Quantum Mechanics 101

The purpose of this paper is to provide a simple and understandable guide to some of the fundamental ideas of Quantum Mechanics. The reason I'm writing this is because I constantly see that people are being "conned" by people who claim to be experts in Quantum Mechanics, and particularly by the complex and obscure language that these people use. I hope that by imparting a very basic guide to the real concepts behind Quantum Mechanics, more people will be able to see for themselves what's likely to be true or false.

The best way of starting is to look at the history of Quantum Mechanics and how it arose.

In the early part of the 20th century scientists finally derived a model of the atom. In this model, an atom was supposed to consist of various subatomic particles like protons, neutrons and electrons. The atom had a nucleus of heavy particles and these were either protons, or a combination of protons and neutrons. Orbiting around the nucleus there were electrons which were much smaller than either protons or neutrons (approx 1800 times smaller).

However, each proton was considered to have a fixed electric charge of +1, the neutron had no charge and the electron had a fixed electric charge of -1. The units of the charge don't matter for this explanation.

The idea was that all stable atoms had to be electrically neutral overall. So if the atom had say 2 protons, then it would also need to have 2 electrons, so that the overall charges balanced out. Each different type of atom was one distinct element on the chemical periodic table. So the simplest atom, which consisted of just one proton and one electron was Hydrogen, the first element in the periodic table of elements. The next one had two protons, two neutrons and two electrons and was Helium, the second element in the periodic table and so on. The number of neutrons didn't affect the overall charge (because neutrons are neutral) and in general in most atoms, the number of protons and neutrons was equal. Atoms in which the numbers of protons and neutrons were NOT equal were determined to be a particular element based ONLY on the number of protons, and the variants with different neutron counts were called isotopes of that element.

Anyway, by studying the elements, chemists and physicists realised that if you heated up atoms of any particular element, they would start to emit light - and the light had specific colours depending on the element. Sodium would give intense yellow, Strontium would give bright red, Copper would give blue-green and so on. Some property of the atom somehow made these colours.

In 1905 Albert Einstein came up with a new theory - he found that elements also responded to certain colours of light, and that by shining light on metals he could cause a voltage to appear across the metal. This was called the Photoelectric effect and was the thing that made Einstein famous and won him the Nobel prize.

Scientists already knew that electrical phenomena were due to the flow of electrons - so with Einstein's discovery they realised that somehow light and electrons were intimately connected. And it was Einstein who proposed that when the light hit the atoms, somehow the energy of the light was absorbed and caused the electrons to bounce out of the atoms and to move around outside, where their movements could be detected as electric current.

The colours of the light that caused the electrons to move in any particular element were the same as the colours emitted when that element was heated to incandescence.

Einstein managed to prove that the different colours of light had different energies and so it followed that electrons were bound to atoms by certain amounts of energy. And that in different atoms, the electrons had different energy levels.

All that was needed now, was to somehow work out exactly what the energy levels were for any given atom, and from that it would be possible to predict exactly what colours of light would be emitted or absorbed by that atom. It didn't seem that difficult at first.

A Danish scientist called Niels Bohr tried to do the calculation. He thought he could make a simple model of the atom and work out the energies using known physics. He started with Hydrogen because it was the simplest atom.

Bohr worked out that the electron was rather like a ball tied to a string which was whirled around the atom. It was easy to see that the "string" was in fact the electrical force between the positive proton and the negative electron. And it was quite easy to come up with an equation for this force. Since the electron didn't go flying off into space, and stayed with the atom, it followed that the centrifugal force experienced by the electron would have to be exactly equal to the attraction between the proton and electron. In that way the atom would be stable. And it was also quite easy to work out this centrifugal force as well.

But Bohr hit a problem! For many years scientists had known that if you accelerated a charged object, that object would start to emit radiation. He suddenly realised that his electron whirling around the atom was a charged object, and that it was accelerating. Yet, under normal conditions, the atom DIDN'T emit any radiation!

You might be confused at this point. How is the electron ACCELERATING? Surely it's just whirling around the atom at constant speed? Yes, it is, this is true. But the definition of velocity is a constant speed in a constant direction. If the direction changed, then the velocity would technically change (because velocity is a vector), and the definition of acceleration was a changing velocity. So technically, because the electron was going in a circle, its direction was constantly changing and so it was accelerating, even though it's overall speed was constant!

When scientists took a single lone electron and whirled it round in a circle OUTSIDE an atom, it did emit radiation as predicted. So there was something special happening inside an atom that made this NOT happen. And this was what confused Bohr.

Why did it matter? Well Einstein had also proved with his famous E=mc2 equation that matter and energy were related. So if the atom were constantly emitting radiation it would constantly lose energy. And the only place that energy could come from would the matter of the atom itself. So if this were true, all atoms would get lighter and eventually fade away. This would affect Bohr's calculation, and it didn't happen in practice. So what Bohr needed was some explanation of WHY this didn't happen and what was special about the atom in order to get his energy calculation right.

Eventually he had a brilliant idea. He proposed that maybe there were special fixed energy states in an atom (remember that these energy states are just different orbits of electrons) and that as long as the electron was only in one of these special orbits it would NOT emit radiation. The problem now was proving it and also how to calculate it.

Other scientists had been experimenting for years with electrons. They had found that electrons usually behaved like small charged balls of matter. But in some cases they had found that electrons could also behave like waves! This was very confusing, it was impossible to determine if the electron was a particle or a wave, and to explain the results they had, it HAD to be both at the same time!

In the end they discovered this was true of all subatomic particles and that it was equally valid to think of them as either particles or waves. Equations were worked out that let the scientists calculate the wavelength of particles. For the electron this became known as its Compton Wavelength, and the wave/particle duality was described by de Broglie.

Bohr knew about this, and it gave him another clue. If the electron was a wave instead of a particle, then he figured that any orbit around any atom must have a total circumference that was exactly equal to a whole number of wavelengths of the Compton wavelength of the electron. To think of this in a simplistic way, imagine fitting a number of electrons into a given space - they would only fit exactly if the space was an exact multiple of their wavelength - you couldn't fit say half an electron into any space - because it was impossible to have half an electron, electrons were always fixed units.

So then Bohr tried redoing his energy calculation but added a constraint - that the solution had to produce an electron orbit, the circumference of which was an exact whole number of electron wavelengths. And his equation worked out and suddenly he was able to accurately calculate all the energy levels of the Hydrogen atom. This was a big success, and everyone was very happy.

Before going on, I need to explain something about those light colours mentioned above. The theory was that an electron could only exist in one of a specific number of fixed energy levels (i.e. orbits that Bohr had calculated to be exact electron wavelength multiples). If that was true then adding energy to an electron would NOT cause it to change its orbit - UNLESS the amount of energy was exactly the amount needed to move the electron from one permitted orbit to another permitted orbit. Because if the electron absorbed just any amount of energy, it could move into one of the non-permitted orbits and would radiate until it disappeared (remember that moving charges radiate energy, except in one of the permitted orbits). Well electrons weren't disappearing, so the idea that only fixed levels were allowed must be right.

So where did the light come in? Well the light that was absorbed by an atom had to be of an exact frequency that contained just the right amount of energy to move the electron from one permitted orbit to another. And if the electron fell from a higher energy orbit to a lower one, it would also emit light of exactly that same frequency. Of course we perceive frequencies of light as colours so that explained why certain atoms seemed to have a preference for certain colours. The colour was just due to the exact frequency of light needed in that atom to shift the electron from one of its permitted orbits to another. And because each atom was different, each had different energy levels, and so different colours.

So it seemed that everything we needed to know about the atom had been worked out by Bohr. The energy levels of hydrogen were known by measuring spectral lines in the spectrum of hyrdrogen and Bohr's calculation predicted them exactly and accurately.

The most important departure from conventional physics was this idea that only certain energy states were permissible. It implied that at the atomic level, all energy interacted in steps, not continuous amounts. These discrete steps were given a name - they were called Quanta, and the whole theory that energy was always stepped was known as Quantum Theory. THIS is what quantum theory is basically all about - it's not that difficult to understand.

Anyway, to continue with the story: after working out the energy levels of Hydrogen, all Bohr and the other scientists then had to do was work out the energy levels of all the other elements. All chemical compounds and all normal matter in the universe is made from combinations of the elements that depend on interactions between these energy levels. So once the energies of all the elements were calculated then any scientist should be able to calculate the energy of any molecule or any normal matter, and from that, work out all its properties.

BUT, there was a problem! When Bohr tried to work out the energy levels of the second most simple atom, Helium, he got stuck! Because Helium has two electrons not one (and two protons and two neutrons). So the calculation not only had to work out the permitted energy levels of the two electrons, it had to take into account interactions between the electrons themselves. Not only that, but the nucleus could shield the effect of one electron on the other depending on where they were positioned. And he ended up in a "chicken and egg" situation, i.e. which came first, the chicken or the egg?

If he assumed the energy level of one electron to be fixed, then it would alter the energy level of the second electron. And the moment that the energy of the second electron changed, it would affect the energy level of the first electron! And so on. So it was impossible to solve! And the problem only got worse with all the higher elements.

This was a MAJOR disappointment to all the scientists. After the success with Hydrogen, they were now stuck with a problem that apparently couldn't be solved, and the great idea of working out all the properties of matter had come to a halt.

But they weren't discouraged. Everyone thought that there MUST be some way of working round the problem with enough advanced mathematics. They tried all kinds of things but nothing worked. Eventually (I think it was around 1923) another scientist called Schrodinger came up with a new way of working out the Hydrogen solution using only waves and not considering particles at all. He came up with a master equation that should solve any energy level in anything. It looked promising. He worked out Hydrogen and his equation decomposed into exactly the same form as Bohr's equation. All well and good. So then he tried to tackle Helium.....and got stuck! Even though he was only using waves, not particles, he hit exactly the same problem as Bohr, one term in the Schrodinger Equation required a mathematical differentiation with respect to the distance between the electrons. But once again the same chicken and egg situation stopped anyone from working out what the distance between the electrons was. So the Schrodinger Equation couldn't be solved either!

Nobody has ever come up with an acceptable EXACT solution to the Schrodinger Equation for multi-particle atoms. But the Schrodinger Equation did have some promise. If it was squared (mathematically) it could be approximated (although not solved exactly) and the approximation to the square gave something called a probability density function for the energy levels of the atoms.

This sounds complicated but really isn't. What it does is it tells you the PROBABILITY of the electron being found in any one place around an atom - more on this in a moment.

Now another scientist called Heisenberg had derived another aspect of quantum theory which was that it was impossible to know exactly both WHERE an electron was at any time AND its exact energy. You could know one or the other, but never both at the same time. The reasons are rather similar to the chicken and egg problem of the two electrons above - the problem essentially was that as soon as you tried to measure something at quantum level, the act of measuring would change it! So the measurement could never be exact. Because measuring the position would change the energy and measuring the energy would change the position!

Putting together the Heisenberg theory (called the Heisenberg Uncertainty Principle) and the probability function of the Schrodinger Equation, it was obvious that you could never know where the electron was at any time with 100% certainty or probability. Because if you knew where it was exactly around an atom, you would know its exact energy as well and you'd be able to solve the Schrodinger Equation properly - which as we already know is impossible.

So the usefulness of the probability function was not to tell you exactly where the electron WAS, but you could estimate with 90% probability where it SHOULD be!

From an analysis of the geometry of these probabilty functions for various atoms, scientists were able to work out that electrons move in complicated geometrical shapes around atoms. These areas of probability corresponded to atomic orbitals and were given special names like the s orbital for the lowest energy one, the p orbitals (there are 3 of them) for the next ones and so on through letters d and f etc. There could also be multiple shells of orbitals so we put a number in front of the orbital name to indicate which shell we're talking about. Hydrogen has one electron in its 1s orbital for example.

The quantum theory was also revised as well. Instead of just concerning ourselves with steps of energy, it was proposed that there were different quantum STATES as well. And so the definition of a quantum became the difference between any two quantum states. Don't worry about this, I'm only trying to give a simple overview here.

I won't go further into the atomic theory because it's not all that relevant at this point. The most important things to understand are the basics of quantum theory itself - and there are two important things to remember from all the above:

1. All energy is quantised, i.e. all energy interactions (or state changes) occur in definite discrete steps called quanta.

2. No quantum function can ever be solved exactly, the best you can do is estimate the probability of something happening.

The science of playing about with quantum functions later became broadly known as Quantum Mechanics.

O.K. so why is Quantum Mechanics so complicated? The simple answer to that is that all of Quantum Mechanics is based on clever mathematical manipulations of things like the Schrodinger Equation. If anyone could solve the Schrodinger Equation exactly, the mathematics would actually be easier, but because it CAN'T be solved the mathematicians have to resort to all kinds of complicated tricks to do anything useful with it at all.

And the second reason is that Quantum Mechanics is NOT an exact science (because of that unsolveable equation and the uncertainty principle). So we can never say that "this equals that" because it's impossible to prove. The best we can do is to say that "there is a 90% probability that this equals that.....most of the time"!

And finally there is a further problem. The equations are so complicated they usually have more than one answer even for the probability! So in quantum mechanics you often get a ridiculous situation where two absolutely contradictory things are both probably equally true at the same time! This is where Schrodinger made up his famous cat question. Schrodinger said that if a cat was placed in a gas chamber and there was some device that would release cyanide gas, and that the device was triggered by the rate of atomic decay of a radiaoactive element, would it be possible to calculate at any given time whether the cat was alive or dead?

It seems simple to solve, work out the atomic decay of the element with time and see if at any given time whether the decay rate was sufficient to have triggered the gas device. If the gas device had been triggered the cyanide gas would have been released and the cat was probably dead. If it hadn't the cat was probably alive.

But the rate of atomic decay of an element is a quantum problem. When you work out the probability functions you get two answers at the same time! In one answer the rate was not enough to trigger the device and so the cat is alive. But the other simultaneous solution shows that the device MUST have triggered and so the cat is dead. The end result of the quantum mechanics therefore proves with 90% probability that the cat is BOTH dead and alive at the same time! :-)

So this leads to another overall conclusion about quantum mechanics. In quantum mechanics almost ANYTHING is possible. You just can't prove whether anything is more likely than anything else (at least most of the time).

Quantum Cons

This finally leads me on the purpose of this paper. To give the reader some idea of when people are talking sense or not about Quantum Mechanics.

The first "rule" of quantum mechanics is that anything is possible and true, but some things are more probable than others.

The second "rule" of quantum mechanics is that it is impossible to solve anything exactly and prove anything with absolute certainty.

Is such a strange system any use to scientists? Yes it is. It takes a lot of hard work but it does give useful answers sometimes.

Here is another question. Is such a strange system any use to con men? And the answer to that is most certainly YES! Because, what could possibly be better for any con man than a system in which ANYTHING he says MUST be true and possible. What a wonderful excuse to cover anything!

But the real question we need to ask (quantum style) is whether it is PROBABLE. And the con men win here too because the mathematics is just so complicated, it's almost impossible to prove with any certainty whether something is probable or not!

Very few scientists and mathematicians have the level of mathematical expertise required to work out complex probability functions. And so when someone comes up with some strange esoteric sounding "quantum" theory, there are very few people who would be able to prove that it's unlikely. And given the complexity of the work, very few of those who can, would ever bother to try! They've got more important things to do than waste their valuable time on debunking bad theories.

So that is one reason why if you go to the internet in particular you will quickly find that every crank has his own personal theory on "quantum this" and "quantum that". The simple fact is that none of them knows whether their theories will ever work or not - and most are quite happy that way because it puts them effectively beyond the reach of the people who are able to debunk them.

Most of these people are not trying to con anybody. They genuinely believe in their own theories. If they are conning anybody, it's probably themselves more often than not!

The ones *I* call "con men", are the ones who rely on the general public ignorance about quantum mechanics and make claims that their theories are fact, that they are proven, or that they have an exact solution, because none of those things are possible in real quantum mechanics. Of course, some of them may not be trying to pull a con, they may simply know so little about real quantum mechanics that they don't realise that such things are inherently unprovable. Either way, any claims like this should be taken with extreme caution.

It may be possible (MUST be possible since we live in a quantum universe - but how probable? :-)) that some clever mathematician or physicist will eventually come up with a real solution to the unsolvable equations. But to date they haven't. So don't be fooled. An exact solution to something like the Multibody Schrodinger Equation is the holy grail of every chemist and quantum physicist. It's not something that is likely to go undiscovered or unacknowledged on the internet by real scientists!

And finally, although quantum mechanics is complicated, it can be explained in simple terms - as I hope I have done here. So if anyone tries to tell you their theory can only be explained using really obscure jargon - don't believe them. Especially don't fall for ridiculous claims about "time reversal" or "quantum consciousness" states etc. No real quantum physicist has ever tried to define "consciousness" and things like that (except as a personal hobby) - I mean let's face it, if a quantum physicist can't even define the energy states of an atom like Helium, then how are they going to be able to tackle “biggies” like consciousness?! And quantum mechanics in normal time is bad enough without anyone trying to introduce time reversal! The only way that time reversal can be verified is with a time machine. I don’t have one and neither does any of the people I’m criticizing - because if they did, they would have been quite able to pop back in time and tell me I’m wrong before I wrote this - or to have warned everyone before to ignore what I was going to say in advance! :-)

DON’T BE FOOLED!

Complexity does not equal credibility. Just the opposite in fact. Anyone who has genuine insight will be able to explain to you in simple language exactly what they mean and you will then be able to verify it with known scientific fact. If they can’t.....well, what do you think?

Aubrey Scoon

24/1/2002 (for the sake of anyone claiming that they will prove me wrong by time travel)! :-)