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/978-1-60960-123-2>
- [13] Tipler F J 2012 *Modern Physics Letters A* **27** 1250019 ISSN 0217-7323, 1793-6632 URL <https://www.worldscientific.com/doi/abs/10.1142/S0217732312500198>

- [14] Vaidman L 1994 *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association* **1994** 211–217 ISSN 0270-8647 URL <https://www.journals.uchicago.edu/doi/10.1086/psaprocbienmeetp.1994.1.193026>
- [15] Deutsch D 1999 *Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences* **455** 3129–3137 ISSN 1364-5021, 1471-2946 URL <https://royalsocietypublishing.org/doi/10.1098/rspa.1999.0443>
- [16] Vaidman L 2018 *The Stanford Encyclopedia of Philosophy* ed Zalta E N (Metaphysics Research Lab, Stanford University) Fall 2018 ed
- [17] Einstein A, Podolsky B and Rosen N 1935 *Physical Review* **47** 777–780 ISSN 0031-899X URL <https://link.aps.org/doi/10.1103/PhysRev.47.777>
- [18] Baily C and Finkelstein N D 2009 *Physical Review Special Topics - Physics Education Research* **5** 010106 ISSN 1554-9178 URL <https://link.aps.org/doi/10.1103/PhysRevSTPER.5.010106>
- [19] Meyer-Ortmanns H 2015 *Why More Is Different* ed Falkenburg B and Morrison M (Berlin, Heidelberg: Springer Berlin Heidelberg) pp 13–39 ISBN 9783662439104 9783662439111 URL http://link.springer.com/10.1007/978-3-662-43911-1_2
- [20] Hermann G 2020 *Journal for General Philosophy of Science* **51** 621–623 ISSN 0925-4560, 1572-8587 URL <http://link.springer.com/10.1007/s10838-020-09531-5>
- [21] Karuppath N K and Panajikunnath A 2010 *NeuroQuantology* **8** 231–236 ISSN 13035150 URL <https://neuroquantology.com/article.php?id=1895>
- [22] Achuthan P and Narayanankutty K 2009 *AIP Conference Proceedings* **1146** 105–112 ISSN 0094-243X URL <https://aip.scitation.org/doi/abs/10.1063/1.3183535>
- [23] Shimony A 1963 *American Journal of Physics* **31** 755–773 ISSN 0002-9505, 1943-2909 URL <http://aapt.scitation.org/doi/10.1119/1.1969073>
- [24] Everett H 1957 *Rev. Mod. Phys.* **29**(3) 454–462 URL <https://link.aps.org/doi/10.1103/RevModPhys.29.454>
- [25] Schwartz J M, Stapp H P and Beauregard M 2005 *Philosophical Transactions of the Royal Society B: Biological Sciences* **360** 1309–1327 URL <https://royalsocietypublishing.org/doi/10.1098/rstb.2004.1598>
- [26] Yao E, Franke-Arnold S, Courtial J, Padgett M J and Barnett S M 2006 *Opt. Express* **14** 13089–13094 URL <http://www.opticsexpress.org/abstract.cfm?URI=oe-14-26-13089>
- [27] Bell R E 1965 *Alpha-, Beta-, and Gamma-Ray Spectroscopy* vol 2 ed Siegbahn K (Amsterdam: North-Holland) p 905
- [28] Laplace P S 2012 *A philosophical essay on probabilities* (Courier Corporation) ISBN 9780486170343 google-Books-ID: dWHCAgAAQBAJ
- [29] Schlosshauer M 2019 *Physics Reports* **831** 1–57 ISSN 0370-1573 quantum decoherence URL <https://www.sciencedirect.com/science/article/pii/S0370157319303084>
- [30] Garritz A 2013 *Science & Education* **22** 1787–1807 ISSN 1573-1901 URL <https://doi.org/10.1007/s11191-012-9444-x>
- [31] Bezrukov F 2013 *Classical and Quantum Gravity* **30** 214001 URL <https://doi.org/10.1088/0264-9381/30/21/214001>
- [32] Sinha K P, Sivaram C and Sudarshan E C G 1976 *Foundations of Physics* **6** 717–726 ISSN 0015-9018, 1572-9516 URL <http://link.springer.com/10.1007/BF00708950>
- [33] Arkani-Hamed N, Finkbeiner D P, Slatyer T R and Weiner N 2009 *Phys. Rev. D* **79**(1) 015014 URL <https://link.aps.org/doi/10.1103/PhysRevD.79.015014>