Is the Many Worlds Interpertation of Quantum Mechanics conistent?

Vijay Shankar A [1] *& Narayanankutty Karuppath* [2]

[1] *Center for Computational Engineering and Networking (CEN), Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, India E-mail: vijaynebula@gmail.com*
[2] *Department of Physics, Amrita Vishwa Vidyapeetham, Amritapuri, India, India E-mail: narayanankuttyk@am.amrita.edu*

Editors:

Article history:

Duality in quantum mechancial wave functions is manifest through the famous measurement problem. There have been several interpretations to explain this duality, but none have seen full consensus among physicists. The Copenhagen interpretation, which is at least to some extent the most widely accepted interpretation has the 'collapse' of the wave function (or state vector reduction) during measurement as a possible narration to circumvent the problem of measurement, yet, it does not attribute a physical reality to the wave function. Moreover, the idea of measurement having a role on defining reality shakes the very foundation of classical physics. On the other hand, the Many worlds interpretation proposed by Everett is a very brave attempt to attribute physical significance to the wave function. Though mathematically sound, 'the splitting of the universe' in the Many Worlds Interpretation lacks realistic and philosophical elegance verging on challenging the very 'common sense'. We revisit Everett's original thought experiment and explore the loop holes in its arguments, revealing its inconsistencies.

1 Introduction

The Rutherford atomic model proposes that the electron revolves around the nucleus in elliptical orbits. In the pre-quantum era it was believed that the electron must emit light as per the electrodynamics of the system. But Quantum mechanics shows that the state of the atom does not change with time, unless there is an external intervention (with the exception of spontaneous emission) [1, 2]. When you measure an attribute of the electron, say a component of the spin in a particular direction, you get a probability for the electron having that spin and it will evolve in that state continuously, if you leave it as it is. Repeat the measurement for say spin in a different direction and you will get a probability of the electron lying in that state. Leave it undisturbed, it will continue to evolve with that state. It is almost akin to saying that the moon exists only when you look at it [22]. This duality has historically resulted in a lot of debates, that led not just to key understanding of quantum mechanics, but which raised questions on the concept of reality as we perceive it.

There are three major common schools of thought when it comes to interpretations of this duality. [3–7] - the realist, the orthodox and the metaphysical. The realist argument is the classical physicist's favorite one. The indeterminacy is due to the presence of a hidden variable which we are unaware of [3]. In the metaphysical interpretation, this and other quantum paradoxes [17, 38] are considered to be a consequence of human consciousness by certain physicists [5, 14–16].

But as per one of the most commonly accepted interpretation(orthodox), the Copenhagen interpretation [7] where the indeterminacy is due to the measurement. A quantum state exists in its most general form as a superposition of several other sub-states and the wave function 'collapses' to a particular state when measured. The probability is a measure of the proportion of the measured sub-state contained in the 'complete' state. The main criticism against CI is that it reduces physical reality into an observer created one, thus smuggling in subjectivity or consciousness into physics [16, 18–21, 25]. Subjectivity in physics, at any level becomes untenable as it goes against the basic tenets of physics or reality. Hence, the only logical conclusion that such a wave function is only a mathematical construct and not physically realizable.

Such conundrums are not limited to CI alone, but almost all the interpretations are associated with some type of 'weirdness' [23, 24]. In addition, a good number of the interpretations fail to keep intervention of the observer and hence, the role of consciousness or subjectivity at bay [25]. Even after over a century of research, the physics world has not come to a consensus on the exact interpretation of quantum mechanics. The most compelling reason for the study of the interpretations of quantum mechanics is mainly the understanding of quantum mechanics itself through the resolution of its paradoxes [25]. As a spin off, it even throws light into modern applications of quantum physics including quantum computing [26, 27].

Among the main interpretations which attempt to restore the classical concept of physical reality is the Many Worlds Interpretation (MWI) [32]. The MWI tries to answer the contradiction between the probabilistic solution to the Schrodinger equation and the time dependent part which is deterministic in nature in a completely different way. Imagine you are in possession of an atom in which an electron is 'revolving around' the nucleus. Your picture is that of a continuous evolution of the electron wave function. Then, your friend serendipitously makes a measurement and obtains an outcome with a particular probability value for one of its states, thereby creating new branch(es) of the world. Thus the world, as per MWI, splits into two or more parallel universes with each measurement!. This splitting of MWI was proposed as a supposed alternative to the collapse of wave function or state vector, where instead of the wave function collapsing into one of the many possibilities, the measurement splits the world into two or multiple worlds, with each measurement. Each of those worlds is associated with a 'Universal Wave function/state vector', thus the MWI tries to espouse a clear physical state rather than a mere mathematical record in contrast with the Copenhagen Interpretation.

In addition, the CI or other 'single world interpretations'(generic term for non many world interpretaions) [28] in the context of quantum locality fails to give any viable explanation for quantum entanglement, while MWI provides a potential answer to understanding quantum entanglement. In single world models, quantum non locality is suggested as one of the basic axioms of quantum mechanics [35], but in general, the very idea of physics is local in nature. Quantum non local entanglement experiments in the past were restricted to the laboratory [9, 11–13]. The most recent ground breaking experiment confirms quantum entanglement at a much larger scale [36]. The assumption of transmission of signals between entangled quantum states violates special relativity explicitly [37]. Though it is proved that such transmissions cannot be faster than light (FTL) there is a tension between the special theory of relativity and quantum mechanics. Special relativity is local and quantum entanglement is not. Quantum non locality may be an evidence to MWI [33, 34]. Corresponding to the measurement of each of the correlated pair of spins of entangled quantum particles the universe splits into separate ones, where each of the spins are local in their own respective universes [33]. In this case there is no explicit contradiction with special relativity, which makes the MWI an interesting case indeed.

2 MWI's original thought experiment: A revisit

Since we will be developing our own thought experiments which are inspired by the original thought experiment of Everett in Ref. [32], let us reproduce their original thought experiment. There are quite a few modifications of the MWI [28, 29], all of them basically depend upon this thought experiment at the very beginning of Ref. [32].

Consider two quantum mechanics experts A and B and A is inside the room carrying out his measurements on a quantum mechanical state Ψ which exists as a super position of several sub states ψ_i, with a total of n sub states. On each measurement A gets a probability $|c_i|^2$ of the quantum state living in one of the sub states.

$$\Psi = \sum_{n=1}^{n} c_i \psi_i \tag{1}$$

$$\sum_{n=1}^{n} |c_i|^2 = 1 \tag{2}$$

Imagine A notes his measurements and the probabilities. On the other hand B who is standing outside, is in full possession of the entire system. Entire system refers to the room, A and his experiment. In concrete mathematical sense, B is in possession of the time dependent solution to the Schrodinger equation $\Psi(t)$ and the wave function evolves in time. B records its behaviour, for say a week.

The only logical conclusion is that the total amplitude of the complete wave function that B possesses, is the sum of the amplitudes of the of the discrete probabilistic measurements made by A (This part is validated if you consider the concept of A's sum of probabilistic amplitudes Eqn.2 and B's normalization of the wave function which are both 1).

But, B possesses the complete wave function only until the current measurement of A. When B opens the door (dramatically) B sees that A gives a probabilistic result $|c_i|^2$ of Ψ being in some ψ_i. Thus the existence of A is due to the 'mercy' of B, that is if B had not opened the door A's result would not exist. Until B opened the door he had a deterministic view of the wave function. When he opened the door, the probabilistic measurement of A comes into existence, thereby creating a new world. Thus there are now two worlds, one where the wave function is deterministic and another one where it is probabilistic in nature.

The above thought experiment and the conclusion is based on the physical duality already forming the basic tenet of quantum mechanics as it is existent today. The MWI is only a manifestation of this duality. If the above thought experiment were correct, then you and I will not exist unless some person doing a quantum mechanics experiment opens his door. In physics, theories are to be accepted only on the basis of experimental validity - or the argument that the splitting of universe must have some observable effect on the current universe we live in. An acceptable theory must be falsifiable [31]. Every time when a quantum experiment is carried out or an observation is made, the universe splitting into many and that we have never had any observational impact on our universe when the universe splits is indeed strange.

3 The Superobserver thought experiment

Let us modify Everett's thought experiment. Instead of B being outside the room, let B be inside the room itself. Let us consider the room having two floors. Let B be the super observer (S) looking from above. At the floor below, the quantum state as in Eqn.1. But instead of just A, let us consider a large number of observers who are making measurements . Let there be a number of observers $A_1, A_2..A_n$ (As) who are making observations on the quantum system represented by Eqn.1. Each of those observers simultaneously measure the system to be in $\psi_1, \psi_2..\psi_n$ with probabilities $|c_1|^2, |c_2|^2..|c_n|^2$ which follow initially. But, after a small amount of time t, for each of those observers, the system will evolve in a unitary way : $\psi_1(t) = \psi_1 e^{\frac{-iE_1 t}{\hbar}}, \psi_2(t) = \psi_2 e^{\frac{-iE_2 t}{\hbar}}..\psi_n(t) = \psi_n e^{\frac{-iE_n t}{\hbar}}$ (Where E_i represents the eigen value or observable of the measurement). Now, for each of those observers, their own quantum wave should represent the full picture of the system.

But S is watching all this from above. The super observer(as the name suggests), will observe all of the observers below making their respective measurements. The super observer collects the initial probabilistic measurements of the observers below and thus the initial wave function at time t=0 is as in Eqn.1. At a later time t, S collects the wave functions $\psi_1(t), \psi_2(t)..\psi_n(t)$, which the observers below possess, each of which only represent a part of the complete picture (according to S). Which means all of them are only a part of the total wave function $\Psi(t)$, which have probabilities $|c_1|^2, |c_2|^2..|c_n|^2$ as in Eqn.3.

$$\Psi(t) = \sum_{n=1}^{n} c_i \psi_i e^{\frac{-iE_i t}{\hbar}} \tag{3}$$

Where E_i represents the eigenvalue or observable of the measurement. That is at a later time t, the probability to find the system in any one of $\psi_1, \psi_2..\psi_n$ is going to be $|c_1|^2, |c_2|^2..|c_n|^2$. This is like the weighted sum total of the wave functions of the observer below. If we assume the time elapsed t, as the same for every one, for every increase in t, As update S with the wave functions.

The results are in direct contradiction of the world splitting as assumed by Everett. If each of the observers in the bottom floor were to split into separate worlds according to the MWI, then according to S, all their worlds split right in front of his eyes. This will never happen practically. But one more thing, S needs the time evolved wave functions continuously from the observers below him to construct his full wave function as in Eqn.3, thus all those observers are very much part of his world, hence the world can not split even by the logic of MWI. Because if it splits S can not build his wave function, but he does build it.

4 Composite Systems thought experiment

In this 'gedanken' experiment, let us closely follow the footsteps of Everett, but let us consider a simple yet composite system. This thought experiment is inspired by problem 3.32 in Ref. [6]. Instead of following the 'Shut up and calculate' recipe [30] as is common in most quantum mechanics text books, we will take into consideration the interpretational consequence of such a system.

Let us start with A, who is inside a room and B who is outside the room. B is in possession of the simplest superposed wave function.

$$\Psi = \frac{1}{\sqrt{2}}\psi_1 + \frac{1}{\sqrt{2}}\psi_2 \tag{4}$$

For B the wave function will evolve as

$$\Psi = \frac{1}{\sqrt{2}}\psi_1 e^{\frac{-iE_1 t}{\hbar}} + \frac{1}{\sqrt{2}}\psi_2 e^{\frac{-iE_2 t}{\hbar}} \tag{5}$$

With a probability of 0.5 of being in either one of the sub states. Here E_1 and E_2 are the eigenvalues or observables associated with the measurements.

But in the most general form a quantum mechanical state can be expressed as a linear combination or superposition of other states. This goes not just for Ψ in Eqn. 5 but for ψ_1 and ψ_2 as well, as in Equations 6 and 7

$$\psi_1 = \frac{3}{5}\phi_1 + \frac{4}{5}\phi_2 \tag{6}$$

$$\psi_2 = \frac{4}{5}\phi_1 - \frac{3}{5}\phi_2 \tag{7}$$

This same formulation can also be written as

$$\phi_1 = \frac{3}{5}\psi_1 + \frac{4}{5}\psi_2 \tag{8}$$

$$\phi_2 = \frac{4}{5}\psi_1 - \frac{3}{5}\psi_2 \tag{9}$$

If A were to measure ψ_1 and ψ_2 A will get a probability of 0.5 for either of them. For B who is standing outside, the system evolves according to Eqn.5, where the probabilities of being in being in either ψ_1 or ψ_2 as 0.5. Until now the system is very much similar to Sec. 2.

But, further considerations will show that A's picture is much more interesting. Let A measure for ψ_1 he gets ψ_1 with a probability 0.5. Now after this measurement the wave function is expected to live as in Eqn. 6. Now A measures ϕ_1 and the total probability of the system to be in ϕ_1 is $P(\frac{\phi_1}{\psi_1}) = (\frac{1}{2})(\frac{9}{25})$. The system after this measurement lives in the state ϕ_1. Now the probability of finding the state in ψ_1 and ψ_2 will be.

$$P(\frac{\psi_1}{\psi_1,\phi_1}) = (\frac{1}{2})(\frac{9}{25})(\frac{9}{25}) = 0.065 \tag{10}$$

$$P(\frac{\psi_2}{\psi_1,\phi_1}) = (\frac{1}{2})(\frac{9}{25})(\frac{16}{25}) = 0.125 \tag{11}$$

The probabilities measured are considerably different from what A measured for ψ_1 and ψ_2 initially, before he measured ϕ_1. Mathematically, this is a typical case of conditional probability. .In addition, the other probabilities that can be associated with A's measurement of ψ_1 and ψ_2 are $P(\frac{\psi_1}{\psi_1,\phi_2})$, $P(\frac{\psi_2}{\psi_1,\phi_2})$, $P(\frac{\psi_1}{\psi_2,\phi_1})$, $P(\frac{\psi_2}{\psi_2,\phi_1})$, $P(\frac{\psi_1}{\psi_2,\phi_2})$ and $P(\frac{\psi_2}{\psi_2,\phi_2})$, depending upon the sequential order of his choice. These probabilities are all completely oblivious to B who is outside, all he is aware of is ψ_1 and ψ_2 both at 0.5.

The implicit relation between ψ_1 and ψ_2 and ϕ_1 and ϕ_2 is better explained by the Copenhagen interpretation than the Many worlds interpretation. If we go by the Many worlds interpretation when A measures ϕ_1 after ψ_1, he will enter into a completely different world of reality. Now if he again measures ψ_1 he will go back to the initial world. But now the probability associated with ψ_1 is different. The Many Worlds interpretation has no answer for this difference in probabilities associated with the same wave function.

A much better narrative is given by the Copenhagen interpretation where the measurer, the measurement or the experimental arrangement causes the change in probabilities [39]. The Many worlds interpretation thus fails to give a consistent picture for sequential measurements.

5 Conclusions

Reductionism is the notion wherein everything in the world when decomposed into smaller parts, the constituents will follow the same laws as does the object itself. Reductionism has a very deep roots in physics [40]. Quantum mechanics grossly violates the principles of reductionism. In every interpretation of quantum mechanics there is a considerable amount of controversial weirdness. No matter what interpretation one takes there is an element of subjectivity, which makes quantum mechanics so disturbing and intriguing at the same time. A metaphor 'the moon exists only when you look at it', that can be associated with quantum mechanical measurements, makes the whole subject queer.

The main problem with the copenhagen interpretation is the concept of observer created reality [39]. Hence, the narrative is treated as a mere mathematical construct. The beauty of the Many Worlds Interpretation lies in its elegant narrative of physical duality as two different worlds of reality. The attempt may have been to make a physically realizable wave function, but that is replete with logical inconsistencies, some of which we have explored in this paper.

Both the Copenhagen Interpretation and Many Worlds interpretation fail to keep subjectivity at bay. While the Copenhagen Interpretation gives an explanation for the dynamic nature of the probabilities, which is poignant in the case of sequential measurements, the Many world Interpretation does not succeed there. As we have indicated in Sec. 3, the idea of the splitting of worlds or separation of realities is logically inconsistent. The Copenhagen Interpretation on the other hand has a very big role for the measurer and reality as such is an observer created one. This is explained by the collapsible wave function. So what was the state of the quantum mechanical system independent of any measurement?. The Copenhagen Interpretation might not be able to answer this question, but it remains logically consistent in many situations.

The Many Worlds Interpretation is a bold and ingenious attempt to offer a view point alternative to the collapsible wave function. It fails to keep subjectivity away. We have seen in this paper, there are many logical inconsistencies associated with the main thought experiment that was proposed. Moreover it does not provide an option of falsification in any manner, nor provides any observational trace of the world splitting. We have explored some of the logical inconsistencies in the original thought experiment of the Many Worlds Interpretation, but still consider it a very elegant and bold attempt, but one which may fail to live up to the expectations of many of its proponents.

6 acknowledgement

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

References

[1] Bohr N 1913 *Philos. Mag.* **26** 1-25 DOI:10.1080/14786441308634955

[2] Yung-Kuo L 1998 *Problems and Solutions on Quantum Mechanics*(Singapore:World Scientific) DOI:10.1142/3471

[3] Einstein A, Podolsky B and Rosen N 1935 *Phys. Rev.* **47** 777 DOI:10.1103/PhysRev.47.777

[4] D'Espagnat B 1979 *Sci.Am.* **241** 158 DOI:10.1038/scientificamerican1179-158

[5] Darby G 2009 Australas. J. Philos. **88** 227-245 DOI:10.1080/00048400903097786

[6] Griffiths D J 2016 *Introduction to Quantum Mechanics* (Chennai:Pearson) DOI:10.1017/9781316995433

[7] Stapp H P 1972 *Am. J. Phy.* **40** 1098-1116 DOI:10.1119/1.1986768

[8] Bell J S 1964 *Phys. Phys. Fiz.* **1** 3 DOI:10.1103/PhysicsPhysiqueFizika.1.195

[9] Aspect A, Dalibard J and Roger G 1982 *Phys. Rev. Lett* **49** 1804 DOI:10.1103/PhysRevLett.49.1804

[10] Weihs G. et al. 1998 *Phys. Rev. lett.* **81** 5039 DOI:10.1103/PhysRevLett.81.5039

[11] Clauser J F and Shimony A 1978 *Rep. Prog. Phys.* **41** 1881 DOI:10.1088/0034-4885/41/12/002

[12] Selleri F 1988 *Quantum Mechanics versus Local Realism : The Einstein, Podolsky and Rosen Paradox* (New York:Plenum) DOI:10.1007/978-1-4684-8774-9

[13] Home D and Selleri F 1991 *Riv. Nuovo Cimento* **14** 9 DOI:10.1007/BF02811227

[14] Lewis P J 2016 *Quantum Ontology: A Guide to the Metaphysics of Quantum Mechanics* (New Yortk: Oxford University Press) DOI:10.1093/acprof:oso/9780190469825.001.0001

[15] Shimony A 1978 *Inter. Phil. Q.* **18** 3-17 DOI:10.5840/ipq19781818

[16] Narayanankutty K and Achuthan P 2010 *NeuroQuantology* **8** 231-236 DOI:10.14704/nq.2010.8.2.289

[17] Aharonov Y and Daniel R 2005 *Quantum Paradoxes-Quantum Theory for the Perplexed* (New York:Wiley-VCH Publ Co.) DOI:10.1002/9783527619115

[18] Popper K R 1967 *Quantum Theory and Reality. Studies in the Foundations Methodology and Philosophy of Science* (Berlin:Springer) DOI:10.1007/978-3-642-88026-1

[19] Achuthan P and Narayanan K 2009 *AIP Conf Proc.* **1146** 105 DOI:10.1063/1.3183535

[20] Richard A M 1998 *Found. Phy.* **28** 1703-1718 DOI:10.1023/A:1018897710599

[21] Rosenblum B and Kuttner F 2006 *Quantum Enigma:Physics Encounters Consciousness* (New York:Oxford University Press) DOI:10.1080/00107514.2012.661786

[22] Mermin N D 1985 *Phys. Today* **38** 38 DOI:10.1063/1.880968

[23] Peter P 2002 *Am. Sci.* **90** 262-267 http://www.jstor.org/stable/27857662

[24] William J M 2017 *Quantum Weirdness* (Oxford:Oxford University Press) DOI:10.1093/9780198795131.001.0001

[25] Narayanankutty K 2010 Critical studies in aspects of quantum reality, time and some applications *PhD Thesis* Amrita Vishwa Vidyapeetam University, Coimbatore http://hdl.handle.net/10603/2360

[26] Lini G 2016 *Philosophies* **1** 102-110 DOI:10.3390/philosophies1010102

[27] Narayanankutty K and Achuthan P 2011 Einstein-Podolsky-Rosen paradox and certain aspects of quantum cryptology with some applications *Cyber Security, Cyber Crime and Cyber Forensics: Applications and Perspectives* (Pennsylvania:IGI Global) p 231-239 DOI:10.4018/978-1-60960-123-2

[28] Simon S, Jonathan B, Adrian K, and David W 2010 *Many Worlds?: Everett, Quantum Theory, and Reality* (New York:Oxford University Press) DOI:10.1093/acprof:oso/9780199560561.001.0001

[29] Kent A 1990 *Int J. Mod. Phys.* A **5** 1745-1762 DOI:10.1142/S0217751X90000805

[30] Tegmark M 1999 *Fortschritte der Phys.* **46** 855-862 DOI:10.1002/(SICI)1521-3978(199811)46:6/8

[31] Popper K 1963 *Conjectures and Refutations: The Growth of Scientific Knowledge* (New York:Routledge and Kegan Paul)

[32] Everett H, Wheeler J A, DeWitt, Cooper L N, Van Vetchen D and Graham N 1973 *The Many Worlds Interpretation of Quantum Mechanics*(New Jersey:Princeton University Press)

[33] Tipler F J 2012 *Mod. Phys. Lett. A*, **27** 1250019 DOI:10.1142/S0217732312500198

[34] Tipler F J 2014 *Proc. Natl. Acad. Sci. U.S.A.* **111** 11281-11286 DOI:10.1073/pnas.1324238111

[35] Pospescu S 2014 *Nature* **10** 264-270 DOI:10.1038/nphys2916

[36] Sheng-Kai L et al. 2018 *Phys. Rev. Lett.* **120** 030501 DOI:10.1103/PhysRevLett.120.030501

[37] Popescu S and Rohrlich D 1994 *Found. Phys.* **24** 379–385 DOI:10.1007/BF02058098

[38] Selleri F 1990 *Quantum Paradoxes and Physical Reality* (Dordrecht:Kluwer Academic Publishers) DOI:10.1007/978-94-009-1862-7

[39] Shimony A 1963 *Am. J. Phy.* **31** 755-773 DOI:10.1119/1.1969073

[40] Gentile D 2006 *Phys. Today* **59** 12 DOI:10.1063/1.2195298