EINSTEIN AND BOHR AND THE NATURE OF REALITY

July 14, 2013 · *by* The Quantum Realist · *in Hydrogen Atom, Light, Photon, Physics, Quantum Theory, Special Relativity, Standard Model* · *Leave a comment*

Perhaps the most important scientific debate of the 20th Century was that which took place between Niels Bohr and Albert Einstein during the 1930's and 40's. At issue was the very nature of reality. By that time Bohr had become convinced that the laws of physics had to be different on the scale of the atom. This first manifest itself in Bohr's model of the hydrogen atom as the quantum leap: the need for the electron in orbit around the hydrogen nucleus to move from one orbit to another without occupying any place in between. Clearly if the electron were an objectively real particle in the classical sense, that is a point particle having deterministic properties such as mass, position, velocity and so on, this would be impossible.

In order to make his model work Bohr had to make a number of assumptions. Bohr knew that in the classical model of an orbiting system the orbital motion of a charged particle would give off a type of radiation called Synchrotron radiation. This would sap energy from the system, causing the orbit to decay and so leading to the electron following a spiral trajectory towards the atomic nucleus. Bohr chose to ignore this phenomenon and also went on to adopt another assumption first put forward by his fellow physicist John Nicholson. Nicholson had observed that the units of Planck's constant were those of a physical property called angular momentum. Angular momentum is the measure of the propensity of a rotating object to continue its rotation. Nicholson went on to suggest then that perhaps Planck's constant was a measure of the angular momentum of the orbiting electron. But he went one step further and suggested that the angular momentum of the orbiting electron was constrained to take on values which were an integer multiple of this basic value. In effect that angular momentum could only occur in discrete steps or quanta and that these were always an integer multiple of Planck's constant.

Using Nicholson's assumption Bohr was able to derive his model, but this still left the awkward matter of the quantum leap. He was unable to explain it until he found an ally in the form of a French nobleman called Louis de Broglie. De Broglie had read Einstein's 1905 paper on the photo electric effect, in which Einstein showed that light was composed of a stream of particles, later called photons. Debate had raged about the nature of light for several centuries, but by the end of the 19th century the evidence that it was fundamentally a wave appeared overwhelming. Einstein's paper showed that this was not the case. De Broglie reasoned that if light, which had hitherto been thought of as a wave, was in fact a particle, then perhaps it was possible to reverse this logic and suggest that the electron, which had been thought of as a particle was in fact a wave. He went on to calculate the wavelengths for each of the energy states of the Bohr model of the atom and discovered that the base energy state corresponded to one wavelength, the second energy state: to two wavelengths and so on.

Bohr was then able to argue that the electron was a standing wave and that each energy state corresponded to a different harmonic in a harmonic sequence[1]. Changes in energy level could then be thought of as a change of frequency and not the uncomfortable change of position that the quantum leap had implied. It seemed that things really were different on the scale of the atom. Although a closer examination shows that de Broglie's waves are in fact just a restatement of Nicholson's assumption but made in the frequency domain. Somewhat unusually, de Broglie chose to identify the wavelength of his particle waves, not with angular momentum divided by linear momentum, as would be the case at any other scale, but with Planck's constant divided by linear momentum, while at the same time, knowing, according to Nicholson, that Planck's constant is an integer fraction of the total angular momentum (if angular momentum is taken to be quantized). The inevitable result is that any energy level is then associated with a whole number of wavelengths. In effect by choosing to identify wavelength in this way, de Broglie is coercing there to be a different law on the scale of the atom.

The model was still incomplete and it took the work of the Austrian physicist Erwin Schrödinger to develop the equations which described de Broglie's waves. However this still leaves the awkward question as to exactly what it is that is waving. As far back as the 17th Century it had been suggested that space was filled with an invisible substance called the ether which could act as a carrier of such waves. Newton had rejected this idea, reasoning that such a substance would act as a drag on heavenly bodies and so violate his laws of motion. Finally the existence of the ether was disproved experimentally in the late 19th Century by Michelson and Morley (Michelson Morley – the most successful failed experiment). Despite this there is still a yawning gap in the current Standard Model in this area which insists that particles have a wave like form, but still fails to provide an explanation as to just what it is that is waving.

Throughout all of this, Nicholson's assumption about the quantization of angular momentum forms a continuous thread.   It is integral to Bohr's original model for the hydrogen atom, it is effectively restated by de Broglie in the form of his wave particles and, since Schrödinger developed his wave equations based on de Broglie's idea of the wave particle, he too was implicitly adopting Nicholson's assumption. In fact the assumption that angular momentum is quantized does not bear serious scrutiny and yet it still forms the basis of the current Standard Model. In Quantization of angular momentum? I explore this idea in much more detail and show why angular momentum cannot be quantized.

Bohr and his contemporaries thought they were on the right lines but there was still something missing from their model. The model required that particles be thought of as waves, sometimes, but at other times they behaved as particles.   Next on the scene was the young German physicist Werner

Heisenberg. He used matrices to describe the position and momentum (x for position and p for momentum) of the orbiting electron in the hydrogen atom and when manipulating these matrix equations found that he got different results depending on whether he used the product [x][p] or [p][x]. Matrix manipulation was new to physics at the time, although not new to mathematics, and what he had in fact discovered is that matrix multiplication is not commutative.

It transpires that

$$[x][p]-[p][x]=\hbar[I]$$

Where [I] is the identity matrix, the equivalent of unity in matrix mathematics.

The result could vary between two different values as represented by the RH side of the equation, depending on how you did the sums. Heisenberg recognised this as an uncertainty in determining both position and velocity at the same time. Later on Schrödinger showed that his wave mechanics contained an equivalent uncertainty.

Heisenberg put forward a heuristic explanation for this uncertainty which is now called the "Observer Effect". In it he argued that in the limit where the object being measured is of the same order of magnitude as the measuring tool, uncertainty becomes inevitable as the measured variable is affected by the measuring variable. Bohr however convinced Heisenberg that such a heuristic explanation was incorrect and that uncertainty was somehow intrinsic to the wave/particle nature of matter. Bohr had found his answer; the way that the laws of physics differ on the scale of the atom is enshrined in his Copenhagen Interpretation of the nature of reality and is carried forward into today's so called Standard Model. Particles and waves do not exist as such, they exist in some sort of meta state where they are neither one nor the other. It is only when an observer tries to discover one or other property of these wave/particles that it reveals itself. Uncertainty is thus somehow intrinsic to the particle and as a result it is only possible for the wave particle reveal one or other of its properties, the other is in effect destroyed by the very act of measuring the first. Bohr described this process as the "collapsing" of the wave front to reveal the sought for property. In Bohr's universe these mysterious wave/particles require the presence of an observer, or more precisely an observing process, in order to cause the wave/particle to collapse and reveal its properties within the bounds of uncertainty. It is the idea of intrinsic uncertainty and the requirement for an observer which leads to the idea that in the Bohr model that reality is subjective.

It was precisely this idea of intrinsic uncertainty which so upset Einstein and with which he was never able to come to terms.

In Einstein's universe reality is objective. Particles exist as point particles in the classical sense and obey a set of simple laws. They are just what we have always thought of as particles, tiny (probably spherical) lumps of matter which have deterministic properties such as mass, position, velocity, momentum, angular momentum and which possess physical characteristics such as electric charge and spin (in the classical sense).

Our view of these particles takes place from within our own reference frame. The same is true for any other observer who sees the particles and their behaviour from within his or her own reference frame. On a large (cosmic) scale this view is clouded by the effects of the finite speed of light, while on a small (atomic) scale it is clouded by the effects of Heisenberg's uncertainty.

When we look at a star from here on earth, we are always seeing it as it was some time in the past. This is because light travels at a finite speed and takes a finite time to reach us from these distant objects. Even light from the sun takes just over 8 minutes to reach us here on earth. This means that in effect when we look at the sun we are seeing it as it was some 8.33 minutes ago. This is the best **we** can ever do, if the sun were to explode, we would not know about it until some 8.33 minutes after the explosion had happened. Light from the next nearest star (Proxima Centauri) takes almost four and a quarter years to reach us. So **we** can only ever see it as it was 4.24 years ago.

This is not to say that these objects do not exist right now at this very instant, they do, it is just that we cannot see them as they are right now, only as they were sometime in the past. At this very instant in time (in our reference frame here on earth) there is a photon which is just leaving Proxima Centauri, but it will not arrive here on earth for another 4.24 years.

There are thus two ways we can look at the universe. On the one hand there is the view from here on earth as we actually see and experience it. In this view we cannot see the photon which is just about to leave Proxima Centauri, we can only ever see objects as they were in the past. The extent to which this happens depends on the distance to the object and the finite speed of light.

On the other hand we can describe the universe as it actually is at any instant in time in our own reference system. We cannot actually see it, but we know it is there. We can imagine some sort of Cosmic Freeze Frame, in which we take a snapshot of the entire universe and can explore where every object is at that instant in time. In this detached view we can determine where every star and planet is located and, since it can only exist inside our imagination, where every atom and molecule is located.

We can of course transpose ourselves into other reference frames, at least in our imaginations, and view the universe as we would expect to see it were we to be in such a reference frame.

Einstein used this idea in developing the special theory of relativity and again when developing the general theory. Einstein employed a thought experiment to describe special relativity in which he imagined train passing by a stationary observer at close to the speed of light. The train carried a pair of mirrors between which light passed back and forth. Einstein described this from the view of a detached observer and then considered what an observer on the train and the stationary observer beside the track would actually see.

What Einstein showed in his special theory of relativity is that our perception of these realities depends on the reference frame from which we view them. Hence the distance we measure from the earth to the sun from our vantage point here on earth is some 150,000,000 Km, but were we to be in a spaceship traveling from the sun to the earth at say 99.5% of the speed of light, we would see this distance as just 15,000,000 Km, less by a factor of 10 times. Distances are foreshortened in the direction of travel by the effects of relativity by the factor Gamma and at 99.5% of the speed of light, Gamma has a value of 10. Gamma is easily calculated using the formula:

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

This means that 150,000,000 Km represents the maximum distance between sun and earth. It can never be more than this, but it can be less depending on how fast we are travelling towards or away from the sun.

We can extend the idea of a detached view of the universe, the cosmic freeze frame, to have a series of such views, each a short interval apart. This then represents a sort of cosmic movie in which we can view the state of the universe at any instant and from instant to another and explore how time affects our view of things. Of course the interval between these views will depend on the reference frame from which we view them.

Suppose there is a photon just about to leave the surface of the sun when we grab a freeze frame and that we then grab a series of such frames at one second intervals to track its progress as it travels from the sun to the earth. We do this at intervals of one second as measured from our reference frame here on earth. After one second it will have travelled some 300,000 Km, after two seconds it will have travelled 600,000 Km and so on, 300,000 Km every second until it finally arrives on earth some 500 seconds after it left the sun.

A moving observer would see exactly this same sequence of freeze frames, however because he is in a different reference frame he would disagree with us over the distance between these freeze frames and he would disagree with us over the interval between them. Suppose our observer is travelling at 99.5% of the speed of light where Gamma has a value of 10. He would see the distance between the freeze frames as 30,000 Km, not 300,000 Km and he would see the interval between them as 0.1 seconds and not 1 second. The total time for the photon to travel from the sun to the earth would be 50 seconds and not 500 seconds. The speed of the photon would however still be the same a total distance of 15,000,000 Km traversed in 50 seconds as opposed to our view of 150,000,000 Km being traversed in 500 seconds.   This is the essential nature of special relativity, where the velocity, in this case of the photon, is invariant with respect to the observer.

One interesting little side note here concerns frequency. We, stationary observers here on earth, see 500 freeze frames taking place in a total elapsed time of 500 seconds; a frequency of 1 Hz. Our moving observer, on the other hand sees the same 500 events as having taken place in just 50 seconds, in other words a frequency of 10 Hz. This is a characteristic of all relativistic motion; that frequency for the moving observer appears to be multiplied by a factor of Gamma relative to that same frequency as seen by the stationary observer. This has been experimentally verified as recently as 1977 in an experiment involving muons carried out at CERN – Muon Rings and Frequency.

Einstein and Bohr disagreed over the nature of reality with Bohr believing that reality was somehow subjective in nature as a direct consequence of uncertainty being an intrinsic property of the particle (wave). Einstein believed that reality was objective in nature and particles conformed to the classical model of the particle having deterministic position and velocity and that uncertainty was a practical issue to do with measurement, in line with Heisenberg's original idea of the Observer Effect. Bohr believed that the laws of physics, indeed the nature of matter, was different on the scale of the atom, while Einstein believed that the laws of physics are universal, and while he did not explicitly say so, that the laws of physics are therefore the same, independent of scale.

Bohr won the argument as is evidenced by the adoption of his ideas into the currently held Standard Model. I believe that he did so largely by default, he out manoeuvred Einstein politically and he simply outlived Einstein. Since his death in 1955 there has been a concerted campaign to rubbish Einstein as an old man, set in his ways and incapable of accepting the 'new' way of looking at things. But I think this is to misrepresent Einstein's position, which was one of principle.

Any successful theory of fundamental physics must describe the nature and behaviour of two entities if it is to stand any sort of scrutiny; the structure of the atom and the nature of the photon.   The universe is composed of atoms. They come together to form molecules which in turn and along with other atoms form everything we can observe in the universe[2]. The most basic of all atoms is the hydrogen atom, so any theory must start with a plausible description of its structure. The photon is the carrier of information throughout the universe and so an understanding of its nature is essential if we are to understand the universe. Even the smallest error in our sense of how the photon works will, given the vast scale of the universe, colour our judgement. The hydrogen atom and the photon are therefore the building blocks on which any theory needs to be built.

The Standard Model is now almost universally accepted amongst physicists, but on closer examination we can see that it is full of holes. There are numerous examples within the model where we are asked to accept concepts and ideas as acts of faith rather than as demonstrably proven fact.

Particles exist as hybrid wave particles until they are "observed" in some way. The fact that a wave requires a medium in which to exist is conveniently overlooked. These wave/particles are supposed to exist as a wave function which collapses to manifest itself as either a wave or a particle depending on what it is that the observer is looking for. Wave functions are an abstract mathematical concept, it is never described exactly what form they take, what it is that is waving, how the process of collapsing takes place, how the wave function knows it is being observed. In reality particles are things and waves exist solely as the motion of particulate entities – an idea that is totally rejected by the Standard Model in favour of the notion that reality is composed of mathematical entities.

In the Standard Model forces between particles are mediated by other particles, for example the electromagnetic force happens because of the exchange of photons between two charged particles. Rather conveniently we can never observe these photons, since to be effective they must be emitted by one charged particle and totally absorbed by the other and hence cannot by definition be observed directly by a third party. The same is true of other "synthetic" particles such as the Gluon, the W and Z bosons and the Higgs Boson.

The idea that angular momentum is quantized runs like a continuous thread throughout the development of the Standard Model. This idea owes its origins to John Nicholson and its adoption by Bohr. Despite the work of Dirac and others, this assumption overlooks the effects of special relativity and lacks any physical justification. Quantization of angular momentum

Even the photon itself is poorly described, it is sometimes a wave and sometimes a particle while being both at the same time. It is variously described as a packet of energy, but what is a packet? What is it made out of? Where do its boundaries lie? The truth is that in the Standard Model photons exist only as mathematical entities – mathematical descriptions of how they behave, not of what they are[3].

The Standard Model is flawed, and almost every physicist would admit that this is the case, but instead of looking for the flaws within the model, of reconstructing it without any such flaws, physicists appear to take the view that there is something missing from the Standard Model, that it is incomplete. That all we need to do is make one or two more small additions to the model in order to fix it and come up with a theory of everything. Every attempt at tweaking the Standard Model in this way has failed. String theory, superstring theory, brane theory, multiverse theory, the anthropic theory have all been superimposed on top of the Standard Model and each one in turn has led us nowhere. And yet never has the veracity of the Standard Model itself been questioned.

But what if Einstein was right all along and that it is Bohr who got the wrong end of the stick? What if the flaws within the Standard Model lie at its very core? What if Einstein was right about reality, that reality really is objective, that particles have properties which are deterministic, that uncertainty is not intrinsic to individual particles, but is instead a practical issue of measurement, the subject of the Observer Effect? What if Einstein's instincts were correct?

If Einstein was right then Bohr's notion that the laws of physics and the nature of reality are different on the scale of the atom is wrong and it is to the classical laws of physics and mechanics that we must turn in order to find an answer.

If we begin from with the proposition that Einstein was right, that reality is objective and the laws of physics are consistent everywhere and on every scale, then it is necessary to examine those laws and to see just how and where they need to be modified in order to produce a viable model for the atom. Bohr used the laws of classical mechanics to develop his original model for the hydrogen atom, a model that itself turned out to be flawed. It had two fundamental flaws, it ignored synchrotron radiation and it introduced the idea of discontinuity of position (the quantum leap). Bohr then chose to follow the path of describing a completely new set of physical laws and of describing a new type of reality. But suppose Einstein was right, then rather than develop a whole new set of laws, we need to examine the classical laws of physics to see if there is something that has been overlooked. To see, in other words, if there are some simple changes that can be made to the classical laws of physics which would allow us to describe a model for the atom in which the constituent particles are objectively real and which overcomes all of the shortcomings in the Bohr model.

We can make one or two general observations: If such a model were to exist then it is necessary for the orbiting electron to do so at a constant radius and for changes in energy level to be associated with changes in orbital velocity. Only in this way is it possible to have an objectively real electron and to avoid the quantum leap. If the electron is constrained in this way then this would explain the absence of synchrotron radiation and so we would have overcome the two most significant problems posed by the Bohr model. In order to make his model work, Bohr had to make the arbitrary and some might say expedient assumption that angular momentum is quantized. Any new model cannot rely on such arbitrary assumptions and must instead describe the mechanism that leads to quantization of the energy levels within the atom.

It turns out that it is possible to do just such a thing, to come up with a mechanical model for the hydrogen atom which meets these conditions, and that it is remarkably simple; all we need to modify just one very simple aspect of the laws of mechanics to take into account the effects of relativity. If we do so, not only do we obtain a model for the hydrogen atom, but at the same time we overcome all of the problems associated with the original Bohr model. We obtain a model in which the electron orbits at constant radius and is constrained to do so in such a way that synchrotron radiation is not emitted, energy changes are associated with changes in orbital velocity, the energy levels of the atom correspond to those of the empirically developed Rydberg model in just the same way as are those of the Bohr model. Furthermore the model provides us with a mechanism which explains why quantisation occurs and, almost as a fringe benefit, gives us a simple mechanical explanation of the Fine Structure Constant.

The effects of special relativity are normally associated with time, distance and mass, each of which is affected by the relative velocity of the observer and the observed. Velocity is seen as the driver of relativity and is normally taken to be invariant with respect to relativity. Indeed it is this assumption which forms the basis of the justification for relativity. There is however one set of circumstances where this may not be the case and that concerns circular or orbital motion. When an object is travelling in a straight line then we can only measure its velocity in our reference frame by having two clocks, one at the point of departure and one at the point of arrival. We can then find the interval and divide this into the distance to obtain the velocity.

However when an object is in circular or orbital motion, it returns to its point of origin once per orbit. In this case we can measure the orbital period with a single clock. It is then possible to define a velocity term which cross couples the two reference frames, that of the moving observer and that of the stationary observer. Such a velocity term is calculated as the relativistically compressed distance around the orbit as measured by the moving observer divided by the period of the orbit measured by the stationary observer. I have called this type of velocity Relativistic or Coupling velocity because it couples the two reference frames.

If we simply use this coupling velocity in matters relating to orbital motion, notably in calculating angular momentum and centrifugal and centripetal accelerations and forces then something quite magical happens. The electron in orbit around the hydrogen nucleus is seen to orbit at near light speed, not at .729% of light speed as in the Bohr model. It is forced to do so at constant radius, so not only are energy levels seen to be associated with changes in velocity and not changes in radius, but because the radius cannot change there can be no synchrotron radiation and no decay in the orbit. Most interesting of all however is that such a model provides a mechanism which forces the energy levels of the atom to take on discrete values. It is not necessary to invent an arbitrary quantisation of angular momentum to explain these discrete levels. A simple classical model emerges which has as its solutions these discrete energy values. In Sampling the Hydrogen Atom I explore these ideas in more fully and lay out the mathematics behind such a model.

It is possible to describe a model for the hydrogen atom which is consistent with Einstein's ideas of reality being objective. It is not the wave function that collapses to reveal the nature of the wave particle, instead it is the equations themselves that collapse or simplify to reveal the wavelike nature of orbiting particles. The so called wave particle duality, based on de Broglie's ideas of particles as waves collapses to reveal the wave characteristics of the particle as simply a way to describe its orbital motion around the atomic nucleus. In the limiting case where we are concerned with a single particle there is nothing else which can be waving except this particle, and that is exactly what we find.

So with one simple postulate about the nature of orbital velocity we can extend the laws of physics to describe the structure of the atom. We do not need to invent a new set of laws, all we need to do is make one very small adjustment to the laws as we know them on any other scale. Such an adjustment has virtually no effect on any calculations at these other scales, since they seldom involve objects travelling at anything close to the speed of light

Why then would anyone ever need to invent all of the complex paraphernalia of Quantum theory to explain the structure of the atom when with such a simple change a perfectly viable model can be found with all the attendant simplicity of objective reality? Why invent subjective reality? why invent the wave particle duality and wrestle with the idea that waves can exist in a vacuum where there is nothing to wave? Why invent the idea that particles can occupy more than one place at a time, that when observed a complete history of their recent past suddenly comes into existence?

With one further simple postulate it is possible to describe a model for the photon in which it has material form. It is made of something. The photon turns out to be a compound particle, made up of equal quantities of matter and antimatter. Space itself is then seen as being devoid of all properties as we understand them.Properties such as permeability come about as a consequence of the juxtaposition of particles and owe nothing to space itself which is seen as a complete void.
See Shedding some light on the nature of the photon for an analysis and explanation of the photon as a compound particle.

The proof of such ideas lies in the predictions they make. Just like Einstein, some of these are retrospective, so are seen more as explanations of phenomena which are already well known, such as the energy levels of the hydrogen atom. Others such as the idea that the speed of light varies with frequency are completely novel and hold the key to either proving or disproving the theory.

---

[1] In fact since each harmonic is a multiple of a different base frequency, it transpires that the frequencies of the Bohr atom make up an inverse harmonic sequence.

[2] Notwithstanding current ideas about Dark Matter and Dark Energy – the need for which stems out of a blind adherence to the notion that the universe is expanding.

[3] In a somewhat circular argument it is argued that describing what something is can only be possible in a universe of objective reality. In a subjectively real universe such an idea is said to be meaningless hence we can describe an entity such as a photon purely in terms of mathematical concepts.