The Mysteries of the Quantum World

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Abstract

A new way of describing quantum processes is presented which should help students to make sense of the mysteries of the quantum world.

A Teacher's Dilemma

In introducing our students to the mysteries of the quantum world, teachers face a serious problem. In our eagerness to present them with a stimulating intellectual challenge it is very tempting to talk about the photo-electric effect or the double-slit experiment as if it was a murder mystery. You know the sort of thing: 'We *know* that when the photon landed on the screen over here it was a particle because it knocked some electrons off the atoms and caused a detectable signal; but if it was a particle when it left the laser and was a particle when it arrived at the screen, how come it went through *both* slits?' This sounds very like: 'We *know* that Professor Pringle was murdered in his office with the candlestick; but how come the candlestick was found *outside* the office when all the doors were all locked from the *inside*?' Now everybody enjoys a good murder mystery, but only when the solution is credible. If the author of the book has to rely on special candlesticks that can pass through walls, he will not sell many copies.

When it comes to quantum mysteries, physicists are in the same situation; we do not appear to have a credible solution to offer. Some of our brightest students may relish the challenge and even entertain the idea that they might themselves one day contribute to the solution but I fear that many will come to the conclusion that physics is either too difficult for them to understand or has gone off the rails completely and cannot be trusted.

But how can we provide our students with a credible solution to all the mysteries of the quantum world when there is no consensus in the scientific community as to what that solution is? The debate has raged for nearly a century. There are those who believe that photons are really particles, guided by 'pilot waves'; there are those who believe that photons are really waves which 'collapse' into particles when you try to look at them; there are those who believe that the universe is constantly splitting into multiple universes in which everything possible happens at once and there are those who believe that, deep down, there is a classical world hiding there somewhere but we just don't know where to look.

In point of fact, virtually all practising scientists – the people who invent new gadgets and design new drugs etc. – do not believe any of these things. They simply use the well-established mathematical rules of quantum mechanics to get results which they can rely on and let others do the arguing.

So where does this leave us as teachers? Do we go for one of the competing explanations as if it was the truth, or do we try to explain all of them and say, honestly, we don't know which, if any, explanation is correct? Neither course is acceptable. The first is dishonest and the second impractical.

And therein lies our dilemma.

Now, at the risk of bringing on myself heaps of derision from genuine experts in the field as well as utter disbelief from everyone else, I am going to make an important announcement. *I have a solution to all the mysteries of the quantum world*!

No, don't throw this article in the bin yet. Bear with me. I have an idea which, to me makes very good sense and which can be used to explain the wave/particle duality, the measurement problem, entanglement and all the other mysterious properties of the quantum world. It is an idea which contains elements of all the different interpretations of quantum theory which I mentioned above but which is sufficiently different as to suggest a completely new interpretation of what is going on during a quantum process and which could, perhaps, even suggest new experiments to perform and new discoveries which could be made. Are you still interested? Then let us proceed.

The Ontological Field

Photons and atoms, tables and planets: these are all familiar objects, but none of them really exist. In classical physics, a photon is just a localised disturbance in the electromagnetic field; an atom is just a disturbance in the electromagnetic, gravitational and strong nuclear fields; in fact, everything can be described simply in terms of disturbances in the various fields which we know about.

So the whole (classical) universe (and its history) can be described by a single field which I shall call the *Ontological Field* $\boldsymbol{\Omega}$. ('Ontos' is Greek for 'existence') This field has four real dimensions of space and time so for every point (x, y, z, t) the field specifies everything you need to know about that point – the magnitude and direction of the electric field, magnetic field, gravitational field, higgs field etc. etc.. In order to explain and predict the evolution of a field in time, you need a set of differential equations which determine how the state of the field changes from one instant to the next. So far we have been very successful in working out the equations which govern electromagnetism and gravity and you could say that the whole enterprise of developing a 'theory of everything' is really just an attempt to discover the differential equations which govern the behaviour of the ontological field.

All the particles that we have discovered such as photons and quarks can be viewed as localised disturbances in the ontological field but, in so far as these disturbances have an individual identity and have measurable properties, they can be regarded as proper entities in their own right. All these particles can properly be described as *emergent properties* of the ontological field in the same way that a hurricane is an emergent property of the field which describes the Earth's atmosphere or a Mexican Wave is an emergent property of a football crowd.

So far, I have said nothing really controversial. All I have done is wrapped up all of classical physics in a mathematical package and put a label on it. In order to extent this idea to cope with quantum phenomena we must add a new idea.

In addition to the four real dimensions of space and time, the ontological field has an arbitrary number of what I will call imaginary dimensions (in the mathematical sense of other dimensions at right angles to the real ones). As long as the physical process going on are classical (non-quantum) these dimensions carry no information (i.e. the value of $\boldsymbol{\Omega}$ is zero at all points along these axes except where they cross the real axes.) But whenever a system enters a quantum state – for example when a photon encounters a double slit – non-zero values of $\boldsymbol{\Omega}$ appear on one or more of the imaginary axes. It would not be inappropriate to say that the universe splits into two (or more) universes because each point on the imaginary axis in effect defines a separate universe. In one universe the photon goes through one slit; in another it goes through the other. I dislike this language, however, because it suggests some kind of permanent schism. I prefer to think of this development in the ontological field as being just another result to the differential equations which govern its behaviour. In particular, it is important to realise that what happens to the field next depends just as much on one 'universe' as the other. The two universes are not 'real' universes; rather they are both 'possible' universes.

What does happen next? For a while, these two possible universes develop independently but soon the photon reaches the screen. Here it interacts with other atoms and the ontological field has to split into more and more 'possible' universes. Mathematically speaking, $\boldsymbol{\Omega}$ develops non-zero values at more and more places on the imaginary axes.

So far, what I have said is broadly consistent with what is known as the Many-Worlds interpretation of quantum theory. Most people object to this theory on the grounds that the possible universes appear to multiply without limit and that, once they have split apart, there seems to be no reason why things happening in one universe should influence events in another (as they must when the two photons in two different universes interfere with each other when they arrive at the screen)

So what causes all these possible universes to collapse down into one real universe again? This is called the Measurement Problem and it has been bugging theoreticians for nearly a century. Theories of wavefunction collapse are two a penny these days but none of them have turned out to be satisfactory so far. I am not going to add to this dismal tally by adding another theory. All I will say is that I believe that there must be *something* in the differential equations which causes the ontological field to become unstable when too many imaginary dimensions come into play. Perhaps it is because the imaginary dimensions contain non-linear terms which cause the field to behave chaotically. Whatever it is, there comes a point when the value of $\boldsymbol{\Omega}$ becomes zero again on the imaginary axes. In effect, all but one of the possible universes disappear leaving just one actuality behind.

Now I am not for one moment advocating that we should teach all this to our students as if it were the established truth. In order to become that some future Einstein will have to work out exactly what the appropriate differential equations are, and show how their inherent non-linearities bring about the observed collapse of the wavefunction. Moreover, this new theory would have to make significant new predictions which could be tested in the lab. We are a long way from this.

On the other hand, if the theory I have suggested contains any truth at all, then it points the way to a new way of talking about quantum processes which, to my mind, gives a new and wholly satisfactory account of the various mysteries which we encounter in the quantum world.

Suspended Reality

Instead of talking about ontological fields and imaginary axes, we shall refer to the state in which several possible universes exist at the same time as *suspended reality* and the process whereby chaotic instability singles our one winner as *chaotic collapse*. We shall also refer to non-zero values of $\boldsymbol{\Omega}$ on one of the imaginary axes as *potential universes* or *potential particles*.

Let us examine three of the fundamental mysteries of the quantum world by examining a number of different thought experiments and see how these two simple ideas can transform our understanding of them.

The Double-slit Experiment and Wave/Particle Duality

What exactly is a photon? For the purposes of this discussion, I am going to assume that a photon is a localised disturbance in some aspect of the ontological field (the electromagnetic aspect) and that it basically looks like this:

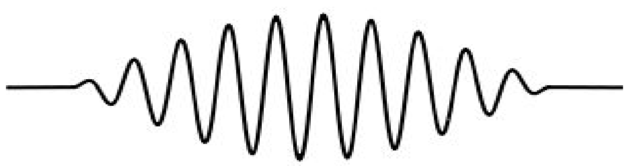

fig. 1: A wave packet

(A localised wave like this is called a wave packet. I shall take up the issue of how many wavelengths the packet contains in due course.) Now when a wave packet like this passes through a single slit, it does not spread out sideways in the way that you would expect light waves to behave. Instead, this ontological wave packet spreads out along one of the imaginary dimensions of the field, each point along which represents a wave packet or photon travelling in a different direction. Only two of these directions are of subsequent interest to us so we summarise all this by saying

(1) *When the photon reaches the first slit, reality is suspended and an infinite number of potential photons emerge, two of which are heading towards the double slit ahead*.

When these ontological wave packets reach the double slit, each splits into an infinite number of new potential photons along a new imaginary dimension. The ontological field now contains information about all the possible ways in which a single photon could pass through the sets of slits. (Note that since all these potential photons are equally valid disturbances in (one of the imaginary dimensions of) the ontological field, the equations will automatically eliminate those potential photons which are excluded by virtue of their mutual interference.) This translates into:

(2) *At the double slit,more potential photons emerge corresponding to all the possible ways in which a single photon could pass through the two slits taking interference effects into account*.

Finally, when the potential photons reach the screen they interact with so many other ontological entities that that chaotic collapse occurs and all but one of the possible photons disappear leaving just one to trigger the detector. We conclude our description by saying:

(3) *When the potential photons reach the screen, chaotic collapse occurs and reality is restored*.

Now read the three italicised statement through on their own. Do you not agree that, provided you can stomach the idea of suspended reality, they make a coherent and credible account of what is going on inside the apparatus? If you do, what is your answer to the question 'is a photon a wave or a particle'? The italicised statements make no mention of waves; they only refer to particles. But we know that at a deeper level, all these particles and potential particles are aspects of a field obeying wave equations. (There is more than an element here of the de-Broglie–Bohm pilot wave interpretation of quantum theory.)

Now I promised earlier to say something about the length of a photon wave packet and as this explains another of the mysteries of the quantum world, I will slip it in here briefly. If you want to measure the wavelength (or momentum) of a wave packet, it must contain a good few wavelengths. The more the merrier in fact, like the wave packet shown in fig 1.

The precise position of a wave packet can only be measured, however, if it is short and sharp like the one shown in fig. 2. But you cannot measure the wavelength of such a wave packet because it doesn't contain enough wavelengths.

fig. 2: A short wave packet

What this means is that if you can measure its position, you can't measure its wavelength. Conversely, if you can measure its wavelength, you can't measure its position. Does this remind you of something? Yes, of course. It is Heisenberg's uncertainty principle.

So how long is the wave packet of a photon? Is it long or short?

The answer is that it is in a superposition of states, being both long and short at the same time. Every photon is in a state of suspended reality. Nature has not made up her mind whether it is a long or a short packet until it encounters a detector. Until that time, the disturbance in the ontological field will have non zero values along one of the imaginary dimensions which correspond to all the possible lengths. When it reaches a detector designed to measure its wavelength, it will be one of the long versions that emerges out of suspension; if the detector measures its position, it will be one of the short versions. What you can't do is measure both its wavelength (or momentum) and its position at the same time with arbitrary accuracy.

Schrödinger's Cat and the Measurement Problem

For the conventional interpretation of quantum theory, the big question is – what constitutes a measurement? Without a mechanism which forces the wavefunction to collapse, there seems to be no reason why a quantum state such as a photon being both here and there, or a cat being both alive and dead, should not persist for ever. The big advantage of any theory which provides a mechanism for wavefunction collapse is that the measurement problem disappears. In my view, chaotic collapse will occur spontaneously as a result of instabilities in the equations which describe the evolution of the ontological field. In simple language, I believe that wavefunction collapse is almost bound to occur when the number of potential particles involved becomes sufficiently large.

In Schrödinger's original scenario the fate of the cat is bound up with the decay of a radioactive atom. If the atom decays within a certain time, the cat dies. Otherwise it lives. Now using the language of suspended reality, a radioactive atom is constantly emitting potential alpha particles which interact with the air molecules around the atom. When the number of potential possibilities becomes too great, the wavefunction collapses and the atom is discovered to have decayed – or not, as the case may be. In other words, wavefunction collapse is occurring constantly in the vicinity of the atom. The region in which reality is suspended never has the chance of getting as far as the cat.

Mr Tompkins' Rainbow Gloves and Entanglement

In order to explain the mystery of entanglement I would like to tell you a little fairy story[1]. Mr Tompkins manufactures magic gloves. They are supplied in a box with a dial on the front by means of which you can specify the colour the gloves will be when you open the box. Set the pointer to white and both gloves will be white. Set it to black and both gloves will be black. One day, by accident, Mr Tompkins' minions sent out a batch of gloves but only put *one* glove in each box. Not surprisingly, a flood of complaints soon began pouring in from irate customers. But then a surprising phenomenon emerged. It became clear that boxes with successive serial numbers (ie boxes which actually contained gloves from a single manufactured pair) were always the *same* colour, even though one box was opened in London while the other box was opened in New York. How did the glove in New York *know* that the customer in London had dialled up the colour white when she opened her box? And what if the customer in NY had opened his box *before* the customer in London opened hers? Do the gloves communicate with each other, or do they somehow know in advance what colour is going to be needed?

Now it is not difficult to set up a similar experiment with polarised photons which can be produced with identical, but indeterminate polarisation. Such photons are said to be entangled and as soon as the polarisation of one photon is determined, the other appears to adopt the same polarisation, even if it is light years away.

This bizarre behaviour is elegantly explained using the language of suspended reality. When the gloves (or photons) are manufactured, they are in a suspended state in which all colours (polarizations) are possible. As soon as one glove (or photon) is measured, chaotic collapse occurs and only one possibility remains – one in which both entities had the same property all along.

This brings me to one final point which I would like to make about suspended reality and chaotic collapse. Once the latter process occurs, it is not only possible to say with certainty what the result of the experiment is now (i.e. the photon which came through the slits landed *here*; or the the cat is, thankfully, *alive*; or that both gloves are actually *white*), we can also say with certainty how it came to be that way (i.e. the photon went through *this* slit, not that one; the radioactive atom *never* actually decayed while the cat was in the box; the gloves were actually *white* all the time). The reason for this is that when chaotic collapse occurs, it defines a state of the ontological field which determines not only the current state of the universe but its whole history as well.

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1 A version of this story was published in *Physics World* **Vol 28 No 2** February 2015 p52