IS QUANTUM MECHANICS A DIGILOG THEORY?

Finding the ultimate “stuff” that light and particles are made of will undoubtedly increase our understanding of how the universe works. The Copenhagen Interpretation, along with other theories and ideas are discussed in attempt to enhance what we know and what we might be capable of finding out.

By Chris Kennedy

In the late 1660’s, astronomer Giovanni Cassini was spending a lot of time looking at the planet Jupiter through his telescope. In particular, he was studying one of Jupiter’s moons and its orbit around the planet. After logging many observations, he noted that the moon revolved around Jupiter with a definitive velocity, creating predictable time periods when the moon would disappear behind the planet and reemerge from the other side. Then one day during one of his tracking sessions, something rather curious was discovered. The predictable orbit times were no longer predictable. As time went on, Cassini discovered that the orbit of the moon was running behind schedule. Cassini turned his data over to fellow astronomer Ole Roemer, who continued to track the orbits and made the same conclusion. The clear pattern that developed was that the farther Jupiter was from Earth, the longer delay in the orbit. Roemer knew that Jupiter’s moon couldn’t have changed speed but he wondered how it was running several minutes behind schedule. What Roemer eventually realized was that it was the light of the moon emerging from the rear of Jupiter that took several extra minutes to reach him at that greater distance.

At that moment Roemer realized that light must travel with a fixed velocity and therefore the longer the distance it has to travel, the longer it will take to reach its destination. Roemer reasoned that what he was seeing through his telescope was in fact, images of Jupiter’s past and not Jupiter’s present. The implications of this was apparently so mind blowing, that Cassini had actually entertained this as an explanation before Roemer did, but quickly discarded it because of how radical a concept it was.

Roemer and others calculated distance and orbit information and figured that light was traveling somewhere in the neighborhood of 150,000 miles per second. A few other scientists later perfected this calculation, and the more accurate velocity of light was determined to be 186,000 miles per second.

The significance of this is that in 1865, a Scottish physicist named James Clerk Maxwell was able to brilliantly determine the velocity that electromagnetic waves traveled through space by mathematically calculating the rate at which electric and magnetic fields continually perpetuate each other. When Maxwell ran the numbers through the formula, he calculated a velocity of approximately 186,000 miles per second. Knowing what the speed of light had already been reported to be, Maxwell quickly and correctly deduced that light itself must be a visible form of an electromagnetic wave.

The scientific community was pretty comfortable with this wave model until 1905, when Albert Einstein proposed that an example of light behavior known as the photoelectric effect, implied that light was made of particles instead of waves. There was no denying the wave behavior of light in previous observations, but there was also no refuting Einstein's discovery that light had to be made of discrete particles at least some of the time.

This was very interesting because at various times in history, scientist debated whether light was a particle or a wave, but Einstein was the first to present light as a wave-particle duality. Namely, the electromagnetic wave-photon duality.

Along Comes Quantum Mechanics

This would be the only duality of its kind until the mid 1920's, when a handful of physicists, while working on a theory that would better explain the atom (and its emitted spectroscopic frequency patterns) developed what would be known as quantum mechanics. With the guiding hand of Niels Bohr, the new theory began as the electron was described to revolve around the center of the atom in specifically located planet-like orbits. This new role for J. J. Thompson's negatively charged particle was an improvement of Ernest Rutherford's atomic model and solved some problems, but still could not explain all of the data that physicists were trying to interpret. What came afterward however was an explosion of creativity as ideas began to pour in from all over Europe.

French physicist, Louis De Broglie fired the first shot at the particle nature of the electron with his mathematical wizardry, and proposed that even something as concrete as an electron has wave characteristics. As unlikely and abstract as this sounded, the wave nature of the electron was eventually verified with an X-ray diffraction experiment by J. J. Thompson's son, G. P. Thompson. (One wonders if either of G. P.'s sons had developed an interest in electrons, would there have been a third property discovered?)

But De Broglie didn't make the electron disappear. Instead the waves he proposed served as "pilot" waves that guided electrons in their movements. As it turned out, this was inspired by Einstein's writings of 1909, where he described light as quantum singularities surrounded by large vector fields which would produce results consistent not only with the photon model but the wave model and its interference patterns as well. De Broglie hadn't quite produced a full-blown electron wave-particle duality yet, but the development of the quantum theory didn't end there – it was just getting started.

As time went on, the limitations of Bohr's simple solar system model were becoming more evident. In attempt to more accurately describe the true nature of the electron, Werner Heisenberg developed a completely non-picturesque model relying on matrix mechanics. One of the results of this development was that the electron was no longer assumed to revolve around the nucleus in simple flat circular orbits. Far from it. In fact, its existence was becoming so fuzzy, that it was concluded that its position and momentum could never be determined simultaneously.

Meanwhile, Erwin Schrödinger was developing his own explanation of electron behavior that produced the same accurate results as Heisenberg without relying on matrices. Instead, Schrödinger developed a somewhat picturesque (yet still abstract) wave mechanical version of the electron.

With contributions along the way from: Wolfgang Pauli, Max Born, Paul Dirac (and many others, of course) along with the continued guiding hand of Bohr, the electron would eventually be viewed not as being *carried* by a pilot wave, but itself *existing as* a quantum probability wave having no described physical nature whatsoever. According to what would become known as the Copenhagen Interpretation - the electron would exist as a particle when looked at or "measured" but most of the time it would exist as this strange quantum wave with no trace of its "particle" property in sight. It would seem that there was a new duality in town.

The Copenhagen Interpretation has been the accepted version of quantum mechanics ever since. In fact, it has been so accepted that many physicists (such as Sir Rudolph Peierls who studied under Heisenberg and Pauli) have objected to the word "interpretation" – which hints that there are several credible interpretations out there. For the vast majority, Copenhagen is not one of many interpretations; it is the *only* interpretation and *is* synonymous with quantum mechanics.

And who could blame anyone for feeling that way? Quantum mechanics has been one of the most successful, if not the most successful theory in the history of science. It has been validated many times over with the study of semiconductors, superconductors, not to mention a number of photon polarization experiments ranging from Aspect to Zeilinger. But as successful as it is, it has never made any attempt to explain more about this mysterious quantum probability wave.

This is because according to the Copenhagen Interpretation, there is really nothing to explain. In fact, it's nothing to apologize for – instead, it's the whole point. Bohr's Principle of Complementarity (which is part of what the Copenhagen Interpretation is based on) essentially says that when the electron is not being observed or measured in any way, it has no real definition. It is the act of measuring that actually gives it those measurable properties - but not a moment before. What this means is that the "uncertainty" in the uncertainty principle is not because the electron's velocity and location values are too delicate to measure simultaneously (which they are). It's more than that. It's that when the electron is not being looked at, it possesses no definitive properties. Instead, it is represented by this mysterious probability wave.

So what can we make of this wave? Do we have any hope of assigning any physical description to this at all? Well, according to distinguished science biographer, Abraham Pais:
We owe to Max Born the beginning insight that this wavefunction, unlike the electromagnetic field, has no direct physical reality.

So it would seem that the accepted quantum theory makes no attempt at describing a physical nature of the electron, and the proponents of the theory will tell you that's because there isn't one. But let's stop for a moment and insert a few more facts into this. For example: There is the Pauli Exclusion Principle, which states that no two electrons (in whatever form they're in) can occupy the exact same space and spin value. So if an unmeasured, unobserved electron is just hanging out in an odd shaped three dimensional orbital (which took the place of Bohr's planet-like circular orbits) in an unphysical, probability wave sort of way, then why can it only go so far until it gets in the way of the unphysical, probability wave sort of electron below it?

These unmeasured electrons seem to obey each other's spatial boundaries, not to mention, the energy equivalent boundaries of the positions they should take with respect to the positively charged nucleus.

Then can we confidently call this a complete state of non-physicality? Regardless of whether it retains its point-like charge identity or dissipates evenly throughout its orbital space, it must be retaining its property of negative charge, since that is the driving force behind its arrangement relative to the nucleus and the other electrons in the atom.

So where does the charge go? Is it spread evenly, in a continuous wave or field-like fashion? Or does the electron dissolve into a hundred, or a thousand, or a million little pieces – each carrying the appropriate fraction of the electron's total charge? Electrons have always been thought to carry charge in lumps (a Feynman term) of exactly (-1) charge, but what if, depending on the circumstances, they have the capability to go into solution (so to speak) and dissolve into countless negative charge fractions? Maybe they prefer this state since pieces of like charges would repel, and only when provoked, do the tiny negative fraction charges condense into the familiar (-1) point charges.

And what about the electron's mass during this wave state? Does the mass completely vanish during the conversion to wave form? It would be hard to believe that this is the same mass-energy interchange seen in nuclear reactions calculated with the $E = mc^2$ conversion. If that were true, you would have to have a whole lot of physical nothing carrying a whole lot of energy equivalent. There does however appear to be something in common with the mass-energy conversion in the sense that a saturation of energy can effectively precipitate out mass, while in the quantum wave model, the act of measurement may cause a similar precipitation, albeit, through a completely different method.

Now, if the electron does retain its physicality, but disperses into thousands of pieces, then that would not only explain the charge problem, but the mass problem as well. Of course, it would however, bring up a new problem.

Out of Orbit

Quantum mechanics also has much to say about the behavior of a moving electron that is not part of an atom. In this case it has no nucleus or other electrons to interact with, yet it is still assumed to take the probability wave form until it is converted to the more recognizable point charge as it arrives at a detection device.

In the famous double slit experiment, electrons are first aimed at a barrier with a single slit to pass through. On the other side of the slit are detection devices that record where the electrons hit. With just one slit to pass through, the electrons behave (as expected) as tiny individualized bullets or lumps. However, with the opening of the second slit, the electrons do not produce hit patterns that correspond to bullets passing through slits. Instead, they produce an interference pattern that is associated with wave propagation!

And here is the best part: Even if electrons are fired at the slits one at a time, each electron will register on the other side as a particle in a specific location, but after many firings the end result will still produce a wave-like interference pattern at the detectors on the other side. In other words – it would appear that each individual electron does not need other electrons to interfere with. It can take a wave form and interfere with itself.

So how does quantum physics explain this? While the electron is in flight, it is not in one specific location; rather it is in a superposition of many location states as represented by the probability wave. It's only at the moment of detection that this wave collapses into one single location for the electron.

Can we attempt a more physical description than that? Let's go back to the electron broken into a thousand pieces: If its pieces were spread throughout the "wave" passing through the slits, the pieces would continue to be spread until the exact moment the detector registered an electron in a specific location. That would mean that in a literal instant, the spread out pieces of electron would cease to exist in all locations but one, and instantaneously transport to the location where the measurement occurs.

In a sense, whether we embrace the quantum probability wave, or the thousand piece model, we would have to accept that all of the locations on the wave front are "entangled" so that when the electron appears in one location, it instantly knows not to appear in all other locations. If there is a collapse, testing whether the collapse is truly instantaneous would surely be impossible to determine. The only hope would be if the exact velocity of the wave was known, then one could hypothetically match that with the expected arrival time at the detector and see if it differs from the actual arrival time, hinting at an interval representing collapse. In any event, it is interesting to note that if there is nothing physical to the probability wave, and the wave is all there is to the described state of the electron, that the waves are stopped by the barrier and only pass through the slits. In this case, the barrier can not only stop an electron, but the nonphysical wave representing one.

Return of the Pilot Wave?

As time went on, quantum physics had little or no use for De Broglie's specific pilot wave theory, despite the fact that his math formula used to determine wavelengths of particles was, and still is very much in play. But in the 1950's there was one physicist by the name of David Bohm who was very dissatisfied with the lack of physical description provided by the quantum mechanical model. (At this point it should be stated that quantum mechanics can be confusing as it is – the fact that three particular people involved in it are named Bohr, Born and Bohm doesn't make it any easier, so be careful.)

Bohm's theory, bearing similarity to De Broglie's theory, first described the electron as not disappearing at all. Instead, the electron was guided by unseen physical variables that were analogous to the unseen atoms guiding the apparent random movements in Einstein's Brownian motion. Bohm further proposed that there is physicality to the Schrödinger wave and provides a force or guidance for the movement of the electron. Presented this way (similar to Einstein's original photon idea in 1909) the electron would retain its particle property in a way that would also explain the familiar wave-generated interference patterns in the double slit experiment and therefore be consistent with the predictive results of quantum mechanics. And since the electron would always be pulled to areas of high intensity of the wave, the electron wouldn't have to worry about disappearing altogether, if it ever started in a spot destined for destructive interference. Not that electrons worry.

Bohm then evolved the rigid point-charge electrons into actual particle-like concentrations that are always forming and dissolving. If an electron dissolves in a certain place, it is very likely to re-form nearby. This is an interesting idea that can lead to questions about quantized movement, space and time. It would be fascinating if all movement measured in the universe turned out to be particle or wave information transmitted to the piece of quantized space next to it as it would continue to do in its perceived direction of travel (much like the illusion that lights are streaming across a theater marquis when actually they are a well-timed series of on-off switching). And if the passage of time occurs in quantized discrete steps, then this continued displacement could be one of the fundamental behaviors that quantized time is based on.

In any event, by the time the 1980's came, Bohm and collaborator Basil Hiley had further refined this description to suggest that the accompanying wave was a quantum potential that acted as an information wave similar to radar communication. Almost instructing or directing the electron in a way.

With the exception of a very small minority, the bulk of Bohm's ideas have never been taken seriously. Not surprising, since his theory attempted to explain things that quantum physicists insisted were unexplainable in an absolute sense.

Is there an experiment that can be conducted that would verify or rule out the De Broglie-Bohm hypothesis? Probably not. With our current knowledge of particle and wave behavior, the only thing remotely possible would be to carefully examine the difference between the interference pattern of an offset double slit and the tracking of individual electrons passing through the farther slit with the nearer one closed. If some of the electrons in the Bohm model sit in a destructive interference position and jump to the nearest area of high wave intensity, the electron distribution in the final pattern may be required to be slightly different than the pattern distribution expected for nonphysical electrons traveling as a smooth wave.

Then a Bell Went Off

On more than one occasion Einstein and Bohr debated about the accuracy and completeness of quantum mechanics. Bohr was perfectly content being certain of the uncertainty, and Einstein was constantly trying to poke holes. This came to a head in 1935 when Einstein (along with Boris Podolsky and Nathan Rosen) published a paper questioning the completeness of quantum mechanics using two electron spin values that would be dependent on one another. EPR argued that if the spin of an electron traveling in one direction were measured, then we would know the spin value of the other electron and if they correlated as predicted, the spin values must have been pre-determined for both electrons all along, rather than being in a mysterious quantum uncertain state.

Bohr held fast and continued to argue that the spin states of the electrons would be in a superposition state with no real spin property until the end when a spin was measured. Of course, Einstein pointed out that electron A must be communicating its spin value to electron B instantaneously, and that would be impossible since nothing travels faster than light.

We would have to wait thirty years before someone would devise an experiment to settle this score. That someone was John S. Bell. In his now famous inequality paper of 1964, (which has since been put to the test many times using photon polarization measurements instead of electron spin) Bell set up a mathematical pass/fail test that would exploit whether Einstein's deterministic local variables are present, or whether quantum physics is correct and nonlocal variables instantaneously communicate or are connected in a more fundamental way. When the results from these experiments came in, they showed unequivocally that the flying photons had no real polarization values until they hit the detection device. It should be noted that by the time the first experiment of this kind was conducted, Bohr and Einstein had long since passed, so Einstein was spared from hearing the words "checkmate."

Where Do We Go from Here?

If we trust that the photon polarization experiments, show that the Copenhagen Interpretation is the only correct interpretation, then electrons truly are waves or particles depending on if you are looking at them or not. We would certainly need something big to overthrow Bohr's theory as it seems to have gained even more strength and credibility in the past 30 years. But the question is: Do we now have enough evidence to absolutely eliminate the need for further investigating the possibility of a more physical model that would also be consistent with the experimental data?

If your answer to that very long question is yes – chances are, you are probably correct, but in any event, here are a few thoughts you should consider:

Is there any explanation for why a photon and an electron will produce the same pattern in a double slit experiment? Especially curious, since electrons possess electric and magnetic fields while photons are points representing moving locations in those same changing fields. For light, how does the electromagnetic wave relate to the quantum wave? For that matter, how does the photon relate to the electromagnetic wave? We know a photon in a superconductor becomes heavy and slows due to the effect the superconductor has on the electric and magnetic fields, so if something happens to one it obviously affects the other.

For light, is there a wave-particle-wave triality? What are each of them doing as they pass through the slit? When a particle is in its nonphysical wave form, why are certain values or properties such as spin and polarization indeterminate, yet the wave continuously possesses the identity of the specific particle the entire time? In other words, why doesn't an electron ever pop back into existence as a muon, or a cheeseburger? To borrow a theme from Einstein: Is this God's way of saying that he doesn't know what numbers the dice will land on, but at least he's sure what color the dice are and how many he's throwing? And what happens to the electric field and magnetic field of an electron that is in a superposition of states? Are the fields generated *by* the electron, or is the electron an excitation in the fields? Which is the tail and which is the dog? If there is nothing physical about the probability wave, then how can the detector touch it in some way while it is in this nonphysical state and trigger it to condense into a physical entity such as an electron. What happens during that magic moment?

And then there is the *Many Universes Theory*. (And when they say many, they mean a lot!) This is where every possibility arising out of every quantum superposition actually becomes expressed in its own universe. So when the quantum coin is flipped, two universes will branch from the one and one universe will have a coin that landed on heads and the other tails. If a photon has a 50/50 chance of going left or right, a universe is manufactured on the spot for each possible outcome. Of course you only see the universe that you live in with the specific outcomes that have happened, but you would have to accept that somewhere, in unseen dimensions, there have been a near-infinite number of universes created to accommodate every possible outcome for every quantum crossroads, so to speak. One could argue that this theory is not very likely since in one of the many possible universes, everything would be the same as we see it now except that scientists have figured out how to communicate with these other universes (including ours) and since none of us have received any messages….

Moving on to entanglement – How about a case where one photon is detected and its partner photon is purposely not detected right away? Is the second photon still in a superposition of states even though we know what the polarization of the first one is? If it isn't, then how did its superposition collapse without anyone measuring it? Is it possible that spin and polarization values constantly fluctuate for entangled particles during flight, but they mirror each other's fluctuations so they always match each other at any point in time? (Of course, this would suggest determinacy and conflict with experimental results.) The bottom line is that we will eventually have to better explain the results of the photon polarization experiments and other entangled situations. We have a couple of starting points to work from:

1) *The quantum behavior of particles is completely probabilistic* (as the accepted form of the theory dictates) and the way for the particles to maintain their proper spins or polarizations is through some unfamiliar faster than light, or nonlocal form of communication between the distant particles. The choices here are instantaneous communication, or established extra-dimensional link, or not instantaneous, but much, much faster than light signaling. There may be some never-before-detected form of communication between entangled particles that is not subject to the same speed limit that our conventionally detected particles and waves are subject to. Something in our space may be creating a drag that this unknown transmission does not experience.

   or

2) *Bell's Inequality theorem does not apply to the actual behavior of entangled photons observed in experiment*. In other words, although the experimental results correlate with the results Bell assigned to indicate preservation of quantum mechanics and possible nonlocal linkages, someone would have to show that Bell's Theorem would

> not be applicable in this case. Similar to (ironically) Bell showing how John von Neumann's No-Hidden-Variable proof, although self-consistent, was not completely applicable to the quantum mechanical theory. This would of course be the long shot of long shots but if it is possible, it would have to be done by showing how the actual property of polarization itself, with the changing positions of the slits - could produce the same experimental results with photons that do in fact possessed pre-determined polarizations.

With all that we know, obtaining more information will come down to convincing quantum physicists to be less comfortable with knowing so little about a theory that correctly predicts so much. And although many are comfortable with what we currently know, others can't wait to see what tomorrow will bring. In the meantime, we will have to settle for our future knowledge of quantum mechanics as being in a superposition as we patiently await collapse.

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