Is determinism completely rejected in the standard Quantum Mechanics?

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Abstract

Determinism is related to other fundamental concepts such as causality. However, with the growth of quantum physics, determinism became a scientific "dilemma" and has created many challenges in various contemporary sciences. Most of modern physicists chose elimination of determinism. The basic question is: Is determinism completely removable? To answer this question, this paper is to investigate this concept analytically. At first we consider different aspects of the terminology and definition of determinism. Particularly, we pay attention to different kinds of determinism including global/local domain, complete/incomplete form, and the main factor in the formation of events. It is discussed that although determinism took a complete and universal form in classical physics, because of some philosophical ideas, determinism changed into a different concept, even as a problem and an undesirable element, in the standard (Copenhagen interpretation of) quantum mechanics. It is explained that determinism is a complex concept with a number of aspects and characteristics. Prediction, the world accessibility, and connection between the past and the future are the characteristics of the concept of determinism which cannot be set aside from the science. The final result is that, without any pre-assumption or alternative interpretation as what is done in already known realistic and deterministic theories as Bohmian quantum mechanics and/or many worlds interpretation of quantum mechanics, determinism cannot be completely denied in the standard (Copenhagen interpretation of) quantum mechanics.

Keywords: Determinism; Prediction; Causality; Quantum Mechanics

1. Introduction

It is noteworthy that the concept of determinism is discussed today in many sciences, such as biology, sociology, physics, and ethics (Sarkar, Pfeifer, 2006: 198) and even in theology (Popper, 1991: 5). This concept is related to other fundamental concepts such as causality, prediction, and even notions such as law, free will, intelligence, and chance (Carnap, 1966: 218). The concept of determinism has created many challenges in various contemporary sciences. Although some insist on this idea that determinism is a dead issue, it is a robust doctrine and is quite hard to be killed. Nonetheless, it is fragile in other respects and requires various enabling assumptions to give it a fighting chance (Butterfield, Earman, 2007: 1369). In the classical history of science, most of the natural scientists and materialist philosophers substantiated and developed the concept of determinism (by F. Bacon, Galileo Galilee, Descartes, Newton, Lomonosov, Laplace, Spinoza, and the French 18th-century materialists) (Frolov, 1984: 104). They believed determinism is necessarily mechanistic and abstract (Frolov, 1984: 104). The scholars of that era combined causality and necessity and denied the objective character of chance. So, determinism became unrivaled. But in the twentieth century and in the modern age of physics, the continuity, the causality, the reality and the possibility of representation were denied by most physicists. Both in physics and philosophy, the mechanical age was ended. Determinism was so influential in modern physics; some ones regarded the birth of modern physics as the result of the abandonment of determinism (Jeans, 1943: 125). With the growth of quantum physics, determinism became a scientific dilemma. The physicist's solution was the elimination of determinism (Jeans, 1943: 151). Is determinism really removable? Is there a way to maintain determinism in quantum physics? These are important questions we want to consider in this paper. In our opinion, the root of the problems refers to the conceptual ambiguity of determinism. If we understand the concept of determinism correctly, many misunderstandings (problems) in natural sciences, especially physics, can be removed (solved). As a step towards this, we first consider the terminology of determinism and its definitions. Then, different kinds of determinism with its important characteristics are introduced. Finally, we try to clarify the dilemma of determinism in modern physics. Specifically, we shall show that quantum physics isn't a completely (globally) indeterministic theory. It is mentionable that all we don't want to consider an alternative approach and/or theory as what already has been considered in some well-known models; but, we want to argue about this fact that if we can have a correct analytical consideration of determinism specially by setting aside some misconceptions about it, even in the standard Copenhagen interpretation of quantum theory won't completely reject determinism.

2. A short review of some definitions of determinism

Among a number of other possible definitions of determinism, eight already well-known ones are as in the following:

I) William James's definition (simple determinism): " It professes that those parts of the universe already laid down absolutely appoint and decree what the other parts shall be" (Earman, 1986: 5).

II) Laplace's determinism (classical determinism): " We ought to regard the present state of the universe as the effect of its antecedent state and as the cause of the state that is to follow. An intelligence knowing all the forces acting in nature at a given instant, as well as the momentary positions of all things in the universe, would be able to comprehend in one single formula the motions of the largest bodies as well as the lightest atoms in the world, provided that its intellect was sufficiently powerful to subject all data to analysis; to it nothing would be uncertain, the future as well as the past would be present to its eyes. The perfection that the human mind has been able to give to astronomy affords but a feeble outline of such an intelligence" (Laplace, 1820: 4).

III) Popper's determinism (scientific determinism): Popper introduces a particular type of determinism and calls it 'scientific determinism': " The doctrine of 'scientific determinism' is the doctrine that the state of any closed physical system at any given future instant of time can be predicted, even from within the system, with any specified degree of precision" (Popper, 1991: 36).

IV) Causal determinism: Some determinists formulate determinism like this: (a) every event has a sufficient cause; (b) at any given time, given the past, only one future is possible; (c) given knowledge of all former conditions and all laws of nature, an operator could predict at any given time the subsequent history of the universe exactly (Audi, 1999: 228).

V) Logical determinism: This doctrine supports the view that future events (i.e. changes in the states of affairs) are determinate, just like what happened in the past, and that statements about them are determinately true or false (Birx, 2009: 299). In other words; if an accident is going to happen, it is true in advance that it will happen (Algra et al., 1999: 519), since it is proven that every statement is true, and if it is not so, it is false. This means that no third truth value other than true or false can be attributed to any statement. If this is the case, then it might be maintained with regard to statements about the future (Borchert, 2006: 5).

VI) Epistemic determinism: If it is recognized that an accident will happen, then that accident cannot fail to occur (Algra et al., 1999: 519). This definition is focused on the external realization or non-realization of the event, unlike 'logical determinism' that focuses on what is true or false.

VII) Metaphysical determinism: The doctrine which supports that all accidents in this world are steady, invariable, or predetermined. It does not claim that they are known to everybody or predictable by scientific means. Rather, it acknowledges that the future is as little changeable as is the past. Everybody knows what we mean when we say that the past cannot be changed. It is exactly the same sense to say that the future cannot be changed, according to metaphysical determinism (Popper, 1991: 7). In Popper's opinion, " Metaphysical determinism is not clearly testable." (Popper, 1991: 7) However, with the right theology and intellectual reasoning we can understand it.

VIII) Theological determinism: This doctrine argues that God determines all things that happened in the past or things that will happen in the present or future, and the cycle of events that he knows will fall out, can fall out. According to some theological theories, the concept of God regards the one who is, among other things, absolutely good, omniscient, and omnipotent and upon whom, moreover, the entire world and everything in it, down to the minutest detail, are absolutely dependent for existence and nature (Borchert, 2006: 8).

3. Classification of determinism into global/local and complete/incomplete kinds

In this section, we consider two/four kinds of determinism as in the following:

I) Global and local determinism: Determinism can have many instances. If the desired definition includes all instances, we have "global determinism", which refers to the full range. On the other hand, if it includes limited instances, we have "local determinism", which indicates limited cases of a given moment of time. For example, in Laplace's definition, we face a global determinism (Müller, Placek, 2018: 215–252).

II) Complete and incomplete determinism: The state of any closed physical system at any given future instant of time can be predicted completely, even from within the system, with any specified degree of precision; as a result, this is "complete determinism". And if the time, prediction, or degree of precision is not complete, we have "incomplete determinism". Therefore, the forecast will be vague or very probabilistic.

4. Classification of determinism based on the main factor in the events formation:

Various factors in the past can be considered as determining the future. According to each factor, a special type of determinism might be achieved:

a) External cause determination: The determination of the effect by the impressive (external) cause. For example, (a) If a bullet is fired against a glass, it breaks, and (b) if an electromotive force is applied to the ends of a piece of copper, an electric current is set up in the copper in accordance with Ohm's law (Bunge, 1979: 18)**.**

b) Targeting determination: Determining objects to achieve the desired goals. For instance, standardization is pursued in industry in order to lower production expenditures.

c) Self-determination: Determination by the former resultant. For example, the incessant positions of a freely moving macroscopic body are uniquely determined by its situation and speed at any prescribed instant of time (Bunge, 1979: 18).

d) Mechanical determination: The determination of the consequent by the precedent, usually with the addition of efficient causes and reciprocal functions. For instance, forces change the state of motion of bodies (but motion may exist before the application of the forces) (Bunge, 1979: 19).

e) Statistical determination: The determination of the end result by the joint function of independent or quasi-independent entities. For example, in the game of dice, the long-run intermittence of the event "throwing two aces in succession" is 1:36 (Bunge, 1979: 19).

f) Structural (or holistic) determination: The determination of the parts by the whole. For instance, the behavior of an odd (a molecule in a liquid, a person in a social group) is determined by the over-all structure of the collection to which it belongs (Bunge, 1979: 19).

g) Dialectical determination: The determination of the total process by the internal "strife" and eventual following synthesis of its essential opposite ingredients. For example, the changes of state in matter in bulk are constructed by the interaction and final preference of one of the two opposite trends: thermal agitation and molecular attraction (Bunge, 1979: 19).

5. Two opposite viewpoints on the concept of determinism

During serious discussions on the concept of determinism, two opposite viewpoints have been formed as in the following:

I) Global and complete determinism

The ultimate development of "global and complete determinism" was in the 19th century by Laplace. He asserted that the state (or the condition) of the universe at any moment of time, future or past, is completely determined if its conditions (or situation) is given at some moment, for example, the present. The reason is that he believed "If an intelligence, for one given instant, recognizes all the forces with animate nature, and the respective positions of the things which compose it, and if that intelligence is also sufficiently vast to subject these data to analysis, it will comprehend in one formula the movements of the largest bodies of the universe as well as those of the minutest atom: nothing will be uncertain to it, and the future as well as the past will be present to its vision" (Laplace, 1820 :3-4). Laplace's determinism is not dependent on God, because when the Emperor Napoleon Bonaparte (1769-1821) questioned him about whether or not he had mentioned God in his treatise Celestial Mechanics, Laplace is said to have responded, 'Je n'avais pas besoin de cette hypothese-la' (I did not need that hypothesis) (Cushing, 1998: 169). Therefore, in the nineteenths century, a complete universal and mechanical determinism appeared which was not theological.

II) Determinism as a dilemma

The twentieth century was the culmination of developments on the concept of determinism. It is interesting to note that there were two different stances toward the concept of determinism. Physicists hated determinism, but it was accepted into the social sciences.
The greatest problems about determinism emerged in modern physics, in particular the quantum mechanics. Various physicists have tried to dismiss determinism of physical interpretation and analysis. There had been various motives for denying determinism; it seems the writings of Renouvier, Boutroux, Kierkegaard, and Hoffding have been influential in this regard. Renouvier criticized the strict validity of the causality principle as a regulative determinant of physical processes. He denied the belief that causality is a principle without which the experience of an intelligible world would be impossible and a realistic principle of order in the cosmos instead of causality. Renouvier raised a phenomenalism according to which all that we immediately know is but a particular phenomenon or representation (Jammer, 1966: 174). Boutroux had similar ideas, and denied real and direct knowledge of the universe. In fact, he believed that "All experimental finding is reduced, in the end, to confining within as close limits as possible the value of the measurable elements of phenomena" and so " we never reach the exact points at which the phenomenon really begins and ends" (F. Rothwell, 1920: 28).

Charles Sanders Peirce took a firmer step and suggested the notion "Nature is not regular" (Peirce, 1935, v5: 213) and "Chance is a factor in the universe" (Peirce, 1935, v6: 137). According to him, things and events cannot be related to each other and thus we cannot predict any incident by knowing its past. The logical consequence of his arguments was that in order to properly analyze the process of experimental observation, the absolute chance, and not an indeterminacy arising merely from our ignorance, is an irreducible factor in physical processes (Peirce, 1935, v6: 156). It is noteworthy that he had commented before Heisenberg's uncertainty principle. From Exner's point of view, it is impossible to directly and accurately understand the particles of the microscopic world because he believed "... Every single, however specialized, physical measurement produces only an average value resulting from billions of individual motions... but to predict in physics the outcome of an individual process is impossible" (Jammer,1966 :176).

Physicists insist on differentiating between the probabilities posed by scholars such as Boutroux and Exner and the probabilities of classical physics. They also believe that in classical physics, probabilistic propositions were the product of the human's ignorance of the exact details of the individual event, or because of the insufficient resolving power of our measuring instruments while in the new conception of probability, it is assumed that macroscopic determinism is a statistical effect and that the individual microscopic or submicroscopic event is purely contingent. Ponckare acknowledged this difference in his review of the Planck's theory of quanta (Jammer, 1966: 177). With these interpretations, realism is being rejected and prediction is rendered to be impossible.

It seems the above-mentioned considerations provided the basis for the so-called "Copenhagen interpretation" of quantum physics by Niels Bohr. Moreover, Bohr's own scientific background should be considered too. In his youth time, Bohr was a pupil of Harald Hoffding (Niels' father, Christian Bohr, colleague and intimate friend), who was in turn an ardent student and brilliant expounder of Kierkegaard's teachings. The young Bohr got acquainted with Kierkegaard's thoughts through Hoffding lectures. The centerpiece of Kierkegaard's work was philosophy of life and religion, the so-called "qualitative dialectic". It seems his inconsistence between thought and reality, his conflicting conceptions of life, and his perseverance on the necessity of choice had apparently left a deep impression on Bohr's youthful mind. Kierkegaard insisted on the practical value of thought, opposed the construction of systems, and persisted that thought could never attain reality because as soon as it thinks to do something it falsifies reality by changing it into an imagined reality.

Referring to Kierkegaard's indeterministic theory of "leaps", Hoffding believed " It seems to be clear that if the leap occurs between two states or two moments, no eye can possibly observe it, and since it therefore can never be a phenomenon, its description ceases to be a description" (Hoffding, 1905: 114). When we do not have access to the whole truth, an object cannot be recognized; consequently, " causality cannot be described" (Jammer, 1966: 180). Kierkegaard's and Hoffding's emphasis on the practical and pragmatic significance of truth reverberated in Bohr's frequent remark, " It is not the question at present whether this view is true or not, but what arguments we can honestly draw with respect to it from the available information" (Rosenfeld, Bohr, 1945: 8). Bohr emphasized: " It is clearly impossible to distinguish sharply between the phenomena themselves and their conscious perception" (Bohr, 1958: 27).

Bohr was also strongly influenced by William James; James' famous sentence " We must find a theory that will work" is still used in modern physics (Jammer, 1966: 182).

Because of these philosophical contexts and approaches, physicists eventually denied the " mechanical determinism" or " metaphysical causation", and Heisenberg formulated his principle of uncertainty. Although some great physicists as Einstein dismissed Bohr's theory as an incomplete theory (EPR, 1935: 777), because of some reasons as the positivistic viewpoint and wonderful apparent experimental successes of modern quantum mechanics, the Copenhagen interpretation (as an indeterminstic interpretation) was recognized as the standard interpretation.

5. The characteristics of determinism concept

This concept is made up of various scientific and philosophical presuppositions which may be considered as its characteristics. To solve problems and puzzles corresponding to determinism, one must pay attention to these characteristics. Indeed, the origin of the differences in the various definitions and the formation of various types of determinism corresponds to the characteristics of the determinism concept. At the following we have considered three characteristics of the concept of determinism:

I) Prediction

When discussing about determinism, we are not merely looking for the objective relevance of events; rather, we are considering them from the human perspective or the human mind.
The Laplace's demon can predict the future accurately, because it knows everything. The complete and accurate determinism comes about as a result of the accurate prediction. Human beings are naturally curious about the future, and as their various needs enforce them to prepare themselves for the possible dangers of the future, they must be able to predict the future. In fact, throughout history, the human beings have been trying to replace the vague rules of the past with the more detailed scientifically known laws so that they can predict the future more accurately. Determinism may be considered as a tool by which the humans have tried to predict the future.

II) The world accessibility

If there is no access to the world or there were no way that we had been able to understand the world, understanding and defining an event in the universe does not make sense, and so, determinism will not exist. Even anti-realists like Poincare didn't deny access to the world (Poincaré, 2015:123); the world accessibility is one of the tenets of determinism.

III) Connection between the past and the future

If there is no connection between the past and the future, there will be no determinism. So the "connection between the past and the future" is one of the main characteristics of determinism.
It is quite clear that there is a kind of connection between the future and the past. Therefore, via the knowledge of the past, the future can also be known. This connection may be a "causal relationship" that somehow becomes "necessary" or a "permanent interoperability relationship" (Earman, 1986: 6; Bunge, 1979: 10; Jammer, 1966: 170), or something similar to Leibniz's "principle of sufficient reason" (https://plato.stanford.edu, 2019).

6. Can determinism be denied completely?

In fact, a complete denial of the concept of determinism in the natural sciences is impossible; this is because the characteristics of determinism are always found in the natural sciences. If "the world accessibility" and "prediction" are denied utterly, it is the science that has been denied, since science without "the understanding of the world" is nothing. If one denies "the connection between the past and the future" and "prediction", such a person cannot talk about the scientific laws. Since prediction, laws, and the discovery of the world cannot be removed from the science, complete denial of determinism isn't possible. In fact, no scientist would accept such a removal (Gattei, Agassi, 2016: 37).

Moreover, considering social sciences considerations, the complete denial of determinism leads to the elimination of the "will and power of choice" as well as the "moral and legal responsibility", because of the assumption of unpredictability!

7. Types of determinism based on its characteristics

Given the characteristics of determinism, we can maintain it as in the following:

a) If "prediction" is used for all things, "global determinism" is being taken into account, and if "prediction" is not applied to all things and is only used for a specific area, "local determinism" is considered.

b) If accessibility to the facts is complete, then "complete determinism" or "strong determinism" is established. On the other hand, if the world accessibility is in a state of uncertainty or probability, then "incomplete determinism" is achieved.

c) If the connection between the past and the future is the causal relationship, then "causal determinism" is established. Besides, if the connection between the past and the future is to achieve a goal, then "teleological or targeting determinism" is meant (Bunge, 1979: 17). Moreover, if the main factor of the connection between past and future is mechanical, then "mechanical determination" is established.

Other types can be made similarly based on other characteristics of determinism.

8. Is it possible to solve the dilemma of determinism in modern Physics?

In the scientific and physical literature, especially in the Copenhagen school of physics, it is claimed that the results of quantum physics laws and experiments reject determinism (Gattei, Agassi, 2016: 34) (Hawking, Mlodinow, 2010: 34). However, it seems followers of such an idea haven't paid deep attention to the concept of determinism with its variety of characteristics and considerations; because, the Copenhagen school actually accepts the three above-mentioned characteristics of determinism (as an example from quantum mechanics see the next section). Even some believe that they have accepted causal relationship (Plotnitsky, 2006: 51-54). Yes, the Copenhagen school rejects "universal and complete determinism" or "classical determinism" (Müller, Placek, 2018: 221; Bunge, 1979: 15). The reason is that the adherents of this school realized that: (a) observation cannot show the whole of reality, and unlike "classical physics", all observables are not obvious; (b) the scope of the universe and its complexities are more extensive than that of classical physics; and (c), instead of going to the components within the collection, it is necessary to investigate the collections themselves (Plotnitsky, 2006:2).

Standard quantum physics has abandoned the "absolute determinism"; because, in the view of its scholars, the uncertainty is a fundamental aspect of nature (Krane, 2012:126-128). Hence, they should accept the "incomplete, local, and statistical determinism".

At last, but not at least, it is noticeable to mention that there is a fundamental difference between what we have considered and explained about it in this paper and some other already well-known alternative interpretation of quantum mechanics as those based on hidden variable theories (the most famous one is Bohmian Quantum mechanics, Bohm, 1952: 166-193 and 1953: 458-466) or the so-called many worlds interpretation of quantum theory (Everett, 1957: 454-462) which has been considered in: Quantum theory and determinism (Vaidmann, 2014: 5-38). Indeed, such alternative theories and approaches have been presented to save determinism/causality and realism at an underside (substratum) level for the standard formulation of quantum theory while here we have tried to explain about this fact that even Copenhagen interpretation of quantum mechanics cannot reject determinism completely/absolutely because although some ones may set aside this deep concept based on some misconceptions, it has some characteristics those aren’t simply deniable.

9. An example from quantum mechanics

As an example from quantum mechanics, consider an electron (not a statistical beam but just one electron) in an un-polarized state whose spin is to be measured by for example a Stern-Gerlach apparatus. The standard quantum mechanics teaches us that if one does the experiment, she/he shall finds out an up (+1/2) outcome with a probability of 50 percent and a down (-1/2) outcome with a probability of 50 percent and thus a probable indereministic situation exists; moreover, repetition of the experiment with the same conditions doesn’t result in the same result as before. Well, even if we accept this example without considering any statistical substratum and without any doubt about the guarantee of repetition of the experiment as the same as before, there are still a kind of "predictability" (determinism) in this experiment and not an absolute indeterminism; because, clearly confirmed by the standard quantum mechanics, we can "predict" the resulting outcome is up or down and not another unknown result (e.g. +1/3 or -1/7 or other infinite possible results). In other words, the result of the experiment is pre-determined in a specific area but not as an exact point. Moreover, as we know, the time evolution of the spin state of the electron is under government of the Schrödinger differential equation in which any present state is a function of the past state and the initial state for the future. So, although there isn't classical/mechanical/absolute determinism in the experiment, it is a deterministic experiment in an incomplete manner. Even for phenomena dealing with infinite experimental outcomes as for example the energy states of a particle in a box or the energy levels of the electrons in atoms, although there are infinite possible energy values, all them are under the government of a specific mathematical formula and not an arbitrary (by chance) value; thus, the results are pre-determined in a specific "area" or "domain".

10. Summary and conclusion

The definitions of determinism with its different kinds including, the "global/local domain", "complete/incomplete form", and "the main factor in the formation of events" were considered. The evolution of the concept of determinism, particularly its change into a different concept in quantum mechanics, was explained. Since Copenhagen school physicists, especially Bohr, regarded determinism as a problem and an undesirable element, we designed a new framework to analyze the concept of determinism and tried to solve the dilemma of determinism through this framework. It was discussed that determinism is a complex concept with a number of characteristics as prediction, the world accessibility, and connection between the past and the future which cannot be set aside from the science. The final result was that determinism cannot be completely denied in modern science; in particular, the standard (Copenhagen interpretation of) quantum mechanics is a deterministic theory but in an incomplete manner.

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