Do Electrons Have Free Will?

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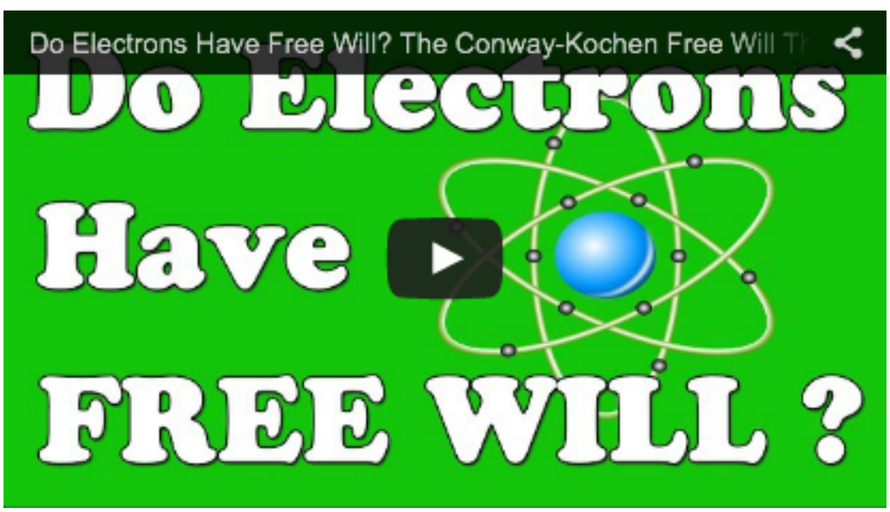
Quantum Physics & Free Will – Part 2: The Conway-Kochen Free Will Theorem – Closing the Free Will Loophole



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Introduction to the Conway-Kochen Free Will Theorem:

In this second video on Quantum Physics and Free Will, I'd like to look at another fascinating theorem that digs deep into the foundations of Quantum Theory. It is called the Conway-

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Kochen Free Will Theorem.

The Conway-Kochen Free Will theorem was proved by John Conway and Simon Kochen in 2007, and it provides us with another robust result which – like Bell's Theorem – highlights some of the important philosophical issues that lie at the core of quantum mechanics. In the context of this particular theorem, a free choice is defined as type of choice which is not determined by prior conditions, that is, not determined by the past history of the universe (in any inertial frame). Note that this is essentially the same definition we encountered earlier, in my previous video, when discussing Bell's theorem.

So what does Conway and Kochen's Free Will theorem state? The theorem states that, if we assume that we have a certain amount of free will, then, subject to certain other assumptions, elementary particles must have free will too. Put another way, the theorem states that – given certain other axioms – if the two experimenters in question are free to make choices about what measurements they are going to make (that is, if their choices are not determined by prior conditions in the universe) then the results of their measurements cannot be determined by anything previous to their experiments either.

The Kochen-Specker Theorem:

This argument follows from another important theorem, the Kochen-Specker theorem – a complement to Bell's theorem – which places certain constraints on the permissible types of hidden variable theories which would attempt to explain the probabilistic nature of quantum mechanics in terms of a deterministic model featuring hidden states. Kochen and Specker showed that the properties of particles – such as the squared spin in a particular direction – cannot have a fixed or definite value before it is measured.

The Kochen-Specker theorem not only shows that the result of any individual measurement was not pre-determined independently of the experimenter's choice of measurement, but it also shows the impossibility of Einstein's assumption that quantum mechanical observables represent real elements of physical reality, and hence – in line with non-

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realism – it highlights the ever important interplay between freedom of choice, observer and observed.

Experimental Set-Up – Space-like Separated Laboratories:

Now, coming back to Conway and Kochen's Free will Theorem… In order to understand what it's all about, let's go back to the same experimental setting I introduced you to in my previous video when talking about Bell's theorem.

We have two experimenters, Alice and Bob, in two different laboratories. Again, the laboratories are space-like separated, which means that no information can travel from one to the other, according to Einstein's theory of relativity, within a pre-stipulated period of time, unless it was travelling faster than the speed of light. In other words, the fact that Alice and Bob are space-like separated means that the question of who made the choice first of what to measure is meaningless here, because Alice and Bob's choices are not in each other's future or past light cones.

So, according to Einstein's relativity, the fact that their laboratories are space-like separated means that their respective choices of measurement cannot in any way influence each other, because no information signal can be sent from one to the other through the fabric of space-time. In addition, note that either of their choices could be said to have happened first, because in special relativity, the time order of space-like separated events is not absolute, but relative.

The 3 Axioms in Conway & Kochen's Theorem:

Well, turns out that this assumption is actually one of the axioms in Conway and Kochen's theorem. In their strong Free Will theorem version, they call this axiom MIN, and it follows directly from Einstein's theory of relativity. MIN is the assumption that Alice and Bob are space-like separated and that they can 100% freely and totally independently choose what type of measurement to make; that is, that their respective choices are neither a function of the past nor can they influence each other in any way.

The second axiom in Conway-Kochen's theorem is called SPIN, and it is related to the Kochen-Specker Theorem I mentioned earlier, which shows that the properties of the particles which are being measured in the present cannot be assumed to exist prior to them being measured. Therefore, the SPIN axiom follows directly from the foundations of quantum mechanics.

Finally, the last axiom, called TWIN, is related to quantum entanglement. It has to do with Bell's Theorem, which – as we saw in the previous video – describes how twinned particles can be used to experimentally test entanglement, that strange interconnection between particles which Einstein called spooky action at a distance. The TWIN axiom basically assumes this strange interconnection to exist.

From these 3 axioms, Conway and Kochen derived their Free Will theorem, which states that if the two experimenters are free to make choices about what measurements to make, then the results of their measurements cannot be pre-determined by anything previous to the experiments. In other words: if we have free will, then elementary particles have free will too.

Again, remember that Conway and Kochen's theorem is not in any way about proving human's free will, but rather, the theorem takes our free will as a starting axiom, a starting premise, an assumption, to show that if we indeed have a certain degree of free will, then so do elementary particles.

Extracts from John Conway's interviews:

"I know what I mean by humans having free will," says Conway, "I believe, and you don't have to, that I just picked up this pen and it wasn't determined at the start of the Big Bang; it's not a function of the past history of the Universe. I think I just did that in the last few seconds and before then, there was nothing in the world that you could have analysed to tell you that I would do that."

"For the Free Will Theorem, I assume that some of my actions are not given by predetermined functions of the past history of

the universe. A rather big assumption to make, but most of us clearly make it. Now, what Simon and I proved is, if that is indeed true, then the same is true for elementary particles: some of their actions are not predetermined by the entire past history
of the universe. That is a rather remarkable thing."

"The particles will either emerge on the left or right-hand side of a screen […] and what a particle will do is not a predetermined function of the past. Even if you knew the entire past history of the universe (in any inertial coordinate frame) this would not contain the information about what the particles will do in the experiment."

"That's why I insisted on using this evocative language," Conway says. "Many people thought I should say the particle's behaviour is indeterminate. But it would be really rude if I told you that you were indeterminate! It's the same property and I don't see why we should be required to speak of it as if it were a different property. Our theorem says that if human's have it, then so do particles."

Free Will Defined in line with Indeterminism:

It is worth stressing again that Conway and Kochen are not trying to prove that free will exists. Their argument would be completely circular if that was the case. What they are doing is – by explicitly making the free choice of the experimenter a fundamental axiom in quantum mechanics – they are ultimately attempting to close one of the last loopholes in Bell's inequality tests, the so-called "free-will" loophole.

Again, remember that an indeterministic world is not the same as a random world. It is a common misconception to think of the world as being either completely random or absolutely deterministic. Indeterminism does not need to entail absence of causation either. Indeterminism is just the failure of determinism. It does not need to equate with a world governed by completely random events or actions, but it allows for a wide range of possible scenarios that lie somewhere between the two extremes where free will would be an impossibility (absolute determinism or complete randomness).

Indeterminism is the idea that there is a branching of possibilities lying ahead of us, rather than just one possible outcome uniquely determined by the past history of the universe. Indeterminism is a necessary condition for our everyday notion of free will to be real. We can still have adequate causality and partial self-determination in a non-deterministic world. Indeterminism simply allows for the existence of alternative futures and pasts, as opposed to pre-determinism, which implies just one possible future and one possible past.

Closing the Free Will Loophole:

The loophole that Conway and Kochen's theorem is trying to tackle is often called the "free choice" or "free will" loophole. If absolute determinism were to be true (often called super-determinism in this context), then, as explained in my previous video, it would mean that all our experimental tests, including our choices, had already been pre-determined in advance to make us think that quantum mechanics is correct, to make us conclude that we live in a world that is not quite what it really is! You may think that this is a crazy idea, but no matter how convoluted, it still has a few supporters, which means that more experiments need to be done in order to close these remaining loopholes.

Scientists around the world are working very hard to devise experiments that can successfully deal with these loopholes. Personally, I think it would be great if we started performing quantum mechanical experiments where actual human choices were being used. So far, only random-number generators have been used as a way to replace human's free choices. The main reason for this is that human action is way too slow for the type of experiments that are being performed so far, where we are dealing with speeds of the order of magnitude of c – the speed of light – and relatively short distances between the laboratories.

If you think about it, in order for a random number generator to function, we still need a human experimenter to choose what random number generator to use, and to set it up, turn it on, and so on… So one could argue that the same idea applies in this situation: the human experimenter is still required to make choices, choices which will eventually lead to the random number generator making its so-called free choices.

Ultimately, what we are doing is testing whether certain variables are correlated to other variables in such a way that realism and locality may need to be abandoned. And in order for the results of these tests to make sense, either the experimenter or the random number generator are required to be able to make at least some of their choices 100% freely.

Despite this, I think that it'd be great if we could experimentally put to the test the assumption that some human choices can be 100% free, in the context of a quantum mechanical experiment, by not having to resort to using random number generators… but just using human's choices, and see what happens.

This is a recent article in Nature magazine that caught my attention. I'll quote the most relevant parts. It says:

"The issue is whether the settings in one laboratory are uncorrelated with variables (hidden or otherwise) in the other. If they are correlated, then the experiment violates the assumptions of Bell's theorem, opening the free-choice loophole, so called because of how it can be closed: the only things correlated with free choices are their effects, so (by Einstein's principle) settings that are freely chosen late enough would be uncorrelated with the other variables, as desired.

Human choice and action are slow, so Bell experiments thus far have used random-number generators rather than free choice to change the detector settings. There is no reason for such random numbers to be correlated with anything on the other side. But if one is inclined to reject the principle of common cause (as localists are) then one must admit that correlations can occur without any reason. Thus, to be rigorous, experimenters must choose the settings freely.

Using human free-choice while closing the separation loophole would require separating the experimenters by much more than one Earth diameter (only 40 light-milliseconds). Putting one experimenter on the Moon (1.3 lightseconds away) would also allow time for them to consciously register the results — a requirement to rule out a fourth and final loophole, the 'collapse loophole'. This arises from the possibility that the set of potential results recorded by a detector does not 'collapse' to an actual individual result until observed by the experimenter, so that before the experimenter gets involved the result could be influenced, long after the photon arrives, by some bizarre (but not faster-than-light) causal influence from the distant laboratory.

Such an Earth–Moon experiment is a worthy challenge for the next 50 years."

Nature, "Physics: Bell's theorem still reverberates", Howard Wiseman, 19 June 2014

100% Free Will??

Personally, I must admit that the requirement that some of the experimenter's choices must be 100% free from any influences in his own past, in the same sense that it would be required from a random number generator, sounds a bit extreme to me. Surely there is a wide range of possibilities other than super-determinism, complete self-determination or complete randomness when it comes to human being's choices.

Requiring a human being to be able to perform a 100% free choice, in the sense defined by Bell or Conway & Kochen, sounds a bit unhuman to me because – for all intents and purposes – we are equating this human free choice with a random choice. Is it really possible – I wonder – to choose between up and down, right or left, or 0 and 1 in a manner that is not influenced in any way by our past history?

What if we have a tendency for choosing right over left, or up over down, or 1 over 0? The fact that we may have this tendency to choose one option over the other would mean that our past history would indeed have an influence on our present choice. While there would still be a branching of possibilities in front of us, in this case two branches, our choice would NOT be 100% free! There would indeed be a higher probability that we would choose one branch over the other! And yet, the fact that our choice was not 100% free would not in any way imply that it was 0% free, but maybe that it was say… 20%, or 30% or 75% free from past influences. The way I see it, there is a wide range of possibilities to consider here!

This is a very interesting topic and I will continue discussing it in my next video… I will take it from here, where I left.

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One comment on "Do Electrons Have Free Will?"

Evan Thomas says:
March 27, 2015 at 12:38 am

Another great video! Looking forward to the next in the series. 🙂

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