# The Quantum Measurement Problem:

# Collapse of the wave function explained

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Abstract

Quantum physicists have made many attempts to solve the quantum measurement problem, but no solution seems to have received widespread acceptance. The time has come for a new approach. In *Sense Perception and Reality: A Theory of Perceptual Relativity, Quantum Mechanics and the Observer Dependent Universe* I suggest the quantum measurement problem is caused by a failure to understand that each species has its own sensory world and that when we say the wave function collapses and brings a particle into existence we mean the particle is brought into existence in the human sensory world by the combined operation of the human sensory apparatus, particle detectors and the experimental set up. This is similar to the Copenhagen Interpretation suggested by Niels Bohr and others, but the understanding that the collapse of the wave function brings a particle into existence in the human sensory world removes the need for a dividing line between the quantum world and the macro world. The same rules can apply to both worlds and the ideas stated in this paper considerably strengthen the Copenhagen Interpretation of quantum mechanics.

The Quantum Measurement Problem has been around for about eighty years, ever since Niels Bohr, Werner Heisenburg, Max Born and others proposed the Copenhagen Interpretation of quantum physics. As part of the Copenhagen Interpretation they suggested quantum entities such as photons, electrons and other subatomic particles only come into existence when an observation is made. Before an observation is made quantum entities and their properties, such as electron spin or photon polarization, do not really exist and all that can be known about them is described in the Schodinger wave function. The wave function gives the mathematical probabilities of the state of a quantum

entity before an observation is made. The quantum entity only comes into existence and acquires definite properties when an observation or measurement is made of the entity. This is known as the collapse of the wave function as the indefinite qualities of quantum entities turn into definite qualities.

The idea that quantum entities could only come into existence when observed has been questioned by many people who believe things should exist independent of observation. They consider this is how things exist in the macro world and the quantum world should be the same. This has led to the idea that there is a problem in our understanding of the quantum world. More particularly, the problem is whether the wave function collapses when an observation is made, and if so, why does it collapse when an observation is made? Critics of the idea of quantum entities not existing before an observation, and of observations collapsing the wave function and bringing quantum entities into existence, usually consider macro level entities exist independent of observation and the same should apply to quantum entities. They include Albert Einstein and Erwin Schrodinger. Erwin Schrodinger invented the ideas of the wave function and a thought experiment known as Schrodinger's Cat designed to show how absurd the idea of observations bringing quantum entities into existence, was.

The belief that macro entities can exist independent of observation is highly questionable. Recent scientific work in the area of animal perception makes it clear other animals acquire a very different view of the world than we do, due to each species possessing very different sensory apparatus. Given that we have acquired our sensory apparatus through a process of biological evolution, just as all other species have acquired their sensory apparatus, there does not seem to be any reason to regard the human view of the world as truer or more real than that of any other animal. The question needs to be asked "If something exists independent of observation, does it exist in the form one animal sees it, or the form any other of the million or so species of animal perceives it?" In the third edition of *Sense Perception and Reality* (Phil Papers) pages 14 -15, I state:

"There are millions of different animal species on this planet. Each species sees the same thing in different ways. This suggests there is no single, true, real view of what is being observed and no particular form in which, what is being observed, can exist in when it is not being observed. Each of the many different views, different species can have, can only come into existence when an observation is made. Before the observation is made, the particular view seen by an observer is not seen by anyone, so it does not exist. The particular view will continue only for so long as an observer keeps observing. Once the observation stops the particular view will disappear as no other being will see the particular point in space-time in that particular way. This means that things will only come into existence when they are observed and must acquire their properties, such as shape, size and colour, only when they are observed. If something existed independent of an observation, in what form does it exist? The form in which a human perceives it, or the form an antelope, dog, bat, snake, bird, frog or insect perceives it? All these animals will see a particular thing in a variety of different ways and some may not perceive it at all.

If something exists independent of observation, does it have the colours that some animals will see it possessing or colours other animals will see it having, or something in black and white as other animals will perceive it? Surely a thing cannot be of one set of colours and another set of colours and black and white at the same time. The only situation where something can be of alternative sets of colours, or black and white, at the same time, is where it is observed at that time by different observers whose sensory apparatus will give it different appearances. But if there are no observers and no sensory apparatus you cannot have something being of different colours or black and white at the same time. So it is hard to see how anything can exist unless it is observed. What you see may well

exist in some form when not observed, but it certainly does not exist in the form in which you see it, as that form is created by your sensory apparatus, and if the sensory apparatus is not working then, what you see ceases to exist.

The arguments given in the previous paragraphs are very strong so I will restate them in a slightly different form. Some animals can see only in black and white, so everything is a shade of grey, others can see in various colours. If you cease to look at something and it continues to exist, what color does it have? The color one species sees it in, or the color another species sees it in? Clearly it can't be grey and have another color at the same time. The same applies to other sense perceptions, a vibration in the air sounds different to different species, the same odour can smell different to different species. Remove the observer, what sound or smell continues to exist? The way one observer hears the sound or the way the other observer hears it? Does an odour continue to exist the way one observer smells it or the way another smells it? Something cannot be of different colors, smells or sounds at the same time. Clearly the sense perceptions a particular observer has disappear when the observer ceases to be making an observation.

The problem is most people have a human centric view of the world and think everything exists in the form humans perceive it and continues to exist in that form when there is no human observer. But there are millions of other views every bit as valid as ours. Why should something continue to exist in the form a human sees it and not in the form other species see it? There seems to be no way we can justify a belief that the human view of the world is so special that it continues when there is no observer, while other species views of the world disappear.

When we say things don't exist unless observed, it means they don't exist in the human sensory world. They may exist in other species worlds and possibly in other forms quite different from any species world. Our normal ideas of existence are too simplistic; there are multiple ways in which things can exist and multiple worlds they can exist in. The human sensory world is only one such world. Tables, trees and people only exist in the human sensory world when observed with the human sensory apparatus.

Each species has its own sensory world, which are often very different from each other species sensory world. There is some overlap between these worlds but there are many aspects of one species world which will be completely unknown to members of other species. The human view of the world is only one view and is no more valid than that of any other species."

It seems quite plain that different animals see the world in quite different ways due to each species having different sensory apparatus. The sensory apparatus of all species arose through a process of biological evolution, so while they are all different, there seems to be no reason to regard any of them as providing a truer or more real view of the world than any other of them. If no particular species view is truer or more real than any other species view, they would all be equally real. If each species views of the world are different and each is equally true, then there is no real or true state in which anything can exist in, when not observed, that is known to any conscious being. If such a state exists, it is not a state known to any conscious being.

It is sometimes considered that science, maths and logic will enable us to perceive the real world. All our scientific discoveries take place within the human sensory world in that they must be perceived, understood and interpreted by our sensory apparatus. They extend our sensory world but they remain part of our sensory world. Science, maths and logic give an improved width and depth of understanding to the human sensory world, but it remains a sensory world dependent upon the human sensory apparatus. While science, maths and logic widen the human sensory world, the human sensory world remains very limited and is still just one view of the universe, and there remains many,

maybe millions, or an infinity of other views, all as true and valid as ours. They give us additional subjective views of our world; they do not give us a single, objective, true or real view of a world that exists independent of observers. The human view of the world, even when extended or enlarged by science, maths and logic remains a sensory world created by a particular sensory apparatus.

Scientific discoveries and experiments have the same problem that our sensory apparatus has, they have thresholds and limitations, so they only provide us with some information about the world we observe. All scientific information must go through our existing sensory apparatus so it is subject to the same problems as all the other information going through our sensory apparatus. It gives a view of the world, not a true or real view of a world that exists independently of observers. Humans can apply mathematics to the information we receive about the world but it is only mathematics about our world and the things in our world. It still gets us no closer to a true or real observer independent world. We can use logic and rationality about the things we perceive but the conclusions we reach are only conclusions about the world created by our sensory apparatus. They do not tell us about a real or true observer independent world, only about the world produced by our sensory apparatus. General Relativity is usually considered the best explanation of the universe we have, but it is based on our sense of sight. In *Sense Perception and Reality* page 8, I suggested a very intelligent dog could produce an explanation of the universe every bit as true as general relativity, but based upon the sense of smell. The dog's view of the universe, based on its sense of smell, would be just as true and real as the human view of the universe based on our sense of sight. But neither view will tell us how the universe really is.

Science, maths and logic are unable to provide us with a real or true view of the universe, although they do provide additional information about our universe. The limits of science, maths and logic can be seen by the ideas of conventionalism, scientific revolutions, falsificationism, our inability to prove cause and effect and the problem of induction. Conventionalism is the idea proposed by Henri Poincare who famously wrote "If a phenomena admits of a complete mechanical explanation, it will admit to an infinity of others, which will account equally as well for all of the peculiarities disclosed by the experiment." Basically any observation can be explained by an infinite number of theories; we simply accept the simplest theory. The classic examples are planetary orbits which Newton considered to be elliptical orbits in flat space but which were later described by Einstein as circular orbits in curved space. However any description of the orbits will fit in with observations if you adopt an appropriate view of the shape of space. Alternatively any view of the shape of space is consistent with particular planetary orbits. There are an infinite number of theories that can explain the solar system; we just believe the simplest theory. You can always add ad hoc modifications to make any theory work, but we prefer a theory without them.

Scientific revolutions were explained by Thomas Kuhn in *The Structure of Scientific Revolutions* and they involve new scientific theories replacing old theories as new facts are discovered that contradict the old theories. An obvious example is where the planet Mercury did not conform to the Newtonian theory of planetary orbits. A new theory, General Relativity, was produced which provided a better and more accurate explanation of planetary orbits.

Falsificationism, developed by Karl Popper, suggests a scientific theory can never be proved true and the most that scientists can do is to try to falsify a theory. If the theory survives attempts to falsify it, it can be accepted as the best theory available, but it can never be regarded as completely true.

We can never absolutely prove cause and effect as we can never show a necessary connection between a cause and an effect. All we can show are co relations between phenomena and more and more co relations especially in a variety of situations can make belief in cause and effect more

plausible. It is however not possible to totally rule out, that what appears to be cause and effect are just co relations caused by another event.

The problem of induction is the problem that despite repeated observations of the same phenomena, you can never be sure that new observations of the phenomena will be the same as the previous observations. A common example is the belief that all swans were white, until black swans were discovered. This means there is no guarantee future observations of nature will be consistent with prior observations.

If we were dealing with, and had access to, a single observer independent reality, none of the problems of conventionalism, inability to prove cause and effect, falsificationism, the problem of induction and scientific revolutions would exist. We would know with certainty what was the correct theory, we would be able to be certain of cause and effect, we could prove theories rather than just falsify incorrect theories, new observations would not contradict old observations and there would be no scientific revolutions in which old knowledge would be replaced with new knowledge. These problems and imperfections in science all suggest we are dealing with an observer dependent world rather than a single real observer independent world.

Science, maths and logic provide a greater understanding of the phenomena within our sensory world. They reveal patterns and relationships between phenomena in our sensory world and they extend our sensory world but it still remains a sensory world. They do not give us a single, real, objective world that exists independently of observers.

The idea of an observer dependent universe has been considered to be inconsistent with a modern objective science. But this is not the case as an observer dependent universe is a physical, solid, tangible universe that is coherent and consistent over time. Science takes place within the human sensory world and although people do not perceive the human sensory world in exactly the same way, they do perceive it in very similar ways, as all humans have very similar sensory apparatus. Similar sensory apparatus, means humans live in the same sensory world and all scientists get the same results when they do the same experiments, assuming they carry out the experiments correctly. This allows what David Lindley, in *Where does the Weirdness Go?* pages 159-161, called a weak objectivity, which is sufficient for the practice of modern science. If we perceived an observer independent world, our world would not have the limits on modern science shown by conventionalism, the inability to prove cause and effect, scientific revolutions, falsificationism and the problem of induction. All these difficulties for modern science are consistent with science being practised in a particular tangible, consistent and coherent observer dependent sensory world where scientists all get the same results from scientific experiments.

The Quantum Measurement Problem comes down to what we mean when we say “comes into existence” and “reality”. We normally say something comes into existence when it comes into existence in the human sensory world created by the human sensory apparatus. This is because we are unaware of the existence of anything outside the human sensory world. When an observer stops observing something, it does not stop existing in any form other than in the observer’s sensory perceptions and in the observer’s sensory world.

When an observation is made it may bring something into existence if it is capable of perceiving it. Another sensory apparatus may look at the same point in spacetime and not bring something into existence if it is outside the thresholds of the sensory apparatus. If the sensory apparatus is capable of picking something up i.e. it is within the sensory apparatus thresholds, it will do so. If the thing is outside the thresholds it will fail to perceive it. In that sense the sensory apparatus and an act of observation brings something into existence.

The reason things don't exist until observed in the macro world is because by exists we mean exists in the human sensory world created by interaction between the human sensory apparatus and whatever is out there. The human sensory world is the world we live in and know and it is the only world we live in and know. It has been extended by the use of a variety of scientific instruments and experiments, so that it is something that can change over time. Scientific discoveries are part of the human sensory world.

How can we say something exists unless we have awareness of it? We can only have awareness of anything if it exists in the human sensory world. We cannot talk meaningfully about anything existing except in our sensory world, as expanded by our scientific instruments and experiments. If it does not exist in the human sensory world, then we would say it does not exist in any scientific or factual sense. Belief in a God or Gods is a belief in a supernatural world beyond the scope of this article.

We erroneously believe our sensory apparatus shows us everything that can be perceived and we describe that which can be perceived as existing and that which cannot be perceived as not existing. Existing means existing in the human sensory world or being capable of being detected by our scientific instruments. If anything exists outside the human sensory world, we consider it does not exist because we have no awareness of it.

What we regard as "existence" or "reality" should be understood as the human sensory world created by the human sensory apparatus interacting with the external world. We know nothing about the external world; we cannot even be sure it exists. It is the human sensory world we know and live in and that is what we mean when we use words like reality and existence.

The idea that the world is observer dependent is not derived solely from our observations of other animal perception and of the operation of sensory apparatus, in the macro world. It is also derived from observations of the results of experiments on quantum entities in the world of quantum mechanics. There are a number of such experiments but the one usually cited is the double slit experiment, where quantum entities are considered, in the Copenhagen Interpretation, only to come into existence when they are observed. In the Third Edition of *Sense Perception and Reality* (Phil Papers) pages 48 to 49 I state:

"The consequences of the Copenhagen Interpretation are that the observer plays a critical role in determining how the world is. The behaviour of quantum entities depends on whether an observation is being made. If it is, then the wave function collapses and they behave as particles. If no observation is made, then quantum entities behave as waves as is shown by the phenomena of interference in the double slit experiment. The waves however are probability waves which do not have any material form; they are just mathematical concepts. They do not really exist. The probability waves are however able to interfere in the same way that material waves do. (Gribben, 1995, 11). Heinz Pagels in *The Cosmic Code* p 144 states "There is no meaning to the objective existence of an electron at some point in space, for example at one of the two slits, independent of actual observation. The electron seems to spring into existence as a real object only when we observe it". The act of observation brings the particle into existence. Based on the results of the double slit experiments, Niels Bohr, the most prominent proponent of the Copenhagen Interpretation, considered that whether you get waves or particles depends on the whole experimental set-up including the quantum entities, the slits, the detector screen and the human observer. If you set up the experiment in certain ways (e.g. one or two slits open, detectors at one or other of the two slits or no detector at the slits, deciding to have the detectors on or off after the electrons or photons have gone through the slits) you will get

certain results. (Gribben, 1995, 14). What you see depends upon the observer, the experimental set up and that which is being observed.

There has been much controversy about what is meant by an observation causing a quantum entity to come into existence. The controversy is caused by ambiguity in the meaning of terms such as existence and reality. No one seems to know what they mean in the context of quantum mechanics, so I will explain what they mean. The correct interpretation is that when we say that quantum entities do not exist except when observed, we mean they do not exist as part of the human sensory world, created by the human sensory apparatus, when an observation is made. The human sensory world is the world we know and live in, and is the world given to us by our sensory apparatus. There is nothing to stop quantum entities existing in other worlds when being observed in the human sensory world and when not being observed in the human sensory world. In addition all observations made by a human observer are personal to that observer, although other human observers will perceive something very similar to that which is observed by other human observers due to having very similar sensory apparatus. The evidence we perceive in our experiments which indicates the presence of quantum entities should be treated in the same way as our perceptions of tables, trees and people in the macro world.

Such a view of quantum entity existence provides a logical explanation for the quantum measurement problem which is consistent with the explanation for the working of the human sensory apparatus provided in Part I of this book. We don't actually see quantum entities, we see macro level evidence the quantum entities exist, and this macro level evidence comes into existence in exactly the same way as everything else in the macro world. The solution to the quantum measurement problem, lies not in the quantum world, but in how the human sensory apparatus works in the macro world."

In the macro world light is either emitted from a light source like a star or an electric light or reflected off an object. Most of it just passes through space or the Earth's atmosphere without being detected. Some of the light is detected by the human eye and other light is detected by other animal's eyes. That which is detected by the human eye is turned by the operations of the human eye and brain into an image which becomes part of the human sensory world. Photons detected by other animals are turned by the operations of their eyes and brains into images which form part of their sensory worlds. In order for something to become part of a particular species sensory world an observation is required otherwise the photons do not become part of any conscious being's world. They are lost in that they are not detected by any sensory apparatus. What human beings call "reality" is simply the human sensory world and nothing can become part of the human sensory world unless it is observed by the human sensory apparatus. Hence an observation is required before anything can become part of the human sensory world and when we talk about "reality" and "existence" we mean the human sensory world. We cannot mean anything other than the human sensory world because there is nothing other than the human sensory world known to us.

All the other human senses work the same way as the sense of sight. Some vibrations in the air, feelings derived from the sense of touch, chemicals in the air or in the mouth are detected by the human senses of hearing, touch, smell and taste and become part of the human sensory world. Some vibrations in the air, feelings derived from the sense of touch, chemicals in the air or in the mouth are detected by other animals and become part of their sensory world and other vibrations, feelings and chemicals are not detected by any conscious being and do not form part of the sensory world of any conscious being. In order for sounds, smells, feelings and tastes to be part of the sensory world of any conscious being there must be an observation or perception. If there is no observation or perception the sounds, feelings, smells and tastes will not be part of the sensory world of any conscious being.

To put the question into its opposite format “How can anything exist in the human sensory world, without it being perceived?” Plainly nothing can exist in the human sensory world without being perceived as perception is required whenever anything exists in the human sensory world. It may exist outside the human sensory world but for it to exist in the human sensory world there must be some form of perception. What is required is a mental change from the idea, the world is how we perceive it, to the idea that our view of the universe is simply a view and that there are vast numbers of other views every bit as valid as ours.

The belief that “existence” and “reality” are synonymous with the human sensory world is just a case of human centrism that fails to recognise that the human view of the world is just one view of the universe and that there are many other views just as valid as ours. It is an irrational bias or prejudice that cannot be justified as our sensory apparatus arose through a process of biological evolution, the same as those of all other species. It is also obvious our sensory apparatus is not any better than that of other species. It is our careless, sloppy and imprecise use of language, and our failure to understand the existence of other sensory worlds, that constitutes the problem with wave function collapse.

What causes the collapse of the wave function? It is the entry of stimuli into the sensory apparatus of a conscious observer, such as photons of the right wavelength hitting the human eye and entering the eye through the cornea and pupil and then through a lens which focuses the light onto the retina. The retina then sends a signal to the brain via the optic nerve and the brain turns the information into the images we see. Those images and information from the other senses constitute the human sensory world. Clearly the images and other information could not exist without observation. Nothing else in the human sensory world exists without an observation being made, so why should the results of experiments, indicating the presence of quantum entities, which show in macro level experimental apparatus be any different?

Particle detectors work in the same way as the human sensory apparatus. They detect some things and there are some things they cannot detect. This leads to the creation of sensory worlds created by particle detectors. The particles and particle information they can detect are in a sensory world, but particles and information they cannot detect will not exist in the same sensory world created by the particle detector, but they may exist in other sensory worlds. The other sensory worlds may be created by natural sensory apparatus, the human eye and other animal eyes are photon detectors, or they may be created by other artificial detectors.

Particle detectors come in great variety. They are used to detect, tract and identify radiation and subatomic particles such as electrons and other quantum entities. They can measure particular properties of particles such as charge, momentum, spin and energy. In the past bubble chambers, cloud chambers and photographic plates have been used but now there are a great variety of detectors.

A scintillation counter is an instrument designed to detect and measure ionizing radiation. An ionizing particle moves through scintillator material and produces ionized atoms which pursue particular paths. Charged particles move along a path being the path of the ionizing particle. Uncharged gamma rays are converted to an energetic electron by the photoelectric effect, pair production or Compton scattering. Low energy photons are also produced in proportion to the energy of the ionizing particle. Some of the low energy photons hit the photocathode on a photomultiplier tube, which produces one electron for each photon hit by means of the photoelectric effect. The electrons hit the dynodes of the photomultiplier tube and produce more electrons which eventually reach the anode of the photomultiplier tube which produces a measurable pulse which provides information about the energy of the original incident radiation of the scintillator material.

A Geiger counter is an instrument used for detecting ionizing radiation such as alpha particles, beta particles and gamma rays using a Geiger-Muller tube. The tube contains an inert gas such as helium, neon or argon at low pressure. A high voltage electric charge is applied to the gas in the tube. The tube briefly conducts an electrical charge, when a particle or photon of incident radiation makes gas conductive by ionization. The ionization is increase by the Townsend avalanche effect which creates an easily measured pulse, which is detected by electronic instruments. The instruments can produce a counts or radiation dose measurement of the radiation. The counts display shows the number of ionizing events over a period of time, such as per second. The counts display is usually used for the detection of alpha and beta particles. The radiation dose measurements are more complex and are commonly used for detecting gamma and x-rays. Geiger counters are unable to differentiate between types of radiation due to the output pulse being at the same level, regardless of the energy of the incident radiation. Geiger counters are also unable to detect high radiation levels due to "dead time" in the tube. "Dead time" is a period, after each ionization of the gas, during which additional incident radiation is unable to be detected.

The way particle detectors work is very similar to the way the sense of sight works in the macro world. Radiation enters the detector and is processed and turned into an electric charge that is subject to further processing which produces an image which is able to be perceived by the human sensory apparatus. The experimental apparatus should be considered as an extension or even a part of the observer's sensory apparatus. Change anything in the human sensory apparatus, such as the eye or how the brain processes information from the sense organs, and you perceive different sense perceptions. Equally change the experimental apparatus and you also get different sense perceptions and experimental results. The sense perceptions we receive are created by the operation of the human sensory apparatus. Our sensory apparatus are detection devices not greatly different from other detection devices such as particle detectors which detect subatomic particles. Particle detectors are sensory apparatus just like our naturally evolved sensory apparatus.

All our scientific instruments and our scientific experiments are just different ways of seeing the world. The world we perceive through our unaided sensory apparatus is just one view of the universe. Change the sensory apparatus and you change the world you live in. At present we have no way of knowing how the world really is, if it has some real form at all. All our knowledge of the world comes through our sensory apparatus and our scientific instruments and experiments and they give us views of the world conditioned and controlled by the nature of our sensory apparatus, scientific instruments and experiments. If anyone was able to get to a real world not controlled or conditioned by sensory apparatus, instruments and experiments, it may be the greatest intellectual achievement in human history.

# Bibliography

## Philosophy and Perception


Armstrong, D. M. (1961) *Perception and the Physical World*, Routledge & Keegan Paul: New York
Audi (ed) (1995) *The Cambridge Dictionary of Philosophy*, Cambridge University Press, Cambridge
Ayer, A J (1956) *The Problem of Knowledge,* Penguin Books: London
Berkeley, G (1710) *Treatise concerning the Principle of Human Knowledge*
Broad, C D (1965) *Some Elementary Reflexions on Sense Perception* in Perceiving, Sensing and Knowing (ed) Swartz, R: University of California Press, Berkeley
Broad, C D (1965) *The Theory of Sensa* in Perceiving, Sensing and Knowing (ed) Swartz, R: University of California Press, Berkeley
Burton, Robert (1973) *Animal Senses*, A H & A W Reed, Wellington, New Zealand
Chabris, Christopher and Simons, Daniel (2010) *The Invisible Gorilla and other ways our intuition deceives us*, HarperCollins Publishers: London
Chisholm, R M (1965) *The Theory of Appearing* in Perceiving, Sensing and Knowing (ed) Swartz, R: University of California Press, Berkeley
Cresswell, M J *Jackson on perception* in Theoria Vol.XLVI (1980) Part 2-3
Davies, P (1977) *Space and Time in the modern universe*, Cambridge University Press: Cambridge
Dowling, John E (1998) *Creating Mind: How the Brain Works*, W W Norton & Co, New York
Downer, John (1988) *Supersense: Perception in the Animal World*, BBC Books, London
Einstein, A (1923) Geometry and Experience in *Sidelights on Relativity*, E P Dutton, New York
Greenfield, Susan A (1997) *The Human Brain: A Guided Tour*, Basic Books, New York
Hughes, Howard C (1999) *Sensory Exotica: A World Beyond Human Experience*, MIT Press, Cambridge, Massachusetts
Jackson, Frank (1977) *Perception,* Cambridge University Press: Cambridge
Kaku, M (1994) *Hyperspace*, Oxford University Press: Oxford
Kelly, David (1986) *The Evidence of the Senses,* Louisiana State University Press: Baton Rouge
Kline, M (1959) *Mathematics and the Physical World*, Thomas Y Crowell Company: New York
Kline, M (1980) *Mathematics*, Oxford University Press: New York
Locke, D (1967) *Perception and our Knowledge of the External World*, George Allen & Unwin Ltd: London
McKeachie, Wilbert J and Doyle, Charlotte L, (1966) *Psychology*, Addison-Wesley Publishing Co Inc: Reading, Mass
Mill, J. S. (1889) *An examination of Sir William Hamilton's Philosophy*: London
Russell, B (1912) *The Problems of Philosophy*, Oxford University Press, Oxford
Schiffman, H. R. (1982) *Sensation and Perception*, John Wiley & Sons: New York
Smart, J. J. C. (1963) *Philosophy and Scientific Realism*, Routledge & Keegan Paul: New York
Winston, Robert (2003) *The Human Mind*, Bantam Books London


Websites


www.ratbehavior.org
https://en.wikipedia.org/wiki/Telescope
https://science.nasa.gov/science-news/science-at-nasa/1999/features/ast20apr99_1

# Quantum Theory


Al-Khalili, Jim (2003) *Quantum: A Guide for the Perplexed*, Weidenfeld & Nicolson: London
Baierlein, R (1992) *Newton to Einstein*, Cambridge University Press: Cambridge
Cushing, James T. & McMullin, E. (1989) *Philosophical Consequences of Quantum Theory*, University of Notre Dame Press: Notre Dame, Indiana
Davies, Paul (1980) *Other Worlds* Penguin Group: London
Davies, P. C. W. & Brown J. R. ed (1986) *The Ghost in the Atom*, Cambridge University Press: Cambridge
d' Espagnat, Bernard The Quantum Theory and Reality, in *Scientific American*, November 1979, 128-140
Feynman, R, Leighton, R & Sands, M (1965) *The Feynman Lectures on Physics*, Mass: Addison-Wesley
Forrest, Peter (1988) *Quantum Metaphysics*, Basil Blackwell: Oxford
Gibbins, Peter (1987) *Particles and Paradoxes*, Cambridge University Press: Cambridge
Greenstein, G & Zajonc, A (1997) *The Quantum Challenge* Jones & Bartlett Publishers: Sudbury Massachusetts
Gribbin, John (1984) *In Search of Schrodinger's Cat,* Black Swan: London
Gribbin, John (1995) *Schrodinger's Kittens*, Phoenix: London
Healey Richard (1989) *The Philosophy of Quantum Mechanics* Cambridge University Press: Cambridge
Herbert, Nick (1985) *Quantum Reality*, Anchor Press/Double Day: Garden City, New York
Hey, Tony & Walters, P (1987) *The Quantum Universe*, Cambridge University Press:Cambridge
Horner, J (1987) *The Description of Nature*, Clarendon Press: Oxford
Hooker, C A (1972) The Nature of Quantum Mechanical Reality: Einstein v Bohr in *Paradigms and Paradoxes* (ed) Colodny, R University of Pittsburgh Press
Krips, Henry (1987) *The Metaphysics of Quantum Theory*, Clarendon Press: Oxford
Lindley, David (1996) *Where does the weirdness go*, Vintage: London
Mermin, N. David (1990) *Boojums all the way through*, Cambridge University Press: Cambridge
Mermin, N David Is the moon there when nobody looks? Reality and the quantum theory in *Physics Today* April 1985 38-47
Rae, A (1986) *Quantum Physics: illusion or reality*, Cambridge University Press Cambridge
Ridley, B. K. (1976) *Time, Space and Things*, Cambridge University Press: Cambridge
Squires Euan J. (1986) *The Mystery of the Quantum World*, A Hilger: Bristol
Wolf, Fred Alan (1981) *Taking the Quantum Leap*, Harper & Row: San Francisco
Zohar, Danah (1991) *The Quantum Self*, Flamingo: London