Does quantum mechanics support indeterminism philosophy essay

The quantum theory is the theoretical basis of modern physics that explains the nature and behaviour of matter and energy on the atomic and subatomic level, and is the most important theory at the micro level. It was the first to shake the foundations of deterministic interpretation of the universe that had dominated every branch of science – physical, social, medical etc.

The aim of the project is to discuss whether the quantum theory supports determinism or indeterminism by exploring its elements, principles and interpretations my project presents arguments for and against determinism, completeness of the theory; also reviewing some of the arguments that has been given on both sides. I will do this by looking at the discussing the principles of quantum mechanics, incompleteness, experimental limitations caused by measurement etc.

I will firstly argue for indeterminism by stating how the principles of quantum mechanics relate to indeterminism and appear indeterministic in nature. However I will also argue that quantum physics is incomplete hence we cannot be sure that whether it is indeterministic; In fact indeterminism could simply be due to incompleteness. My project concludes that more information is needed to answer the question. Eventhough the EPR paradox fails to prove that quantum mechanics is incomplete and hidden variables are existent, quantum mechanics is nonetheless still incomplete. An incomplete theory, along with many epistemological limitations is not strong enough to prove indeterminism.

Introduction

Indeterminism is the concept that events are not caused. It is linked to chance and probability and is the opposite of determinism[2]

The philosophy of physics examines the fundamental philosophical questions that are caused by modern physics. One branch of physics, quantum mechanics, has created much controversy due to its counterintuitive principles and interpretations, and its theories have contradicted many philosophies of the time such as determinism. The question of whether the universe is deterministic or indeterministic is a recurring philosophical problem and since the advent of quantum mechanics, many physicists feel that the issue has been settled in favour of indeterminism at the microscopic level. However, the question remains as to whether the macro-level is indeterministic as well.

At one time it was assumed that if the behaviour of a physical system cannot be predicted, it is simply due to the lack of information, and an investigation with enough information will be a deterministic theory. For example knowing all the forces acting on a dice will allow one to predict which number comes up.

However, since the advent of quantum mechanics, many believed that systems are sometimes indeterministic in nature. The two sources of quantum indeterminism are the Heisenberg uncertainty principle, and the collapse of the wave function where the state of the system cannot be predicted after measurement.

The theory of indeterminacy states that particles of extremely low mass are unpredictable because any observation or measurement will change their initial state. Supporters of a deterministic universe have criticised the random nature of quantum physics. For example Einstein stated that “ God does not play dice with the universe.” to which Niels Bohr replied “ Stop telling God what to do”.

Literature review

Determinism

Determinism was the dominant philosophy in the 18th century. It states that the universe is governed by laws and, with sufficient knowledge, it is possible to predict the future behaviour of any system. Most advocates of determinism argue that our incomplete knowledge is the cause of uncertainty. There are two types of determinism[3]:

Ontological determinism or causal determinism: every event has a cause upon the occurrence of which the event inevitably follows

Epistemological or predictive determinism: If we knew enough, we could accurately predict the entire future of the universe at any point in time

Quantum mechanics

Quantum mechanics is the ‘ science dealing with the behaviour of matter and light on the atomic and subatomic scale’[4]It allowed scientists to explain phenomenon produced by some experiments which previously could not be explained by classical mechanics, which describes the motion of macroscopic objects.

It was realized that quantum mechanics defies some of the basic principles of classical mechanics. These principles are:[5]

The principle of space and time: physical objects, or any collection of masses(many particles) must exist separately in space and time meaning that they can are localizable and countable, physical processes in which these objects take part in also exist in space and time.

The principle of causality: any cause must precede its effect, nothing is random.

The principle of determination: everything is determined, and are caused by forces external to the will

The principle of continuity, all objects that goes through physical processes from an initial to final stage will go through any intervening state uninterrupted.

The principle of the conservation of energy: energy cannot be created or destroyed, only converted into other forms.

Fundamental Concepts

The uncertainty principle – " The more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa"[6]

Pauli Exclusion Principle- no electrons can be in the same quantum state, a set of mathematical variables that describes a quantum system. The quantum state can be described by the four quantum numbers:[7]

the principle quantum number : describes the energy level

the magnetic quantum number: direction of orbital angular momentum

the azimuthal quantum number: magnitude of the orbital angular momentum

spin quantum number: Direction of its spin

3. Wave particle duality- all particles have properties of both waves and particles. In 1924 Louis de Broglie stated that wave particle duality applies to all matter, not just light.[8]

4. Entanglement- multiple particles are linked in a way that the measurement of one particle’s quantum state determines the possible quantum states of other particles[9]

5. Nonlocality- the direct influence of one object on another, distant object, this violates Einstein’s theory of special relativity.

Interpretations

The two major interpretations of quantum are the Copenhagen interpretation and the many-worlds theory

The Copenhagen interpretation of quantum mechanics was proposed by Niels Bohr and states that objective reality doesn’t exist; an object exists in a superposition of states until an observation is made, after which the superposition collapses into one state.

We can illustrate the Copenhagen interpretation using Schrodinger’s Cat. The ‘ Schrodinger’s Cat’ thought experiment was proposed and devised by Austrian physicist Erwin Schrödinger in 1935. In 1935 he wrote that “ One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed.”[10]According to the Copenhagen interpretation the cat is in a superposition of states, and when we open the box the superposition is lost and the cat is either dead or alive.

The second interpretation was proposed by Hugh Everett in 1957. This interpretation dismisses the collapse of the wave function; they just continually evolve and split into other wave functions. It is like a never-ending tree where each branch is a separate universe. It states that whenever a measurement is made, or when the potential for an object to be in any state exists, the universe splits into a number of parallel universes equal to the number of states the object can be in. The many worlds interpretation also implies that different wave functions of different universes coexist with ours i. e. all possible worlds coexist with us, similar to a radio where there are hundreds of different radio waves broadcasted from various locations; however a radio can only detect one frequency at a time because other frequencies are not in phase.[11]

History

Classical mechanics

Classical mechanics, also known as Newtonian mechanics deals with the motion of bodies under the influence of forces or with the equilibrium of bodies when all forces are balanced,[12]and are based on Newton’s laws of motion.

Prior to quantum mechanics, the world was dominated by Newtonian mechanics, which is completely deterministic in nature. To Newton, the universe was metaphorically a clock that has been ticking ever since its creation and everything in it obeys his three laws of motion in a precise and predictable way. Newton’s deterministic laws had causally explained how any object in the universe behaved; he proves that if one knows the position and momentum of any object they can determine the future states of the object by using his laws of motion. The motions celestial bodies such as stars, planets can be predicted with great accuracy thousands of years before they occur. Newtonian mechanics was highly accurate and effective in predicting the states of large ‘ macrophysical objects’ such as the moon. However, when physicists were able to examine the movement and behaviour of small ‘ microphysical’ objects such as particles, they could not apply Newton’s laws of motion to them. For instance it was long known that electrons orbit the nucleus of an atom in a manner similiar to planets orbiting the sun. However, classical mechanics/physics predicted that if they orbited the nucleus in this way, the electrons would spiral and crash into the nucleus, making life impossible. This, along with many experiments that classical mechanics could not explain, led to the formation of quantum physics.[13]

Bohr-Einstein debates

The Bohr-Einstein debates were a series of debates and disputes about quantum mechanics between Niels Bohr and Albert Einstein, who were two of its many founders. In each debate, Bohr argues against determinism and Einstein argues for it. Einstein proposed a barrage of thought experiments to demolish the quantum theory by showing that it's theoretically possible to measure both the momentum and position of a particle at the same time. In 1930, Einstein proposed a ' coup de grace' to the quantum theory. He considers a box that contains a gas of photons and a clock which controls a shutter that covers a hole. The shutter is closed until a random time't' where it opens and briefly releases a single photon. In order to disprove indeterminism it is necessary to be able to measure the energy the photon has. He then states that since one can measure the shutter speed precisely and the photon's energy with e= mc2, one can determine the state of the photon with infinite precision, hence violating the uncertainty principle. However, Bohr was able to find a tiny flaw in Einstein's argument the next day. After the emission of the photon, the box would be displaced since it is slightly lighter, when the box is displaced, so is the clock and the shutter inside it. In order to restore to box to its original position weights must be added but this means the weight box itself must be measured. If one calculated the uncertainty in weight and shutter speed, he can conclude that the box exactly obeyed the uncertainty principle.[14]

EPR Paradox

In 1935, Einstein, Podolsky and Rosen published an article called ‘ Can Quantum-Mechanical Description of Physical Reality be Considered Complete?’ to prove that indeterminacy only exists as a result of measurement, and not because of the physical properties of a system. The paradox is based on quantum entanglement and makes two fundamental assumptions:[15]

- If, without in any way disturbing a system, we can predict with certainty

(i. e., with a probability equal to unity) the value of a physical quantity,

then there exists an element of physical reality corresponding to this physical quantity.

- Two systems cannot in¬, uence each other instantaneously when they are a

large distance apart; all interactions are local.

The spin of a particle is its intrinsic angular momentum. An unstable particle with 0 spin decays into two particles e. g. an electron and a positron which travel in opposite directions so that they have opposite spins, one is ½ and the other is -1/2 because they have to add up to 0.

Suppose scientist A measures the y-axis spin and finds out that it's upwards, and scientist B can measure the x direction spin of the positron and finds out that it's rightwards. As soon as we measure the spin of Particle A, we know for sure the value we'll get from measuring the spin of Particle B. The paradox arises because if scientist B knows the spin of both the x and y direction, which is impossible according to Heisenberg's uncertainty principle that states that you can't both measure the y component and x component at the same time. Scientist B is allowed to measure the y direction spin of the positron but can't measure the x direction spin because he'll know both. There are two reasons the positron know if scientist A measured the vertical spin of the electron.[16]

Either they can instantaneously communicate with each other, however this requires them to travel faster than the speed of light; breaking the rules of special relativity.

They have hidden variables, information embedded within them that governs their behaviour such that they always act in a complementary way, however they must have a huge amount of information embedded inside them, and they have no idea what interactions they have with other particles.

A positron won't live for more than a fraction of a second because it will quickly meet another electron, when they meet they will annihilate each other and form energy. The only ways the electron will that the positron doesn't exist anymore is that either they communicate instantaneously or they have hidden variables, both which are highly unlikely.

The only way this is true is that if all electrons know what is happening to every other particle in the universe i. e. the Pauli Exclusion Principle applies. This implies electrons have to have consciousness and know what quantum state is still available.

In 1964 John Stewart Bell proposed a set of inequalities known as Bell’s inequalities to show that deterministic results that supported hidden variables does not support quantum mechanics. The inequalities would not work if quantum mechanics were true. After experiments were performed it was proven that they didn’t and that there can’t be hidden variables. Hence, if we rule out the possibility of hidden variables, we are left with a conclusion that the two particles are communicating instantaneously thus violating special relativity and locality.

In 1952, physicist David Bohm proposed an alternative theory to quantum mechanics. It is considered to be a hidden variable theory; however by being non-local it satisfies Bell’s inequalities. He states that there is a quantum force that moves particles around so that they behave similar to quantum mechanical predictions. Bohm’s theory is epistemologically deterministic because one can predict every subsequent position of every particle by knowing its initial states; however it is impossible to know the configuration of all particles. Hence the universe appears indeterministic eventhough it is due to our ignorance. Although Bohm’s particles are classical in the sense that they have precisely de¬ ned values for all physical quantities, their behaviour is distinctly non-classical.

Bohm's theory allows for instantaneous communication between particles over long distances hence it must be non-local. In fact, his theory must also be contextual in order to escape Bell's inequalities. This means that the results of a measurement can depend of the results of measurements that has been made on other systems. Thus, in the EPR experiment, the result of a measurement on the second electron may depend on which has in fact been made on the ¬ ﬁ rst electron. Bohm's theory is contextual, in addition to being non-local. However non-locality and contextuality were judged by most to be too high a price to pay for determinism.

Discussion.

This project ultimately decides between two hypotheses:

1. The system is governed by genuinely stochastic, indeterministic laws (or by no laws at all), i. e., its apparent randomness is in fact real randomness.

2. The system is governed by underlying deterministic laws, but is chaotic. [17]

Philosopher Patrick Suppes asserts that it isextremely difficult to decide whether the random behaviour arises from it random nature or from deterministic chaos. He states that that " There are processes which can equally well be analyzed as deterministic systems of classical mechanics or as indeterministic processes, no matter how many observations are made." And concludes that " Deterministic metaphysicians can comfortably hold to their view knowing they cannot be empirically refuted, but so can indeterministic ones as well."[18]

Indeterminism due to principles and concepts

Wave particle duality

If we randomly shoot a small object e. g. marbles through two parallel slits at the screen we see should see two bands at the screen. If light consists of particles they should form a band like the marbles, conversely if they were comprised of waves an interference pattern should form. Experiments had shown that an interference pattern is created and proved that light consists of waves.

However, near the end of the 19th century experiments proved that light also consists of particles (photons). One experiment involved shining a beam of light of very low intensity to colour a photographic sheet one spot at a time. Instead of colouring the sheet slowly over the whole area, it produced black photographic grains which indicates that each particle was detected individually. When enough particles were detected, their pattern was similar to a wave with a central maxima and adjacent minima. Hence the particles seem to propagate as a These discoveries led to a paradoxical situation: some experiments proved that light consists of particles, and others proved that it consists of waves.[19]

When scientists fired particles through two slits they didn’t create two bands, instead, the light arrives in varying concentrations at widely separated points, creating an interference pattern. Even when they fire them one at a time there is still an interference pattern. They deducted that the single electron leaves a particle, becomes a wave, goes through both slits, then interferes with itself, and hits the screen as a particle. The distribution of its collisions with the target can be calculated quite accurately but there is no way to know where in the resulting interference pattern the photon would end up.

If you measure a particle's position when it's at rest, you can measure it quite precisely because it's not moving, however since particles sometimes exhibit wave properties it will be harder measure its position because waves are energy over an area whereas particles are a point on a wave. Every individual electron is described by a wavefunction and when one measures it and locates it at x, the wavefunction collapses to a single point because it's the probability that the electron can be found at a point.

Uncertainty principle

The uncertainty principle states that " The more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa"[20], because if you want to measure its position you have to have it collide with a detector where it will lose momentum. This implies that nature has a probabilistic nature and is not completely deterministic.

The ¬ ﬁ rst uncertainty relation was derived by Heisenberg in 1925. Heisenberg realised that in order to measure the position of an electron he has to illuminate it and detect the reflected light. At least a photon is needed to measure the position because light consists of photon, and the accuracy of the measurement is directly proportional to the energy of the photon; the measurement becomes more precise as the energy of the photon goes up. However when a photon hits an electron, the electron suffers a recoil which causes its momentum to change. Moreover the higher the energy of the photon, the more the momentum is changed. Hence, if we want to make a very precise measurement of a particle's position, we greatly disturb its momentum. Similarly, if we make a very accurate measurement of a particle's momentum, we greatly disturb its position. It is impossible to measure something physical without interacting with it in some way. From this logic, there will be no way to get the momentum and location information at the same time.

Schrodinger's Cat

The unstable gas has a 50% chance of releasing and a 50% of doing nothing. Until we look into the bunker, we don't know if it's dead or alive. But if we repeat the experiment enough times, we can see that half the time cat survives, and the other half dead. A strict determinist will propose that the cat can only be dead or alive however the cat was in a probabilistic state before the observation; there is a 50% chance for the atom to decay as mentioned above. Since it is a probabilistic event, causal determination can't be true.

Many-Worlds Interpretation

' Agent-Causality is the idea that agents can start new causal chains that are not pre-determined by the events of the immediate or distant past and the physical laws of nature'[21]. The person opening the box has the ability to cause the universe to ' split', this is similar to the notion of agent cause, the only difference being that the cat is alive in one and dead is another. This disagrees with determinism because a strict determinist would state that anything within the parallel universes would be identical and do identical things

Indeterminacy Due to Experimental and Conceptual Limitations

Those of this opinion state that the interaction between the observer and the observed at the phase of experimentation results in uncertainty. Assume that an electron is being observed, in order for it to be seen light should reflect from it and reach our eyes. Similarly for us to see the moon light must reflect from it to our eyes. Eventhough light contains photons; it is too insignificant to influence the position or speed of macroscopic objects. However at a microscopic level the photon from the light would affect both the position and speed of the electron, thus leading to uncertainty. Hence, our epistemology should take into account the influence of the observer. To determine the future state of the universe requires one to be an external observer i. e. not part of the universe. However in quantum physics, the problem for the observer is that they are part of the observed system through the act of measurement. We have to accept that anyone inside that universe i. e. any internal entities will find it epistemological indeterminate, it wouldn't matter whether determinism actually exists.

External entities

The universe may be epistemologically deterministic for external entities such as God, or other deities. Laplace's demon is an articulation of determinism and a thought experiment devised by French physicist Pierre-Simon Laplace that involves a super-intelligence that could know the positions, velocities, and forces on all the particles in the universe at one time and have sufficient powerful reasoning, therefore able to determine the past and future values and states of everything with the laws of classical mechanics, nothing being uncertain. In other words it's a concept where one can use classical mechanics to predict the entirety of the universe.

Laplace said: ' We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at any given moment knew all of the forces that animate nature and the mutual positions of the beings that compose it, if this intellect were vast enough to submit the data to analysis, could condense into a single formula the movement of the greatest bodies of the universe and that of the lightest atom; for such an intellect nothing could be uncertain and the future just like the past would be present before its eyes.'[22]

Laplace's demon was based on the principles of reversibility and classical mechanics, and that the past, present and future contains the exact same information. This was eventually disproved by the second law of thermodynamics which states that entropy irreversibly increases. Rudolf Clausius, who introduced the concept of entropy, summarised the second law: " The entropy of an isolated system not in equilibrium will tend to increase over time, approaching a maximum value at equilibrium."[23]In addition, due to its deterministic nature, Laplace's demon is incompatible with most interpretations of quantum mechanics because of the uncertainty principle.

Philosopher Karl Popper argued that, however complete the information provided to the demon about its own past or present state, there will always be questions about its own future state which the demon cannot answer[24]. This is the thesis of non-self-predictability. Earlier on I mentioned that it's impossible for an observer to predict all the states of a system in which he/she is contained in. Hence if one wants to maintain the notion of predictability, the demon has to be excluded from the universe, in other words it is an external observer. This also explains why Laplace's demon is a supernatural entity.

Deterministic chaos

Chaotic systems amplify small uncertainties into large effects. Minuscule errors produced during measurement such as small invisible fluctuations will accumulate and eventually become serious. This was called chaos.

Classical mechanics assumes absolute linearity, which means any effect is proportional to its cause. For example it assumes if you want to push a car twice as fast you have to push twice as hard. However this is not the case because most practical situations are not perfectly linear. Predictions are accurate to a high extent but are not absolutely reliable.

The weather is a chaotic system. The meteorologist Edward Lorenz coined the term ' butterfly effect' which is the ' sensitive dependence on initial conditions'[25]. He shows that if a butterfly flaps its wings, then this tiny fluctuation in the weather in an area will have a significant effect in another part, thus explaining why the weather is so hard to predict.

The physicist turned priest John Polkinghorne states that in 10-10nanoseconds a molecule would have about 50 collisions with its neighbours, and if one neglected the gravitational attraction of any electron, the calculated position of a particle would be entirely different compared to a particle whose calculated position included the gravitational pull of an electron. This is because the uncertainties would mount up exponentially after each successive collision if the calculation didn't include all the factors. In his lecture, he describes the consequences of this :" It turns out that my calculation of how these billiard ball molecules would be moving will be badly out if I have neglected to take into account the presence of an extra electron on the other side of the observable universe interacting with the molecules through its gravitational force".[26]

However, chaos can occur even if systems are deterministic in nature due to our epistemological insufficiency. Because it exhibits ' sensitive dependence on initial conditions', minute errors during measurement will make predictions in the long term impossible. If we repeat the experiment, we have to start it with the exact same initial conditions however because of our inability to measure; the initial conditions are slightly different each time. Hence, this would lead to ignorance. The system would be unpredictable in practice.

Indeterminism due to Incompleteness

If we want to know whether quantum physics or science in general is complete we have to decide whether science is compatible with physics. Judge William Overton stated a scientific theory must be:[Share this: Facebook Twitter Reddit LinkedIn WhatsApp