The Metaphysical Implications of the Double-slit Experiment

Janet Eniraiyetan (August 2019)

Abstract:

Within quantum mechanics, indeterminism and randomness are notions which have been observed and accepted by physicist. However, the theory of quantum mechanics does not provide us with any laws to explain why it is there or how it affects the world we live in. The double-slit experiment is an experiment which clearly shows this indeterminism through what is known in physics literature as The Measurement Problem, and it is a phenomenon I witness while conducting the experiment. In this paper, I consider different ways this indeterminism can affect our understanding of the world, looking specifically at metaphysical indeterminism and Kit Fine's Fragmentalism.

We live in a universe governed by physical laws which were discovered from our observation of the way the world presents itself to us. This allowed the development of the theory of physics from deductive experimentation to predict how the world will behave over time. However, indeterminacy is a concept which continues to manifest in these physical experiments, especially in quantum systems. An example of this is in the double-slit experiment. There are various ways in which the indeterminate nature of the world presents itself in quantum systems, e.g. the measurement problem. As a result, philosophers and physicists remain at odds as to how it should be understood and its effects on our understanding of reality. This paper will consider the metaphysical indeterminacy proposed by quantum mechanics as depicted in the double-slit experiment. From this, we will explore three consequences of this indeterminacy and how it can be understood, focusing on Kit Fine's theory of Fragmentalism.

The double-slit experiment first conducted by Thomas Young in 1801 sent beam of light through two very small slits (holes). The light from each slit interferes and generates a fringe interference pattern. When this same experiment is conducted with a single particle of light (a photon) rather than a beam of light, its results resist causal explanation as the exact same fringe interference pattern is gradually created. The reason for this is as follows: for the same pattern to be created, the photon must have passed through both slits simultaneously in order to interfere with itself and create the fringe interference pattern. This is in direct contradiction with some assumptions made about the nature of the universe. The first being that observation does not affect the system being observed and the second that reality is determinate. For this reason, the results from the double-slit experiment is a metaphysical issue, as it forces us to question some assumptions we have made about the nature of the world.

If one attempts to measure the position of the photon while it's passing through the two slits, the wave function, which is a property of the photon breaks down and the photon is found either in slit 1 or slit 2, never in both (as this is impossible). As a result of this measurement, the interference fringe pattern also breaks down and only a single point is detected, which demonstrates the particle nature of a photon. Physicist have tried to account for this peculiar phenomenon (the breakdown of the interference pattern once the system has been measures/observed) by trying to describe the photon as a wave, which also offers an explanation of how the photon is able to pass through both slits at the same time. However, the nature of a wave does not permit the reduction of a light beam to a single photon as a wave is nothing more than a continuous stream of energy. Furthermore, it is problematic to view a quantum system such as this as a particle alone, as it does not always have a single position, as evident when the photon passes through both slits at the same time prior to being measured.

This caused physicists to conclude that quantum systems such as light must be considered as both particles and waves, they must exist in a superposition of both states and the behavior of light as a wave or a particle is contingent on the system at hand. Here, superposition can be understood as the intrinsic part of quantum mechanics wherein the superposed assumptions of a system does not apply. In relation to the position of the photon, it is not the case that the photon is in slit 1 or slit 2 or both or neither, rather it is the case that the photon is in a superposition of both slits at the same time. This superposition state is not equivalent to the photon going through both slits. As it is impossible for an object to exist in two different positions simultaneously, the property of 'superposition', which is represented by a mathematical linear vector space named Hilbert Space[1], allows us to discuss the photon existing in an unknown combination of the two slits. This is represented using state-vectors as $\frac{1}{\sqrt{2}}(|Slit1 > +|Slit2 >)$.

This result from the double-slit experiment leads us to what is known as the Measurement Problem [2]– the notion that we are unable to reach a definite conclusion on the nature of a quantum system as there are different fundamental laws describing a quantum system before and after measuring/observing the system. It can be said that before measurement, we must consider the

[1] *A Dictionary of Physics,* 8th Edition, 2019, s.v Hilbert Space, accessed November 29 2019, https://www.oxfordreference.com/view/10.1093/acref/9780198821472.001.0001/acref-9780198821472-e-1406?rskey=xx1YuX&result=1681

[2] David Albert, *Quantum Mechanics and experience,* (United States of America: Harvard University Press, 1992), 73-80.

photon to be in a superposition of being in both slit 1 and slit 2, and after observing the system, the wave function of the photon collapses and we observe the photon to be in either slit 1 or slit 2. For this reason, we must conclude that the position of the photon is indeterminate before observation. These results oppose the assumption which physics is built upon - that reality is determinate. The indeterminate nature described above is limited to the microscopic world, this is because the process of measurement and observing in quantum mechanics (and in the microscopic world) is an active process which changes the measured system. While the process of measurement in the macroscopic world is one which we are accustomed to and can always be explained through the principle of cause of effect.

There are three different stances one can take on the metaphysical implications of the indeterminacy proposed by Quantum Mechanics: (a) one can accept Quantum Mechanics as a wholly deterministic theory. Disregarding the wave-particle duality and the instantaneous collapse of the wave function as depicted in the double-slit experiment. An example of this approach is the wave-pilot theory, also known as the Bohmian mechanics[3]. (b) One accepts the internally indeterminate nature of the world and reject the view of hidden variables, such as the Objective Collapse theory[4]. And (c) one can view the consequences of the measurement problem as one which is based on our misrepresentation of reality. We will be exploring the last two stances as the consequences of Bohmian mechanics, as a physical theory drastically defer from our understanding of physics.

Here, the term 'indeterminacy' is the metaphysical indeterminacy. The indeterminacy which is found in the first principle of things. In other words, the indeterminacy which remains after all forms of semantic and epistemic indeterminacy has been clarified but might not necessarily be of the world itself. We can adopt C. Calosi and J. Wilson's idea of a determinable-based indeterminacy when considering this form of indeterminacy. According to this form of indeterminacy, to claim that an entity E is indeterminate in a given system S at a time t is to say that (i) E has a determinable property Q at time t and (ii) for a precise level of determination, L, E does not have a unique L of Q at time t [5].

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[3] Dan Flak, "New Support for Alternative Quantum View"*, Quanta Magazine*, May 16 2016, https://www.quantamagazine.org/pilot-wave-theory-gains-experimental-support-20160516/

[4] *Stanford Encyclopedia of Philosophy*, s.v. "Collapse Theories", accessed November 29 2019, https://plato.stanford.edu/entries/qm-collapse/

[5] Claudio Calosi and Jessica Wilson, "Quantum Metaphysical Indeterminacy", *Philosophical Studies,* 176, no. 627 (2019): 2599-2627. *https://link.springer.com/content/pdf/10.1007%2Fs11098-018-1143-2.pdf*

Stance (b) deems metaphysical indeterminacy to be an intrinsic part of quantum mechanics. This was Neil's Bohr's understanding of the results of the double-slit experiment. Bohr following in the positivist mindset of the 19th century and considered the consequences of the double-slit experiment, and other quantum systems to be instrumental in that it informed us of the degree of impression of the macroscopic world compared to the quantum world. That is to say that that quantum theory informs us of how incorrect we are about the macroscopic world[6]. Bohr viewed the indeterminacy demonstrated in the double slit experiment as simply a description about the way the world is. For example, it is an intrinsic part of the world that once a property of a quantum system is known, such as an electron's spin in the x-direction, this knowledge entails that the spin in the y-direct is a superposition of the two possibilities (up or down). Bohr considers this to be the complementary nature of quantum systems[7], and this description exhausted all possible ways we can account for observable phenomenon. This is because, all we can know about the world is what we can measure, thus, quantum mechanics is a good and complete theory. However, this approach is unsatisfactory. We can accept Quantum Mechanics as a formalism of the way the world is, as it does not stipulate a physical ontology of the world, nor does it provide any laws regarding how the world behaves through time. However, it is unacceptable to agree that indeterminacy as portrayed by Quantum Mechanics is an intrinsic feature of the world. To propose that this indeterminacy is an intrinsic property of the world, it must follow that this exact form of indeterminacy is independent of human existence. However, every testable hypothesis formed will be subject to the metaphysical indeterminacy mentioned above. It must follow that this form of indeterminacy is a feature of our representation of the world, not of the world itself. Thus, this metaphysical indeterminacy cannot be an innate part of the world.

On the other hand, stance (c) suggests that one should consider alternative representations of reality, as metaphysical indeterminacy may be due to our misrepresentation of the world. To do this, we can look at the theory of Fragmentalism. Fragmentalism is the view that reality is not a metaphysically unified whole and can include incompatible facts across different fragments of reality[8]. This view initially propose by Kit Fine is built on 4 metaphysical principles of reality. (1) the Principle of Realism – reality consist of tensed facts. (2) the Principle of Neutrality – there is no time which is before or after another time. The tensed facts which make up reality do not point towards

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[6] Henry Krips, *The Metaphysics of Quantum Theory,* (New York: Oxford University Press, 1987), 22.

[7] *Stanford Encyclopedia of Philosophy,* s.v. "Bohr's Correspondence Principle", accessed December 05 2019, https://plato.stanford.edu/entries/bohr-correspondence/

[8] Martin A. Lipman, "On Fine's Fragmentalism", Martin A. Lipman, 2015, http://www.martinlipman.org/wp-content/uploads/2016/02/OFF.pdf

one specific time as opposed to another, but rather, they are descriptions of reality at different times. (3) the Principle of Absolutism – the composition of reality is absolute and not relative to time and (4) the denial of the Principle of Coherence – the notion that reality is not contradictory or made up of incompatible contents.

Fine considers fragments to be 'maximal coherent collections of facts' [9], which we come to identify by taking the relation of coherence between facts to be a primitive notion. Each moment of time is identified with these fragments and all facts which belong to a fragment are compatible with each other. In addition, this theory introduces a new primitive notion, named co-obtaining[10]. Co-obtaining relates different states of affairs without relating them spatiotemporally. Therefore, in systems where two properties do not co-obtain, it is an example of two distinct fragments of reality. Furthermore, from to the notion of co-obtaining, when a quantum system is in a superposition of state, it is an example of two different fragments of reality, which are both equally real. In Johnathan Simon's 2017 article[11], he refers to Fragmentalism as 'conservative realism' as it allows the retention of our intuitive conception of what things and properties are fundamental (such as nothing can be in two places at once) as well as agrees with the theory of quantum mechanics that the quantum state provides all the information you need to understand a quantum system.

From this view of Fragmentalism, the wave function from quantum mechanics can appear in this interpretation in two different ways; (i) as a primitive property of fragments or (ii) as the primitive relation between different fragments. With either definition of the wave function, we can see the collapse of the wave function simply as a fragment coming into reality rather than a determinate of the photon's position coming into reality. Hence, the statement "the photon is in a superposition of both slit 1 and slit 2" can be understood as in one state of affair, the photon is in slit 1 and in another state of affair, the photon is in slit 2. These two states of affairs are incompatible with each other and so they cannot co-obtain, therefore, they express two different fragments of reality.

Fragmentalism also presents a for the amplitude of the wave-function to be understood. From the Born Rule, we know that the probability of obtaining a measurement outcome of a wave is equal to the square of the amplitude of the wave function of that wave. It follows from our understanding of

[9] Ibid, 3

[10] Fine refers to this notion as 'coherence' (2015), while Lipman labelled it 'co-obtaining' in his 2015 paper

[11] Jonathan Simon, "Fragmenting the Wave Function", *Oxford Studies in Metaphysics* 11, (2018): 123-145, https://jonsimon.net/papers/Fragmenting.pdf

Fragmentalism that the square of the amplitude of the wave function can now also be understood as the probability the corresponding state of affair is more likely to exist that the other.

Fragmentalism is a strong theory as it provides different interpretation of how the indeterminacy proposed by quantum mechanics can be understood in reality, while retaining our understanding and assumptions about the way the world is. Nevertheless, it is not a theory that can be accepted as it stands. If the collapse of the wave function is assumed to be a description of a fragment coming into reality, it follows that there is a movement of time which allows that fragment to 'come into the present'. However, as discussed above, Fine's Fragmentalism was formulated on 4 principles, one of which is the Principle of Absolutism. Consequently, the collapse of the wave function cannot be a time dependent event as the theory originally denies a relation between events and time. This may point to a reality in which time is unreal, which may be a discussion for another essay.

In conclusion, theory of Fragmentalism is a useful illustration of how metaphysical indeterminacy can alter our view of reality. This is a strong example of how Quantum Mechanics as it stands fails as a physical theory as it does not specify a physical ontology of the world, nor does it stipulate any laws regarding how the world behave through time, as a theory should. However, quantum mechanics does show that the idea of real, metaphysical indeterminacy, one which has no epistemic or semantic limitation plays a genuinely explanatory role in our understanding of reality. Further research should take the idea of metaphysical indeterminacy into consideration when attempting to understand the nature of reality.