The Quantum Level of Reality

Contents

Introduction

In this chapter I venture rather far away from my areas of expertise and present some ideas that I have read about and believe on the basis of generally-accepted scientific consensus. The ideas, in brief, are these:

- There is a level of physical reality at which things and events are quite tiny, less than about 100 nanometers long. This level is called the "quantum" level of reality.

- Things and events at the quantum level of reality behave differently from things and events that are larger. They are indeterminate, meaning that the outcomes of events cannot be predicted in advance, except in statistical terms. In other words, an initial configuration of things and forces does not determine a subsequent configuration. Mathematics can describe the probability of a range of outcomes, but cannot predict a single outcome.

- The synapses in the human brain are small enough – about 20 nanometers – that quantum indeterminacy operates there. Distances within the neuron where critical events such as the influx of calcium ions happen are even smaller. Hence it is in principle not possible to predict whether any given neuron will fire or not.

- Our thoughts, perceptions, emotions and intentions are correlated with neural functioning. Once something happens at the synaptic level of the brain, ordinary physical causality takes effect and we experience thoughts and feelings, etc. But what initiates those thoughts or feelings is not pre-determined.

From these ideas I infer the following:

- It does not contradict scientific knowledge to say that something nonphysical determines whether a neuron will fire or not. Thus, it does not contradict scientific knowledge to say that the quantum level of reality is where something nonphysical intervenes in the physical world.

Quantum Physics

"Quantum" is a word derived from the Latin word meaning "how much." In this context it refers to a characteristic of things that are very small, less than 100 nanometers long. The magnitudes of certain properties of such things can take on only discrete numerical values, rather than any value, at least within a range. For example, the energy of an electron bound to an atom at rest is quantized, so electrons orbit their nuclei only at certain discrete distances, not in between. This accounts for the stability of atoms, and matter in general. Light also is quantized. A photon, being a unit of light, is a "light quantum." Quantum Mechanics is the field of study of physical reality in such small dimensions, and we call this the "quantum level" of reality.

Things behave very strangely at the quantum level. We can't see them with the unaided eye, of course, but we can detect them through instrumentation, and their properties and behavior can be described mathematically by a formula called the "wave function." Under certain circumstances the wave function divides into two or more pairs or branches, each with its own consequences. Each of these branches represents a potential future or a potential version of reality. When observed, only one of these branches is perceived; that is, only one of the potential futures becomes the actual perceived present.

There are some famous experiments, which have been widely replicated, that reveal the strangeness of this level of reality. Two of them are the Double-Slit experiment and the Stern-Gerlach experiment.

The Double-Slit Experiment

The Double-Slit experiment consists of sending a beam of coherent light[1] through two side-by-side vertical slits to a recording medium, such as film. It illustrates that light can behave both as a stream of particles and as a wave. When light is sent through one slit at a time, a vertical band appears. Light acts like a series of particles that go through the slit, hit the recording medium and make an impression. If the experimenter opens the slit on the right, the band appears on the right, and if the experimenter opens the slit on the left, the band appears on the left. One would expect that if both slits were opened, the result would be two side-by-side bands. In fact, however, the result is a strong band in the middle, the expected bands on the left and right, and then dimmer bands extending outward in each direction. Light in this case acts like waves that cause interference patterns. That is, when a crest meets a crest, a more intense crest results; and when a crest meets a trough they cancel out. The bands

[1] "Coherent" means that all the light waves have the same frequency; hence they can interfere with each other. Lasers emit coherent light. If you shine an ordinary light through a small pin-hole, the light that gets through is largely coherent as well.

of light are from the crests reinforcing each other, and the darkness in between is the from crests and troughs canceling each other out.

Even more interesting, when light is emitted one photon at a time and aimed at the two slits, it shows the same interference pattern. One would expect that a photon would go through one slit or the other. In fact it appears to act like a wave that goes through both slits, interferes with itself, and results in an impression in one and only one of the bands.

One cannot predict in advance in which band the photon will make an impression.

One can predict that given a great number of photons, they will result in bands. That is, they won't all end up in the same place, but rather in various places according to their probability distribution. But there is only a probability, not an absolute certainty, that any single photon will end up in one place or another.

One of the questions engendered by this experiment is what causes the wave, which is mathematically described as a collection of probabilities of being detected in various places, to be in fact detected at only one place. I'll return to this question later. For now, note the "quantum indeterminacy," our inability to predict the final location of any single photon. A photon is not like a billiard ball. If you know the mass of two billiard balls, the amount of force and its direction applied to one, and the angle at which it hits the second, you can predict in what direction and how fast the second ball will travel. Not so with quanta.

The Stern-Gerlach Experiment

The Stern-Gerlach experiment, named after the scientists who first performed it, consists of sending a series of electrons through an inhomogeneous magnetic field, which deflects them. On the other side of the field from the emitter is a recording medium, which registers where the electron hits the medium. Each electron is detected at one of two places on the medium, depending on what is called the "spin" of the electron. An important finding of this experiment is that electrons are detected in only two places rather than in a range between them. Thus, an electron's spin can take only two values; it is quantized. This corroborates the quantum nature of reality at this level.

Another finding is confirmation of quantum indeterminacy: one cannot predict in advance in which place the electron will be detected.

Again, given a great number of electrons and the known characteristics of the magnetic field, one can predict the relative number of impressions at each detection point. But there is only a probability, not an absolute certainty, that any single electron will end up in one place or another.

Causal Discontinuity

At the quantum level of reality there is a radical discontinuity of causality. Here are some descriptions:

> "The mathematics of quantum mechanics does not predict which path will be taken. This is the indeterminacy, or randomness, of quantum mechanics." (Blood, *Science Sense and Soul*, p. 64)
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> ". . . in what sequence members of a series of singly emitted things (e.g., electrons) will arrive is completely unpredictable." (Wikipedia, "Double-slit experiment")
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> "The electrons (and the same applies to photons and to anything of atomic dimensions used) arrive at the screen in an unpredictable and arguably causeless random sequence . . . ." (Ibid.)
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> "In quantum mechanics, the value of a physical quantity (usually called an observable) cannot in general be predicted with certainty." (National Science Teachers Association, "The Stern-Gerlach Experiment")
>
> ". . . the apparent random selection of which outcome state [appears] remains one of greatest mysteries of science." (Wikipedia, "Consciousness Causes Collapse")
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> ". . . the appearance of there being an uncaused event (because of the unpredictability of the sequencing) has aroused a great deal of cognitive dissonance and attempts to account for the sequencing . . . ." (Wikipedia, "Double-slit experiment")

In ordinary life and in classical (non-quantum) physics, we have a clear concept of causality: a cause is something that reliably produces an effect. Given the same or a similar set of circumstances, we expect the same results to appear. Hitting the billiard ball at a certain angle and with a certain force will always cause it to move in a certain direction and at a certain speed. This conception of causality has three parts:

- Regularity – A cause always produces its effect according to physical laws that can be discovered by observation and experiment. (Here "law" means observed regularity, not something moral or legal.)

- Temporal Sequence – The cause always precedes its effect in time. The cause never follows the effect.

- Spatial Contiguity – There is always some physical connection or spatial contact between the cause and its effect, or a chain of such connections.

At the quantum level, the regularity is missing. There is no set of circumstances that causes the photon or electron always to land in a specific place.

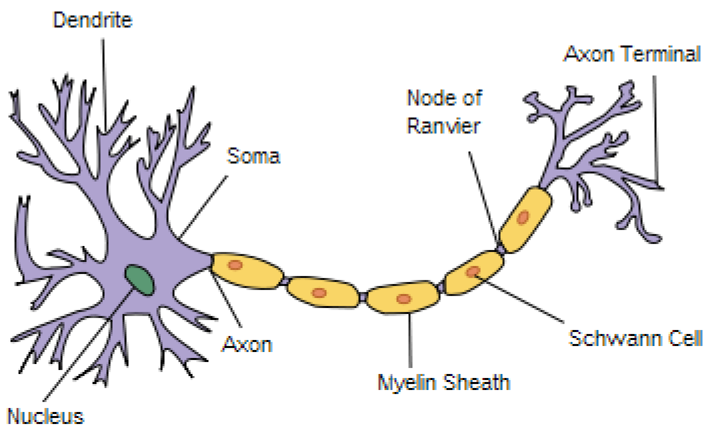
Once the photon or electron has landed – that is, has been detected – then the ordinary chain of causality takes over. "[T]he beginning of a macroscopic event can be dependent upon a microscopic event. In that case, each microscopic possibility at the beginning can lead to a different macroscopic event at the end." (Blood, *Science Sense and Soul*, p. 72) Physicist Erwin Schroedinger postulated a famous thoughtexperiment: Put into an isolated chamber a cat, a radioactive substance, a Geiger counter and a device that will kill the cat when the Geiger counter is triggered. Whether an atom of the substance will decay within an hour is indeterminate; thus during that time the state of the cat is also indeterminate. Schroedinger's point, among others, was that this seemed absurd. Surely the cat is either alive or dead, regardless of whether anyone observes it. My point is merely that it is widely recognized that quantum events, once they have become detected, are then determined and can cause further events to happen.

But what causes the quantum event to cease being merely a probability and start being something that is detected and exists at a certain place? Not anything in the physical world. Perhaps it is something nonphysical. It is possible – that is, it does not contradict the scientific evidence to assert – that something nonphysical decides which probability to actualize.

This becomes important when we consider that some events in the brain happen at the quantum level.

The Brain

The human brain is a mass of electrochemical activity. It contains approximately 100 billion nerve cells, or neurons, and up to five quadrillion connection points between neurons. A neuron is the fundamental element of the brain; it transmits electrochemical impulses to and from other neurons, sense organs or muscles. Some impulses are triggered by sense organs, and some by the excitation of neighboring neurons. Some impulses excite or inhibit neighboring neurons and some cause muscle contractions that move the body. Here is a picture of one (Wikipedia, "Neuron"):



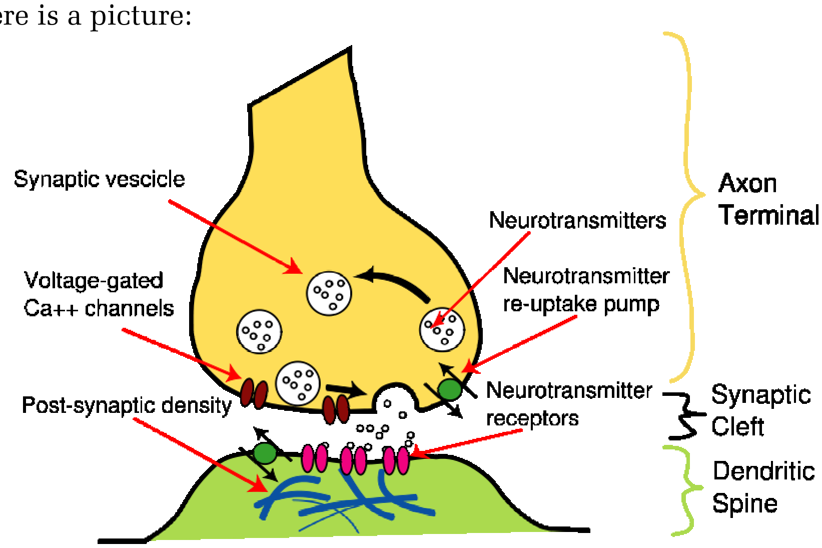
A neuron looks a bit like a tree and consists of several parts: numerous dendrites (from the Greek for "tree"), a cell body called *soma* (Greek for "body"), and a single axon (from the Greek for "axle"), which branches at the end to many terminals. Dendrites are the incoming channels; they extend from the soma and subdivide into smaller and smaller branches. Some nerve cells have dozens of dendrites, and some have hundreds, depending on the cell's function. Dendrites receive electrochemical impulses from other cells. These impulses pass through the soma and then out the axon. The soma is the core of the nerve cell and contains the elements common to all cells that keep it metabolizing, synthesizing proteins, receiving nutrients and excreting waste, etc. Each nerve cell has a single axon, a fiber that passes the impulse from its terminals to synapses. A synapse (from Greek roots meaning "to clasp together") is a gap between neurons only twenty nanometers wide. On the other side of the synaptic gap, also called the synaptic cleft, is a receptor area on a dendrite of a neighboring cell. An axon can have many terminals, and each dendrite can have many receptor areas. Thus each neuron transmits impulses to and receives them from a great many neighboring neurons. As each one has many dendrites, some neurons receive impulses from up to 10,000 neighbors. Some in the cerebellum receive up to 100,000. Clearly the brain is an organ of almost unimaginable complexity.

An impulse traveling through the neuron is an electrical charge called an action potential, which travels through the nerve at up to 200 miles per hour. When this happens we say that the neuron "fires." A neuron either transmits the impulse or it does not; it is a binary element, either on (firing) or off (not firing). When the electrical charge reaches the synaptic cleft, it triggers the release of neurochemicals; hence we call brain activity electrochemical. There are more than sixty of these neurochemicals, called neurotransmitters because they seem to transmit information from one nerve cell to another. Some excite neighboring neurons and some inhibit them.

The end of the axon, called the nerve terminal, contains vesicles, tiny containers that hold the chemical neurotransmitters. The neurotransmitters are released into the synaptic cleft when an electrical charge reaches the vesicles. On the other side of the cleft, the dendrites contain specialized receptors that bond to the neurotransmitters and cause electrical activity when excited by them. This is how impulses travel from neuron to neuron. When the electrical activity caused by incoming neurotransmitters reaches a certain threshold, the neuron fires and sends an action potential to its axon.

A single release of a neurotransmitter might be too weak to trigger the action potential of the receiving neuron, but since each neuron forms synapses with many others and likewise receives synaptic inputs from many others, the combination of several inputs at once can be enough to trigger it. Or the receipt of an inhibitory neurotransmitter can prevent an action potential that otherwise would have fired. The output of a neuron thus depends on the input of many others, each of which may have a different degree of influence depending on the strength of its synapse with that neuron.

The mechanism by which neurotransmitters are released is of particular importance. Here is a picture:



> Within the pre-synaptic nerve terminal, vesicles containing neurotransmitter sit "docked" and ready at the synaptic membrane. The arriving action potential produces an influx of calcium ions through voltage-dependent, calcium-selective ion channels. Calcium ions then trigger a biochemical cascade which results in vesicles fusing with the presynaptic-membrane and releasing their contents to the synaptic cleft. (Wikipedia, “Chemical synapse”)

The channels through which calcium ions enter the nerve terminal from outside the neuron are tiny, only about a nanometer at their narrowest, not much bigger than a calcium ion itself. The calcium ions migrate from their entry channels to sites within the nerve terminal where they trigger the release of the contents of a vesicle. At this submicroscopic level of reality, quantum indeterminacy is in play. A given calcium ion might or might not hit a given triggering site; hence, a given neurotransmitter might or might not be released; hence the receiving neuron might or might not get excited (or inhibited).[2] [3]

In other words, at the most fundamental level, brain functioning is not causally determined.

This causal indeterminacy pertains at quadrillions of synapses, each of which contributes to the overall state of the brain. Submicroscopic events trigger larger events, which are then causally determined. But the initial events, the beginnings of chains of causality, are indeterminate, and there are a great many of them. The whole state of the brain can become a quantum cloud of uncertainty. Noted quantum physicist Henry Stapp says

> . . . a conscious brain … must be expected to evolve into a state that represents a superposition of macroscopically different alternative possibilities for the brain . . . . (Stapp, *Mind, Matter and Quantum Mechanics*, p. 154)

> . . . [T]here is no likelihood that during periods of mental groping and uncertainty there cannot be bifurcation points in which one part of the quantum cloud of potentialities that represents the brain goes one way and the remainder goes another, leading to a quantum mixture of very different classically-describable potentialities. . . . [A]ny claim that the large effects of uncertainty principle at the synaptic level can never lead to quantum mixtures of macroscopically different states cannot be rationally justified. (Stapp, *Mindful Universe*, pp. 31, 32)

To rephrase Stapp's double negative, quantum uncertainty at the synaptic level can lead to causal uncertainty at the level of the whole brain.

Researchers have made much progress in identifying the neural correlates of consciousness, the patterns and groups of nerves that fire when certain experiences take place. Brain scans reliably show the areas of the brain that "light up" during perceptual tasks. Whether patterns of neural firings cause conscious experiences or

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[2] Nerve terminals are not the only places that calcium ions have an effect. Calcium ions play a major role in controlling the functioning of all cells of the body. By entering the cell plasma they cause the specific action of the cell, whatever this action is: secretory cells release secretions, muscle cells contract, synapses release synaptic vesicles, etc. Only in the nerve terminal does quantum indeterminacy have a large effect on the activity of the nervous system. Here the different triggering sites are very close together and the macroscopic effects of the firing of different nerves can be quite different.

[3] This account of neural functioning assumes that what is observable in carefully-controlled scientific experiments pertains as well to parts of reality not directly observable. We cannot actually observe the impact of a calcium ion on a triggering site because the act of setting up the observation would kill the organism containing the nerve being observed. I assume that the behaviour of reality is consistent at the quantum level whether we can observe a particular instance of it or not. In order to make that assumption I also assume that the description of the quantum level of reality is not only epistemological, pertaining to our experience of nature, but ontological as well, pertaining to what actually happens in nature whether or not a human being observes it. See the discussions titled "Quantum Theory and Biology" and "The Heisenberg Ontology" in Stapp, *Mind, Matter and Quantum Mechanics*, pp. 123-128.

conscious experiences cause patterns of neural firings or both is a matter of debate. Since we live in a world of physical causality and we ourselves are physical creatures, it seems reasonable to assume that the state of the brain at least heavily influences, if not causally determines, our perceptions, thoughts, feelings and actions. Anti-depressant drugs, for instance, work by altering the chemistry of the synapse.

If there is causal uncertainty at the level of the whole brain, then human conduct is not fully causally determined in the physical world.

What causes a quantum event – in this case the impact of a calcium ion on a triggering site – to cease being merely a probability and start being something that happens at a certain place? Not anything in the physical world. Perhaps it is something nonphysical. It is possible – that is, it does not contradict the scientific evidence to assert – that something nonphysical decides which probability to actualize, thereby exerting a causal influence on our experiences, our perceptions, thoughts, emotions and actions.

Beyond the Causal Veil

There is a causal discontinuity in nature. Events at the quantum level of reality have no physical cause, but are themselves causes of subsequent events. What is on the other side of the causal discontinuity?

At this point we move beyond what physics can tell us. A number of things might be appropriate here. With Wittgenstein, we could simply shut up about it. Or we could postulate an incorporeal soul with free will or a God that intervenes in nature or a multitude of deities. Science can neither prove nor disprove such assertions. We must look elsewhere – in introspective analysis of our own experience of making a choice, for instance, or in patterns of coincidence or synchronicity – for evidence. Such evidence would not hold up in the public court of scientific inquiry, but might well be decisive for how we choose to live our lives.

Some say that the causal uncertainty at the quantum level of reality is merely statistical. Events happen randomly; hence, no conclusion can be drawn about nonphysical causality, free will, the existence of a soul or of God, or any such thing. But random as they may be individually, quantum events considered as a group certainly do exhibit regularities. Light passed through double slits exhibits distinct patterns, not random noise.

Consider a pointillist painting, which consists of distinct dots of pigment. If you look at it up close, all you see is random dots. When you view it from afar, you see identifiable forms and shapes, recognizable objects. I assert that the influence of the nonphysical on the physical world could be like that. What appears to be the random firing of a neuron may in fact be part of a larger pattern that extends through space and time.

Each one of us must determine for ourselves the nature and import of that larger pattern.

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Revision History

Version	Date	Author	Change
0.1	7 Oct 2007	Bill Meacham	First draft for review
0.2	10 Dec 2007	Bill Meacham	Removed references to “al-Lah” in Intro, Physics and Brain sections. Added footnote about calcium ions.
0.3	14 Dec 2007	Bill Meacham	Enhanced “Beyond the Causal Veil.”
0.4	14 May 2008	Bill Meacham	Fixed a typo. Added footnote on epistemology and ontology and citations from Stapp, *Mind, Matter and Quantum Mechanics*.
1.0	27 June	Bill Meacham	First publication. No difference from v 0.4c.