2020 FSHS

The Philosophy

Behind Quantum Mechanics

Philosophy ASSIGNMENT

By Mani Shayestehfar

Keywords

Quantum mechanics, spin, atom, black-body radiation, quantum state, quantum system, Schrödinger's equation, the uncertainty principle, Newtonian physics, relativity, measurement problem, the many worlds interpretation, Copenhagen interpretation, EPR interpretation, localisation, double-slit experiment, Thomas Young probability density function, wave-particle duality, wave-function, Niels Bohr, Max Born, Max Planck, quantum decoherence, superposition, quantum entanglement, electron orbitals, Bryce DeWitt, David Bohm

Introduction

Before the introduction of quantum mechanics in 1920's, Einstein's relativity theories challenged the previously accepted concepts of the classic Newtonian physics, defying our understanding of objects moving with drastically high speed. Additionally, quantum mechanics was established upon the 'double-slit experiment' conducted by Thomas Young to expand this array of doubt in the physical properties of drastically small particles. The critical issue with such mechanics was known as the *'measurement problem'*. Essentially a sudden change between wave to particle properties. Prior to this, Schrödinger and Heisenberg had accomplished in writing about wave properties and more; Our understanding of quantum mechanics broke down such propositions as different interpretations of the subject required philosophical backup.

Before the changes in perspective towards the physics of such particles, a detailed analysis over the philosophy of quantum mechanics was required. From ethical questions such as the importance and determinism of humans as an observer, up to paradoxes in the most fundamental sections of logic, the philosophy following the trend of quantum theory was obliged to move parallel with further advancements in purpose of gaining meaningful insight within the subject.

*It is highly recommended to watch this video before advancing to gain a thorough knowledge about the basis of quantum mechanics and the 'double-slit experiment'.

The Uncertainty principle

" The more precisely you know the position of a particle, the less precisely you can measure its momentum and vice versa "

German physicist Werner Heisenberg

Introduced first in 1927 by physicist Werner Heisenberg, *The uncertainty principle* is a quintessential part of quantum mechanics. This is due to the 'wave-particle duality' of matter in the universe. To be exact, this *is* what quantum theory extrapolates and is also what creates an understandable meaning from the occurrences within it. *Particles* exist at any point in space and in time. However, *waves* are only disturbances created within space causing no displacement in the position of an object they interact with. The wavelength that can be measured from waves is pivotal as it provides direct information about the matter's momentum and hence the position. (turns out these are the only properties required to figure out any other fact from any matter!)

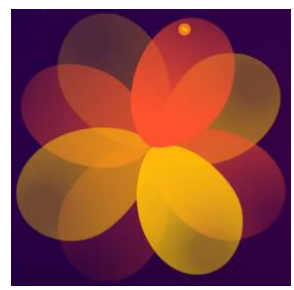
Although not directly interlinked, this uncertainty brings about one of the most problematic philosophical aspects of quantum mechanics. *'The measurement problem'* is the problem in which the wave function collapses. For many years, it was universally accepted that based on the classical views, the observer's role in an experimental system is negligible. That is to say there is no difference between reality and what is measured by an observer. Such limitation can be considered from an uncertainty of position and momentum where the observer of a quantum state (the experiment being conducted) can only measure one of such qualities.

Schrödinger's role

$$H(t)\,|\,\psi(t)\rangle = i\hbar\frac{d}{dt}\,|\,\psi(t)\rangle$$

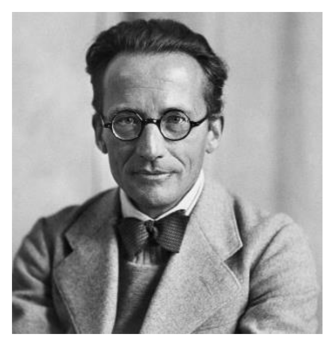
Erwin Schrödinger was one of the main constructors of quantum theory. Prior to his contribution along with Niels Bohr and many others, 'Schrödinger's equation' established the groundwork for any measurement in quantum mechanics. Electrons are incredibly small. Accepting that everything in the universe has a wavelength proportional to the inverse of its mass, this fact means that the wavelength of electrons can heavily affect their behaviour. In fact, this proves that electrons can travel as waves!

Imagine a 'ceiling fan' in its motionless position. The propellers can be easily observed. However, when we turn the fan on (we create substantial change in motion) the appearance of the previously visible propellers become distorted. If looked closely, they reminisce a cloud of matter that can vaguely be distinguished, certain parts such as edges can be less visible while certain sections are bolded with propeller material, almost as if the propellers have higher probability of existing in particular regions. If the same scenario is pictured with electrons, it is figured out that contrary to the deterministic nature of matter in classical physics, matter (or more specifically electrons) seem to exist in a probabilistic nature, until they are observed by an observer. In simpler words, the electrons exist in an unknown clouds of *probability density* (also referred to as orbital) until they are measured.

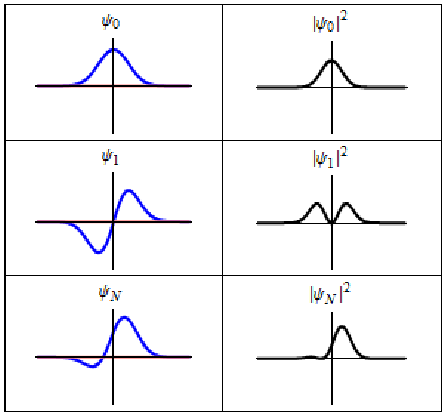


Shape of a cloud of probabilities of electron similar to a moving propeller

The wave-like behaviour of electrons can be measured by the [*wave function*]() (ψ). A solution found for the issue raised by our understanding of this concept is dealt with by *Schrödinger's equation.* This equation plays the role of Newton's 2nd law of motion ($F = ma$) in the context of quantum mechanics. It proves the conservation of energy within a quantum system and more importantly, allows us to understand and predict the behaviour of a quantum particle. Confused? If we look at a quantum system (the area in which the experiment is being conducted) as a graph of waves below, Schrödinger's equation can help us perceive the probability of a particle existing in an instance of time. Predicting the existence of the electron where the graph is at its peak with a very high accuracy.



Austrian physicist Erwin Schrödinger

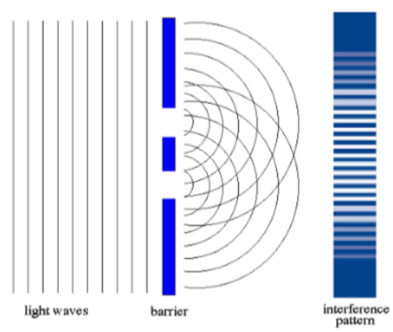


What is Quantum theory?

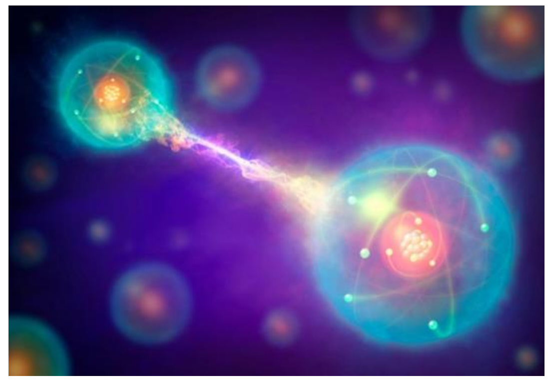
"I think I can safely say that nobody understands quantum mechanics."

- *Richard Feynman, Prof. of physics*

As explained previously, *Quantum Mechanics* is the field in physics which explains the fabric of nature in the microscopic scale.



Our understanding of Quantum theory begins with the 'double-slit experiment'. This experiment played a major role in the acceptance of the 'wave theory of light'. In his journals during late 19th century, German physicist Max Plank came to a conclusion that light exists and behaves as a wave. However, his colleague and friend Albert Einstein used Planck's papers on the black-body radiation problem to demonstrate light as packets or *quanta* of energy which is what we now recall as 'photons'. This was a direct contradiction to the nature of light as proved by the double-slit experiment led many physicists to confusion. In 1923, Louis De Broglie published his work, stating that light exists as wave AND particles. In fact, this is applicable to any form of matter meaning that anything has a particular *wavelength* (explained earlier) associated with it. This wavelength is extremely small for larger objects so that it is impossible to be observed by any measuring device. This leads quantum physics to the philosophical controversy of *localisation*. Developed by Max Born, localisation is a hint to the investigation of wave function. It states that if matter seems to be defined by a wave function, therefore while considering the issue of measurement along with the natural facts of the uncertainty principle, the quantisation of matter only exists if and only if it is measured by an observer. Confused? This simply means that while you sit comfortably staring at your monitor, any object (say a coffee mug or even a person) behind you that you cannot observe does not exist in its conventional shape and is only an accumulation of many wave-like transformations. It is only through the act of watching the subject that the electrons appear to exists outside of a probability density and become localised and visible to human eye!



One of the most famous philosophical debates amongst many ideas in physics is known as the *quantum entanglement*. In brief, it has been told that every object has a wavelength. Considering the double-slit experiment, two particles can be shot towards the slit. Since the two particles interact with each other after contacting the slit, they appear to have opposing or conjugate *spins* (another property quantum particles). As they become entangled with each other and are a part of a connected system now, this means that such two particles can contact each other, no matter the distance or time between them, even quicker than the speed of light! Philosophically, this means that unimaginable ideas such as time travel may be completely trivial. Albert Einstein called this interaction *"Spooky action at a distance"* due to his perplex and confusion over quantum entanglement.

The Copenhagen interpretation

The Copenhagen interpretation is a description of logic in quantum mechanics mainly contributed by Niels Bohr and Werner Heisenberg. This interpretation of quantum behaviour was developed 1925-1927 and still remains as one of the most accepted and scholar methods of dealing with quantum mechanics. It is also from this very interpretation that many philosophical paradoxes and contradictions are formed.

The Copenhagen interpretation states that *"a quantum particle doesn't exist in one state or another, but in all of its possible states at once"*. It's only when we observe its state that a quantum particle is forced to choose one probability from the sea of probability densities, and that is the state that we observe. Since it may be forced into a different observable state each time, this explains why a quantum particle behaves peculiarly.

Confused? So was the genius physicist Erwin Schrödinger who despite his very own discovery of the probabilistic nature of quantum particles, found this state of ***superposition*** (ability of a quantum system to be in multiple states at the same time until it is measured) unbelievable. To explain this, he established a famous thought experiment known as *Schrödinger's cat*. Schrödinger's cat is as follows:

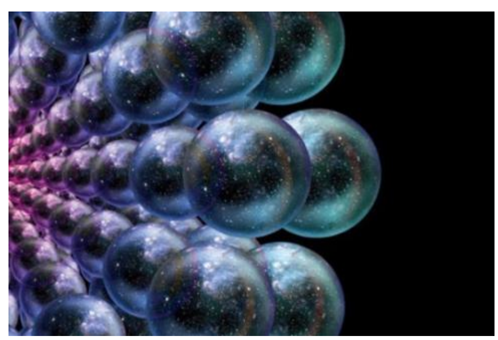
"A cat is penned up in a steel chamber, along with a poison releasing device there is a bit of radioactive substance, so small, that perhaps in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if the atom decays, the poison is released causing the definite death of the cat. Otherwise, maybe not! 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. This means that in this period, the cat exists in a state of both dead and alive, all at once!"

Although Schrödinger crafted this superposition paradox to demonstrate the ambiguity of quantum mechanics, this quote is currently used as an accurate model for the Copenhagen interpretation. The main issue risen from this interpretation is also the measurement problem. It is when the observer measures the testing particle in the 'double-slit experiment' that the wave function collapses, resulting in an instantaneous change of particle-to-wave observation of the measurement. This interpretation also breaks our philosophical understandings of a deterministic and physical world in which actions are followed by discrete causes and replaces it with a probabilistic realm in which nothing can have a cause for certain. To emphasise this fact, even a great mind such as Albert Einstein critiqued this constitution as he believed that *"God does not play dice with the universe!"*. Einstein battled his belief against the Copenhagen interpretation through the *EPR interpretation* which is a detailed topic for further discussions.

The Many Worlds' interpretation

Imagine playing in a football world cup final as a player. You stand behind the ball to take the last penalty which ultimately determines the fate of your team and country in the world cup. If you score, you win. Otherwise, you lose. No pressure. As your foot moves closer to the ball, the quantity of possible outcomes your action will have change as well. You end up kicking the ball in the back of the net. You win! However, one might ask what happened exactly a moment before kicking the ball? What caused the outcome to be as it is? Perhaps in that blink of second, there may have existed exactly two different variations of reality. One which you live in right now (the one in which you scored and won) and another very similar reality in which you failed an entire nation's hopes! If you were in fact the size of a subatomic particle, this would not sound as bizarre as it does now. In quantum physics, this interpretation of measurement in which a particle state to a wave state results in a diverged reality is known as the ***Many worlds' interpretation***. It must be initially stated that due to the highly repetitive notion of such situations, one must come to a conclusion that there are *infinite* universes of such kind in which moments after moments are diverged, however, this is not necessarily true. For instance, the increments on a ruler clearly represent a distance between 1 and 2 centimeters while we are aware that there are infinite numbers only between 1 and 2. It is the scale and category of infinity that determines such an outcome. In the case of quantum, this is not possible to prove!

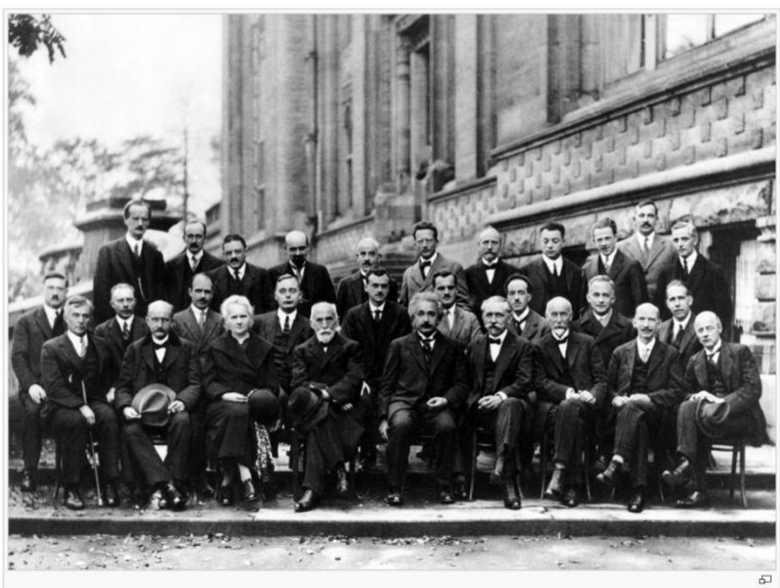
The many worlds' interpretation developed by Hugh Everett III is another interpretation of quantum mechanics which as gained a lot of reputation in the pop culture due to its interesting and intuitive view point on reality. Built singularly upon Schrödinger's wave equation, this interpretation attempts to explain how the fabric of universe(s) look like based on this principle.



This means that contrary to the Copenhagen interpretation, no collapse of the wavefunction after the measurement occurs within the quantum system. To understand better, another reference to Schrödinger's cat it required. Imagine an analogous situation with the cat. Without the observer's measurement, the cat appears to live in a state of superposition, both dead and alive. However based on Everett's interpretation, when the box's lid is lifted, a decoherence in realities occurs in which two different clone versions of the same world with only one differing factor will be formed. In one world the cat is alive, and in another not so much!

This interpretation of quantum physics was considered ridiculous amongst the physicist for a long time and it was no earlier than 1970's and contribution of physicists Bryce DeWitt and David Bohm that the interpretation was considered legible between the society of physics.

This interpretation of quantum mechanics is certainly considered as one of the most philosophically shaking perspectives as it defies almost all of the logic known to mankind! With enough quantisation and with the help of entanglement within this philosophical interpretation, time-travel may seem effortless and the concept of determinism and a unique sense of consciousness outside of human body in relation to *behavioralism* may collapse from its core.



A. Piccard, E. Henriot, P. Ehrenfest, E. Herzen, Th. de Donder, E. Schrödinger, J. E. Verschaffelt, W. Pauli, W. Heisenberg, R. H. Fowler, L. Brillouin;
P. Debye, M. Knudsen, W.L. Bragg, H. A. Kramers, P. A. M. Dirac, A. H. Compton, L. de Broglie, M. Born, N. Bohr;
I. Langmuir, M. Planck, M. Curie, H.A . Lorentz, A. Einstein, P. Langevin, Ch.-E. Guye, C. T. R. Wilson, O. W. Richardson

Fifth conference participants, 1927. Institut International de Physique Solvay in Leopold Park.

Even the brightest minds struggled with the concepts of quantum mechanics!

References

- Feynman, R., Leighton, R. and Sands, M., 2011. Six Easy Pieces. London [etc.]: Penguin Books.

- Cox, B. and Forshaw, J., n.d. The Quantum Universe. Penguin.

- Greene, B., 2013. The Hidden Reality. New York: Vintage Books.

- Greene, B., 2004. The Fabric Of The Cosmos. New York: A.A. Knopf.

- Omnès, R. and Sangalli, A., 2015. Quantum Philosophy. Princeton, NJ: Princeton University Press.

- Garden, H., HowStuffWorks, Science, Innovation and Questions, 2020. How Quantum Suicide Works. [online] HowStuffWorks. Available at: <https://science.howstuffworks.com/innovation/science-questions/quantum-suicide4.htm#:~:text=The%20Copenhagen%20interpretation%20was%20first,its%20possible%20states%20at%20once.&text=Since%20it%20may%20be%20forced,a%20quantum%20particle%20behaves%20erratically.> [Accessed 27 June 2020].

- Foundation, C., 2020. CK12-Foundation. [online] CK-12 Foundation. Available at: <https://flexbooks.ck12.org/cbook/ck-12-middle-school-physical-science-flexbook-2.0/section/3.17/primary/lesson/electron-cloud-atomic-model-ms-ps> [Accessed 10 June 2020].

- Plato.stanford.edu. 2020. Philosophical Issues In Quantum Theory (Stanford Encyclopedia Of Philosophy). [online] Available at: <https://plato.stanford.edu/entries/qt-issues/#QuesQuanStatReal> [Accessed 8 June 2020].

- ANON 2020. [online] Available at: <https://www.youtube.com/watch?v=mqofuYCz9gs&t=319s> [Accessed 30 June 2020].

- The double-slit experiment (Apr 27, 2017) YouTube video, added by Professor Dave Explains [Online]. Available at https://www.youtube.com/watch?v=uva6gBEpfDY [Accessed 25 June 2020].

- The Quantum Theory that Connects the Entire Universe (Mar 20, 2019) YouTube video, added by SciShow [Online]. Available at https://www.youtube.com/watch?v=JLv2MX1DnrY [Accessed 23 June 2020].

- Parallel Worlds Probably Exist. Here's Why (Mar 6, 2020) YouTube video, added by Veritasium [Online]. Available at https://www.youtube.com/watch?v=kTXTPe3wahc [Accessed 28 June 2020].

- Quantum Mechanics and the Schrodinger Equation (May 2, 2017) YouTube video, added by Professor Dave Explains [Online]. Available at https://www.youtube.com/watch?v=O6g-7rUgrdg&t=292s [Accessed 29 June 2020].

- What is the Heisenberg Uncertainty Principle? (Sep 16, 2016) YouTube video, added by TED-Ed [Online]. Available at https://www.youtube.com/watch?v=TQKELOE9eY4&t=1s [Accessed 10 June 2020].

- Schrodinger's Equation (Apr 15, 2016) YouTube video, added by Physics Videos by Eugene Khutoryansky [Online]. Available at https://www.youtube.com/watch?v=jvvkomcmyuo [Accessed 20 June 2020].

- Schrödinger Equation Explained (Oct 19, 2018) YouTube video, added Parth G[Online]. Available at https://www.youtube.com/watch?v=BFTxP03H13k [Accessed 27 June 2020].

- The Heisenberg Uncertainty Principle Explained Intuitively (Sep 20, 2018) YouTube video, added Up and Atom[Online]. Available at https://www.youtube.com/watch?v=qwt6wUUD2QI&t=33s [Accessed 21 June 2020].

- Heisenberg's Uncertainty Principle EXPLAINED (Dec 16, 2018) YouTube video, added by Parth G [Online]. Available at https://www.youtube.com/watch?v=iZ96TuP_veY&t=552s [Accessed 24 June 2020].

- What is The Schrödinger Equation, Exactly? (Jul 6, 2018) YouTube video, added by Up and Atom [Online]. Available at https://www.youtube.com/watch?v=QeUMFo8sODk [Accessed 21 June 2020].

- Quantum Mechanics: Animation explaining quantum physics (Mar 23, 2013) YouTube video, added by Physics Videos by Eugene Khutoryansky [Online]. Available at https://www.youtube.com/watch?v=iVpXrbZ4bnU [Accessed 20 April 2020].

- Quanta Magazine. 2020. Why The Many-Worlds Interpretation Of Quantum Mechanics Has Many Problems | Quanta Magazine. [online] Available at: <https://www.quantamagazine.org/why-the-many-worlds-interpretation-of-quantum-mechanics-has-many-problems-20181018/> [Accessed 31 June 2020].

- Science, L., 2020. What Is Quantum Mechanics?. [online] livescience.com. Available at: <https://www.livescience.com/33816-quantum-mechanics-explanation.html> [Accessed 22 June 2020].

- PhysLink.com, A., 2020. What Is The Schrodinger Equation, And How Is It Used?. [online] Physlink.com. Available at: <https://www.physlink.com/education/askexperts/ae329.cfm#:~:text=The%20Schrodinger%20equation%20is%20used,particle%20at%20a%20certain%20position.&text=The%20solution%20to%20this%20equation,quantum%20aspects%20of%20a%20system.> [Accessed 18 June 2020].

- Ling, S., Sanny, J. and Moebs, W., 2020. The Heisenberg Uncertainty Principle. [online] Opentextbc.ca. Available at: <https://opentextbc.ca/universityphysicsv3openstax/chapter/the-heisenberg-uncertainty-principle/> [Accessed 26 June 2020].

- Jha, A., 2020. What Is Heisenberg's Uncertainty Principle?. [online] the Guardian. Available at: <https://www.theguardian.com/science/2013/nov/10/what-is-heisenbergs-uncertainty-principle> [Accessed 1 July 2020].

- Physics, T., Friebe, C., Kuhlmann, M., Lyre, H., Näger, P., Passon, O., Stöckler, M. and Publishing, S., 2020. The Philosophy Of Quantum Physics | Cord Friebe | Springer. [online] Springer.com. Available at: <https://www.springer.com/gp/book/9783319783543> [Accessed 24 June 2020].