# Relativity and the Dual Nature of Reality

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Abstract

The current received wisdom is that quantum theory is correct but incomplete. However an examination of the history of the development of quantum theory shows that it is based on an unproven assumption. That assumption, that angular momentum is quantized, leads to the absurdity of the quantum leap and so cannot be valid. All subsequent theories which rely on this assumption must therefore be incorrect. A model for the hydrogen atom is developed based on the idea that the orbital radius must remain constant for all the various energy levels and it is shown that this is possible if certain velocity terms are considered to be affected by relativity. This idea is then used to develop a model for the photon as a compound particle comprising an electron and a positron locked in mutual orbit. From these two models it is evident that for every reference frame there are two views of the universe leading to the idea of the dual nature of reality.

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# Chapter 1 A Brief History of Physics

*"It should be possible to explain the laws of physics to a barmaid"* – Albert Einstein

## Atoms

The Greek Empedocles is credited with the theory which was to dominate the natural sciences for almost 2,000 years; it was Empedocles who introduced the idea that the universe was made up of four elements: Earth, Air, Fire and Water. For all of that time it could claim to be the most successful theory to explain the natural world that had ever been devised. Despite this evident success it ultimately proved to be incorrect. From the outset he theory did have its detractors. The idea that matter was made up of small particles was first proposed by Indian philosophers of the Nyaya and Vaisheshika schools, in the 6$^{th}$ Century BC. It was introduced to Western thought by the Greek philosopher Leucippus, a contemporary of Empedocles, in the 5$^{th}$ Century BC. It was Leucippus' more famous pupil, Democritus, from where the word democracy originates, who first coined the word Atomos, meaning *uncuttable* or indivisible, from which the word atom derives.

The world seemed to settle on the theory of the four elements and the idea of atoms was overshadowed and lay more or less dormant until the 17$^{th}$ Century when Robert Boyle (1627 – 1691) was to argue that matter was made up of small particles or corpuscles. Newton certainly thought in terms of particles in relation to light, but it was in the late 18$^{th}$ century that the idea of matter composed of atoms first began to take hold. The French chemist Antoine Lavoisier (1743-1794) investigating combustion was the first to identify oxygen and to demonstrate the role played by oxygen in the rusting of metals and in respiration. He also demonstrated that mass is conserved during a chemical reaction and clarified the concept of an element as a chemical substance which could not be broken down.

We owe our modern view of the atom to John Dalton (1766 - 1844) who developed the atomic theory as it is understood by chemists today. Dalton suggested that matter is made up of atoms and that atoms are chemically indivisible. He suggested that all atoms of one element are identical, but that different elements have different types of atom, and that atoms can neither be created nor destroyed. He also identified compounds as substances that are made up of two or more atoms combined together to form molecules.

Final confirmation that substances are made up of atoms however did not occur until the early 20$^{th}$ century when Albert Einstein published his paper on Brownian motion. In it he showed that the random motion of pollen grains in a liquid, which had been observed by Brown some 80 years before, could be accounted for if the liquid itself were made up of atoms which were themselves in motion.

## The Book of Optics

Abū Alī al-Hasan ibn al-Hasan ibn al-Haytham (al-Haytham) was an Arab philosopher born in the year 965 in Basra in what is now Iraq. He became a civil servant and, having become somewhat disillusioned with religion, he devoted himself to science. He moved to Cairo where he was commissioned by the Caliph, al-Hakim, to regulate the flow of the Nile by the construction of a dam at Aswan.  After travelling up the Nile to survey the river, al-Haytham reached the conclusion that to try to dam the river there was impossible.  On his return to Cairo, and fearing for his life at the hands of al-Hakim for his failure, al-Haythan feigned insanity and was confined to his house until after the death of al-Hakim in 1021.

Al-Haythan is important for a number of contributions he made to science.  He wrote *Kitab al-Manazir,* a seven volume work on optics which was translated into Latin as *Opticae thesaurus Alhazeni* in 1270 and is sometimes more popularly referred to as the Book of Optics.  In it he showed that light travels in straight lines, he analysed refraction and reflection from plane and curved surfaces.  Crucially he made it clear that his investigation of the behaviour of light was based on experiment rather than abstract theory.   Al-Haythan is sometimes referred to as the father of optics but his use of experimentation to develop and prove his theories means that his is the father of much more than simply optics.  It is to Al-Haythan that we can trace the origins of modern science based on the experimental method.

In the Book of Optics Al-Haythan argued that light was composed of a stream of tiny particles, predating Newton's corpuscular theory of light by over 650 years and Einstein's photon by almost 900 years.

## Occam's Razor

William of Occam, a Franciscan friar, was born in the village of Ockham, near Guildford in England in 1288.  He moved to Oxford in 1309 where he studied theology but never graduated.  Because of this is acquired the name *Veneralbilis Inceptor*, or Worthy Beginner, but was also later known by the name *Doctor Invincibilis*, the Invincible Teacher.

As a student he was argumentative and his views proved controversial. He was summoned in 1323 to Bristol to defend them.  News of William's beliefs spread and eventually reached the pope, John XXII, who at the time was in exile from Rome and living in Avignon.  William was subsequently summoned to Avignon in May 1324 to appear before the pope to answer these charges.  While in Avignon William was effectively under house arrest, required to be on hand should the need arise to answer questions. Nevertheless after a protracted period of investigation he was effectively cleared of all charges.

This was a time of religious turmoil and at the time there was a conflict between the pope, John XXII and the Franciscan order which centred on the idea of "Apostolic Poverty". William was asked to adjudicate on the matter on behalf of his order.  He eventually came down on the side of the Franciscans, declaring the pope guilty of seventy errors and seven heresies, in effect declaring that John XXII's position as pope was illegitimate and that he was not entitled to call himself pope.  Not surprisingly the John XXII was not best pleased with this verdict.

Fearing for his life, William and a group of fellow Franciscans stole some horses and fled Avignon, initially for Italy and eventually to Munich in Germany where they sought sanctuary under the protection of Louis of Bavaria.  William was to spend the rest of his life in Munich and died there in 1347 aged sixty.

William’s ideas on human freedom and on the nature of reality greatly influenced the political thinker Thomas Hobbes and helped fuel the Reformation.  You cannot fail to admire someone who during his turbulent career managed to offend the Chancellor of Oxford University, disagree with his own ecclesiastical order and get himself excommunicated by the Pope.

Among his many writings, William was the first person to advocate the separation of church and state, pre-dating the authors of both French and US constitution by over four centuries. His most notable achievement however is the Principle of Parsimony otherwise known as Occam’s Razor.

This states that the explanation for a phenomenon which makes the fewest assumptions is most likely to be the correct explanation.  The Razor is not a law, it is a principle, and this means that is not always going to be the case that the simplest explanation is correct.  It deals with the probability or likelihood that an explanation is correct.

William of Occam is important because, like al-Haythan, he lays one of the foundations of what was to become a cornerstone of modern science, the experimental method.

It was a near contemporary of William of Occam, Roger Bacon, another English Franciscan Friar of the Order of Friars Minor, was instrumental in introducing the ideas of Al-Haythan and other Muslim scholars to European philosophers.

Bacon was born in Ilchester in Somerset in 1214, he died in 1294.  After his death he became known as *Doctor Mirabilis* (Wonderful teacher). He is also credited with being the first to discover that white light could be split into a spectrum of colours, some four centuries before Isaac Newton.  In his *Opus Majus* he writes about mathematics, optics and alchemy.  He also described how to manufacture gunpowder and studied astrology and astronomy, writing about the position and size of celestial bodies.  His writings on optics in particular are thought to derive directly from the writings of Al-Haythan.

## The Experimental Method

A namesake of Roger, Francis Bacon (1561 – 1626), writing some 350 years later, also played an important role in the development of modern experimental science. Francis Bacon was born into an aristocratic family and studied at Trinity College Cambridge and later at Gray’s Inn, London.  He travelled to Paris in the company of the then ambassador but on the death of his father he returned to England and became an MP.  He struggled both financially and politically under the then queen, Elizabeth, but rose to become Lord Chancellor under her successor, James 1.

Until Bacon, philosophy was rooted not so much in reason as in faith.  In the case of natural philosophy (science) this meant faith in the works of Aristotle in particular.  In 1620 Francis Bacon published his book the *Novum Organum* (New Instrument), a clear reference to Aristotle’s *Organum,* in which he documented his method for scientific investigation. Although he was not a practitioner of what he preached, he advocated an empirical approach to science based on a set of axioms in which ideas were tested by experiment.

## The Road to Enlightenment

William Gilbert (1544 – 1603) who was born in Colchester in England to wealthy family studied at Cambridge where he obtained a BA in 1561, an MA in 1564 and an MD in 1569. He was appointed a senior fellow of his college, St John's, set up a medical practice in London and became a member of the Royal College of Physicians. He was appointed physician to Elizabeth 1 and reappointed to the same post under James 1 until his death in 1603, possibly of the plague.

Gilbert was a Copernican and believed that the earth was not the centre of the universe. His most notable work was *De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure (On the Magnet and Magnetic Bodies, and on the Great Magnet the Earth)* published in 1601 which quickly became the standard work on electricity and magnetism throughout Europe. Gilbert was a pioneer in the area of experimental science. *De Magnete* was based, not on hearsay or received wisdom, but on a series of experiments performed by Gilbert himself.

He coined the term *electricus*, meaning like amber, from which the word electricity derives. He conducted extensive experiments on magnetism and static electricity, being the first to show that if a magnet is cut in half, then both halves form magnets each with north and south poles. He proposed the idea that the earth was itself a magnet and this explained why compasses point towards the North Pole. He was the first to propose that the earth's core was made of iron. He was also one of the first people to attempt to unify the forces of nature. He suggested that magnetism and gravity were both manifestations of the same fundamental force, although he was subsequently proved wrong in this regard.

## The Age of Enlightenment

Taking a lead from the likes of Bacon and Gilbert not to mention Galileo in Italy, the middle of the 17$^{th}$ Century saw the emergence of the first scientific institutions. They organised lectures, experiments and demonstrations and most important they circulated information and scientific papers published as proceedings. The founding of such institutions as the Royal Society in the UK and Académie des Sciences in France led to a distribution and sharing of ideas which brought about significant advances. The Royal Society was the first such institution in the UK and boasted among its early members; Robert Boyle, Robert Hooke, Christopher Wren and Isaac Newton.

Boyle was a gentleman scientist, independently wealthy who is now chiefly remembered for his work on gasses and the law which bears his name. Hooke started his professional scientific career as Boyle's assistant but went on to make significant contributions including the law on springs which bears his name. Hooke also investigated the properties of light and was involved in several disputes with Newton over precedence.

Elsewhere in Europe the scientific movement was beginning to stir. The French philosopher Rene Descartes (1596-1650) proposed that light travelled through the 'Plenum' in the form of a wave. The Plenum he described as a continuous substance out of which the universe was made. In 1637 he published a work in which he described a theory of refraction, arguing that it was caused by a difference in the velocity of propagation of light in the two media between which the light is refracted. This was the first shot in an intellectual war over the nature of light which was to rage for almost four centuries and is an issue which is still far from resolved.

## Newton

Newton's achievements are too numerous to list but include work on calculus, on the laws of motion, on gravity and optics. He is credited with being the first to show that white light is composed of a spectrum of other colours, although Roger Bacon almost certainly deserves the credit. He is perhaps best remembered for his three laws of motion and for the law of universal gravitation.

The laws of motion:

The first law
Every object in a state of uniform motion remains in that state of motion unless acted upon by an external force.

The second law
A force acts on an object to accelerate it. The acceleration is proportional to the mass of the object. This law is often expressed as the equation

$$f = ma \qquad \text{Equation 1-1}$$

*(Force equals mass times acceleration).*

Up until then it was the commonly held view that an object remained in a state of rest unless acted upon by a force. Newton was one of the first to recognise that uniform motion was the quiescent state rather than stasis. Although Newton did not formulate the laws of conservation, this in particular formed the groundwork for the laws of conservation of momentum and of energy.

The third law
For every action there is an equal and opposite reaction.

The universal gravitational law describes the relationship between mass, distance and the gravitational force between two objects. Kepler had shown that the orbits of the planets were elliptical and believed that the force acting between such bodies varied in some way with the inverse of the distance between them, but a simple linear model did not provide results which fitted with the observations. Hooke and Wren, both then members of the Royal Society, believed that the relationship was based on the inverse of the square of distance but lacked the mathematical skills necessary to prove it.

Edmond Halley took the problem to Newton who claimed to have developed just such a proof several years before. Pressed by Halley, he eventually sent him a copy of the proof that the gravitational force between two bodies is proportional to the inverse of the square of the distance between them. His claim that he had developed the proof several years before his meeting with Halley was just one of the subjects of the dispute between Hooke and Newton.

The inverse square law as it applies to gravity can be expressed in the form of an equation:

$$f = G\frac{m_1 m_2}{d^2} \qquad \text{Equation 1-2}$$

Where $m_1$ and $m_2$ are the masses of the two bodies, $d$ is the distance between them and $G$ is a constant which is known as the Universal Gravitational Constant or Newton's Gravitational Constant.

In 1798, some 71 years after Newton's death, Henry Cavendish (1731 - 1810) set up an experiment to measure the density of the earth. The value of $G$ was calculated based on Cavendish's results, but did not appear until well into the 19th century.

## Waves and Particles

Hooke and Newton had disagreed over who held precedence in the discovery of the inverse square law. This set them on a path at loggerheads for the remainder of Hooke's life. It has even been suggested that Newton tried to obliterate the memory of Hooke from the archives of the Royal Society. Another area of disagreement between Newton and Hooke concerned the nature of light. Newton believed that light was made up of tiny particles or "corpuscles". Hooke on the other hand held the view that light was a wave, in line with the theories of the Dutch physicist Christiaan Huygens (1629 – 1695) and Rene Descartes' ideas about the Plenum. This debate over the nature of light, whether it was a wave or a particle, was to continue to the 20th Century and is still not fully resolved.

Throughout the 18th and 19th Centuries scientists tried to resolve the issue of waves versus particles. They did so based on the observation of phenomena associated with light such as refraction, diffraction, reflection, diffusion and interference. Euler, the Swiss mathematician, born in Basel in 1707, died in St Petersburg in 1783, argued that diffraction was more easily explained using a wave model rather than a model based on particles in his *Nova Theoria Lucis et Colorum* (1748).

In 1720 James Bradley carried out a series of experiments to try to measure stellar parallax. The experiments failed to detect any stellar parallax, but they did throw up an interesting result which he described as stellar aberration. He noticed that the apparent position of the star changed as the Earth moved around its orbit. In much the same way that raindrops appear to follow a slanted path to a moving observer, so light from a distant star appears to strike the earth at a slight angle due to the earth's motion. Bradley calculated this angle by adding the earth's motion to that of the incident light as a simple vector sum. Knowing the angle of aberration, he was able to estimate the speed of light. Bradley's explanation was based on Newton's corpuscular theory and so suggested that light was made up of stream of particles.

Meanwhile, the discovery of interference by Thomas Young in the early 1800s added weight to the wave theory as did the discovery of polarisation at about the same time. The theory was further reinforced by the work of Fresnel (1788-1827) who independently developed many of the same ideas as Young and wrote about diffraction based on a wave theory.

Up until the 1820's the only magnets that were known were lodestones and magnets made of iron such as compass needles. Then in 1820 Hans Christian Oersted was conducting a demonstration of the heating of a wire by means of an electric current. Coincidentally he also planned a demonstration of the effects of magnetism for which purposes he had provided himself with a compass needle mounted on a stand. He noticed that whenever he switched on the electric current, the compass needled moved. Oersted had unwittingly discovered a relationship between electricity and magnetism.

Oersted conducted further experiments and later published his results and this attracted the interest of other researchers. Andre Marie Ampere thought that the effect was due to a magnetic force being created by the electric current. He set up an experiment in which he was able to show that a force existed between two parallel wires each carrying an electric current. The force varied as the inverse of the square of the distance between the wires and was either attractive or repulsive depending upon whether the two currents were parallel or anti-parallel.

Between 1820 and 1835 Michael Faraday went on to discover more about the relationship between electricity and magnetism. Michael Faraday (1791-1867) had been born into a poor background in south London. He was largely self-taught, having been apprenticed as a book binder and learned about science by reading the books that he was supposed to be binding. In 1812 he attended a series of lectures by Humphrey Davy and subsequently wrote to Davy asking for a job as his assistant. After initially being turned down, he was subsequently appointed as Davy's assistant at the Royal Institution a year later and not long after that accompanied Davy on an 18 month tour of Europe, where he was to meet many of the leading scientists of the day.

Faraday showed that when a current flowed in a conductor it induced or created a magnetic field around the conductor. He also showed that a change in magnetic field induces an electric current in a conductor. Faraday's discovery forms the basis of modern day electric generators, alternators, electric motors and transformers. In 1845 he showed that light was related to electricity and magnetism by demonstrating that polarised light is affected by a magnetic field in a phenomenon known as Faraday rotation, leading Faraday to propose that light was a high frequency electromagnetic oscillation.

## James Clerk Maxwell

Next to take up the challenge was James Clerk Maxwell, who in 1862 put forward the idea that light was a form of electromagnetic radiation. In 1873 Maxwell published *A Treatise on Electricity and Magnetism* where he showed the mathematical relationship between electricity and magnetism as it affected light. These equations, known as Maxwell's Equations showed that the speed of propagation of these waves was roughly 300,000 km/sec which matched the speed of light. The German physicist Heinrich Hertz confirmed Maxwell's theoretical results by generating and detecting radio waves. He went on to show that these waves shared many of the properties associated with light such as reflection, refraction, interference and diffraction.

By the late 19$^{th}$ century the wave theory was dominant. It looked as if Newton's particles of light did not exist, but there were still a number of unanswered questions. Principal among these concerned the ability of light to travel through a vacuum. It had long been understood that a wave relied on the presence of a medium. In fact a wave as such does not exist directly in its own right; it only exists by virtue of some sort of disturbance of the medium through which it is travelling. So for example a wave on the ocean is created by the movement of the water. It is the oscillations of the water molecules, moving around some nominally fixed position, which creates the wave.

The problem with the wave theory of light was that light can travel through a vacuum. In a vacuum there is no medium which presented the wave theorists with their biggest headache. Descartes' plenum and the so called ether were both attempts at resolving this problem. Other problems were also beginning to emerge, the photoelectric effect appeared to show properties which were inconsistent with a wave theory, but which were consistent with a particle based model. The case for light as a wave suffered its most severe setback in 1887 when two American physicists Albert Michelson (1852-1931) and Edward Morley (1828-1923) at what is now Case Western University (Case School of Applied Sciences and Western Reserve College) published the results of a series of experiments that had been designed to show the presence of the luminiferous ether.

The luminiferous (or light bearing) ether was the descendent of Descartes' plenum. It was a supposedly universal medium which pervaded all of space. The ether was a continuous medium which had no mass but did have elastic properties which enabled it to transmit the wavelike motions of electromagnetic radiation.

Michelson and Morley reasoned that the earth must be moving through the ether which must therefore be acting like a wind with a flow in some particular direction. A measurement of the speed of light made parallel to the direction of the ether wind would either be increased or decreased depending on whether it was made in the direction of the flow or against it. A measurement made at right angles would not suffer this change and so would be different. They set about trying to measure these differences.

Michelson had constructed an apparatus called an interferometer which took a single beam of light and split it with a half silvered mirror, sending the two beams off at right angles. The beams were reflected back to a detector where they were recombined, any differences in the time taken by the two beams to complete their journey would alter the interference pattern caused by their recombination. Michelson's original apparatus was not sufficiently sensitive to measure the expected difference in the two velocities, so he teamed up with Morley. Working together they refined the apparatus by folding the optical path of the two light beams using mirrors to increase the path length and so increase the sensitivity.

The whole experiment was mounted on a massive turntable made out of a block of marble floating in a bath of mercury. This allowed them to rotate the experiment, so making the comparison in any direction. As the experiment was rotated through 360 degrees they expected each of the two arms to line up with the ether wind twice, once where it would act to add to the velocity and once where it would subtract from the velocity and so they expected to see the differences in velocity as a sine wave. There might still exist the possibility that they had chosen to make both measurements normal to the direction of the ether wind. To guard against this possibility the experiment would have to be repeated at different times of day when the earth's rotation would present the apparatus at a different angle to the ether wind. They also took the step of making measurements at different times of year arguing that the earth's orbital path would mean that at certain times of year the velocity of the earth in its orbit around the sun would add to the ether wind and at other times it would subtract from it.

Despite all their careful preparation and meticulous efforts Michelson and Morley were not able to detect any differences which would indicate the presence of an ether wind and an ether like substance. The Michelson Morley experiment has since come to be known as the most successful experimental failure in history, since it set out to prove the existence of the ether and to measure its properties, but in failing to do so it effectively proved that the ether does not exist. Space it seems is a vacuum, and that vacuum is devoid of anything.

In more recent times variations on the original Michelson-Morley experiment have been carried out using lasers and masers. The first of these was developed in 1958 by Charles H Townes (1915 – 2015) and demonstrated that, if there was an ether, it had to be moving with respect to the earth at less than 30 m/s. In 1978 this experiment was repeated with even more accurate results showing the ether drift to be less than 0.25 m/s and since then it has been shown to be less than $10^{-13}$m/s.

The ether does not exist, and yet scientists have been reluctant to give up on the idea, since a medium of transmission is central to the idea of a wave. Without the presence of some sort of ether the current models for the way in which light travels break down. As recently as 1951 Paul Dirac acknowledged that *"we are rather forced to have an ether".* More recently still a version of the ether called quantum foam has emerged. This seeks to suggest that virtual particles pop into existence and then disappear to sustain the photon as it passes through otherwise empty space.

In reality, the nature of light and the conflict between wave and particle theories and the need for a wave theory to support the idea of an ether remains an enigma to this day. Modern science rather fudges the issue by accepting both wave and particle descriptions of light without really explaining the underlying mechanisms which bring this about.

## Kinetic Theory of Heat

In 1738 in his book *Hydrodynamica*, Daniel Bernoulli (1700 – 1782) was the first person to suggest the kinetic theory of gasses. He argued that a gas is composed of a large number of molecules which are in constant motion and that the effects of temperature and pressure are a direct result. Pressure is the result of the collisions of these molecules with the walls of the container and temperature is related to their velocity. Energy in the form of heat is then simply the kinetic energy associated with the movement of the molecules.

Although not accepted initially, others worked on and developed the theory, notably Maxwell and Boltzmann. It was not until the beginning of the 20th Century however when Einstein showed that atoms were real that the theory came to be fully accepted.

## Electrons

Early attempts by Faraday to drive electricity through a vacuum failed, largely because he was not able to produce a sufficiently high vacuum. However a German glass blower, Heinrich Geissler (1814 – 1879), was able to produce low pressure gas discharge tubes and the German physicist Julius Plucker (1801 - 1868) used these Geissler tubes to carry out experiments on electricity.  Plucker was able to establish an electric current and, depending on the nature of the vacuum was able to observe a glow around the positive electrode.

The English physicist William Crookes (1832 – 1919) developed an improved vacuum tube and showed that the current was passing from the cathode (negative electrode) to the anode (positive electrode) and that whatever was carrying the current cast a shadow on the wall of the tube and so must be travelling in straight lines.  The German physicist Eugen Goldstein (1850-1930) gave them the name Cathode Rays.

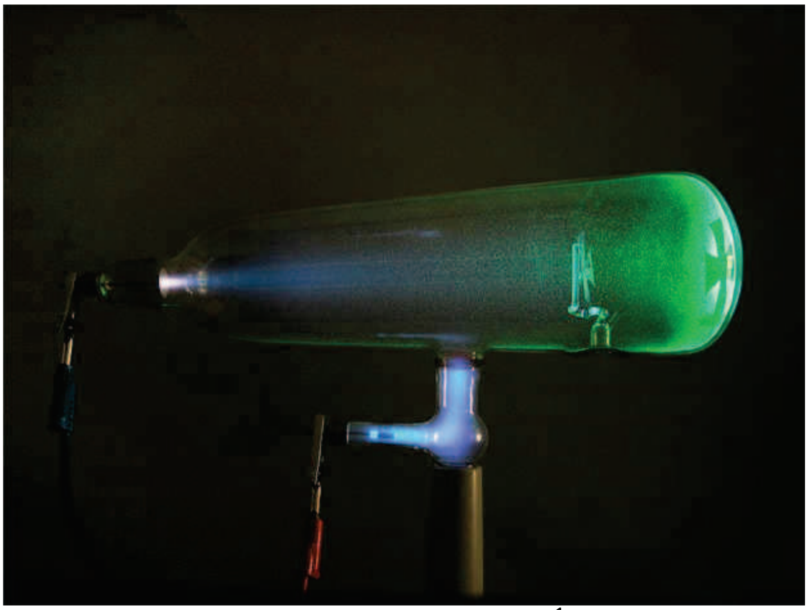

Figure 1-1 Crookes tube[1]

To the German physicists working in this field it appeared that Cathode rays had some of the properties of light, and since light was at that time assumed to be made up of wave, naturally it was assumed that cathode rays were also made up of waves.  Many English physicists on the other hand argued that cathode rays were made up of a stream of fast moving particles.

If cathode rays were made up of particles then they should be deflected by both electric and magnetic fields while if they were made up of waves such deflections would either not exist at all or would be minimal.  Experiments by Plucker and Hertz proved inconclusive, the rays appeared to be deflected by a magnetic field, but not by an electric field.

Then, in 1897 the English physicist J J Thomson (1856-1940), who was Cavendish professor of physics at Cambridge University, began a series of experiments using highly evacuated tubes.  He was able to show that cathode rays were indeed deflected by an electric field and furthermore was able to determine the ratio of their charge to their mass.

Thomson's results appeared to show that either the particle carried a massive electric charge, several hundred times that of an ionised hydrogen atom, or that the particle was very small, much smaller than the hydrogen atom.  Finally in 1911, the American physicist Robert Andrew Milikan (1868 – 1953) devised an experiment to directly measure the charge

[1] Image courtesy of D-Kuru/Wikimedia Commons, License: CC BY-SA 3.0 AT

on the particle now named the electron, a term coined in 1891 by the Irish physicist George Johnstone Stoney (1826-1911). It was thus possible to determine its mass, which turned out to be 1/1837 that of the hydrogen atom. The electron was thus the first sub atomic particle to be discovered.

These cathode ray particles: electrons, were the atoms of electricity, but were themselves smaller than all of the known atoms. J J Thomson suggested that electrons were the constituent parts of atoms and that an atom consisted of a cloud of electrons held together by an invisible positively charged soup in what is now referred to as the "plum pudding" model of the atom.

## Ions

The idea of ions first appeared in the 19th century when it was found that water in which salts were dissolved conducted electricity and could separate the dissolved salts into their component parts. It was Michael Faraday who first formulated the laws governing such processes. Although the name Ion was first coined by Faraday, it was a Swedish physicist Svante Arrenius (1859- 1927) who provided an explanation. He proposed that a current flowed because the atoms of the compound were either stripped of electrical charge or gained electrical charge, so while the molecule was electrically neutral its component atoms, ionised in this way, were charged and so allowed a current to flow.

The smallest positive ion is now known to be a hydrogen atom, stripped of its orbiting electron. When dissolved in water these positive ions give the water a sour taste and make it acidic. Ions are also produced from heavier atoms so for example the discharge in a fluorescent tube is the result of ionisation of a rarefied gas.

## X Rays

Wilhelm Conrad Roentgen (1845 – 1923) was studying cathode rays at the University of Wurzburg, when in November 1895 he noticed a green glow from a nearby fluorescent screen. He determined that the fluorescence was caused by invisible rays which originated in a Hittorf-Crookes tube he was using to study the cathode rays. The rays appeared to penetrate opaque black paper which was used to wrap the tube.

Roentgen had discovered X-Rays. Over the next several months he refined his experiments and in one experiment exposed a photograph of his wife's hand wearing a wedding ring in what is the first ever medical X-Ray.

Figure 1-2  The first medical X-Ray

He reported his results in "On A New Kind Of Rays" (*Über eine neue Art von Strahlen*), which was published on 28 December 1895.

## Radioactivity

Antoine Henri Becquerel (1852 – 1908) was born into a family of scientists; both his father and grandfather were eminent physicists, his father Alexander Edmond having done research on phosphorescence and solar radiation and his grandfather Antoine César having been a Fellow of the Royal Society and having invented the electrolytic method for extracting metals from their ores.

His early work concerned the plane polarisation of light, phosphorescence and the absorption of light by crystals.  Following the discovery of X Rays by Roentgen in 1895, Becquerel decided to investigate whether there was any connection between these new rays and phosphorescence.  He used uranium salts, which phosphoresce on exposure to sunlight.  To his surprise however he found that even when not exposed to sunlight the uranium salts would fog a photographic plate covered with opaque paper.  He found that these rays were common to all uranium salts, that they caused gasses to ionize and that they differed from X-Rays in that they could be deflected by a magnetic field.

Investigation of these new rays was taken up by a husband and wife team, Pierre (1859-1906) and Marie Curie (1867 - 1934).  Pierre Curie was a well-established scientist when he met and married Marie in 1895, having discovered, along with his brother Jacques, the piezoelectric effect and the so called Curie point: the temperature above which the magnetic properties of a material disappear.

The Curies began a systematic investigation of Becquerel's newly discovered rays. They coined the term *radioactivity* to describe these new rays. After extracting the radioactive uranium from the samples of ore, Marie noticed that there was a residual radiation which was much more active than pure uranium. Eventually she was able to isolate two new elements; radium and polonium.

The story is next taken up by Ernest Rutherford (1871-1937), often regarded as the father of nuclear physics. After studying in his native New Zealand he came to England in 1894 to work under J J Thomson at the Cavendish laboratory in Cambridge. In 1898 he went to Canada to take up a post at McGill University and returned to England in 1907 to take up a chair at Manchester University.

It was during his first spell in England that Rutherford began investigating radioactivity, work which he carried on in Canada. He identified and named the different types of radiation, calling them alpha, beta and gamma radiation. By applying a magnetic field he was able to show that alpha particles are positively charged and much heavier than the negatively charged beta particles, while gamma rays are electrically neutral. Returning to Manchester University in 1908, and working with the young Hans Geiger (1882 – 1945), he was able to show that Alpha particles were in fact ionised Helium atoms, stripped of their two electrons, and therefore positively charged, carrying two units of electrical charge. The beta particle was shown by Becquerel to be identical to the electron, which at that time had only recently been discovered by J J Thomson.

Rutherford together with Frederick Snoddy (1877 - 1956) worked on a theory that radioactive processes were atomic called "disintegration theory" and not chemical or molecular. They argued that bits of the atom were broken off and emitted as alpha particles leading in 1919 to the transmutation of one element into another.

By the beginning of the 20$^{th}$ century, a picture was starting to emerge. It was becoming evident that matter was made up of particles called atoms and that these combined to form molecules, but that atoms themselves, long thought to be indivisible, were in fact made up of smaller components which we now know to be electrons, neutrons and protons. It was also evident that light was just a small part of a much broader spectrum of electromagnetic radiation which took in Radio Waves, Infra-Red, Ultraviolet, X and Gamma Rays. Light appeared to be composed of particles, later named photons, but also appeared to possess some of the properties traditionally associated with waves, such as diffraction and interference.

It seemed by the beginning of the 20$^{th}$ century that physics was finally revealing all of its secrets, so much so that Lord Kelvin (William Thomson (1824 – 1907) famously addressed the British Association for the advancement of science in 1900 with the words *"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement."*

How wrong he proved to be.

## Special Relativity

1905 was to be a seminal year for physics due almost entirely to the work of an obscure Swiss patent clerk. This was the year that Albert Einstein published three landmark papers that were to change the face of physics forever. It was also the year in which he finally obtained his doctorate from the University of Zurich. The doctoral thesis was completed in April 1905 and submitted in July of that year.

The first of Einstein's three papers dealt with the photoelectric effect and showed that Planck's quanta of energy were real and not just a mathematical trick.

His second paper showed that atoms were subject to Brownian motion and finally ended the debate about whether matter was made up of atoms.

Einstein's third paper published in June 1905 was entitled (in English) - *"On the Electrodynamics of Moving Bodies"* - but is more famously remembered as the paper that introduced his ideas on Special Relativity. The paper is based on the concept of inertial reference frames. An inertial reference frame is nothing more or less than a co-ordinate system associated with an observer and so consists of an orthogonal set of axes in the X, Y and Z directions. Einstein reasoned that there was no absolute frame of reference within the universe; instead everything had to be related to the frame of reference of an observer.

Einstein based his subsequent theory on two postulates. The first of these asserted that the laws of physics appear the same to any observer in any inertial reference frame. Einstein's second postulate concerned the speed of light and in a sense is merely an extension of his first postulate. Einstein postulated that the speed of light in free space is the same for any observer in any reference frame. In adopting this second postulate Einstein had to give up the notion that time was universal. Time according to Special Relativity ran at different rates in different reference frames, depending on how fast they were moving with respect to one another.

Einstein developed his theory using a simple thought experiment. He imagined an observer on a train (at the time trains were the fastest known means of transport). On the train are arranged a pair of mirrors, one on the floor and one on the ceiling. The mirrors are a fixed known distance apart. A beam of light is made to bounce back and forth between the two mirrors. The observer can measure the distance between the mirrors and the time it takes for a pulse of light to travel between them. A second observer is located on the side of the track. He can also see the mirrors and the pulses of light and he too can measure the path taken by the beam of light and the time it takes to travel from one mirror to the other.

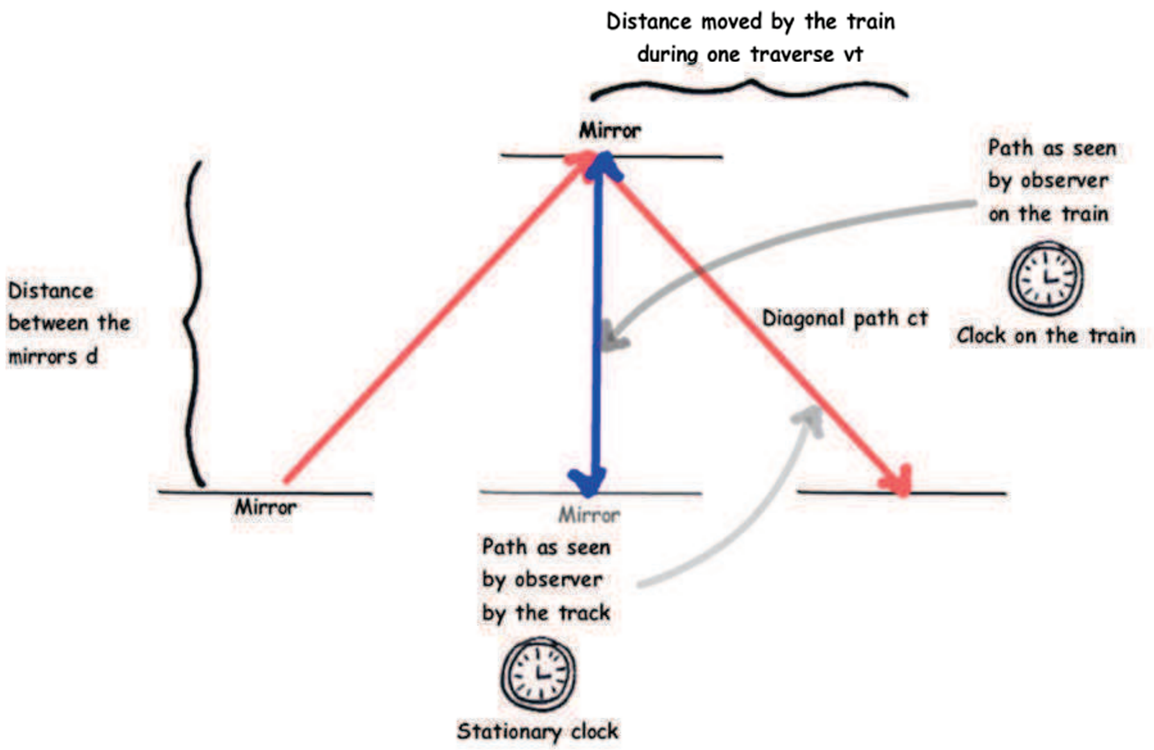


Figure 1-3 Special Relativity

To the observer on the train the light appears to travel vertically up and down between the two mirrors separated by the distance *d*. The train is moving at a significant fraction of the speed of light and so the observer on the side of the track sees the light beam trace out a longer diagonal path. The length of this longer path is *ct* in Figure 1-3, while the railway carriage has moved forward by a distance *vt*, where *t* is the time it takes for the light to travel from floor to ceiling for the observer beside the track. For the observer on the train the distance d must equal *cT*, where *T* is the time it takes for the light to travel from the floor to the ceiling of the train. Hence there are two different values of time, one, *T*, for the observer on the train and another, *t*, for the observer beside the track. Simple application of Pythagoras' theorem shows that

$$c^2t^2 = v^2t^2 + c^2T^2 \qquad \text{Equation 1-3}$$

where *c* is the speed of light.

Hence

$$\frac{t}{T} = \gamma = \frac{c}{\sqrt{c^2 - v^2}} = \frac{1}{\sqrt{1 - \frac{v^2}{v^2}}} \qquad \text{Equation 1-4}$$

To the observer beside the track, the clock on the train appears to be ticking slower than his own stationary clock by a factor 1/γ. In fact the clock on the train **is** ticking slower than that of the stationary observer by a factor 1/γ.

Gamma is a well-known factor that was first introduced by the German physicist Hendrik Lorentz (1853-1928) and hence it is given the name: the Lorentz factor. The value of γ (Gamma) varies from 1 to infinity as the velocity goes from zero to the velocity of light. Its value remains relatively small even for velocities which are a significant proportion of that of light, so for example at 10% of the velocity of light gamma has a value of just 1.005; at 50% it has a value of 1.155 and it is not until the velocity reaches 99.5% of c that gamma reaches a value of 10. Thereafter it rises rapidly towards a value of infinity at velocity c.

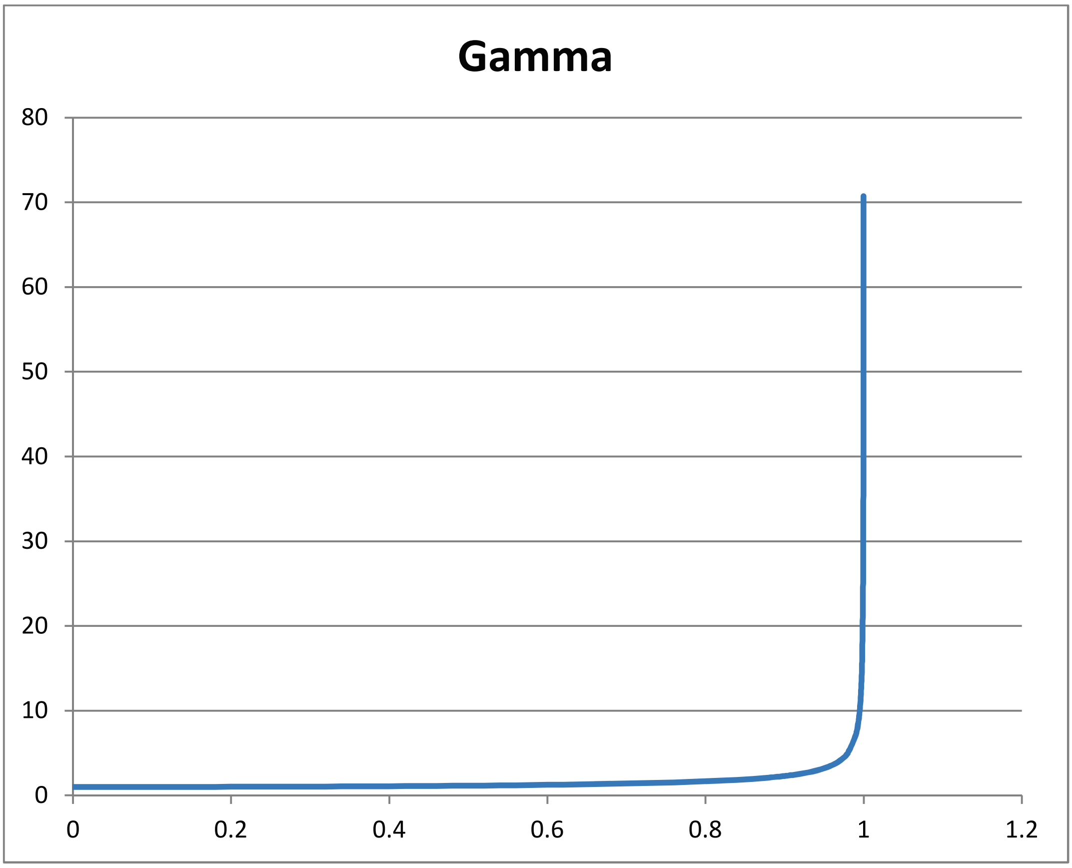


Figure 1-4 Graph of Gamma versus v/c

Having considered the effect of relativity on time, Einstein next considered the effects of relativity on length and on mass. According to the stationary observer the train moved forward a distance $L = vt$ during the time it took for the pulse of light to travel between the two mirrors. According to the moving observer on the train however the time taken to traverse this distance was only $T$ seconds equal to $t/\gamma$. Since both observers agree on their relative velocity, this must mean that to the observer on the moving train, the distance covered is less, distance has been foreshortened by a factor $1/\gamma$.

Einstein went on to show that mass is also affected by relativity. He did so by considering how momentum was affected by changes in length and velocity during a collision. An object which is not moving displays what is now referred to as its rest mass. Objects which are moving have a mass whose value is higher than the rest mass by a factor γ. It is important to understand exactly who perceives what under the effects of special relativity. It is the moving observer who perceives time as having slowed down, it is the same moving observer who perceives that distances are foreshortened but it is the stationary observer who perceives that the mass of a moving object has increased.

For an object travelling at 99.5% of the speed of light the value of Gamma is approximately 10. An observer travelling at 99.5% of the speed of light would therefore experience time at one tenth the rate of a stationary observer. The distance travelled by such an observer moving at 99.5% of the speed of light appears shorter by a factor of 10 than it would for an observer travelling at what we regard as normal non relativistic speeds. To an external observer the mass of an object moving at 99.5% of the speed of light appears to have increased by a factor of 10.

Take as a simple example the case of an astronaut travelling from the earth to the moon. When traversed at normal, non-relativistic speed the distance from the earth to the moon is approximately 400,000km. If the astronaut had a super spaceship which could cover the distance at 99.5% of the speed of light then he would measure the distance between the earth and the moon, not as 400,000 km, but as 40,000 km. For the astronaut the distance to the moon would be compressed or foreshortened by Gamma whose value in this case is 10.

Not only would the moon seem much nearer to our intrepid astronaut, but the time it takes to get there would be shorter. The clocks on the astronaut's spaceship would run slower than those on the stationary earth. So the number of seconds which ticked by during his journey would be less than that if he were travelling at lower speed. At 99.5% of the speed of light, Gamma has a value 10 and this is the factor by which his clock would slow down.

A speedometer fitted to his spaceship would however still show the speed as being 99.5% of the speed of light. This is because speed is calculated as distance divided by time and both distance and time are affected equally by relativity.

$$v = \frac{D}{T} = \frac{d/\gamma}{t/\gamma} = \frac{d}{t}$$ Equation 1-5

Both distance and time are affected by the same factor Gamma which therefore cancels to give the same value for the speed no matter whether it is measured by the astronaut or by a stationary observer. Speed is said to be *invariant* with relativity. Indeed this invariance property of velocity is one of the axioms on which special relativity is based.

A slightly different way to view the effect of relativity on distance, rather than imagine that the distance between points changes, is to imagine instead that the scale on which distance is measured is stretched. It is as if the measurements are made with a tape measure made of elastic, the faster one travels; the more the tape measure is stretched, but only when making measurements in the direction of travel. So for the astronaut travelling at 99.5% of the speed of light, any measurements made in the direction of travel are done so with a tape measure which has been stretched by a factor of 10 and so distances will appear to be less by the factor 10.

There is a further effect of relativity: to the stationary observer the astronaut will appear to have gained mass. The mass of the astronaut and of his spaceship, indeed the mass of all the atoms inside his moving environment, will have increased and once again the extent of the increase in mass is determined by the same factor Gamma, 10 in this case.

There is a great deal of experimental evidence to support Einstein's Special Theory. One of the more convincing experiments was carried out at CERN in 1977 and involved measuring the lifetimes of particles called muons in an apparatus called the muon storage ring[i]. The muon is an atomic particle which carries a charge, much like an electron, only more massive. It has a short lifetime of around 2.2 microseconds before it decays into an electron and two neutrinos.

In the experiment muons are injected into a 14m diameter ring at a speed close to that of light, in fact at 99.94% of the speed of light. At this speed the value of Gamma is around 29.33. The muons, which should normally live for 2.2 microseconds, were seen to have an average lifetime of 64.5 microseconds; that is the lifetime of the muon was increased by a factor Gamma. This comes about because the processes which take place inside the muon and which eventually lead to its decay are taking place in an environment which is moving relative to us at 99.94% of the speed of light and where the time, relative to us is running 29.33 times slower. Hence the muon, in its own domain still has a lifetime of 2.2 microseconds, it's just that to us, who are not moving, this appears as 64.5 microseconds.

Traveling at almost the speed of light a muon would normally be expected to cover a distance of 660 metres or roughly 7.5 times around the CERN ring during its 2.2 microsecond lifetime, but in fact the muons travelled almost 20,000 metres or 220 times around the ring. This is because distance in the domain of the muon is compressed so what we stationary observers see as being 20,000 metres, the muon sees as being just 660 metres.

Relativity therefore affects all three types of fundamental measurement, length, mass and time. The term Special Relativity was adopted later, after Einstein had gone on to develop the General Theory of Relativity, and was used to indicate the fact that Einstein had only considered the special case of objects moving at constant velocity. The General theory would go on to consider the effects of acceleration.

This was a radical departure from the dynamics of Newton. Newton had supposed that there was a universal reference frame, a background against which everything moved and to which all motions could be referred. Einstein shattered that idea, now the only reference was that of the observer or the observed and the behaviour, indeed the basic measurements, depended on how these reference frames related to one another.

Almost as an afterthought to this his third paper Einstein calculated that as a consequence of his ideas energy and mass were equivalent. This led him to add his famous equation $e=mc^2$ to a later edition of the paper.

The Muon Ring experiment emphasizes another, often overlooked aspect of special relativity, and that concerns frequency. During its lifetime the muon completes some 220 turns around the ring and both parties are agreed on that. We stationary observers see this as having taken place in some 64.5 microseconds, corresponding to a frequency of 3.58 MHz, while the muon sees these 220 turns as having been completed in just 2.2 microseconds or a frequency of just over 100MHz.. Hence for the muon and indeed all objects moving at close to light speed frequency is multiplied by a factor Gamma relative to that of a stationary observer.

There is yet one more aspect of the effects of relativity on orbiting objects that is worthy of explanation. The orbital radius is the same for both parties, in this case 7m. It is unaffected by relativity because it at all times is normal to the direction of travel. As stationary observers we see the total angle subtended by the muon as being 20,000/7 = 2860 radians. For the muon things are slightly different. The distance travelled around the circumference as experienced by the muon is however just 660m. Hence the total angle subtended is 660/7 = 94.3 radians. In other words the angle subtended at the orbital centre is reduced by a factor Gamma from the perspective of moving object, relative to that of the stationary observer.

## General Relativity

Following the success of his 1905 paper on special relativity, Einstein began to consider what would happen if the reference frames were not simply moving at constant speed with respect to one another but were accelerating. As before he began with a thought experiment; this time he considered what would happen to an observer in an elevator. When the elevator is stationary the observer would be subject to the force of gravity. If the elevator were in free fall, accelerating due to gravity at 9.81 $m/s^2$, the observer would feel weightless. He compared this to an observer in a similar elevator out in deep space. If this elevator were stationary, the observer would feel weightless but if it were accelerating at 9.81 $m/s^2$ the observer would weigh exactly the same as the stationary observer on earth. Einstein called this the principle of equivalence.

Einstein then went on to consider what would happen to a beam of light crossing the elevator at right angles to the direction of acceleration in the elevator in deep space. It would appear to be bent. He reasoned that due to equivalence the observer in the stationary elevator on earth would see the same bending of a beam of light.

From this simple experiment, Einstein was able to construct a model for the way in which gravity affects the motions of celestial bodies. To do so he created a set of co-ordinates combining the three spatial dimensions with a fourth dimension of time, calling the combination Space-Time. Einstein was able to show that massive bodies distort space time to be curved and that objects follow paths which are straight lines in space time but which map to curved trajectories in conventional space.

In line with Einstein's approach of proposing a theory which could be tested by experiment, general relativity made a number of predictions. Among these was the idea that light could be bent by gravity. The theory could be tested by observing light from distant stars first against a background with no massive body between the earth and the stars and then with a massive body present between the source and earth. The massive body in question was the sun, but to measure the position of distant stars close to the sun could only be done if there was a total solar eclipse. The theory was first published in 1915 but because of the First World War, it was not possible to test this idea during the war. It was not until 1919 that there was a suitable total eclipse and that an expedition could be launched to photograph a distant star field.

Arthur Eddington (1882-1944) was secretary to the Royal Astronomical Society during the First World War. Together with Astronomer Royal he organized two expeditions to test Einstein's General Theory of Relativity. One to Sobral in Brazil and the other, headed by

Eddington himself, to Principe, an island off the west coast of Africa. Eddington photographed the star field in the area close to the sun during a total eclipse. The photographs were then compared to those of the same star field photographed when the sun was elsewhere in the sky. If Einstein was correct, the positions of those stars close to the solar disk would be shifted due to the effects of the sun's gravity.

Eddington published his results the following year 1920 [ii] in the Philosophical Transactions of the Royal Society. They showed conclusively that Einstein's predictions were correct and that light was indeed bent by a gravitational field. Einstein shot from being a modestly well-known physicist to superstardom almost overnight.

# Chapter 2  A Brief History of Quantum Theory

*"Anyone who is not shocked by quantum theory has not understood it."*
Niels Bohr.

*"I think I can safely say that nobody understands quantum mechanics. "*
Richard Feynman - The Character of Physical Law (1965) Ch. 6

*"Physicists use the wave theory on Mondays, Wednesdays and Fridays and the particle theory on Tuesdays, Thursdays and Saturdays."* - William Henry Bragg

## The Quantisation of Energy

In 1900 at the age of 42 Max Planck was Professor of Physics at the University of Berlin. Germany had been united since 1870 and was trying to establish its position as a major world power and beginning to flex its industrial muscles. One of the emerging technologies at the time was that of the incandescent electric light and the major German electrical companies, anxious to establish a world lead, commissioned Planck to investigate how they might maximise the efficiency of their incandescent light bulbs. The problem to which Planck turned his attention was to understand the relationship between the frequency at which a hot black body[2] radiated energy and its temperature.

All materials emit radiation when they are heated. At higher temperatures this is seen as first a dull red glow which gets brighter as the object gets hotter, passing first through red heat then white and finally blue. Interestingly the colour or frequency of the radiation is independent of the material involved so for example, iron gets red hot at exactly the same temperature as ceramic or indeed as any other material.

A physical law relating the temperature to the colour had been proposed in 1893 by the German physicist Wilhelm Wien (1864 – 1928) which worked well for higher frequencies but which failed at lower ones. A few years later another attempt was made in the form of the Rayleigh-Jeans law, first proposed in 1900 and later modified in 1905, while this worked at lower temperatures, it failed at higher ones. Planck himself had published what is referred to as the Planck-Wien law in 1899, but this too failed to match the experimental evidence.

Finally in December 1900, Planck presented a paper to the German Physics Society (Deutsche Physikalische Gesellschaft) in which he made the assumption that energy could only be released in discrete multiples of some elementary unit. The size of this unit of energy or quantum was proportional to the frequency and related by what is now known as Planck's constant. Light it would appear could only exist in discrete lumps or quanta the energy of which was proportional to their frequency. The new model fitted the data perfectly at both low and high temperatures.

[2] The term *black body* is used to describe a theoretically ideal emitter of energy.

Mathematically the energy in each such quantum is proportional to the frequency and the constant of proportionality is Planck's constant. So the energy of an individual quantum is given by the equation:

$$e = hf \qquad \text{Equation 2-1}$$

Where $e$ represents the energy of the quantum of radiation, $f$ the frequency and $h$ is the constant of proportionality, now known as Planck's constant.

Because it is not a pure number, Planck's constant can have different values depending on the units being used. In SI units the value of Planck's constant is $6.62606896{\times}10^{-34}$ $\mathbf{m^2kg/s}$ or **J s.** However it is often represented as what is known as the Reduced Planck's constant or Dirac Constant, which is simply this value divided by 2π. It has the value $1.054571628{\times}10^{-34}$ $\mathbf{m^2kg/s}$ or **J s** and is given the symbol $\hbar$. The use of the reduced Planck's constant, $\hbar$, is consistent with representing the frequency as an angular frequency in radians per second rather than Hz or cycles per second. In this form Planck's equation can be written as:

$$e = \hbar\omega \qquad \text{Equation 2-2}$$

Energy and frequency have different units or dimensions, which means that Planck's constant must itself have units or dimension. The units of Plank's constant are the product of a length, a velocity and a mass and match those of angular momentum.

Planck was not happy with his assumption that energy could only be released in discrete quanta. He regarded it as a mathematical device or trick, rather than having its origin in any sort of physical phenomenon. A number of physicists, including Rayleigh, Jeans and Lorentz refused to accept the implications of Planck's discovery and insisted on setting the value of Planck's constant to zero. Planck's uneasiness with his own discovery led him to spend much of the next 20 years trying to eliminate this quantisation effect, but the effect was real. Somewhat unwittingly, Max Planck had introduced the idea of the quantum into theoretical physics.

If it was Planck who introduced the idea, it was Albert Einstein who was responsible for establishing the quantum as an integral part of modern physics. Einstein himself was something of a rebel. Disagreements with his course tutors at university, born in part out of his independent spirit, meant that he was not able to get a job in academia. Instead he had to rely on family connections to secure a job in the Swiss patent office as a junior clerk. Fortunately Einstein found that the job was not very demanding which left him with sufficient time to pursue his interest in physics.

The first of the three landmark papers concerned the photoelectric effect and was published in March 1905. Experiments by the Hungarian physicist Philipp Lenard (1862 – 1947) had shown that when light was incident on an electrode in a vacuum tube, electrons were emitted. The current which flowed as a result was proportional to the intensity of the incident radiation. It also varied with the frequency of the radiation, but at low frequencies the emission of electrons ceased completely. In the world of classical theory, this should not have been the possible, as Planck had shown, the energy of radiation varied with its frequency so an intense beam of radiation at low frequencies would contain as much energy as a less intense beam at higher frequencies and yet this latter beam would cause electrons to be emitted, whereas the lower frequency radiation would not, no matter how intense the beam.

Einstein reasoned that the electrons were bound into the electrode in some way and that it took a finite amount of energy to dislodge them. He then argued that the beam of radiation was itself composed of particles each of which had a finite amount of energy and that the energy of each individual particle was itself proportional to its frequency in line with Planck's idea on radiation. If the incident radiation is of a low frequency then no single incident particle has sufficient energy to dislodge an electron and so no emission takes place. At higher frequencies all of the incident particles have sufficient energy to dislodge an electron and so the number of electrons emitted is proportional to the intensity of the incident beam.

Planck had shown that black bodies radiate in discrete quanta. This type of thermal radiation takes place primarily in the infra-red part of the spectrum but extends into the visible part of the spectrum. Einstein, with his interpretation of the photoelectric effect, showed that all of visible light is also quantised. It is now understood that all electromagnetic radiation, from radio waves at the low end of the spectrum right the way through to gamma rays at the high end, is composed of particles in this way. The name for Einstein's particles of light, the Photon was first coined in 1926 by Gilbert N Lewis (1875-1946). It is now taken to refer to any form of electromagnetic radiation from across the entire electromagnetic spectrum.

Einstein's second paper, published in May 1905, concerned the motion of tiny particles in suspension in a fluid; its English title is *"On the Motion Required by the Molecular Kinetic Theory of Heat of Small Particles Suspended in a Stationary Liquid"*. This phenomenon had been observed some time before when grains of pollen are in suspension in water. It was documented in 1828 by the Scottish botanist Robert Brown (1773-1858) and hence was given the name Brownian motion.

Following the introduction of the kinetic theory of heat, in which phenomena associated with heat, temperature and pressure were explained by molecular motions, various attempts were made to explain Brownian motion in similar terms, but the scale of the pollen grains compared to that of the water molecules was such that the impact of a single molecule on a pollen grain would have little effect. Individual water molecules were just too small to affect grains of pollen, which were massive in comparison.

Einstein took a different approach and reasoned that the movement of the grains of pollen was caused by collisions with molecules that were similarly moving in random patterns. Einstein then used statistical methods to show that, while a single impact would have little effect, the cumulative effect of many such impacts could indeed cause such motions.

The Brownian paper is notable for two reasons. The first is that Einstein did not set out the paper as an explanation of Brownian motion. Instead he set out to show that molecules of water had random motions, the consequences of which were that they would cause larger particles to take on random motions. Brownian motion was thus a consequence of molecular motion. In setting the paper out in this way Einstein was establishing a pattern in which he explained a phenomenon and then went on to describe an experiment or observation which would, as a consequence of his explanation, show the theory behind the explanation to be true.

The experimental method normally requires that a theory based on assumptions should make predictions which can then be tested by experiment. In this case the experiment had been carried out some 80 years earlier and so the prediction was somewhat retrospective, more of an explanation of a phenomenon that had already been described.

The second reason why the Brownian motion paper is significant is that it firmly established the existence of molecules and atoms as the basis of all material substances. Einstein had thus shown that both light and matter were discrete in nature.

## Atoms

By now it was becoming evident that significant aspects of the structure of matters were quantised. Planck had shown that energy came in discrete quanta, Einstein had shown that light too was quantized, it was clear that electricity was carried in discrete packets called electrons and Einstein had confirmed what many suspected, that matter was itself discrete and made up of atoms. It was also clear from work on ionisation and with the discovery of the electron, that atoms were not entirely indivisible. In the early part of the $20^{th}$ century physicists began to turn their attention to the atom and to work on gaining an understanding of its structure.

J J Thomson had put forward his idea of the "plum pudding" model of the atom, but this was just wild speculation. There were several other such dead ends; models that turned out not to be viable.

Meanwhile Rutherford began using radiation to probe the structure of the atom. In Canada Rutherford had noticed that Alpha particles were sometimes scattered as they passed through a thin sheet of mica. Rutherford, now back in Manchester, and assisted by Geiger, started a series of experiments to examine this scattering in more detail. He used thin sheets of gold foil, bombarding them with Alpha particles and detecting the particles as they were scattered by the gold. Rutherford found that, as with the mica, while most Alpha particles passed straight through, a small proportion of the Alpha particles were deflected.

A young undergraduate, Ernest Marsden, joined the team and was given the job of investigating the extent to which the Alpha particles were deflected. Much to their surprise, they found that particles were sometimes deflected by very large angles, and indeed that some were reflected back directly towards the source. Rutherford described it as *"… like firing a fifteen inch shell at a piece of tissue paper and it came back and hit you"*. He spent the next 18 months trying to understand what was happening.

Rutherford knew that Alpha particles carried a positive electric charge and he also knew that this would cause them to be deflected as they passed close to charged particles within the gold atom. He knew that some of these were negatively charged electrons, which were relatively light and would have very little influence on the much heavier alpha particles. But he also knew that the atom was electrically neutral and therefore had to contain something which was positively charged to balance out the negative charge of the electrons now known to form a part of the atom.

He reasoned that the behaviour of the alpha particles could be explained if all of the positive charge in the atom was concentrated at a single point at the centre of the atom.  He called this point the nucleus.  In Rutherford's model the nucleus was positively charged and contained most of the mass of the atom, the negatively charged electrons spread around at a distance, resembling a mini solar system.

Rutherford's planetary model of the atom still presented some difficulties.  An atom with positive charge concentrated at the centre and stationary electrons disposed around it would be unstable.  The negatively charged electrons would be attracted inexorably towards the positively charged nucleus.  If on the other hand the electrons were in orbit around the nucleus the centrifugal force could balance the electrical force, however in order to complete their orbits the electrons would be undergoing a continuous acceleration towards the central nucleus, and when an electron is accelerated it radiates energy.  This so called "synchrotron radiation" would sap the orbiting electron of its energy causing it to spiral in towards the nucleus.

Despite these evident complications Rutherford chose to publish his results in 1911.

Coincidentally in the process of refining their measurements, Rutherford, Geiger and Marsden discovered the relationship between atomic weight and the number of orbiting electrons.  Except in the case of hydrogen which has one orbiting electron and unit atomic weight, all other atoms had an atomic mass of double the number of electrons. This in itself was an important step in understanding the composition of atoms.

Rutherford's experiments bombarding gold foil with alpha particles showed that the atomic nucleus contained centres of positive charge.  The idea eventually emerged that these were themselves particles and were given the name protons.  It was also evident that protons on their own did not account for all of the mass of the nucleus and that there must be other particles involved. In 1920 Rutherford proposed what he called his *neutral doublet*, a particle with roughly the same mass as the proton but electrically neutral.

In 1928 the German physicist Walter Boethe and is student Herbert Becker created an experiment in which they bombarded beryllium with alpha particles and found that it gave off a very penetrating, electrically neutral radiation.  At first they believed this to be high energy gamma radiation.   In 1932 Irene Joliot-Curie, one of Madam Curie's daughters and her husband Frederic Joloit-Curie, decided to investigate Boethe's radiation.  They bombarded a paraffin target with Boethe's radiation and found that it caused protons to be emitted.  It was unlikely that this could be caused by gamma radiation, which lacks mass and would have insufficient momentum to dislodge protons.

James Chadwick, who was working for Rutherford in Manchester at the time, reported these results to Rutherford.  He set about re-creating the experiment, but went much further, bombarding other targets including helium and nitrogen.  By comparing the recoil energies of the protons that were being emitted from the targets, Chadwick was able to calculate that the beryllium emissions contained a neutral particle with approximately the same mass as the proton. In 1932 James Chadwick published his results in Nature in a letter entitled *"Possible Existence of a Neutron"*.  In 1935 James Chadwick received the Nobel Prize for his discovery of the neutron.

## Atomic Spectra

In the early 1800s the English chemist William Hyde Wollaston and independently the German physicist Joseph von Fraunhofer discovered that the spectrum of the sun contained a series of dark lines. Fraunhofer mapped the frequencies of these lines which are now named after him.

It was subsequently discovered by Robert Bunsen and Gustav Kirchhoff that each chemical element can be associated with a set of these spectral lines. The lines are caused by absorption of light by the atoms of the element at very specific frequencies. The presence and frequencies of these lines is a characteristic of the type of atom, rather like a fingerprint or a barcode.

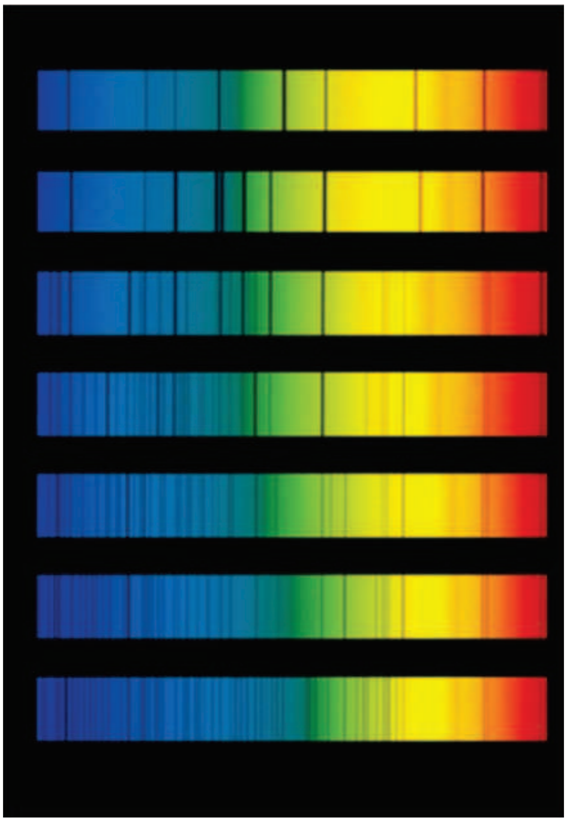

Figure 2-1 Absorption Spectra

A similar set of lines exists, and at the same frequencies, at which an atom emits light. It appeared that under certain circumstances atoms could absorb energy, but only at very specific frequencies, while under slightly different circumstances those same atoms would emit energy at those exact same frequencies.

Joseph Jakob Balmer (1825-1898) was a Swiss mathematician and numerologist who, after his studies in Germany, took up a post teaching mathematics at a girls' school in Basel. A colleague in Basel suggested that he take a look at the spectral lines of hydrogen to see if he could find a mathematical relationship between them. Eventually Balmer did find a common factor ($h = 3.6456*10^{-7}$ - *h* here is not to be confused with Planck's constant) which led him to a formula linking the lines to one another.

$$\lambda = \frac{hm^2}{m^2 - 4}$$ Equation 2-3

Where $m$ is an integer with values of 3 or higher

Balmer originally matched his formula for m = 3,4,5,6 and based on this he predicted an absorption line for $m$ = 7 which was subsequently found to match a new line that had been found by Ângström.

Balmer's formula was later found to be a special case of a more general result which was formulated by the Swedish physicist Johannes Rydberg.

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$ Equation 2-4

Where $\lambda$ is the wavelength of the spectral line
$R_H$ is called the Rydberg constant for hydrogen
$n_1$ and $n_2$ are integers and $n_1 < n_2$

By setting $n_1$ to 1 and allowing $n_2$ to take on values of 2, 3, 4 … ∞ the lines take in a series of values known as the Lyman series. Balmer's series is obtained by setting $n_1$=2 and allowing $n_2$ to take on values of 3, 4, 5... .Similarly for other values of $n_1$ series of spectral lines have been named according to the person who first discovered them and so:

| *n1* | *n2* | Series |
|---|---|---|
| 1 | 2 … ∞ | Lyman series |
| 2 | 3 … ∞ | Balmer series |
| 3 | 4 … ∞ | Paschen series |
| 4 | 5 … ∞ | Brackett series |
| 5 | 6 … ∞ | Pfund series |
| 6 | 7 … ∞ | Humphreys series |

Other series beyond these do exist, but they are not named.

By substituting different values for $R$, it was found that Rydberg's formula worked for all so called *hydrogenic* atoms. Such atoms consist of a nucleus with just one orbiting electron. These represent a special case, a class of problems where there are just two bodies involved, the atomic nucleus and the orbiting electron. Other atoms for example where two electrons and a nucleus are involved form a class of problem called a three body problem which have proved much more difficult to solve.

## The Bohr Model

Niels Bohr (1885-1962) was born into a wealthy family in Copenhagen. It was in Copenhagen University where he undertook his doctoral thesis in Mathematics, receiving his PhD in 1911. Bohr won a Carlsberg scholarship to work under J J Thomson at Cambridge but Bohr and Thomson never quite hit it off, and so eight months into his one year scholarship, Bohr moved to Manchester to work under Rutherford's tutelage.

Bohr began his work at Manchester studying the position of atoms in the periodic table. His work led him to conclude that the position of an element in the periodic table was due to the number of positive charges in the nucleus, its atomic number, and not its atomic weight. He failed to persuade Rutherford to let him publish his results and so it was Soddy who got the credit for atomic number when he worked out a similar theory. Undaunted, Bohr moved on and began to work on the structure of the atom, having been inspired by a flaw that he had found in the work of another of Rutherford's accomplices, Charles Galton Darwin, grandson of Charles Darwin.

Bohr knew that Rutherford's planetary model of the atom was unstable. The electrons could not be stationary or they would collapse into the nucleus, they could not be in motion because they would spiral towards the nucleus as they radiated energy. Bohr chose to ignore the problem of stability and instead to concentrate on the dynamics of the atom. Only after he had solved this problem did he intend to look at the problem of stability.

Bohr was convinced that certain laws of physics broke down on the atomic scale and things were no longer smooth or continuous, so he "quantised" the orbits of the electron.

Taking hydrogen, the simplest of the atoms, as an example; it is now known that the nucleus of the hydrogen atom comprises a single proton. In order for the hydrogen atom to remain electrically neutral this proton must be balanced by a single electron which Bohr assumed was in orbit around the nuclear proton in line with Rutherford's model of the atom.

The electrical force between these two particles is given by the inverse square law for electric charge:

$$f_e = \frac{Kq^2}{d^2} \qquad \text{Equation 2-5}$$

Where *K* is the electrostatic force constant, *q* is the charge on the electron and on the proton and *d* is the distance between them. For the case of an orbiting electron the distance is the orbital radius which can be written as *r*.

Bohr simply assumed that the electron orbit was circular and balanced the electrostatic force with the centrifugal force:

$$\frac{Kq^2}{r^2} = \frac{mv^2}{r} \qquad \text{Equation 2-6}$$

Bohr found the inspiration for his next assumption in the work of a former colleague at Cambridge, John Nicholson (1881-1955). Nicholson had been working on his own model of the atom and in doing so had made an important assumption.

An object moving in a straight line has a propensity to continue to do so. This propensity is termed the *momentum* of the object and is calculated as the product of its mass and its velocity. For an object that is rotating there is a similar quantity called its *angular* *momentum* and for a point object or a particle in a circular orbit the angular momentum is given by the product of its mass, its velocity and its orbital radius.

What Nicholson had understood was that Planck's constant, the factor relating the quantisation of energy to its frequency, has the units of angular momentum. He reasoned therefore that the angular momentum of the orbiting electron was equal to Planck's constant. But he went one step further and assumed that this was just one value for the angular momentum, and that it could take on a series of values which were each integer multiples of Planck's constant.

Mathematically this can be written as

$$l = n\hbar = nmvr$$ Equation 2-7

Where *ħ* is Planck's constant, *m* is the rest mass of the electron, *v* is the velocity of the electron and *n* is an integer with values 1, 2, 3, 4, 5 ….

Bohr now had two equations with two unknowns, *r* and *v*. He could solve these to calculate the orbital radius and the velocity of the orbiting electron for each of the different energy levels, *n*.

For *n = 1* which is referred to as the ground state, base state or lowest energy state.

$$kq^2 = mrv^2 = \hbar v$$ Equation 2-8

$$\boldsymbol{v = \frac{Kq^2}{\hbar} = 2187803.961}\ \textbf{m/s}$$ Equation 2-9

This is frequently referred to as the Bohr Velocity and is just under 1% of the velocity of light.

And

$$r_n = \frac{\hbar^2}{mKq^2} = 5.29149 * 10^{-11}\ \ \textbf{m}$$ Equation 2-10

Commonly referred to as the Bohr Radius

And for the general case of the *n*th energy state:

$$v_n = \frac{Kq^2}{n\hbar}$$ Equation 2-11

In the Bohr model the velocity of the orbiting electron varies as the inverse of the energy level. In other words, somewhat paradoxically, the velocity gets less as the energy level increases.

And

$$r_n = \frac{n^2\hbar^2}{mKq^2}$$ Equation 2-12

The radius for each energy state increases as the square of *n* over the Bohr Radius meaning that the atom gets bigger as the energy level increases.

At first sight it would appear that the energy of the electron in the Bohr model gets less with increasing energy state. However this is not the case, since in moving from a low energy state the electron loses kinetic energy, but gains potential energy. The exact amount is given by the virial theorem and is equal to double the kinetic energy in each state.

Bohr's model appeared to accurately describe the behaviour of the hydrogen atom but in doing so Bohr had to introduce Nicholson's idea that the angular momentum of the orbiting electron could only take on these very specific values which were integer multiples of Planck's constant. Bohr failed to explain just why this should be the case, and there was another problem which defied explanation. To satisfy the requirements of the Bohr model, when the energy of the atom changes from one energy state to another the electron has to jump between two energy states, in effect jumping between two orbits of different radii. The electron has to make the transition from one orbit to another instantaneously and without ever occupy any position in between the two orbits. Such transitions between orbits represent discontinuities of position and appeared to defy rational explanation. They were given the name Quantum Leap and the term has since come to mean any seemingly improbable change of position.

When a charged particle is subject to acceleration it normally emits a type of radiation called *synchrotron radiation*. The electron in the Bohr atom is subject to centripetal acceleration and so should emit such radiation. If the Bohr atom were to emit such synchrotron radiation the energy of the electron would be sapped resulting in the orbit decaying over time. Bohr had chosen to ignore the question of stability and that of synchrotron radiation, preferring to come back to this at a later date. In fact he never did so and so these questions remain open to this day. Bohr also ignored the effects of relativity on the mass of the electron, which for hydrogen is very small, but the Bohr model works for all so called hydrogenic atoms, that is; atoms which are ionised such that they have a single orbiting electron. For more massive atoms, the effects of relativity become increasingly significant.

## Extensions to the Bohr Model

In the 1890s the technology of spectroscopy had improved sufficiently that it was possible to distinguish that certain of the lines in the Balmer series were not single lines at all, but each consisted of a pair of closely spaced lines. By 1915 these experiments had proved repeatable and conclusive and so Bohr was forced to admit that there was a problem with his model.

The solution came from a German physicist, Arnold Sommerfeld (1868 – 1951) who wrote to Bohr in 1915. In order to simplify his model, Bohr had constrained the orbit of the electron to be circular. Sommerfeld decided to lift this constraint. He knew that the circle is merely a special case of a more general curve, the ellipse, and so he re-evaluated Bohr's model but this time using elliptical orbits. The solution worked and Sommerfeld was able to satisfactorily explain the splitting of the Balmer lines.

In 1897 a Dutch physicist, Pieter Zeeman (1865 – 1943) had discovered that a magnetic field also had the effect of splitting the spectral lines into a number of separate lines. This became known as the Zeeman Effect. And in 1913 the German physicist, Johannes Stark, discovered a similar effect caused by an electric field.

Once again it was Sommerfeld who provided the answer. Both Bohr and Sommerfeld when examining the line splitting effect had assumed that the orbits of the electrons all lay in a plane. By removing this constraint and allowing the orbits to take on a different orientation, Sommerfeld was able to introduce another variable into the equation which satisfactorily explained the Zeeman Effect. The results were proven experimentally five years later in 1921.

Another type of splitting of the line spectra of hydrogen, one which occurred in the absence of either a magnetic or an electric field, was also observed in the early 1920s. In 1925 it was proposed by Dutch physicists, Samuel Abraham Goudsmit (1902 – 1978) and George Eugene Uhlenbeck, that this could occur if the electron itself were spinning. Originally thought of as a rotation of the electron about its own axis, modern quantum theory has extended the idea of spin and it is no longer described as a rotation about an axis. Quantum spin is now seen as a more abstract property of the particle.

## The Fine Structure Constant

The Fine Structure Constant was first described and introduced into physics in 1916 by Sommerfeld. It was while he was looking into the absorption spectra of hydrogen and noticed that the orbital frequencies of the Bohr model were related to the corresponding frequencies of emitted or absorbed radiation. They matched perfectly if he introduced a correction factor. That correction factor is now known as the Sommerfeld Fine Structure Constant and is again found as the ratio between the orbital velocity of the electron and the speed of light in the base energy state of the Bohr model for the hydrogen atom. Numerically it has a value of 0.007297352533, but is often referred to by its reciprocal, which is 137.036.

Since 1916 it has been found to exist elsewhere in numerous other areas, and especially in Quantum Electro Dynamics (QED), but no-one knows exactly what it signifies or why it should have this particular value. Various attempts have been made to explain it in terms of numerology or to relate it to other physical constants.

## Compton Scattering

Arthur Holly Compton (1892 - 1962) was born in Wooster Ohio, the son of a professor and Dean of Wooster College. He studied at his father's college and then went on to obtain a Master's degree and a PhD at Princeton in 1916. After a period spent in industry with the Westinghouse Lamp Company in Pittsburgh, he went back to his studies at before taking a post at Washington University, St Louis and subsequently moved to the University of Chicago in 1923 as Professor of Physics.

In his early years at Princeton, he devised an elegant method of showing the earth's rotation, but soon went on to study X-Rays, which were to become a central theme of his later life's work.

In 1922 he discovered that X-Rays which he used to bombard crystals emerged having a longer wavelength than when they were entered the crystal. He reasoned that this was as a result of collisions taking place between the X-Rays and electrons in the crystal matrix and further that this could only be the case if the X-Rays were a stream of particles. In later experiments he was able to track the electrons which resulted from these collisions in a bubble chamber and to demonstrate that the X-Ray scattering and the electron recoil happened simultaneously.

This proved conclusively that X-Ray photons were particles. It also contradicted the views of some theorists who were trying to reconcile quantum theory with classical theory. For this work he was awarded the 1927 Nobel Prize for physics and the effect has come to be known as the Compton Effect or Compton Scattering.

The debate over whether light was a particle or a wave was beginning to hot up once again as Einstein's and now Compton's particulate photon vied for position with Maxwell and the 19$^{th}$ Century view of light as a wave.

## Wave Particle Duality

Bohr's model appeared to describe the energy levels of the atom, but something was missing. His model failed to explain why this quantisation should occur. Next to enter onto the scene was a French aristocrat called Louis de Broglie.

Louis de Broglie (1892 – 1987) was born into an aristocratic French family in August 1892 in Dieppe. Louis first studied history, but developed an interest in physics as a result of working with his older brother Maurice. Maurice had been a naval officer where he worked on early radio systems for ship to ship and ship to shore communication. In 1904 he left the navy to study physics. Maurice pursued his interest in physics by setting up a private laboratory to study X-Rays. He attended the first Solvay conference, held in Brussels in 1911, in the capacity of scientific secretary. It was after reading the proceedings of this conference, largely written by his brother Maurice, that Louis decided to abandon his studies of history and to focus instead on physics. After graduating in 1913, Louis was called up for military service. Events in Europe meant that before his military service was completed, France was at war and Louis was to remain in the army for another 4 years. His time spent in the army was not altogether wasted; he spent most of his military service as a radio engineer working at the base of the Eiffel tower in Paris.

In 1905 Einstein had shown that the hitherto wavelike nature of light concealed an underlying particle-like behaviour. In 1923 de Broglie was struck with the idea that maybe this situation could be reversed, that perhaps what had hitherto been thought of as a particle could be described in terms of wave. De Broglie discovered that if he assigned a wavelength and a frequency to an electron he could explain the location of the atoms in the Bohr model of the atom. He found that the orbiting electrons could only occupy orbits which contained a whole number of such wavelengths. De Broglie published his theory in 1924.

De Broglie's idea hinges around the notion of standing waves. A standing wave occurs for example in a taught string, anchored at both ends, that is plucked. The fundamental frequency occurs when the whole length of the string vibrates. Other modes of vibration are also possible, for example where the centre of the string remains stationary and the two halves of the string each vibrate at what is referred to as a second harmonic frequency. This can also happen at the third, fourth and other higher harmonics. Here then was a possible explanation as to why the electron orbits could only take on whole number multiples of a base value.

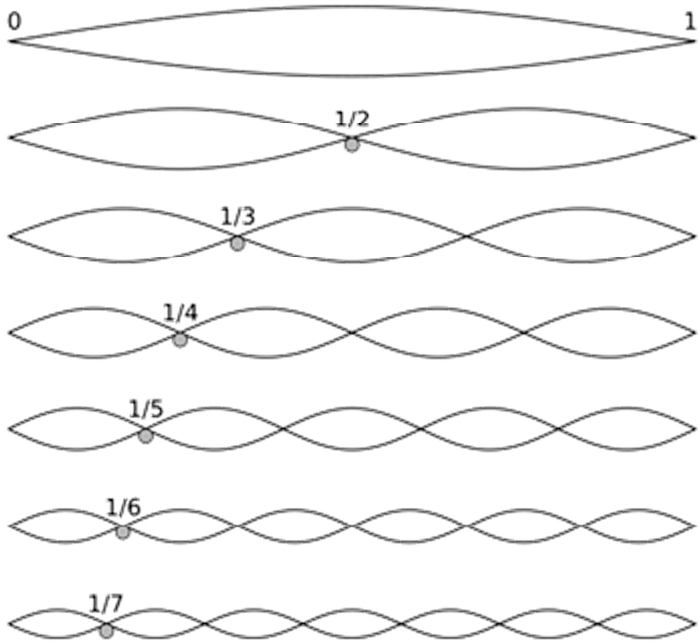


Figure 2-2 Standing Waves

In the base energy state the electron is oscillating at the fundamental frequency that is there is one whole cycle of the electron as a wave during one complete orbit. In the second energy state the electron is oscillating at exactly twice the frequency of the orbit of the electron, forming a standing wave where two wavelengths are required to describe one complete orbit. This carries on in the third and higher orbits.

Bohr realised that this could possibly address his problems with the quantum leap. Instead of moving from one orbit to another, the electron simply had to change the mode in which it vibrated from that of one harmonic frequency to that of a higher or lower harmonic frequency.

In 1929 Louis de Broglie received the Nobel prize for Physics.

## The Heisenberg Uncertainty Principle

Werner Heisenberg (1901 – 1976) was a German physicist who studied physics and mathematics in Munich. He studied under Arnold Sommerfeld alongside Wolfgang Pauli, but it was when he first met Niels Bohr that his interest in quantum physics and his career took off.

In 1926 he was working on a way to explain the relative intensities of the emission and absorption lines of hydrogen when he stumbled onto an idea which was to have far greater importance. He chose to represent the frequencies and intensities of the various absorption and emission lines as a table of values. It was while trying to manipulate this table that he discovered that the normal rules of multiplication did not seem to apply. What Heisenberg has unwittingly discovered was matrix manipulation. Matrix manipulation is now commonplace in mathematics and was known in mathematical circles in the 1920's, but Heisenberg was a physicist and not a mathematician, so he struggled for some time to come to terms with his discovery. Multiplication of matrices is not commutative, that is [A][B]≠[B][A], the result of multiplying two matrices together is different depending upon the order in which the multiplication is written.

When Heisenberg applied this to the momentum and position of a particle he found the relationship:

$$[X][P] - [P][X] = \hbar[I]$$ Equation 2-13

Where [ $I$ ] is known as the identity matrix and is the equivalent of unity in matrix multiplication, so $\hbar$[ $I$ ] is the equivalent of a constant in matrix multiplication.

Heisenberg realized that the non-commutative nature of this matrix multiplication implied that it was not possible to know both the position and the momentum (velocity) of a particle to an arbitrary degree of accuracy. There was an uncertainty inherent in the system which was related through the constant term to Planck's constant, which appears in the right hand side of the equation. This subsequently became known as the Heisenberg Uncertainty Principle.

Heisenberg first sought to explain the uncertainty principle involves looking at the way in which things are measured. In order to determine the momentum of a small particle such as an electron it is necessary to measure both its mass and its velocity. All electrons have the same rest mass, so to measure the momentum it is sufficient to measure just the velocity. Velocity can be determined by measuring position at two points separated by a small interval of time. On the scale of the electron however, the only tools available to measure the position are other sub atomic particles such as electrons or photons, which are of comparable size and have comparable energies.

The situation can be likened to that of trying to measure the position and velocity of a golf ball when the only tools available to make the measurements are other golf balls. By firing a stream of golf balls at the subject golf ball, eventually one will hit. The position of the subject golf ball can then be determined by detecting the fact that one of the incident balls scored a hit and deviated from its trajectory. Unfortunately the very fact that there was such a collision means that the velocity of the subject golf ball has changed. Furthermore the extent of such a change is indeterminate and so it is now impossible to perform a meaningful second measurement in order to discover the velocity of the subject golf ball.

The position of an electron can be measured by bombarding it with photons. The accuracy of such a measurement is proportional to the wavelength of the incident light. The lower the energy of the incident light, the less the disturbance when it interacts with the subject electron, but at the same time the accuracy of the measurement is reduced. Using light of a longer wavelength and hence a lower frequency means less accuracy when measuring position. Using light of a shorter wavelength and higher frequency while it improves the accuracy of the measurement of position has a secondary effect in that it presents more of a disturbance to the electron which is the subject of the measurement, making the measurement of the electron's velocity less accurate.

If the incident light has a wavelength of $\lambda$ then the photons each carry momentum of $h/\lambda$. This means that the higher the frequency of the incident light the greater its momentum and the more the effect it has on the momentum and position of the electron which is the subject of the measurement. If $\Delta p$ and $\Delta x$ are the standard deviations in the measurement of momentum and position respectively then it can be shown that:

$$\Delta p \Delta x \geq \frac{\hbar}{2}$$ Equation 2-14

In this case position and momentum form what is termed a conjugate pair of measurements. The uncertainty principle applies to any such conjugate pair. Another example of such a pairing is time and energy. In this case the uncertainty principle can be restated as:

$$\Delta e \Delta t \geq \frac{\hbar}{2}$$ Equation 2-15

Heisenberg thought initially that uncertainty was a practical problem associated with measurement brought about because the object being measured and the tools available to measure it were both of the same order of magnitude. The effect came to prominence at the atomic scale because such particles were the smallest tools available for measurement. He was later persuaded that this was not the case largely as a result of discussions and theories proposed by Niels Bohr.

## The Schrödinger Wave Equation

Independently of Heisenberg the Austrian physicist Erwin Schrödinger (1887 – 1961) took a different approach but arrived at much the same conclusion. Schrödinger had been made aware of de Broglie's ideas that particles could be regarded as waves as a result of correspondence with Einstein. He set about discovering a wave equation to describe de Broglie's matter waves.

Schrödinger developed his equation in two forms. One form took account of time and so is referred to as the time dependent form of the Schrödinger wave equation. In the other form time is eliminated and so it is referred to as the time independent form of the equation.

The equation whose solution is a wave is an undamped second order differential equation. By taking such an equation in its canonical or standard form and substituting de Broglie's wavelength for the more conventional wavelength term gives the basic form of

Schrödinger's equation. All that is then necessary is to recognise that the total energy is made up in part of the kinetic energy and a separate potential energy term.

The time independent form of the equation is then

$$\frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} + \frac{\partial^2\psi}{\partial z^2} + \frac{2m}{\hbar^2}(E - V)\psi = 0 \qquad \text{Equation 2-16}$$

Where E is the total energy of the system and V is the potential energy. $\Psi$ is the wave amplitude.

Schrödinger's wave amplitudes have no direct physical interpretation they are the self-same waves as proposed by de Broglie. Max Born (1882 – 1970) went on to show that the square of the amplitude represented the probability distribution of the particle.

The Schrödinger wave equation only has meaningful solutions only for certain discrete values of the total system energy. In the case of the hydrogen atom these are found to correspond to the discrete energy levels of the atom. The solution shows the probability that the electron will be found at a particular radius from the nucleus. In the case of the hydrogen atom the peaks in these functions for the various energy levels correspond to the orbital radii predicted by the Bohr model.

Just as with the Bohr model, the equation can only be solved analytically for hydrogen itself and for other so called *hydrogenic* atoms, that is atoms which are ionized so as to have a single orbiting electron.

Eventually Schrödinger, Carl Ekhart and Paul Dirac each independently showed that Heisenberg's matrix mechanics and Schrödinger's wave equations were mathematically equivalent and were in fact just different manifestations of the same phenomenon.

Schrödinger believed that he had eliminated Bohr's awkward quantum leaps. Energy changes in the Schrödinger model were represented by changes in the probability that the electron occupied one particular orbit or another in a way that is analogous to the way in which the frequency of a violin changes from one note to another. But this is where quantum theory really started to take on a surreal quality.

## The Copenhagen Interpretation

Bohr thought that Heisenberg's explanation of uncertainty was flawed. Heisenberg's original idea, that uncertainty was a practical problem of measurement, did not sit with Bohr's idea that the laws of physics were different on the atomic scale. Bohr took a holistic view in which the observer and the observed could not be separated and argued that light, for example, exists as both a wave and as a particle. It only manifests itself as one or the other form when it is measured or observed. It is at the point where an observer chooses how to measure the particle that its nature becomes fixed. Instead of being capable of description as either a wave or a particle, objects can be described in terms of a *wave function*. Bohr described the process of observation as the *collapsing* of the wave function into either a particle or into a wave.

According to Bohr the original wave function contains all of the possibilities within it. It manifests itself as one form or another, not because it changes in nature from one form to another, but because the observer is looking for that particular form.

In essence what Bohr was arguing was that Heisenberg's uncertainty was an inherent property of the individual particles themselves, not a phenomenon associated with their measurement. Schrödinger's probabilities were not a property associated with a population of particles in the way that probability normally occurs, but were somehow integral to the very nature of the individual particle.

This idea that uncertainty is an intrinsic property of matter is central to modern quantum theory. It implied that reality could not be separated from the process of observation, in other words that reality was somehow subjective. The idea was to result in a schism in the world of nuclear physics between those who accepted such a subjective reality and those who did not. The principle protagonists in this debate were Einstein and Bohr, with Bohr an advocate of subjective reality and Einstein an advocate of an alternative objective reality.

## Schrödinger's Cat

Scientists were understandably sceptical about Bohr's ideas and about the Copenhagen interpretation. Einstein in particular was never reconciled to it and spent the rest of his life trying to disprove it. De Broglie spent many years trying to establish what he called a causal relationship between his wave mechanics and classical mechanics and in fact never managed to do so. Another in the sceptical camp was Erwin Schrödinger himself. Schrödinger set about trying to ridicule the idea by proposing a thought experiment.

Schrödinger sought to explain just how ridiculous was the Copenhagen interpretation by using an example based on everyday objects rather than objects on an atomic scale. Schrödinger imagined a cat sealed in a box. Also in the box was a device, inaccessible to the cat, which contains a vial of poisonous gas and a triggering mechanism. The trigger contains a small amount of radioactive material, sufficient that there is a 50% probability that the device will trigger in a one hour period. Thus the outcome of the experiment is that the cat stands a 50:50 chance of being killed during the one hour it is locked inside the box.

Schrödinger argued that, following the logic of the Copenhagen interpretation that during its one hour spent in the box the cat exists in a fuzzy state of being neither dead nor alive while simultaneously being both dead and alive. It is only when the box is opened that the fate of the cat becomes evident, to coin the terminology of the Copenhagen interpretation its status *collapses* when the box is opened revealing the cat to be either alive or dead. Even more radical is the idea that the history of the cat over the previous hour also *collapses* when the box is opened to either be that of a living cat or that of a cat that died during it hour long ordeal.

Although Schrödinger is now lauded as one of the pioneers of quantum theory, he never quite came to terms with it or its implications, siding with Einstein in the ensuing debate.

## Quantum Electro Dynamics (QED)

Physicists Richard Feynman (1918 - 1988), Freeman Dyson (1923 – present), Julian Schwinger (1918 - 1994) and Sin-Itiro Tomonaga (1906 – 1979) developed Quantum Electro Dynamics (QED) to describe the behaviour of particles in the quantum domain.

Schwinger and Feynman were contemporaries at MIT, both having joined as students in the same year, while Dyson knew Feynman professionally and took over Feynman's professorship at Cornell. Both Schwinger and Tomonaga in Japan had developed significant work in relativistic quantum field theory although Tomonaga's approach was simpler. Around spring in 1948, Dyson and Feynman became friends. Dyson became familiar with Feynman's methods during a road trip they took together to Ann Arbor Michigan and was later able to show that Schwinger and Feynman's theories were equivalent. Feynman, Schwinger and Tomonaga were awarded the Nobel Prize in 1965 for their work in this area. Dyson was not included in the list to receive the prize despite his contributions. As a consequence he has been described as the *best physicist never to receive a Nobel Prize*.

Implicit in QED was the acceptance of Bohr's view that things behave differently on the scale of the atom and that a different set of laws applies on this scale. Central to this idea is that all interactions between particles are themselves mediated by other "virtual" particles. So, for example, QED describes electromagnetic interactions between charged particles as being mediated by virtual photons.

Feynman developed a way of drawing simple diagrams to keep track of these interactions and to help deal with the complex calculations involved. For example there are nine ways in which two electrons could exchange two photons; the two photons could cross in mid-flight, one might be emitted then the second before the first is absorbed, the second might be absorbed before the first and so on. Feynman's diagrams provided a shorthand tool for describing these sequences of events. Feynman diagrams have since become commonplace tools in dealing with events on the quantum scale.

A simple example of a Feynman diagram is shown. Here a pair of electrons is initially on convergent paths AB and DE. The electrons both have negative charge and negative charges repel one another. In QED the force mediating particle for the electromagnetic force is the photon, so one of the electrons emits a virtual photon at E which collides with the other electron at B. The exchange of momentum as the photon is emitted at E causes this electron to follow path EF, away from the other electron, while the impact at B causes this electron to follow the divergent path towards C.

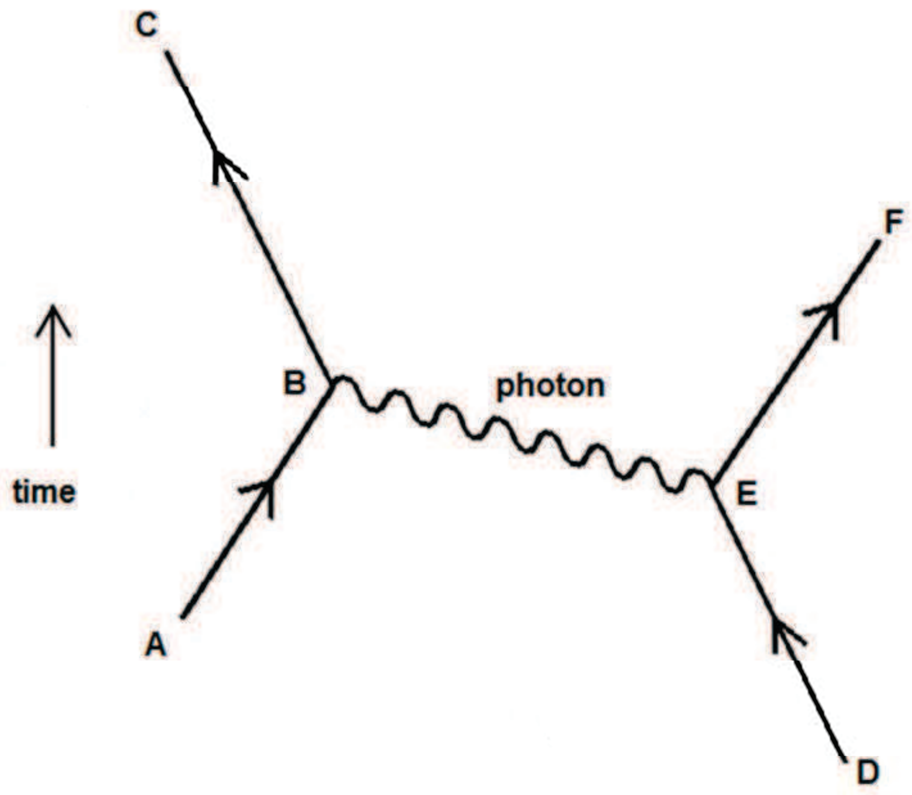


Figure 2-3 Feynman Diagram

QED is concerned with probabilities, it was after all Schrödinger and Bohr who had suggested that such probabilities were an inherent property of the individual particle, Feynman and Schwinger took on these ideas and built on them to consider the probability that a particle would follow a particular path. In a sense this brings the ideas of intrinsic uncertainty not only to the position and velocity of a particle but also to the path a particle might follow between two points.

In this QED takes some of its inspiration from Fermat's principle concerning reflection and refraction. Fermat had shown that of all the possible paths light could take when travelling from a point within a refractive medium to one outside, the path that it actually took was the one which represented the shortest journey time, given the different speeds of light in the two media.

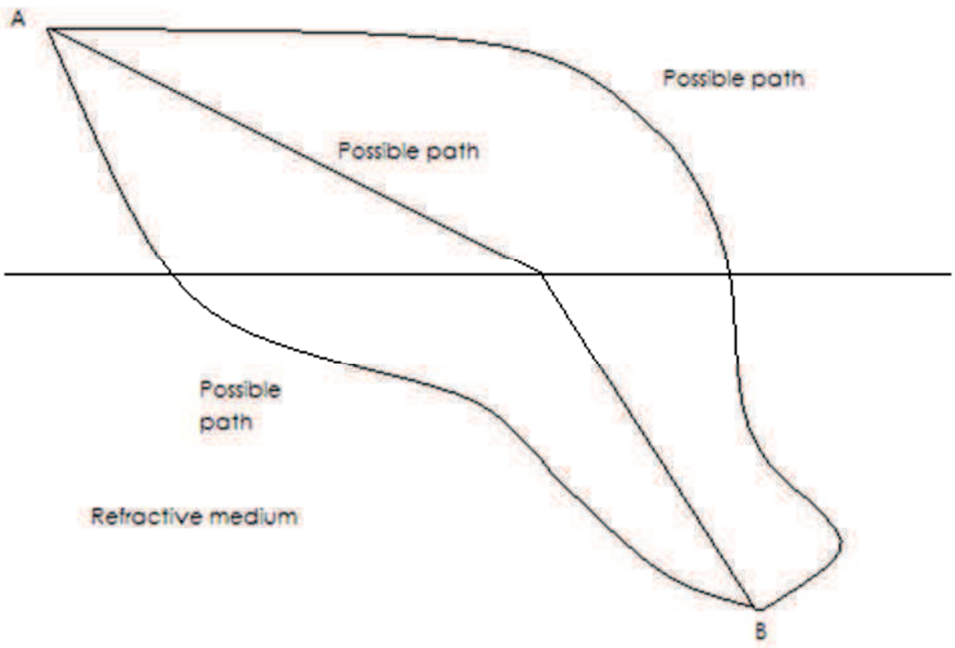


Figure 2-4 Possible and Probable Paths

QED describes the behaviour of particles as being similar to Fermat's principle in that it is necessary to consider all of the possible paths a particle might take and sum the probability along each possible path. The particle will then follow the path which is most probable. Strictly speaking, according to QED, just as with Schrödinger's cat, the particle actually takes all possible paths which collapse to the single most probable path when the particle is observed.

## The Dual Slit Experiment

Feynman was a charismatic physicist, given to practical jokes and seemingly enamoured with the idea that quantum physics has many weird characteristics. He delighted in illustrating this by means of examples of such weird behaviour. One of his favourites was the so called Dual Slit Experiment. The experiment is based on one first carried out by Thomas Young (1773 – 1829) in 1803 which he used to demonstrate the wavelike nature of light. Young's used the experiment to show that two beams of light produced an interference pattern, a phenomenon associated with waves and not particles. The modern Dual Slit Experiment is a variation on Young's original experiment.

It is a simple experiment involving shining light through a pair of slits and onto a screen some distance behind them. If the light is monochromatic and coherent then the light falling on a screen placed some distance away forms an interference pattern. This much was demonstrated by Young and used to show that light had wavelike properties.

In the modern version, the intensity of the incident light is reduced, until photons are incident one at a time. The interference pattern still persists. This in itself is puzzling, but it is in the next steps that Feynman sought to demonstrate the strange nature of quantum behaviour.

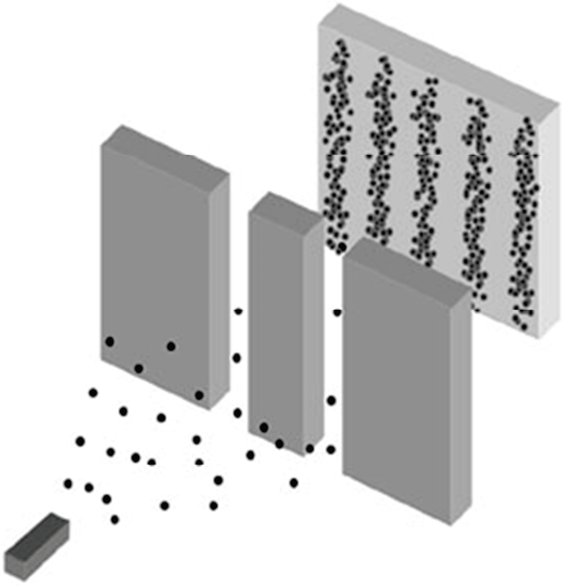

Figure 2-5 The Dual Slit Experiment

A detector is placed in the path of the light passing through one of the slits in order to determine through which slit the photon is passing. If the detector is tuned to detect every photon passing through the slit, then the interference pattern disappears. It doesn't matter whether the detector is placed in the path of the left hand slit or the right hand slit, the effect is the same. Indeed if detectors are placed in both paths, the effect is the same: the interference pattern disappears. Any detector placed in such a position as to detect all of the photons passing through either of the slits causes the interference pattern to disappear. It is almost as if the photons knew that an attempt was being made to detect their paths and they chose to foil the observer.

If the detector is desensitized such that it only detects a proportion of the photons, a so called "leaky" detector, then the interference pattern re-appears. Two leaky detectors, one on each path, similarly produce an interference pattern.

In one version of the QT explanation of this aspect of the phenomenon, detector is an observation process that detects particles and so the introduction of a particle detector causes the photon to reveal its particle like nature and to hide its wave like nature. Interference on the other hand is a phenomenon associated with waves and so when there are no particle detectors present, the photon reveals its wave like nature. Of course the main problem with this line of reasoning is that the rate of incident photons is one at a time, which is clearly a particle like property and so there should be no interference pattern at all.

## Nuclear forces

Scientists knew that atoms were made up of a central nucleus consisting of Neutrons and Protons surrounded by a number of electrons. The electrons appeared to be organized into groups or shells and it was the electrons in these outer shells which interacted with other atoms to give the atom its chemical characteristics.

The problem however lay in the nucleus. This consisted of a number of protons and neutrons. The neutrons do not present much of a problem since they were electrically neutral. The protons however do present a serious problem. Protons carry a positive charge and positive charges repel one another. Moreover the atomic nucleus was small; Rutherford had shown this to be the case. This meant that the positively charged protons must be in very close proximity to one another, and since electrical repulsion obeys the inverse square law, this meant that the forces of repulsion between atomic protons must be quite large.

Feynman's and Dyson's ideas that forces were mitigated by particles appeared to provide an answer. All that was necessary was to invent a particle and describe its properties and this would explain the means by which nuclear protons were bound together. The particle, called the Meson, was first predicted by Hideki Yukawa in 1935.

## The Standard Model

In 1964 two physicists, Murray Gell-Mann and George Zweig independently proposed that neutrons and protons were themselves composed of yet smaller particles called Quarks. Quarks combine to form Hadrons, the most common of which, and the most stable of which, are the neutron and the proton. Quarks can never exist in isolation, but only in combination with one another where they form hadrons.

According to the theory there are six types of quark referred to as *flavours*: up, down, charm, strange, top and bottom. Quarks are classified in pairs or generations according to their mass. Up and down quarks have the lowest mass of all the quarks, charm and strange are more massive and top and bottom more massive still. Heavier quarks rapidly decay into either up or down quarks and so these more massive quarks can only be produced in high energy collisions such as those found in particle accelerators or cosmic rays.

Quarks together with Leptons form the basis of what is now called the Standard Model. There are six types of Lepton, the electron, the electron-neutrino, the muon and muon-neutrino and the tau and tau-neutrino. As with quarks, leptons are divided in pairs into generations and the more massive muon and tau types rapidly decay into electrons and electron-neutrinos. The electron, muon and tau all have electric charge and the other leptons are electrically neutral.

The Standard Model also takes on board the idea that forces are transmitted as a result of the exchange of force carrier particles along the lines of QED. It identifies four fundamental forces, the strong force, the weak force, the electromagnetic force and gravity. The electromagnetic force and gravity both obey the inverse square law and so, at least in theory, operate over distances up to infinity. The weak and strong forces only operate over a very short range and so their effects are confined to the scale of the atom.

In the Standard Model forces are exerted by the exchange of force carrier particles all of which belong to a general class of particles called bosons. The strong force is carried by a particle called a Gluon, the electromagnetic force is carried by the photon and the weak force by a W and Z bosons. This leaves gravity and the suggestion is that there is another particle responsible for carrying gravity which has been called the Graviton.

While QED was a term coined to describe the interactions between particles on an atomic scale, the term Quantum Chromo-Dynamics (QCD) has been adopted to describe such interactions on a nuclear scale.

From these basic assumptions a whole plethora of particles and compound particles have emerged. They can be broadly classified into Fermions, which are themselves classified into Quarks and Leptons. Leptons include Electrons, Muons and Tauons as well as their three Neutrino variants, the Electron Neutrinos, Muon Neutrinos and Tau Neutrinos. All of these also occur as antiparticles forming a family called Antileptons.

The other family of particles, alongside the Fermions, is the Bosons, which can be sub-divided into Photons, Gluons, W and Z Bosons and it is postulated Gravitons and the Higgs boson.

Other particles are composites made up of combinations of these basic particles so the Hadrons include Nucleons such as the Proton and the Neutron as well as Mesons.

The Standard model also introduces the idea of Virtual Particles. Virtual particles are particles which exist for a short interval of time and occupy a limited trajectory in space governed by the uncertainty principle. Virtual particles are viewed as the quanta which describe the fields of the basic force interactions. Space is viewed as seething with these virtual particles which together with their antiparticles come into existence for a short interval of time and then disappear.

Virtual particles are used to describe the existence of fields such as the electric and magnetic fields. So for example the forces attracting the electron to the atomic nucleus are said to be mediated by an exchange of virtual photons.

Virtual particles are also said to be involved in particle decay. When an unstable sub atomic particle decays, it first forms a virtual particle as an intermediate step in the decay process.

## String Theories

The Standard Model goes some way to explaining the way that the universe works on an atomic scale, but it leaves unanswered a number of important questions. While it appears to unify three of the four forces that it describes, the weak, strong and electromagnetic forces, it ignores gravity as described by Einstein's General Theory of Relativity. String theories grew out of the need to combine the discrete world of quantum theory with the classical world described by general relativity.

The classical view of an elementary particle is as a point of zero or near zero size. Models based on such particles presented problems in that they yielded results which would, under certain circumstances, diverge to infinity. Mathematicians devised a trick to deal with this called renormalization. Renormalization introduces another set of infinities which cancel out the ones in the original equation, leaving a real residue which then forms the result.

It was found that if the elementary particles were regarded not as points, but as lines or strings, many of these problems disappeared. This led to the development of string theory. Particles and energy are regarded as one dimensional strings of around $10^{-33}$ m in length and held under tension with forces of the order of $10^{44}$ Newtons. The strings vibrate at resonant frequencies, and it is theses frequencies and their harmonics which describe the fundamental forces of nature and characteristics of the particles.

The first string theory, Bosonic string theory was developed in the 1960's. This required that space be composed of 25 spatial dimensions and one of time. Three of the spatial dimensions were those of height, width and length which are used to describe conventional spatial relationships. The remaining spatial dimensions existed on such a small scale that they cannot be detected directly.

Bosonic string theory had a problem in that it only predicted the existence of bosons, which are considered to be particles of force mediation within the Standard Model. It left out all of the fermions; particles which have mass. Furthermore it predicted that some particles had imaginary mass. These tachyons would travel at speeds faster than that of light and so violate Einstein's ideas about relativity.

This led in the 1970s to the development of what are known as superstring theories. Eventually no fewer than five such theories emerged, type 1, type 11A, type 11B, HO and HE. Each of these required only 9 spatial dimensions and one of time. In the mid 1990's Edward Witten at the Institute for Advanced Studies tried to show that these five string theories were all just different ways of viewing a single overarching theory which he called M Theory. M Theory requires an extra dimension over and above those of superstring theory, making 11 dimensions in total.

To date none of this has been demonstrated experimentally. Indeed there are many detractors who say that string theories are really non-theories because they make no predictions which are capable of experimental verification.

## Multiverse

The term Multiverse describes a number of different theories in which there are more than one universe, these include parallel universes, many worlds, alternate universes, quantum universes, parallel dimensions. Some of these theories date back to ancient times, but for the most part they have emerged in the latter half of the 20th century and probably as a result of a lecture given by Erwin Schrödinger in Dublin in 1952 in which he said:

*"Nearly every result [the quantum theorist] pronounces is about the probability of this or that or that ... happening—with usually a great many alternatives. The idea that they may not be alternatives but all really happen simultaneously seems lunatic to him, just impossible. He thinks that if the laws of nature took this form for, let me say, a quarter of an hour, we should find our surroundings rapidly turning into a quagmire, or sort of a featureless jelly or plasma, all contours becoming blurred, we ourselves probably becoming jelly fish. It is strange that he should believe this. For I understand he grants that unobserved nature does behave this way—namely according to the wave equation. The aforesaid alternatives come into play only when we make an observation—which need, of course, not be a scientific observation. Still it would seem that, according to the quantum theorist, nature is prevented from rapid jellification only by our perceiving or observing it ... it is a strange decision."*

There have been various attempts to classify these various theories so for example one type is seen simply as an extension of our existing universe, another in which the different universes exist with different physical and chemical constants. The *Many Worlds* interpretation asserts that our universe is the one with a particular probability, but that other possibilities exist and that each of these is seen in another universe. In one version every interaction between particles results in a splitting of the universe based on the probabilities of the various outcomes.

The Anthropic principle is an extension of this idea which holds that there are many universes and that we exist in this universe because out of all the possible universes this is the one where we can exist.

# Chapter 3 The Trouble with Quantum Theory

*"By denying scientific principles, one may maintain any paradox."*- Galileo Galilei.

Anselm of Aosta was a monk of the Benedictine order in the $11^{th}$ Century. He rose through the ranks of the church to become Archbishop of Canterbury and eventually a Saint. He is remembered for establishing Canterbury as the principal seat of the English church. Anselm was of the opinion that belief in God was more than just an article of faith but was also rational. He sought to show this by proving the existence of God using logic. His logic was convoluted, but the essence of his argument was that if we postulate that God exists then we can, through a series of logical steps, prove that God exists. Such a circular argument is of course invalid. It is simply not the case that by assuming something to be true you can prove that therefore it must be true. And so belief in God remains an article of faith.

A case in point is that of quantum entanglement. Quantum entanglement is said to occur in certain processes when two particles are created at the same time and have related characteristics. Quantum theory asserts that these characteristics are not manifest until the particle is subject to an observing process, in the interim both particles are said to exist in a quantum indeterminate state. However when one of the particle is observed and its characteristics are revealed, the other particle assumes its version of the characteristic, instantly and over any distance. This violates Einstein's theory of relativity which holds that nothing can travel faster than light.

There is however another possible explanation. If particles are not subject to quantum uncertainty and carry with them all of their characteristics in a manner which is deterministic, then no such instant communication need take place. This was Einstein's view and is the subject of the so called EPR thought experiment.

The matter could easily be resolved if was possible to exploit this instant communication in a way that allowed information to be transmitted. If information could be transmitted at a speed faster than light then there could be no doubt that entanglement was a real phenomenon. Unfortunately the definition of an observing process is such that it precludes such a possibility. A particle is said to have been subject to an observing process if that process would have allowed information to be transmitted, which means that information can never be transmitted based on entangled particles.

Which of these two possible explanations you accept comes down to a matter of belief. If, like Einstein, you believe that action at a distance is impossible, then you accept that particles are objectively real and all of their properties are deterministic. If on the other hand, you agree with Niels Bohr, that particles exist in a state of quantum uncertainty until they are observed then you accept that reality is somehow subjective or at best probabilistic. And so belief in quantum entanglement remains an article of faith.

The debate over objective and probabilistic reality has a knock on effect regarding the Heisenberg uncertainty principle which provides us with a similar dilemma. Heisenberg stumbled into the existence of uncertainty when he tried to manipulate the velocity and momentum of the electrons in the hydrogen atom by tabulating them. In effect he had rediscovered matrix algebra. This had been around for some time, but was mainly confined to mathematicians and not physicists. In matrix arithmetic multiplication is not commutative, in other words A times B is not the same as B times A. In this case the difference represented the uncertainty with which the properties of the particle could be known.

Heisenberg sought a physical explanation and eventually came up with the idea that it was not possible to measure both velocity and momentum to arbitrary accuracy at the same time because the tools available, electrons and photons, were of the same order of magnitude as the electrons being measured.

Niels Bohr however had a different idea, one which fitted with his ideas about probabilistic reality. He reasoned the particles themselves were possessed of inherent uncertainty; that they existed in some sort of nether state until they were observed. Eventually Heisenberg himself was persuaded to this opinion.

Once again, which of these two explanations you accept comes down to a question of belief. If you believe in probabilistic reality then this provides you with a satisfactory explanation, equally if you believe in objective reality then the explanation involving the size of the measurement tools is equally valid.

What Anselm's failed proof illustrates is that neither position can be proven one way or the other because the both depend on their respective assumptions.

These ideas are not unconnected with one another, so for example if you accept the idea of intrinsic uncertainty then you have to accept quantum entanglement. Quantum entanglement can be said to depend upon intrinsic uncertainty. There is a lineage of such ideas which we can trace back through the history of the development of quantum theory which leads back to an underlying assumption.

The assumption in question was originally proposed by John W Nicholson (1881-1955). He observed that the units of Planck's constant were the same as those for angular momentum. So he reasoned that the orbital angular momentum of electron in the hydrogen atom was related to Planck's constant. He went one step further and argued that the orbital angular momentum could only take on values which were an integer multiple of Planck's constant. He thus "quantized" angular momentum. Niels Bohr then used this assumption to develop his mathematical model for the hydrogen atom.

This idea that angular momentum is quantized is a cornerstone of quantum theory. Not only did Bohr use it to create a mechanical model for the atom, but so did Louis de Broglie and Erwin Schrödinger. De Broglie argued that the electron could be viewed as a wave, and showed that his waves formed a harmonic series when viewed in the context of the atom. However his waves were the result of assuming that the wavelength is related to Planck's constant, which in turn he assumed to be a quantum of angular momentum in exactly the same way as Bohr. De Broglie's harmonics are therefore pre-ordained since the total angular momentum is said to be an integer multiple of Planck's constant. Schrödinger then developed a set of equations to describe de Broglie's waves and this too incorporates Nicholson's postulate. Indeed the simplest way to derive Schrödinger's wave equation is to substitute quantized angular momentum into the canonical form of an undamped second order differential equation.

Given that quantum theory rests on the assumption that angular momentum is quantized it seems extraordinary that no-one has ever tried to prove that this is the case. It is true that de Broglie did spend some 40 years trying to find what he described as a "causal link"[iii] between his wave mechanics and classical mechanics. He was not able to do so. The best he could ever manage was to conclude that there were two solutions at the same time, but he was not able to convince the likes of Bohr who stuck to their idea of probabilistic reality. However he never let go of this underlying assumption, which is perhaps the reason that he failed.

Anselm's "proof" or rather its failure to prove the existence of God can provide us with some important clues as to how we must go about proving Nicholson's assumption and so validating quantum theory.

The fact that quantum theory rests on the assumption that angular momentum is quantized means that it is not possible validate quantum theory and prove that angular momentum is quantized by consideration of quantum theory itself, since everything that comes after is dependent on the said assumption. This means that there is no way to obtain such a proof by relying on Bohr's model of the atom, on de Broglie's wave particle duality or Schrödinger's wave equation or anything that depends on any of these. Equally no claims about the accuracy of calculations based on any of these ideas can conclusively prove that angular momentum is quantized; there always exists the possibility that some other form of quantization would lead to exactly similar results. If we cannot prove the validity of the assumption from the perspective of quantum theory then the only alternative is to base such a proof on classical mechanics.

A problem arises that if we try to do so using classical Newtonian mechanics, while we obtain a stable atom, the resulting atom has only a single energy level. Such an atom would be incapable of absorbing or emitting photons. In order to prove quantum theory or indeed develop a valid quantum theory it is necessary that we somehow modify Newtonian mechanics in such a way as to present us with an infinite number of energy levels and in such a way that the differences between energy levels matches those of the empirically derived Rydberg formula.

This is exactly what Niels Bohr tried to do when he derived his eponymous model for the hydrogen atom. He argued that the model presented by Newtonian mechanics was incorrect because it did not take account of the idea that angular momentum was quantized into units of Planck's constant. By modifying classical Newtonian mechanics in this way Bohr was able to derive a model which matched the energy levels of the Rydberg formula.

The problem is that this idea of quantizing angular momentum is simply a conjecture. What is needed is a proof. This can only take the form of a modification of Newtonian dynamics which leads to a mechanism that causes the quantization to take place.

While it is not possible to prove that a postulate is true based on the truth of the assumption, the obverse is not the case. It is possible to disprove postulate by first assuming that it is true and then showing that this leads to a contradiction, a paradox or an absurdity. Such proofs are referred to as *Reductio ad Absurdum* and are commonplace throughout mathematics and date back to ancient times. A good example is Euclid's proof that the square root of two is irrational. Euclid first postulates that the square root of two **is** rational and then shows that this leads to a contradiction and hence that it cannot be true. Indeed the so called 'scientific method' is itself based on the underlying logic of *reductio ad absurdum*. This requires that we first put forward an assumption or postulate and based on this develop a model. The model is then tested against experimental or empirical data and if it fails the postulate underpinning the model is deemed to be incorrect. In this case the absurdity is the failure of the experiment used to test the model, but otherwise the logic is essentially the same.

The assumption that angular momentum is quantized is just such a case where we can apply the logic of *reductio ad absurdum*. Using this assumption we can derive Bohr's model for the hydrogen atom, however the model requires that changes in the energy level of the atom occur when the electron moves from one orbit to another without ever occupying anywhere in between the two orbits. This was quickly dubbed the "quantum leap" and is clearly a physically impossibility. It was recognized that this was sufficient to render the Bohr model invalid, but what was not recognized at the time, nor indeed since, is that it means that the assumption that lies behind it is also invalid. That is angular momentum cannot be quantized, at least not in the way that Nicholson and Bohr describe.

To get around this slight inconvenience, physicists will often say that the Bohr model is obsolete and that our view of the world has moved on, that reality is not what it seems, that particles do not exist until they are observed etc. However it is a false premise to proceed along these lines when the underlying assumption has already been shown to be false. What all of these circumlocutions amount to is simply another way of trying to describe the quantum leap but without using the words "quantum" or "leap". The electron for example is described as a wave function which "collapses" when it is observed to reveal the position or the velocity of the electron itself, which is now viewed as being in its particle form rather that its wave like form. The process of collapsing is just another way of describing the instantaneous transformation of the electron into a particle which then exists at some point in space by denying that it existed as a particle prior to this transformation. In reality all such descriptions are simply euphemisms for the quantum leap.

The fact that the Bohr model leads to the absurdity of the quantum leap clearly demonstrates that the assumption that angular momentum is quantized is false. To then argue that it is correct to assume that angular momentum is quantized if we change to viewing the electron as a wave rather than as a particle is equally invalid. It is akin to telling Euclid that the square root of two is a rational number if we change the context in which we view it. It is logically inconsistent to accept that the quantum leap is a physical impossibility and to still assert that angular momentum is quantized. Once a postulate is shown to be invalid it remains irredeemably invalid whatever the context.

We do however know that something is quantized and that this is connected with the discrete energy levels of the atom. This is because there is a relationship between the various energy levels which is linked to a harmonic series. In the case of de Broglie these harmonics are thought to be related to the orbit of the electron as standing waves, existing as multiples of the base orbital frequency but the presence of a harmonic series transcends that limited view.

Wherever we see a harmonic series in nature there must be an accompanying sampling process or quantization taking place. This comes about when we consider the Fourier representation of a harmonic series. The Fourier representation of a harmonic series is unity at the base or fundamental frequency and at every integer multiple of the base frequency and has a value of zero everywhere else on the $j\omega$ axis. For real entities this extends along both positive and negative $j\omega$ axes to infinity. Such a function is commonly referred to as Dirac Comb. The Fourier transform of a Dirac Comb is itself another Dirac Comb, only this time in either the time domain or the space domain. Such a Dirac comb is a sampling function or, if you prefer, a quantization function.

All of which begs the question that if angular momentum is not quantized but we know that something must be quantized, what exactly is the variable of quantization inherent in the structure of the atom?

A possible clue lies in the timeline of events leading up to Bohr's model. For the better part of 250 years it was assumed that Newton's version of classical mechanics was complete. Then in 1905 Einstein showed that it was not, he showed that time and distance and mass varied according to the relative velocity of the observer and the observed. Bohr's model was first published seven years later in 1912 and even at the time was acknowledged to have problems. Bohr chose to ignore relativity, which at the time was not well understood and even rejected by some physicists. So just at the time when we needed to investigate the idea that Newtonian mechanics were incorrect, the idea that one aspect of them is incorrect emerged. Bohr simply overlooked this and sought to introduce another change to Newtonian mechanics. Given the timing of the discovery of relativity and the attempts to describe the dynamics of the atom, it seems highly likely that relativity lies at the heart of any misconceptions we might have about classical mechanics.

In summary: quantum theory can only be validated from the perspective of classical theory and not from within quantum theory itself. This means that there has to be something wrong in our current understanding of classical (Newtonian) mechanics, since as it is currently understood the mechanics of the atom simply do not work. The presence of a harmonic series in the mechanics of the atom means that something is sampled or quantized. Niels Bohr sought to suggest it is angular momentum that is quantized into units of Planck's constant. However this assumption leads to an absurdity, the quantum leap, and so cannot itself be valid. Despite this the assumption has been carried forward without question into subsequent models of the atom. This means that we must seek an alternative explanation, either some other change to classical mechanics, which supports the idea that angular momentum is quantized or, much more likely, based on quantization of some other variable.

We will ultimately gauge the success of any new postulates and models for the atom based on the scientific method, which requires that whatever we postulate as the deficiency in classical mechanics is tested by experiment. In the meantime we can suggest a few pointers to a successful model. First, of course, it must have an infinite number of stable states whose differences return the correct values for the energy levels of the atom by matching those predicted by the Rydberg formula. The dynamics must be such that the orbital radius of the electron remains the same in all the various energy levels, since anything other than this would require the existence of the quantum leap or its latter day equivalent. It should also address the issues of which Bohr was unaware or chose to ignore; these include an explanation for the existence and the value of the Fine Structure Constant, an explanation for the existence of and value of Zero Point energy, an explanation as to why the orbiting electron does not emit synchrotron radiation and it must be seen to fully take into account the effects of relativity. Finally, since all of the variables involved are continuous, it should provide an explanation as to how exactly such continuous variables can interact so as to only be able to take on the discrete values. In effect this is the mechanism which underlies quantization and is the causal link that de Broglie was unable to find.

The challenge that physics needs to address is first to reject the idea that quantum theory is correct but incomplete and recognize that quantum theory is and was fundamentally flawed from the outset and to then seek out a more credible explanation.

# Chapter 4 The Hydrogen Atom

*"To understand hydrogen is to understand all of physics"* Victor Weisskopf

## How far is it around the world?

At first sight it may seem strange to begin a discourse on the hydrogen atom by posing a question about the size of the earth, but hopefully all will become clear. So the question I want to pose is how far is it around the world? More precisely, if I was to set off from a fixed point on the surface of the earth and follow a great circle route, how far would I need to travel in order to return to my point of departure?

The circumference of the earth is some 40,000 km, so at first site it would seem that the answer to the question is 40,000 km, but this is only a partial answer. Nobody said that I had to complete the journey in a single orbit and so 80,000 km would be an equally valid answer as would 120,000 km and so on. In general we could write a simple formula to describe all of the possible such distances:

$$d = 40000n \qquad \text{Equation 4-1}$$

Where $n = -\infty \dots -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, \dots \infty$

It is important to understand that all of these solutions are correct at any one time. Every time I pass over the departure point it is correct to say that I have travelled 40,000 km, 80,000 km, 120,000 km etc. since I was here before. Furthermore since the starting point and endpoint can be chosen arbitrarily anywhere along the great circle route, it is true for any starting point along the chosen path. So no matter where I am on the great circle it is correct to say that I have travelled 40,000 Km, 80,000 Km, 120,000 Km etc. since I was there before.

This phenomenon, where there are multiple, equally valid, solutions to a mathematical problem, is referred to as 'Aliasing' and is frequently encountered in sampled data systems. Each of the values is an alias for the so called base value.

However even this falls short of a complete answer because in our imaginary orbiter we can travel as fast or as slow as we like. The distances we have measured so far are measured at a low speed where the effects of relativity are negligible. But if we were to travel much faster, at close to the speed of light, then the distance we perceive travelling in the orbiter is reduced or foreshortened.

## Special Relativity

It was Einstein who gave us our present understanding of how relativity affects distance. He did so initially for objects traveling at constant speed in what is now called Special Relativity. Later on he was to deal with objects that are accelerating or decelerating in what has come to be known as General Relativity. Here we need only concern ourselves with the special case since our orbiter is assumed to be traveling at constant speed, that is it has constant tangential velocity.

What Einstein showed was that distances measured in the direction of travel are foreshortened or compressed, those at right angles to the direction of travel are unaffected. The extent of this foreshortening is governed by a factor called the Lorentz factor. The Lorentz factor is usually referred to as Gamma (γ) given by a simple formula and tells us the extent of foreshortening for a given speed.

$$\gamma = \sqrt{\frac{1}{1 - \frac{v^2}{c^2}}}$$ Equation 4-2

where *c* is the speed of light and *v* is the velocity of the moving object

For example, if I was to circumnavigate the earth at 86.6% of the speed of light, where Gamma has a value of 2, then I would perceive the distance around the earth for a single orbit as exactly half that seen by a stationary or slow moving observer, that is I would perceive the distance around the world for a single orbit as 20,000 Km. Of course in general he distance around the earth would still be subject to aliasing and have multiple values, in this case of 20,000 Km, 40,000 Km, 60,000 Km and so on.

The dynamic range of Gamma extends from 1, at very low speeds, all the way to infinity at the speed of light. In effect this means that, by suitable choice of the orbital velocity and the number of orbits, we can contrive the distance from point A to point A to be anything we care to make it.

So the correct answer to the question: How far is it around the world? is;

How far do you want it to be?

### How far *do* you want it to be?

Suppose we want to choose a particular distance and then to explore all of the possible strategies for achieving that it. If, for example, we want to find all the possible ways of travelling from A to A while covering a distance of 400 Km. One possible strategy would be to complete one orbit of the earth at speed where Gamma has a value of 100. That would be at a speed of 99.995% of the speed of light. The next viable solution would be to complete two orbits at a speed where Gamma equals 200, that is at 99.99875% of the speed of light. The next would be three orbits at Gamma = 300 and so on. In general we can summarize this as

$$\gamma = 100n$$ Equation 4-3

For $n = 1,2,3, \dots \infty$

There are thus an infinite number of ways in which we could contrive to go around the world while covering a distance of 400 Km. Once again the distances around the world are aliased. For example when $n = 1$ the distances are 400, 800, 1200… km, when $n = 2$ they are 200, 400, 600… km and when $n = 3$ they are 133, 266, 400, 533…km. For each value of *n* all of the respective values are valid, it is just that we are choosing the particular alias where the distance equals 400 km. the situation is summarized in Table 4-1 which shows the possible distances for values of Gamma which are an integer multiplier of 100 and for *n* orbits. The principle diagonal is always equal to 400 km, our chosen distance.

| n / Gamma | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 100 | 400.00 | 800.00 | 1200.00 | 1600.00 | 2000.00 | 2400.00 | 2800.00 |
| 200 | 200.00 | 400.00 | 600.00 | 800.00 | 1000.00 | 1200.00 | 1400.00 |
| 300 | 133.33 | 266.67 | 400.00 | 533.33 | 666.67 | 800.00 | 933.33 |
| 400 | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | 600.00 | 700.00 |
| 500 | 80.00 | 160.00 | 240.00 | 320.00 | 400.00 | 480.00 | 560.00 |
| 600 | 66.67 | 133.33 | 200.00 | 266.67 | 333.33 | 400.00 | 466.67 |
| 700 | 57.14 | 114.29 | 171.43 | 228.57 | 285.71 | 342.86 | 400 |

Table 4-1 Distances under relativity

## Orbital frequency

An often overlooked aspect of special relativity is the affect it has on frequency as perceived by the two different observers. This comes about because as well as affecting distance, relativity also affects time with different observers recording different times depending on their respective points of view. In the example above; for a stationary observer the orbital period remains more or less the same no matter which of the various strategies we choose. The orbital circumference is 40.000 Km and the speed of the orbiter varies from 99.995% c when $n = 1$ to approaching 100% c when $n = \infty$. The time taken to complete one orbit is therefore also substantially constant at 133.425 msecs. The orbital frequency as experienced by the stationary observer is simply the reciprocal of the orbital period and so is 7.5Hz.

The situation for the moving observer is somewhat different. At 99.995% c, where Gamma = 100, time is slowed down by a factor of 100, so the orbital period experienced by the moving observer is 1.33425 msecs. The orbital frequency at this particular speed will be seen as 750Hz. In general the orbital frequency will be multiplied by Gamma with respect to that seen by the stationary observer and so will form a harmonic series as Gamma takes on successive values in the series 100n.

It is left to the reader to work out the various strategies for circumnavigating the earth while covering a distance of 291.9km.

Having looked at the effects of relativity on an object orbiting around the earth, it is time to consider things on a much smaller scale and to look at an electron in orbit around the atomic nucleus.

## The Rydberg Formula and Series

During the 18$^{th}$ and 19$^{th}$ century it was discovered that when shining white light through a gas the resulting spectrum contained dark lines. These were located at wavelengths which were specific to the type of gas and later formed the basis of spectroscopy. Work by a Swiss mathematician and numerologist, Jakob Balmer (1825-1898), led to a formula that linked six of the various wavelengths of these dark lines for hydrogen. Using his formula Balmer was able to predict a seventh spectral line, which was subsequently found by the Swedish physicist Anders Ângström (1814-1874). However Balmer's formula did not predict all of the spectral lines of hydrogen. The Swedish physicist Johannes Rydberg (1854-1919) was able to generalize Balmer's formula in such a way that his new formula was able to predict all the spectral lines of hydrogen.

The atom is seen as occupying one of a number of discrete energy states, that energy being carried by the orbiting electron. Transitions between a high energy state and a low energy state result in the release of energy in the form of a photon. Those from a low energy state to a high energy state are the result of energy being absorbed from an incident photon. The Rydberg formula tells us what the wavelengths of the photons will be for any given transition.

The Rydberg formula is most often quoted as:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$ Equation 4-4

It is important to understand that Rydberg's formula is based on the results of experiment and observation. It does not seek to explain the spectral lines, rather it seeks to describe them and it is complete, that is it describes objectively all of the spectral lines for hydrogen. The Rydberg formula deals only with the differences in energy between the various energy states. It has nothing to say about the absolute value of energy carried by the orbiting electron. The Rydberg formula forms a sort of gold standard against which any successful model for the hydrogen atom may be tested.

As quoted above, the Rydberg formula uses the somewhat obscure wave number (1/λ). It can be expressed more usefully in terms of the energy emitted or absorbed when a transition takes place. This is achieved by multiplying both sides of Equation 4-4 first by *c*, the velocity of light and then by *h*, [3] Planck's constant. Gathering terms and substituting the analytical value for $R_H$ gives:

$$E_{n_1,n_2} = \frac{1}{2}mc^2\alpha^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$ Equation 4-5

Where *m* is the rest mass of the electron and *α* is a constant known as the Fine Structure Constant (Alpha) which was first described by Arnold Somerfield in 1916.

The Rydberg formula tells us the amount of energy released when the electron orbiting the hydrogen nucleus makes a transition from the $n_1^{th}$ energy state to the $n_2^{th}$ energy state, or conversely the amount of energy absorbed if the transition is in the other direction. By letting $n_2 = \infty$ we obtain the energy associated with a transition to or from the maximum possible energy state of the electron and its energy in the $n^{th}$ energy state, that is we obtain the *energy potential*[4] of the atom in the $n^{th}$ energy state. Doing so leads to the Rydberg Series

[3] Note that this is the long form of Planck's constant

[4] Note that energy potential is not the same as potential energy.

$$E_n = \frac{1}{2}mc^2\frac{\alpha^2}{n^2}$$ Equation 4-6

The Rydberg Series is particularly useful because it allows us to easily calculate the energy associated with any energy transition simply by taking the difference between two values in the series.

$E_n$ is the energy potential of the $n^{th}$ energy state and represents the difference between the energy of the electron in the $n^{th}$ energy state and the most energetic energy state possible, the ∞ energy state or *energy ceiling* of the atom. The energy ceiling of the atom represents the maximum energy that an orbiting electron could ever possibly have. It is reasoned here that, since nothing can ever travel faster than the speed of light, the energy ceiling is limited by the speed of light to be

$$E_{max} = \frac{1}{2}mc^2$$ Equation 4-7

It is also reasoned here that the electron orbiting the atomic nucleus must do so at the constant radius, that is to say at the same orbital radius for every energy state. Anything other than this would imply the existence of the physically impossible 'quantum leap', the ability to move from A to B without occupying anywhere in between. This in turn means that there can be no change in potential energy when the electron transitions from one energy state to another energy state. All changes in energy must therefore be kinetic in nature. Hence the energy of the electron in the $n^{th}$ energy state must be

$$E_{vn} = \frac{1}{2}mv_n^2$$ Equation 4-8

where $v_n$ is the orbital velocity in the $n^{th}$ energy state.

It is the difference between the energy ceiling and the energy in the $n^{th}$ energy state that is expressed in the Rydberg series, so by definition

$$E_n = E_{max} - E_{vn}$$ Equation 4-9

$$\frac{1}{2}mc^2\frac{\alpha^2}{n^2} = \frac{1}{2}mc^2 - \frac{1}{2}m\,v_n^2$$ Equation 4-10

Equation 4-10 can be simplified to give

$$c^2 - v_n^2 = c^2\frac{\alpha^2}{n^2}$$ Equation 4-11

And further simplified to give

$$\sqrt{\frac{1}{1-\frac{v^2}{c^2}}} = \frac{n}{\alpha}$$ Equation 4-12

The term on the left hand side of Equation 4-12 will be recognized from Equation 4-2 as the Lorentz factor Gamma (γ) and hence

$$\gamma_n = \frac{n}{\alpha} \qquad \text{Equation 4-13}$$

Since $1/\alpha \; = \; 137.036$ we can rewrite Equation 4-13 as

$$\gamma_n = 137.036\, n \qquad \text{Equation 4-14}$$

Where $n \,=\, 1{,}2{,}3{,}4{,}5 \ldots \infty$

From this we see that the variable of quantization is the Lorentz Factor, Gamma, which takes on values that are integer multiples of the inverse of the Fine Structure Constant.

By setting *n=1* in Equation 4-14 we can calculate the orbital velocity in the base energy state using the equation for Gamma; Equation 4-2 and 137.036 as the value of Gamma. This gives us an orbital velocity close to the speed of light at 99.9973372% of c. This means that the dynamic range of the orbital velocity between the lowest or base energy state and the energy ceiling of the atom is extremely small.

## The Fine Structure Constant

Equation 4-14 also provides us with a physical understanding of the hitherto mysterious Sommerfeld Fine Structure Constant, Alpha, (α). It is seen as the reciprocal of the value of Gamma for the orbital speed of the electron in the base energy state. Successive energy states being associated with integer multiples of this value. In other words it is the extent to which the orbital circumference is foreshortened for the orbiting electron when in the base energy state.

Alpha can be calculated analytically based on the value of other well-known constants and is given by

$$\alpha = \frac{Kq^2}{\hbar c} \qquad \text{Equation 4-15}$$

But from Equation 4-13

$$\alpha = \frac{n}{\gamma} \qquad \text{Equation 4-16}$$

Hence

$$\frac{Kq^2}{\hbar c} = \frac{n}{\gamma} \qquad \text{Equation 4-17}$$

And

$$\hbar = mcR \qquad \text{Equation 4-18}$$

Hence

$$\frac{Kq^2}{R^2} = \frac{mc^2}{R}\frac{n}{\gamma} \qquad \text{Equation 4-19}$$

However, although this equation is in balance, since the electron is travelling at near light speed, the mass terms in Equation 4-18 and Equation 4-19 should each be multiplied by Gamma. In order to preserve the integrity of these two equations therefore it is necessary to introduce a second factor Gamma into the denominator of each equation

$$\hbar = m\gamma\, R\frac{c}{\gamma} \qquad \text{Equation 4-20}$$

$$\frac{Kq^2}{R^2} = \frac{m\gamma\, c^2}{R}\frac{n}{\gamma^2} \qquad \text{Equation 4-21}$$

We are forced to ask where this additional Gamma term comes from and what its physical significance is. None of the terms on the Left Hand Side of these equations is affected by relativity. On the Right Hand Side the radius term *R* is not affected by relativity and we have just accounted for the mass term. This can only mean that these additional Gamma terms are associated with the orbital velocity term. Furthermore the exponents of the Gamma and velocity terms match in the two equations.

In physical terms this means that the effective orbital velocity as far as angular momentum, centripetal/centrifugal force and acceleration are concerned is the actual velocity divided by Gamma.

The idea of a velocity term which is affected by relativity tells us what causes the atom to take on discrete levels of energy, but it still does not tell us why the variable Gamma should be quantized in this way. Gamma is known to vary continuously between one and infinity as the velocity increases, so we need to understand why it only takes on these certain discrete values in the context of the dynamics of the atom. That is we need to understand the mechanism which causes Gamma to be quantized.

## Relativistic Velocity

The conventional wisdom is that both the stationary observer and the moving observer agree on their relative velocity, that velocity is invariant with respect to relativity.

In order to measure the speed of an object moving at close to the speed of light in real time it is necessary for a stationary observer to use two clocks, at least conceptually. One clock must be set up at the point of departure and another at the point of arrival. The two clocks must then be synchronized before the measurement can begin[5]. The time that the moving object leaves the point of departure is noted on the departure clock and the time of its arrival is noted on the arrival clock. At least one of these measurements must then be transmitted to the other location before the difference can be taken and the speed

[5] Since the two clocks are stationary with respect to one another they will run at the same rate and therefore it is possible to synchronize them.

calculated. Any attempt to measure such a velocity in real time is thwarted by the fact that the clock would have to move with the moving object and so would itself be slowed down due to the effects of relativity.

There is however one circumstance where this is not the case, where it is possible to measure velocity using a single clock; that is when the moving object is in orbit. Under this circumstance the object returns to its point of origin once per orbit and so it is possible, conceptually at least, to measure its orbital velocity in real time using a single clock provided the measurement is made over a complete orbit. It is only meaningful to do so over one or more complete orbits. The restriction that orbital period can only be measured or experienced over a whole number of complete orbits amounts to a sampling process and sampling processes lead to aliasing.

Based on this it is possible to define a velocity term which straddles the two domains; that of the stationary observer and that of the moving electron. Such a velocity is calculated as the distance as it is measured by the moving observer, and foreshortened by relativity, divided by the time as measured or experienced by the stationary observer. For obvious reasons I have called this type of velocity 'Relativistic Velocity' as opposed to the Actual Velocity or invariant velocity. It might also be sensibly called 'Coupling Velocity' since it couples the domains of the static and moving observers. When orbital velocity is measured over a complete orbit, the distance value which contributes to the measurement is subject to aliasing as described earlier. The orbital period however is measured in the domain of the stationary observer and so is not subject to aliasing. This means that the distance travelled during the orbital period can be regarded as having multiple values and so therefore does the Relativistic Velocity.

It is postulated here that it is this Relativistic Velocity that applies to phenomena associated with objects in orbit, specifically to centrifugal and centripetal force and acceleration and to angular momentum. Relativistic Velocity has the important characteristic that it gets smaller as the actual velocity approaches the speed of light.

$$v_r = \frac{D}{t} = \frac{d}{\gamma t} = \frac{v}{\gamma}$$ Equation 4-22

## Synchrotron Radiation

When an electrically charged object follows a curved path, it normally radiates a type of radiation called *Synchrotron Radiation*. However the electron orbiting the hydrogen nucleus does not appear to do so. If it did, the electron would lose energy and eventual its orbit would decay and it would spiral into the nucleus. Clearly this does not happen and so we can conclude that the orbiting electron does not emit such radiation.

Although the two Gamma terms in Equation 4-20 would be cancelled to give us the orbital radius, their presence combines to effectively constrain the orbital radius to this value. As Gamma gets larger the scope for the radius to deviate gets less. This provides us with an explanation as to why the orbiting electron does not decay due to the emission of synchrotron radiation. Rather than being driven in any conventional manner to adopt a circular orbit, here the electron is constrained by the combined effects of relativity and Planck's constant to always have a constant value. It is as if the electron is orbiting on a hard surface, one which it cannot penetrate and from which it cannot depart. This is more akin to the way in which we view general relativity, where objects move in straight lines on a curved space.

## Force Balance

As the Actual Velocity increases, getting ever closer to the theoretical speed of light, the Relativistic Velocity decreases and hence the centrifugal force also decreases eventually reaching a point where it matches the electrostatic force tending to pull the electron towards the nucleus. The two forces first come into balance when the Actual velocity is such that Gamma equals 1/Alpha or roughly 137.036. That is when the Relativistic Velocity is equal to $c\alpha$.

The situation is shown graphically in Figure 4-1 which shows the centrifugal force derived from the Relativistic Velocity plotted against Gamma, highlighted in black. It also shows the electrostatic force acting between the electron and the proton (in red) which is independent of Gamma and therefore constant. The two curves intersect when Gamma is equal to $1/\alpha$ that is when it equals approximately 137.03 at which point the orbital circumference as perceived by the electron has a value of $2\pi R\alpha$ as the first of its infinity of aliases.

However as we have seen, the orbital path length is multivalued due to the effects of aliasing and so the Relativistic Velocity must similarly have multiple values. If the Relativistic Velocity is considered to have multiple values then so too does the centrifugal force and which is derived from the Relativistic Velocity. Also shown in Figure 4-1 are the aliases for the centrifugal force, which are in turn derived from the aliases for the Relativistic Velocity. Here the first nine aliases of the derived centrifugal force are shown with respect to Gamma. Only the first is highlighted, corresponding to the base energy state of the atom but all of the aliases are equally valid at the same time and any one of them which has the correct value will result in a stable atom.

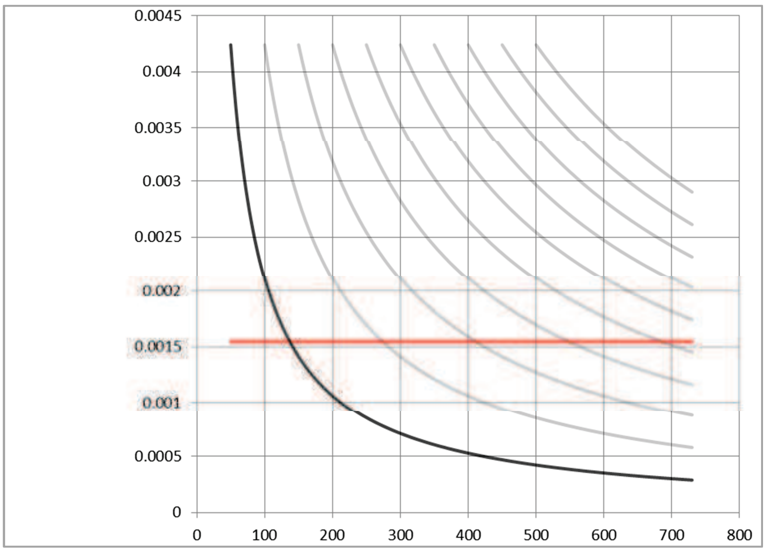


Figure 4-1 Aliased force vs Gamma

Figure 4-2 shows the situation as the Actual Velocity increases; the alias for the Relativistic Velocity associated with *n=2* will eventually have a value such that the forces are again in balance, corresponding to the second energy state at which point the orbital circumference as perceived by the electron has a value of $2\pi R\alpha$ as the second of its infinity of aliases. The situation will repeat for each successive energy state.

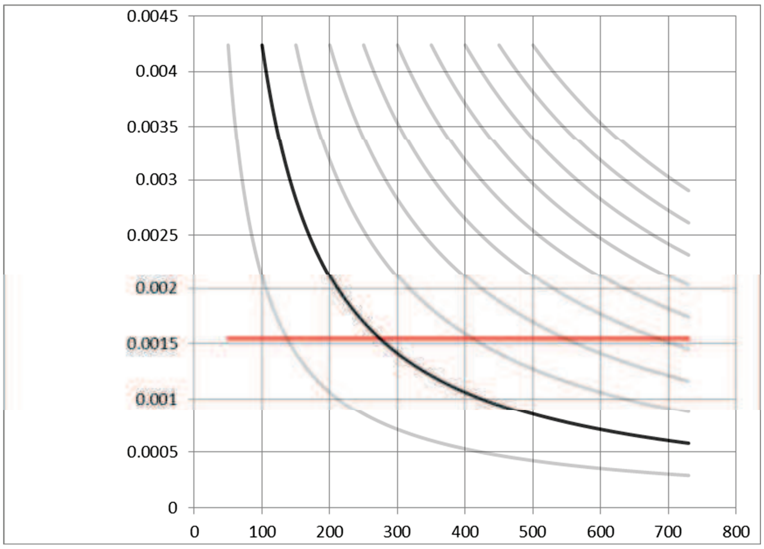

Figure 4-2 The second energy state

The situation is somewhat analogous to the detents in a mechanical gearbox.

## Energy Levels

We can calculate the values of Actual orbital velocity for each energy state since.

$$v_n = c\sqrt{1 - \frac{\alpha^2}{n^2}}$$ Equation 4-23

And the energy is $1/2mv_n^2$

The differences between the energy in the n^th state and the energy in the ∞ state forms the Rydberg series, from which we can calculate any of the other series for the hydrogen atom. These values are given in for the first few energy levels in Table 4-2.

| n | $v_{n\ /c}$ | $1/\gamma_n$ | $\omega_n$ | Energy eV | ΔEnergy eV |
|---|---|---|---|---|---|
| 1 | 0.999973371 | 0.007297559 | 7.76324511E+20 | 255485.925 | 13.607 |
| 2 | 0.999993343 | 0.003648853 | 7.76340016E+20 | 255496.130 | 3.402 |
| 3 | 0.999997041 | 0.002432577 | 7.76342887E+20 | 255498.020 | 1.512 |
| 4 | 0.999998336 | 0.001824435 | 7.76343892E+20 | 255498.682 | 0.850 |
| 5 | 0.999998935 | 0.001459549 | 7.76344357E+20 | 255498.988 | 0.544 |
| 6 | 0.999999260 | 0.001216291 | 7.76344610E+20 | 255499.154 | 0.378 |
| 7 | 0.999999457 | 0.001042536 | 7.76344762E+20 | 255499.255 | 0.278 |
| 8 | 0.999999584 | 0.000912219 | 7.76344861E+20 | 255499.320 | 0.213 |
| 9 | 0.999999671 | 0.000810861 | 7.76344929E+20 | 255499.364 | 0.168 |
| 10 | 0.999999734 | 0.000729775 | 7.76344977E+20 | 255499.396 | 0.136 |
| | | | | | |
| ∞ | 1.000000000 | 0.000000000 | 7.763451838E+20 | 255499.532 | 0.000 |

Table 4-2 Energy level, velocity, frequency energy and Δenergy

It is precisely because the Relativistic Velocity decreases with increasing actual velocity combined with the phenomenon of aliasing that the variable Gamma is quantized and the atom can enter a succession of stable states.

## The Morphology of the Atom

In the Bohr model and all the other models which are based on the quantization of angular momentum, the size of the atom varies with its energy level. In the case of the Bohr model the orbital diameter increases as the square of its energy level, in the case of de Broglie's idea of the wavelength, the orbital diameter associated with each harmonic increases linearly with the energy level. Were this to be the case it would have some interesting consequences. Since there is no upper limit to the energy level of the atom it means that there is no upper limit to its diameter. Under these circumstances it is perfectly possible to have an atom with a diameter of say a meter or even a kilometer.

Under such circumstances it is impossible to imagine how the atom could maintain the same set of physical and chemical properties as its energy level changes. The physical and chemical properties of the atom depend intimately on its morphology. In particular the electrical forces between atoms bound into molecules, even properties such as density must depend on the atom having basically the same morphology over the entire range of possible energy levels.

Here the morphology of the atom remains substantially constant for all of the different energy levels. An atom in the base state has the same orbital diameter as one at the energy ceiling, the only difference is the orbital velocity which varies over a very small dynamic range between 99.9973371% and 100% of the speed of light.

## Orbital Frequency

We saw earlier that the effect of relativity on the perception of orbital frequency for the stationary and the moving observers. For the stationary observer the orbital frequency of the electron in the hydrogen atom remains more or less constant and is given by:

$$\omega = \frac{c}{R} = \frac{mc^2}{\hbar}$$ Equation 4-24

However for the electron, which is moving at close to the speed of light, the orbital frequency is given by

$$\omega = \frac{c\gamma}{R} = \frac{mc^2\gamma}{\hbar} = \frac{c\,n}{R\alpha} = \frac{mc^2 n}{\hbar\,\alpha}$$ Equation 4-25

This means the orbital frequency experienced by the moving electron is that of the increased by a factor of 137.03 times the integer *n* over that of the stationary observer. From the presence of the integer multiplier *n* in Equation 4-25 it can be seen that the frequencies experienced by the orbiting electron form a harmonic series, starting with a base frequency in the base energy state, where *n=1,* and rising in integer multiples with each succeeding energy state. This shows that at the heart of the discrete energy levels of the atom lies a harmonic series, much as de Broglie suggested, only rather than appearing directly in our observable domain, it appears instead in the domain of the moving electron and the mechanism that causes this to occur is relativity.

For the stationary observer, the relationship between frequency, velocity and orbital radius is simply the orbital velocity divided by the orbital radius. It is a similar situation for the orbiting electron, only this time the velocity is the velocity affected by relativity described above. Hence there is a consistent relationship between the wavelike description of the particle and its particulate description, a sort of wave / particle identity, one which is consistent with how we regard orbital frequency generally.

On the other hand there are two different velocity terms, one seen by the stationary observer and one experienced by the moving electron. Equally there are two different frequency terms again one seen by the stationary observer and one seen by the moving electron. We can describe this as a wave duality and a separate but related particle duality.

While trying to justify his ideas about the wavelike nature of the particle, Louis de Broglie hit upon the idea that there are two solutions to the dynamics of the hydrogen atom. He was never able to find a causal link between these two solutions and never able to convince his colleagues that such a link was necessary, largely because he was not able to abandon the idea that angular momentum is quantized. In the end he migrated towards what he called *Pilot Wave Theory*. Here we recognize that there is are two separate but related descriptions of the said dynamics, one viewed from the perspective of the stationary observer and one from the perspective of the moving electron, an idea which resonates with de Broglie's *dual* solution; only here we have found the causal link between them to be special relativity.

## Zero Point Energy

The model also provides an explanation for Zero Point Energy. Debate has raged about the existence and the nature of zero point energy since the concept was first introduced by Planck in 1911. With at least one interpretation showing that the atom is possessed of energy even when it is cooled to absolute zero. When an atom is cooled to absolute zero it ceases to have Brownian motion and therefore has zero kinetic energy. However the orbiting electron still has kinetic energy. The electron is orbiting at close to the speed of light and so has energy equal to $1/2mc^2$ exactly in line with prediction.

## The Atom

In this model for the hydrogen atom the postulate that angular momentum is quantized has been overturned and replaced with the idea that the variable of quantization is Gamma, the Lorentz factor. The driving force behind this quantization is the postulate that certain orbital velocity terms are affected by relativity. The result is a far simpler more prosaic model for the atom. The electron orbiting the atomic nucleus is seen as being objective in nature, having deterministic position and deterministic velocity at all times, overturning the idea of probabilistic reality which lies at the heart of the standard model.

The electron orbits at a constant radius irrespective of energy level and at a velocity close to the speed of light. This is a necessary condition if the quantum leap is to be regarded as an absurdity. The model examines what conditions must apply for this to be the case. The constant orbital radius of the electron means that the morphology of the atom does not change substantially with energy level, consistent with an atom whose physical and chemical properties are the same independent of energy level.

The model is based on the assumption that orbital velocity is a hybrid term comprising distance measured under the effects of relativity with time measured in the domain of a stationary observer, dubbed here as Relativistic Velocity, and it is this combined with the fact that the electron is in orbit that leads to the notion of an implied sampling function. Quantization thus becomes a function of a single variable and so does not involve the complex and unexplained interactions between variables that quantization of angular momentum would imply.

The model produces energy levels which exactly match those of the empirically derived Rydberg formula. The absolute value of energy is seen as being close to $1/2mc^2$ which is considerably higher than that of the Bohr model and of other subsequent models. However it does provide an explanation for the so called Zero Point Energy, which hitherto unexplained but here is seen as the residual energy possessed by the atom when all Brownian motion of the atom as a whole has ceased.

Validation of existing quantum theory can only take place in the classical domain, since everything in the quantum domain is contingent on the assumption that angular momentum is quantized. Other than the concept of Relativistic Velocity, the model here makes use of classical, Newtonian, mechanics and provides an explanation for the discrete energy levels of the atom. As such it effectively unifies quantum mechanics and classical mechanics.

The model also provides an explanation for the hitherto unexplained Fine Structure Constant. Here we see that Alpha is the ratio of two lengths. They are; the orbital circumference as measured by the moving electron and foreshortened by relativity and the orbital circumference measured by the stationary observer both at the point at which the atom is stable. This occurs most obviously in the base energy state when the Actual orbital velocity is such that the Relativistic Velocity is scaled by the factor Alpha. But it also occurs as an alias in each stable state.

The fact that measurements are being made in two different domains, separated by the effects of relativity means that there appears to be two solutions to the dynamics of the electron leading to the idea of a duality of wave like characteristics, such as wavelength and frequency and a duality of particle like characteristics, such as orbital path length and orbital period. At the same time the relationship between the wavelike and particle like characteristics is consistent within each domain leading to the idea of a wave / particle identity, a wave duality and a separate but related particle duality.

Finally the conventional laws of physics apply and are simply extended down from room scale to that of the atom with one slight modification. That is in our understanding of how relativity affects objects with regards to objects in circular motion. There is no need to invent an alternative reality based on probability with all of the exotic paraphernalia that it implies. Uncertainty does exist and is inescapable, but is seen as a practical issue of measurement and not as some inherent property of the particle. There is however no escaping from the myopic view that uncertainty confers. This means that we are forced to adopt statistical means to deal with objects on the scale of the atom and hence much of what is termed quantum mechanics remains valid and unaltered. It is the understanding of what sort of reality that lies behind that changes.

# Chapter 5 The Photon

*"In speaking of the Energy of the field, however, I wish to be understood literally. All energy is the same as mechanical energy, whether it exists in the form of motion or in that of elasticity, or in any other form. The energy in electromagnetic phenomena is mechanical energy."* -- James Clerk Maxwell

## Introduction

Visible light is just a small part of a much of a much broader spectrum of electromagnetic radiation, ranging from radio waves at one end through microwaves, visible light and X Rays to gamma rays at the other end of the spectrum. All of these different and seemingly diverse types of radiation are the various manifestations of one type of particle; the photon. The term Photon derives from the Greek word φως (phos) meaning light and was first coined in 1926 by the American physical chemist Gilbert Lewis (1875-1946).

Light is known to travel through a vacuum at close to 300,000 km per second. It is this high speed which gives the photon its special significance. The fact that light travels at such a high speed means that it acts as a sort of universal messenger, distributing and transporting information and energy throughout the universe. The known universe is only known because of the existence of light and more recently other forms of electromagnetic radiation. It is through our senses and sensors, acting on incident photons, that mankind knows about the very existence of the solar system, the stars, the planets and the galaxies. It is the fact that light travels (more or less) in straight lines which allows us to determine the position of objects in space and from this their motion. Based on an understanding of the photon and the atom, our knowledge extends beyond the mere presence and position of these objects scientists are able to extrapolate to discover the chemistry and composition of these distant objects.

A complete understanding of the nature of the photon is therefore vital to an understanding of the universe itself. Conversely if the model of the photon is even slightly wrong the effects, magnified by the vast distances and times involved, are likely to seriously distort our view of the way the universe works.

## Wave or particle?

A problem that has beset physics for at least the last three hundred years and arguably for as much as two thousand years is the seemingly contradictory nature of the photon. On the one hand it can be seen as behaving like a wave while on the other hand it can be seen to have particle like properties. Despite the work of Planck, Einstein and Compton at the beginning of the 20$^{th}$ Century, debate has continued over the nature of the photon. The origins of this debate go back to at least the middle of the 17$^{th}$ century; to the time of Hooke and Newton. Hooke supported the view of Huygens and believed that light was a wave, while Newton was of the opinion that it was "corpuscular" in nature.

Experimental evidence for light as wave emerged in the early 19th century when Thomas Young described his double slit experiment which clearly showed that light was capable of interference, a phenomenon which is normally associated with waves. This was reinforced later in the 1860's when James Clerk Maxwell published his paper containing his eponymous equations. These wave equations were based on the earlier work of Faraday and showed that electromagnetic radiation propagated as a wave travelling at the speed of light.

Then to counter this, in 1900 Max Planck showed that radiation from black bodies could only occur in discrete packets or quanta[iv]. Initially Planck believed that this quantisation effect was merely a quirk of the mathematics necessary in order to solve the equations; however, in his landmark 1905 paper on the photoelectric effect, Einstein showed conclusively that the quantisation effect was real and this led Einstein to propose the existence of the photon as the particle of light.[v] Further experimental evidence emerged when Compton demonstrated that X Rays are red shifted as they passed through a carbon target, a phenomenon which could only happen as a result of collisions between discrete X Ray photons and electrons in the carbon atoms and which is known as Compton Scattering.

It seems that light has both wave like and particle like properties and can be treated as either a particle or a wave as the circumstances require. Since the middle of the 20th century an uneasy truce has arisen in the form of the Wave Particle Duality. This seeks to suggest that light is simultaneously both a wave and a particle, but that it only manifests itself as one or the other when an observer is looking for that particular property and centres on the idea of subjective reality. But this is more of an uneasy compromise, a truism that fails to explain what the photon is and simply describes what we are able to observe.

Maxwell's equations are predicated on the idea that a changing magnetic field induces an electric field and a changing electric field induces a magnetic field. Taken together these two coupled fields oscillate and the whole propagates at a velocity which Maxwell showed to be equal to the speed of light. There are problems with this idea which Maxwell himself acknowledged[6]. His equations suggest that there are two separate and independent mechanisms which can sustain an electric field. On the one hand there is the presence of a charged particle, while on the other hand electric charge can be sustained by a changing magnetic field and vice versa in the void of empty space. In order to do so it is necessary to endow empty space with those properties necessary to sustain such a relationship, namely permeability and permittivity, and this is effectively to reinvent the ether.

It is highly unlikely that there are two separate and independent mechanisms that could lead to the presence of an electric field. We know for certain that a constant electric field exists in the region of a charged particle and so it must be the existence of an electric field sustained purely by a changing magnetic field in otherwise empty space that has to be called into question. It is reasoned here that Maxwell confused cause and effect. It is not permeability and permittivity that causes light to travel at the speed it does, but the light traveling at this speed which causes us to think that space has the properties of permeability and permittivity.

[6] "In speaking of the Energy of the field, however, I wish to be understood literally. All energy is the same as mechanical energy, whether it exists in the form of motion or in that of elasticity, or in any other form. The energy in electromagnetic phenomena is mechanical energy." James Clerk Maxwell

This must mean that the photon itself contains electrically charged particles and, since the photon is electrically neutral that there must be more than one and that their charge adds up to zero. This begs the question: If all substantial matter has mass and all real particles have substance and therefore mass, how can the photon be a real particle? The problem with the idea of a particulate photon has always been how to reconcile the fact that mass is a fundamental property of all particles with the fact that the photon would appear to have no mass at all.

From here it is a simple step to argue that the photon has zero mass because it is made up of two particles of opposite mass. In other words that mass is capable of existing in both positive and negative forms.

### Negative mass

Conventional wisdom holds that all forms of mass are always positive, however there is no real reason to suppose that this is always the case. It is perfectly feasible for mass to take on both positive and negative values in much the same way that electrical charge can be either positive or negative and if we allow ourselves to do so it is possible to construct an objectively real, particulate model for the photon.

Mass is unusual in that it manifests itself in two quite distinct forms and it is only by judicious choice of constants that these then happen to have the same numerical value. On the one hand there is gravitational mass which is described by Newton's gravitation equation and deals with the static forces between objects that have mass. The equation relates the masses of the two objects to the distance between them and describes the resulting force acting between them.

$$F = \frac{Gm_1m_2}{D^2} \qquad \text{Equation 5-1}$$

The overall form of this equation is similar to that governing the force due to electrical charge, which also obeys an inverse square law.

On the other hand there is inertial mass, which is described by Newton's second law: force equals mass times acceleration.

$$F = ma \qquad \text{Equation 5-2}$$

Inertial mass is a measure of the resistance of an object to acceleration, so the larger the inertial mass, the greater the force that is required to accelerate it at any given rate.

Inertial mass is a dynamic force and so it depends on their being some sort of motion involved. The fact that the object is accelerating must mean that, even if the object was not moving at one instant, then it will be some small interval later. Because the object is moving, it must be subject to the effects of relativity. Normally these do not have any significant effect unless the velocity is close to that of light, but there is one important aspect of relativity which is often overlooked and which applies no matter what the velocity.

Recall that the factor Gamma is defined as

$$\gamma = \frac{c}{\sqrt{c^2 - v^2}}$$ Equation 5-3

The presence of the square root term in the equation means that Gamma can be taken to be either positive or negative. So we can argue while gravitational mass may take on values which are either positive or negative, inertial mass, which is the product of gravitational mass and Gamma, can be thought of as being always being positive.

In practical terms this means that all objects display inertia which acts as resistance to acceleration, irrespective of whether their gravitational mass is positive or negative. It means that Newton's second law should correctly be rewritten as:

$$F = |m|a$$ Equation 5-4

If mass exists in both positive and negative forms then it begs the question as to how this manifests itself and what types of particle have such negative mass? The obvious answer is that it is antimatter particles have negative mass.

We know that for every particle there is an equivalent antiparticle whose properties are diametrically opposed to those of the particle, so where the particle has positive charge, its antiparticle equivalent has negative charge. The conventional wisdom holds that this does not apply to mass, which is taken to be the exception to this rule and so is always positive. There is no reason to suppose that this is the case, antimatter has never been weighed, we have only ever determined its mass, and so we have no way of knowing the polarity of its mass. It is argued here that antimatter is diametrically opposed to matter in respect of its gravitational mass as well as all of its other properties, that antimatter is truly a reflection of matter in all aspects and that mass is no exception. In other words that it has negative gravitational mass and that mass adds arithmetically in much the same way as electric charge.

Such antiparticles would then have some interesting properties; they would be gravitationally repulsive to conventional matter. An antiparticle released into space near a massive object would 'fall' upwards, away from it, rather than towards it. This in part would help explain why antimatter is relatively rare here on earth or indeed anywhere in our galaxy.

Antimatter is the mirror of matter. For each particle of matter there is an equivalent particle of antimatter. So for example the electron has an antimatter equivalent which is called the positron, the proton has an antiparticle equivalent called the antiproton and so on for each of the fundamental particles of nature. However the antiparticle of the photon is the photon.

It is the symmetry of the photon as both a particle and its own antiparticle, combined with the idea that mass is a bipolar additive quantum value and taken with its electrical neutrality which reinforces the idea that the photon is not just a simple particle, but a composite or compound particle. In this the photon can be thought of as being composed of a pair of objects, or possibly pairs of objects, a particle and its antiparticle equivalent, locked in mutual orbit and having zero aggregate charge and zero aggregate mass.

There are a number of reasons to suggest that the particles which go to make up the photon are an electron and a positron. First is that of particle pair formation. When a high energy photon passes in close proximity to an atomic nucleus it can sometimes be seen to disappear to be replaced by an electron and a positron. It would seem reasonable to suppose that the photon itself contains a positron and an electron and that this process is one of decomposition into its component parts.

The opposite effect is also observed; when a positron and an electron collide they are seen to disappear to be replaced by a photon in a process that is termed annihilation. As the positron approaches the electron the attractive electrical force increases as the distance gets less according to the inverse square law. However the two would not simply smash into one another, instead they would approach following a spiral path, creating what is sometimes described as “positronium”, a supposedly short lived element which then decays to a photon. Here we examine what would happen if during that process the pair of particles was seen to enter a stable state where they are able to continue in mutual orbit. The system would have zero mass which in turn would mean that it would accelerate to a speed limited by the speed of light with no expenditure of energy. The system would present itself as having an oscillating electric field and an accompanying oscillating magnetic field. Being a physical entity it would be capable of traversing empty space without the need for a supporting ether or any of the other euphemisms for the ether that have emerged over recent years.

The objective then is to determine what would need to change in our understanding of physical laws in order to bring about such a stable system. We have already explored one such change in the context of the hydrogen atom, namely that orbital velocity for objects orbiting at near light speed is affected by relativity. The second such change is that it is necessary to accept that gravitational mass is bipolar and that antimatter has negative gravitational mass.

## The Photon as a Binary System

Light presents itself as an electromagnetic wave having positive and negative excursions but overall is electrically neutral. A particulate photon must therefore contain both positive and negatively charged elements, however when positive and negative electrical charges are co-located the charges cancel one another out. The two areas representing positive and negative electric charge within the photon must therefore be physically separated, in keeping with the idea that the photon is a composite binary system comprising particles which have symmetrically opposite characteristics. So we need to understand just how and why these particles can maintain their separation and also to understand that despite the fact that they are locked in mutual orbit, they do not emit synchrotron radiation, which would cause their orbits to decay.

Exactly the same considerations as apply to mass can be applied to electric charge. If gravitational mass is bipolar and can take on both positive and negative values then two such particles of opposite polarity would have gravitational mass which cancelled out. The compound particle formed by these two elements would have zero aggregate mass, it could be considered to be neutral with respect to mass in exactly the same way that they would be electrically neutral.

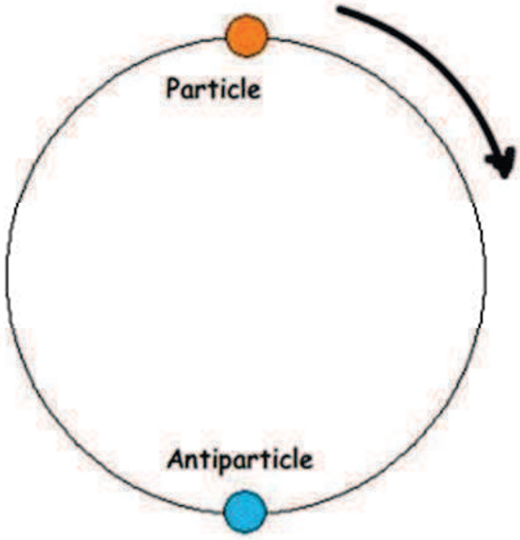


Figure 5-1 The Binary Photon

The model proposed for the photon is that of a binary system consisting of a pair of such particles, an electron and a positron. They are physically separate, but locked in mutual orbit. Where one has positive charge the other has negative charge and where one has positive mass the other has negative mass. The particles form a symmetrical pair with respect to one another and so overall the photon has zero aggregate charge and zero aggregate mass and the is by definition its own antiparticle.

Having zero aggregate mass means that the photon cannot carry any direct kinetic energy. However since the two particles are physically separate they do carry energy associated with their orbital motion. We can think of this as a sort of miniature flywheel composed of two lobes which are diametrically opposed.

The first step is to determine the orbital radius of such a system and how it might vary with frequency. From there it is necessary to analyse the forces involved and explore how they can come into balance forming a stable system.

## Polarisation

Such a binary system provides a simple physical model for polarisation. The particles have equal but opposite mass and orbit around an axis which is perpendicular to, and which bisects the line joining them. It is the orientation of this axis with respect to the direction of travel that expresses the photon's polarization. If the axis of rotation is at right angles to the direction of travel, then the photon is plane polarized. If it is in line with the direction of travel, then it has circular polarization. Any other angle between the axis of rotation and the direction of travel results in elliptical polarization of varying degrees. Both plane polarized and elliptically polarized light can be further described by a second angle with respect to some arbitrary datum, leading to the idea of vertically polarized or horizontally polarized light.

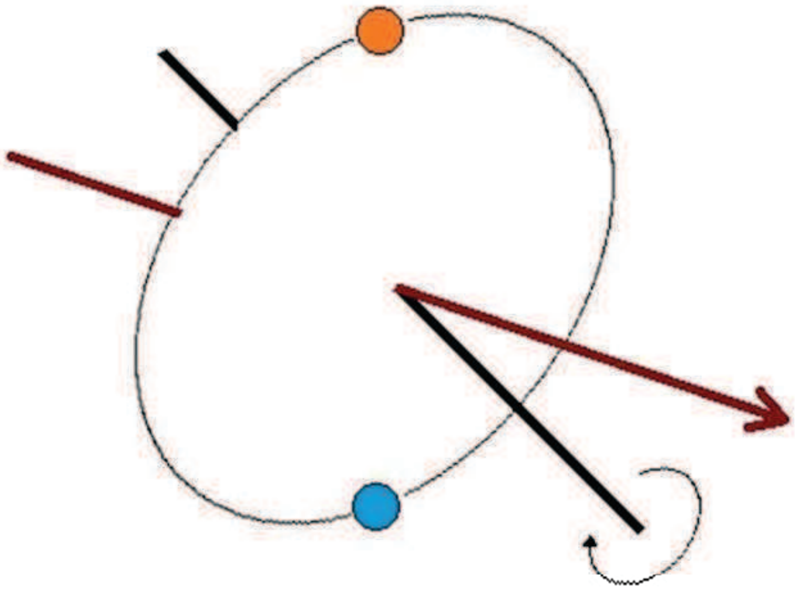

Figure 5-2 Polarization

The paths described by each of the two constituent particles as the photon travels through space are a combination of helix and cycloid; the exact form depending on the polarization. For circular polarized light the two paths will form a double helix. For plane polarized light the two particles follow paths which are overlapping cycloids, while for elliptically polarized light they follow overlapping compound helio-cycloids.

### Trajectories

In all of these cases however the length of the path taken over a complete cycle or over a whole number of cycles is the same. Mathematically the simplest of these cases is that of the double helix, Figure 5-3. Considering just one of these particles and cutting the cylinder along which such a helix is inscribed and unrolling it, it is evident that the path length followed by each particle forms the hypotenuse of a right angled triangle, the other sides being the distance travelled over one cycle and the circumference as shown in Figure 5-4.

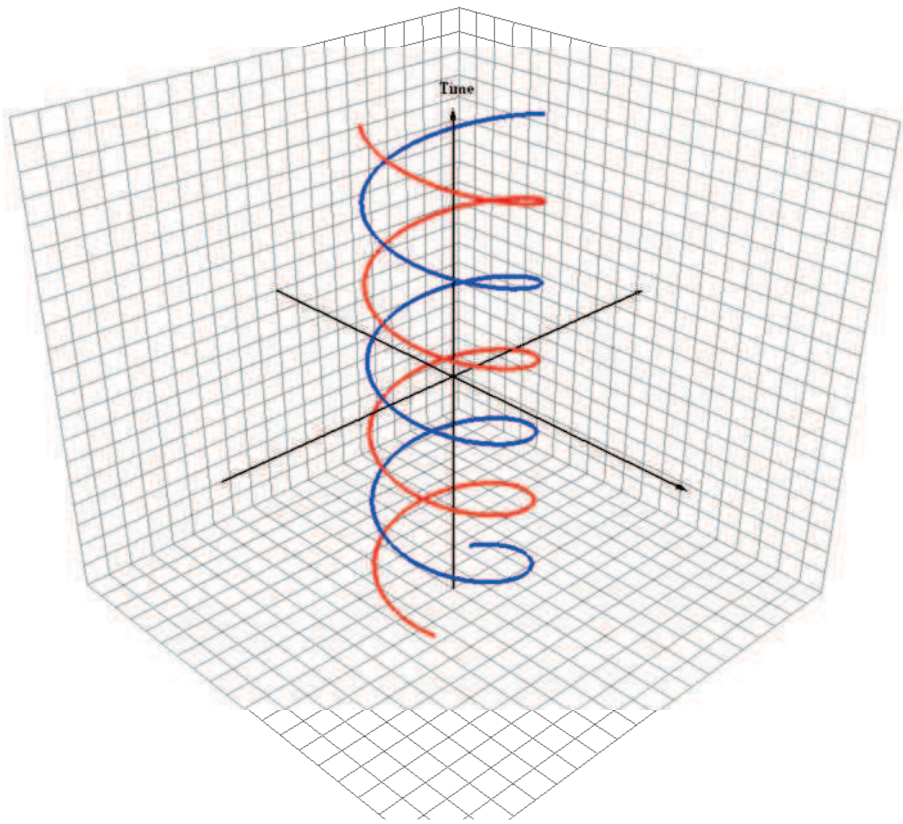


Figure 5-3Trajectories of the Particles

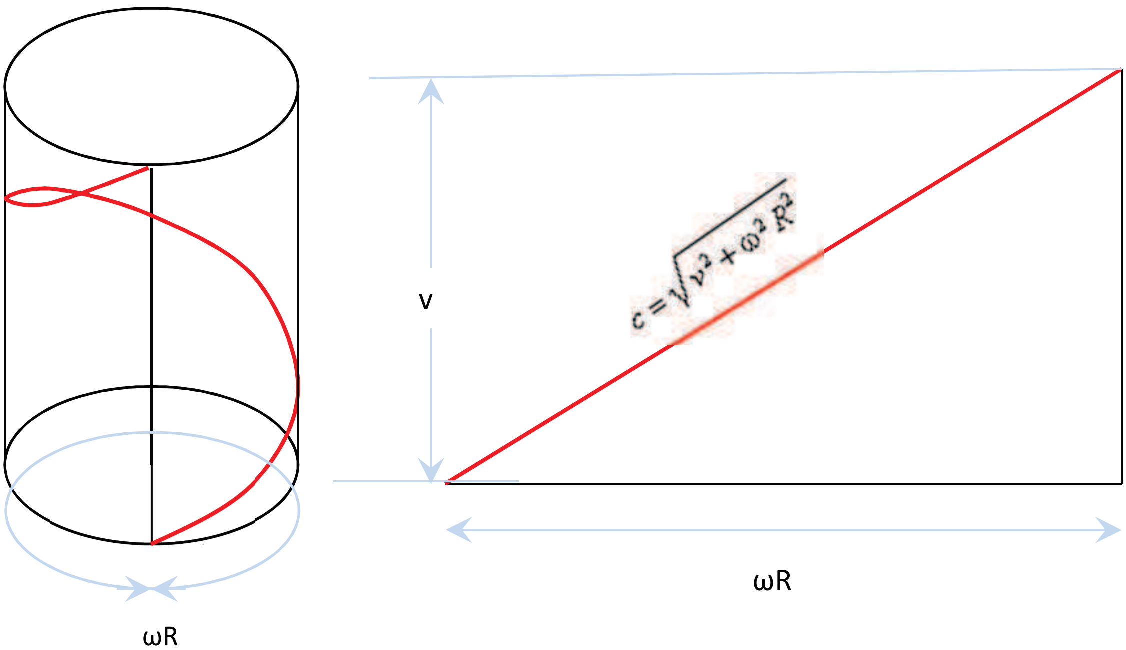


Figure 5-4 Velocity of Propagation

Nothing can travel faster than light, however the two particles are traveling along their respective trajectories at very close to the speed of light and as a first approximation can be considered as traveling along their respective paths at the speed of light.

The progress made in the direction of travel, the propagation velocity, must then always be less than this and can be calculated using Pythagoras theorem as:

$$v = \sqrt{c^2 - \omega^2 r^2} \qquad \text{Equation 5-5}$$

- Where $v$ is the velocity of propagation, $\omega$ is the angular frequency and $r$ is the radius of the photon.

From this it can be seen that $v$ is always less than $c$ and so it seems that not even light can travel at the 'speed of light'!

The term 'speed of light' is something of a misnomer. Here it is used to refer to $c$ which is taken to be the limiting velocity beyond which nothing can travel. The term 'velocity of propagation' is used to describe the speed with which the photon propagates in its direction of travel and the term 'trajectory speed' is used to describe the speed of the constituent particles along their respective trajectories.

## Relativity

Einstein showed in his Special Theory of Relativity that an object's mass varies with its speed in relation to an observer. When the observer and the object are both at rest in the same reference frame the object displays its so called Rest Mass. At any other speed with respect to the observer the object possesses a higher mass known as its Relativistic Mass. In this case the speed of the particles is close to that of light where relativistic effects are significant. Relativistic Mass is always higher than the Rest Mass and is calculated by multiplying the Rest Mass by the Lorentz factor γ (Gamma).

Gamma is related to the velocity of propagation, $v$ and to the "speed of light", $c$ and is given by the formula:

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad \text{Equation 5-6}$$

Which can also be written as:

$$\gamma = \frac{c}{\sqrt{c^2 - v^2}} \qquad \text{Equation 5-7}$$

The photon is moving at velocity $v$, close to the speed of light and therefore subject to the effects of relativity. For us stationary observers, observing the photon, the masses of the two particles which make up the photon are both increased by the factor Gamma.

Equation 5-5 and Equation 5-7 can be combined to eliminate the, as yet unknown, term for velocity, $v$. In the resulting combined Equation 5-8 the two $c^2$ terms under the square root cancel one another out, leaving a simple value for Gamma:

$$\gamma = \frac{c}{\sqrt{c^2 - (c^2 - \omega^2 r^2)}}$$ Equation 5-8

$$\gamma = \pm \frac{c}{\omega r}$$ Equation 5-9

The photon is moving with respect to us stationary observers and so its mass appears to us to be increased by the factor Gamma and so the masses of the particles which form the photon each have a value:

$$m_1 = m_0 \gamma = \pm \frac{m_0 c}{\omega r}$$ Equation 5-10

Where $m_1$ is the Relativistic Mass of the particle and $m_0$ is the Rest Mass of the particle.

**Orbital Radius**

Having calculated the effective or relativistic masses of the two particles, it is then possible to calculate the energy of the photon. This takes the form of the rotational energy of the two particles about a common axis. The energy possessed by a point object rotating in a circular orbit at a fixed radius from an axis is given by the standard textbook formula:

$$e = \frac{1}{2} I \omega^2$$ Equation 5-11

Where $I$ is the Moment of Inertia and $\omega$ is the angular velocity. The rotational energy of such a mass $m$ rotating about an axis at a radius $r$ is given by the standard textbook formula:

$$I = mr^2$$ Equation 5-12

Here however the photon is in a reference frame which is moving at velocity $v$, close to the speed of light, with respect to a stationary observer. The masses of the individual particles are increased due to the effects of relativity by factor Gamma and so:

$$I = \frac{m_0 c}{r \omega} r^2$$ Equation 5-13

Which can be simplified to give:

$$I = \frac{m_0 c r}{\omega}$$ Equation 5-14

This is the case for a single particle, here there are two particles in mutual orbit and diametrically opposed. One of the particles has positive gravitational mass and the other negative gravitational mass, however both are deemed to have positive inertial mass so both contribute equally to the moment of inertia and so to the rotational energy of the system. The aggregate mass on the other hand is zero and so the photon has no direct kinetic energy.

The total energy therefore is:

$$e = 2\frac{\frac{1}{2}m_0 cr}{\omega}\omega^2 \qquad \text{Equation 5-15}$$

After simplification this gives an equation for the energy of the photon as:

$$e = m_0 rc\omega \qquad \text{Equation 5-16}$$

Planck's developed a formula for the energy of the photon, which he expressed in terms of its angular frequency and a constant of proportionality.

$$e = \hbar\omega \qquad \text{Equation 5-17}$$

Equating these two formulas for the energy of the photon; it can be seen that:

$$\hbar = m_0 rc \qquad \text{Equation 5-18}$$

Rearranging this equation we get the radius at which the particles orbit:

$$R = \frac{\hbar}{m_o c} \qquad \text{Equation 5-19}$$

Since $\hbar$, $m_0$ and $c$ are all constant, it follows that $r$, the radius of the photon, is also constant. It also is evident that this must be true for all frequencies. In which case the equation can be rewritten using $R$ to denote that the orbital radius is constant.

## Bandwidth and Maximum Energy

Having determined that the radius of the photon is constant for all frequencies it is possible to re-examine Equation 5-5 relating frequency to velocity and so determine the frequency characteristic of the photon.

$$v = \sqrt{c^2 - \omega^2 R^2} \qquad \text{Equation 5-20}$$

With $R$ as a constant it is evident that there is an upper limit to the frequency of the photon which is reached when the frequency is such the term under the square root reaches zero. This condition occurs when $c = \omega R$ and so it is possible to establish the upper limit for the frequency of the photon as

$$\omega_{max} = \frac{c}{R} \qquad \text{Equation 5-21}$$

Using Planck's equation it is then possible to calculate the maximum energy of a photon.

$$e_{max} = \hbar\omega_{max} = \hbar\frac{c}{R} = m_0 c^2 \qquad \text{Equation 5-22}$$

Where $m_0$ is the rest mass of <u>one</u> of the two particles which make up the photon

At this maximum frequency it can be seen that the velocity of propagation is zero; that is the photon is stationary.

### Orbital Radius

Using the known value for the rest mass of the electron substituting in Equation 5-19 for the radius of the photon it is possible to calculate the value for $R$ as:

$R = 3.86159 * 10^{-13}$ **metres** Equation 5-23

This value is not unknown in physics where it is referred to as the Reduced Compton Wavelength.

Substituting the value for the rest mass of the electron into the equation for the maximum energy of the photon shows $e_{max}$ to be 511 KeV and the maximum frequency $\omega_{max}$ to be $7.7634*10^{20}$ **Radians/sec** or $1.2356*10^{20}$ **Hz**.

Plotting the velocity of propagation against frequency using a logarithmic frequency scale gives the characteristic shown in Figure 5-5.

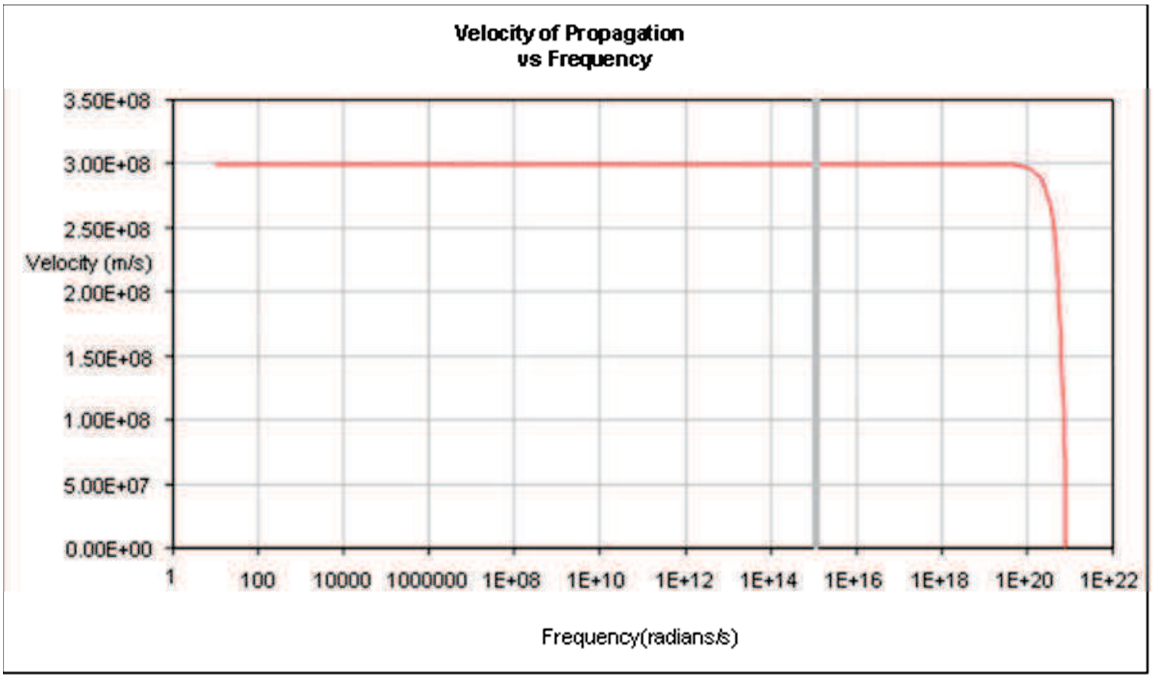


Figure 5-5 Velocity of Propagation vs Frequency

Overall, the characteristic is that of a low pass filter with velocity close to the speed of light over a range of frequencies extending from zero to approximately $10^{19}$ radians/sec, after which the velocity starts to fall off at an increasingly rapid rate to zero. It should be noted that $10^{19}$ radians/second is well into the gamma ray part of the spectrum.

Visible light occupies the frequency range from approximately $2.7*10^{15}$ to $4.7*10^{15}$ Hz and is indicated by the dark band in Figure 5-5. Over the visible spectrum the velocity of propagation lies within $10^{-9}$ % of that of the speed of the particles along their trajectories.

The velocity of propagation remains within 1% of this speed until the frequency is beyond $10^{20}$ and then falls off rapidly to a maximum frequency at $7.7634*10^{20}$ **rads/sec**.

## Time Dilation

According to Einstein's Special Theory of Relativity time is a function of speed. Objects that move fast experience time at a slower rate than other objects moving more slowly. Two clocks, one running on earth and the other running on a spaceship orbiting the earth at high speed, will show different times. The moving clock will run slower than the stationary clock - and it is not just the clock that runs slower, it is time itself, so an astronaut on the spaceship will be younger than his twin brother who stays behind on earth. The effect only becomes significant at speeds comparable to the speed of light.

From Equation 5-9 and Equation 5-21 we see that

$$\gamma = \frac{\omega_{max}}{\omega} \qquad \text{Equation 5-24}$$

Time in the domain of the photon is slowed down. The extent by which it is slowed is the factor Gamma. An external observer sees the photon traveling with velocity $v$ and frequency $\omega$. An observer travelling in the domain of the photon will see the same number of cycles but in a domain where time is slowed. Such an observer will therefore see the frequency of the photon as being higher by a factor Gamma. An observer in the domain of any photon will therefore see it as having a frequency of $\omega_{max}$.

This answers an interesting question which was first posed by Einstein. Einstein once famously asked what it would be like to ride on a beam of light, here finally is the answer. To an observer riding on a beam of light, or at any rate travelling alongside and observing a photon, then no matter what the frequency or energy of the photon in some other domain, the observer will always see it as having the maximum possible frequency and energy in its own reference frame. This does not conflict with Einstein's idea that the speed of light is constant for any observer, since the speed of light refers to the universal speed limit and not the velocity of propagation of the photons. In that sense the photon is subject to the limitations of the "speed of light" and not the cause of it.

All photons thus look the same when viewed from within their own reference frame. At maximum energy a photon has zero velocity of propagation. By arranging to move at the same velocity as a photon, an observer is entering the domain of the photon and in so doing he is adjusting his own clock in such a way that the photon frequency appears to be $\omega_{max}$ and its energy appears to be $e_{max}$.

This also provides another insight into why the photon must have constant radius for all frequencies. To any observer travelling alongside the photon and experiencing time at the same rate as the photon, all photons look alike. They all have the same frequency $\omega_{max}$. The same photon see by an observer in a different reference frame would have a different frequency and would of necessity be moving with respect to that reference frame. It would have to have the same orbital radius however, since this is unaffected by relativity. In a sense all photons are identical, the difference between photons of different frequency and of different energy comes down to a question of the reference frame from which they are observed and how this reference frame relates to that of the photon itself. This is also consistent with the characteristic of Figure 5-5, which shows that a photon with zero velocity of propagation must have frequency $\omega_{max.}$

The idea that photons have a constant radius and are seen to have the same frequency within their own reference frame greatly simplifies the calculations involved in determining their dynamics. It simplifies the calculations concerning the forces that bind the constituent particles together, since it is now only necessary to consider the one domain of the photon itself.

## Binding Force

Viewed from within this inertial frame, the photon appears as a positron/electron pair in mutual circular orbit. The axis around which these particles orbit is stationary, while the particles themselves are orbiting at a frequency of $\omega_{max}$ and at radius $R$.

From Equation 5-19 the orbital radius is given by

$$R = \frac{\hbar}{m_o c} \qquad \text{Equation 5-25}$$

An observer located at the orbital axis would see the electron and the positron passing at a speed close to that of light where the effects of relativity would certainly be manifest. Such an observer would therefore see the mass term ($m_0$) increased due to relativity by a factor Gamma. However the radius is constant normal to the direction of travel. It must have the same value for any observer including one located at the orbital axis. In order to maintain the balance of Equation 5-25 there must be a second Gamma term in the numerator.

$$R = \frac{\hbar}{(m_o \gamma)} \left(\frac{\gamma}{c}\right) \qquad \text{Equation 5-26}$$

Since both $R$ and $\hbar$ are constants, this additional Gamma term can only be associated with the velocity term $c$. This suggests that the orbital velocity should be considered as being affected by relativity. In effect this means that orbital velocity is taken to be the orbital circumference measured in the domain of the electron or positron and foreshortened by relativity, divided by the orbital period as measured by a stationary observer located on the orbital axis. I describe this type of velocity as “relativistic velocity” and postulate that relativistic velocity applies in formulae related to orbital motion including those for angular momentum and centripetal and centrifugal forces. Relativistic velocity is the second of two postulates that form the basis of this paper.

The forces acting between the two particles must be in balance for the photon to be stable. This means that the electrical force of attraction between the two particles must be equal to the centrifugal force tending to pull them apart. However it is argued here that the centrifugal force should be calculated based on the relativistic velocity and not the actual velocity of the respective particles, which leads to

$$\frac{Kq^2}{4R^2} = \frac{(m_0 \gamma)}{R} \left(\frac{c^2}{\gamma^2}\right) \qquad \text{Equation 5-27}$$

Where $m_0$ is the rest mass of the electron and v is the orbital velocity and is close to c where it is necessary to consider the effects of relativity. In particular velocity is affected by relativity. Hence

Combining Equation 5-26 and Equation 5-27 and solving for Gamma gives

$$\gamma = \frac{4}{\alpha} \qquad \text{Equation 5-28}$$

From this it is possible to calculate the orbital speed of the electron/positron pair as 99.9998336% of the speed of light.

## The structure of the photon

The model proposed for the photon is that of a simple binary system. It comprises a particle and an antiparticle pair locked in mutual orbit and is based on two simple postulates affecting the way in which the laws of physics work. Gravitational mass is postulated to be a bipolar additive quantum value capable of taking on values which are both positive, in the case of matter, and negative, in the case of antimatter. Certain velocity terms which are associated with orbital motion are postulated as being affected by relativity. In particular this applies to angular momentum and to centrifugal and centripetal acceleration and force.

The resulting model is mechanically simple. The energy of the photon, radiation energy, is stored and transmitted in mechanical form. Transformations between energy and matter as predicted by Einstein are seen as a simple mechanical process in which particles and antiparticles combine to create photons or in which photons decompose to create matter and antimatter.

The particles themselves are seen to be objectively real point particles in the classical sense. They are possessed of deterministic properties such as charge, mass, momentum, angular momentum etc. The wavelike nature of the photon is then fully explained by the orbital motion of these particles and hence the wave particle duality becomes redundant as an explanation for the physical nature of light.

Uncertainty is then seen to be a practical issue associated with measurement where the measurer and measurand are of comparable physical dimensions. It is not, as the current theory holds, an intrinsic property of the particle.

The model provides a simple explanation for a number of properties of light and other EM radiation, including polarisation, particle paring and the transformation of matter to energy and vice versa.

The photon is seen to have a finite bandwidth beyond which it cannot exist.

# Chapter 5 The Dual Nature of Reality

*"I think that a particle must have a separate reality independent of the measurements. That is an electron has spin, location and so forth even when it is not being measured. I like to think that the moon is there even if I am not looking at it."* - Albert Einstein

## Planck's constant

Bohr's model for the atom was based on the idea that Planck's constant was the fundamental unit of angular momentum and that each energy level was associated with a integer multiple of this basic unit. That assumption was carried over into all subsequent models within quantum theory. The assumption has been shown to be false. Angular momentum is not quantized, instead it is the Lorentz factor Gamma that is quantized. Planck's constant is still seen as the orbital angular momentum of the electron, but rather than being quantized, it remains substantially the same for all energy levels.

But why exactly is Planck's constant; constant?

The answer is inextricably linked to question as to why the electron orbiting the hydrogen atom, or for that matter the electron and positron in orbit within the photon, do not emit synchrotron radiation.

And the answer to both of these is to be found in Equation 4-20 from Chapter 4. This equation links Planck's constant to the orbital radius, the mass and the velocity of the orbiting electron, but it also includes the factor Gamma, only here it occurs twice, once in the numerator, where it acts to modify the rest mass of the moving electron in line with relativity, and once in the denominator where it acts to modify the orbital speed to create a Relativistic Velocity term.

$$\hbar = m\gamma\, R\frac{c}{\gamma}$$ Equation 4-20

As the orbital velocity increases, so does the value of Gamma. This causes the effective mass of the electron to increase, but at the same time the orbital path length, and therefore the Relativistic Velocity decreases. We can think of this rather like a mathematical see-saw, as one goes up the other goes down, with Planck's constant at the fulcrum between these two. The two Gamma terms balance one another out but at the same time they force the angular momentum of the orbiting electron to maintain a constant value. The angular momentum can be said to be invariant with respect to velocity in the region where the orbital velocity is close to the speed of light.

A closer examination of the terms of the equation reveals that the rest mass of the electron is constant and the speed of light is constant. The orbital radius is measured at right angles to the direction of travel of the electron and is therefore unaffected by relativity and so remains constant. The result is that Planck's constant, which is a measure of the angular momentum of the electron, is therefore invariant with respect to orbital velocity and so must be constant.

The effective mass of the electron and its Relativistic Velocity form one sort of see-saw, but so does the orbital radius and Planck's constant form another similar relationship. One cannot alter without the other altering and the sensitivity to any such change increases with Gamma. The higher the value of Gamma, the more tightly these to values are bound to one another. The orbital radius is thus constrained, and it is this that accounts for the absence of synchrotron radiation. There is no force accelerating the electron towards the orbital nucleus, instead the geometry of the space in which the electron exists is curved, in much the same way that space-time is considered to be curved in General Relativity.

## Wave Particle Identity

The pioneers of quantum theory were presented with a dichotomy. On the one hand their solutions treated the particle as a discrete entity with a certain set of parameters and characteristics on the other hand it had the properties of a wave with a different set of characteristics. We normally associate the wave behavior of an object with its orbital motion and the wavelength of an object in orbit with its orbital circumference, so in the Bohr model this would vary with the square of the energy state. However in de Broglie's model of the particle as a wave the wavelength is associated with Planck's constant, considered an integer fraction of the orbital circumference, and increases in line with the energy state. Hence the two representations, that of a wave and that of a particle are substantially different from one another. They have different frequencies and different wavelengths. This extends over the whole range of similar such parameters including orbital radius, frequency, velocity wavelength and period.

The solution adopted by those pioneers was to argue that both forms existed at the same time in what has come to be known as the 'wave particle duality'. In this type of wave particle duality, the duality exists **between** the wavelike characteristics and the particle like characteristics of the entity. As a consequence the conventional relationships between the particle like properties and the wavelike properties break down and so the wavelength can no longer be said to be the orbital velocity divided by the orbital period. It is argued that what we describe as a discrete particle exists as both a wave and a particle at the same time and that the results obtained depend on what is being measured or tested and that both results are equally valid. It therefore becomes necessary to create a new set of physical laws which operate on this scale. This is sometimes described as 'subjective reality' because the results depend on what is being sought and so is specific to the particular property being measured.

In something of a parallel intellectual duality, there were detractors from this point of view. In the 1930's physics was roughly divided into two camps, those who supported the idea of subjective reality and those who argued that reality had to be objective in nature. Notably in the subjective camp were Niels Bohr, Werner Heisenberg and Paul Dirac while in the objective camp were the likes of Albert Einstein, Erwin Schrödinger and Louis de Broglie, in these latter two cases this was despite their having made significant contributions to the theory.

A closer examination of the underpinnings of wave particle duality shows that it is inextricably linked to the idea that angular momentum is quantized. This idea is at the heart of the Bohr model for the atom and is carried forwards into de Broglie's idea for the particle as a wave. De Broglie's waves are a distortion of the classical model of wave where by definition the orbital radius is equal to the orbital angular momentum divided by the linear angular momentum. In de Broglie's idea of a wave this is modified to be Planck's constant divided by the linear momentum of the particle. This together with the idea that the orbital angular momentum is an integer multipole of Planck's constant is what results in the harmonic relationship between the frequencies of de Broglie's waves and those of the Bohr model.

## Duality

Special relativity is unique among physical phenomena in seemingly providing two answers to the same question, a sort of natural duality. So for example there are two distances between points in space, one measured by the stationary observer and one by the moving observer, equally there are two time intervals and, where cyclic behaviour is observed there are two frequencies and two wavelengths. Special relativity would therefore seem to be a natural place to start when looking for duality.

In any reference frame we can imagine a set of measurements such as distance, time mass etc. which are those experienced by a stationary observer. For an object which is moving with respect to that reference frame those same measurements have different values which are related to the first through relativity. Distance is foreshortened, time is dilated and mass is increased. For objects which are moving relatively slowly these two sets of measurements are very similar, with one or two exceptions such as the polarity of inertial mass. At higher speeds these two sets of measurements begin to diverge quite markedly. A particularly significant point of divergence occurs when the speed is such that the Lorentz factor, Gamma, has a value of 137.03 or a multiple thereof. This particular speed is associated with the stable orbits of electrons within the hydrogen atom and with the stability of the bipolar photon. For objects in orbit certain of these measurements take on multiple values all of which are valid at the same time and it is this that leads to the discrete energy levels that are found within the atom.

The wave characteristics of the electron derive directly from its orbital motion. The wave is an **attribute** of the particles, brought about by this motion rather than something which is inherent to the particle. Whether it is viewed from the perspective of the stationary observer or from that of the moving electron, the relationship is consistent and is the one with which we are all familiar in classical mechanics, that angular frequency is equal to orbital velocity divided by orbital radius. For the stationary observer the orbital velocity is to all intents and purposes equal to the speed of light and the radius is $\hbar/mc$ and so its angular frequency is more or less constant at $mc^2/\hbar$. For the moving electron the orbital velocity is its Relativistic Velocity in the particular stable state and the radius is the same as that of the stationary observer. The orbital frequency is given by $nmc^2/\hbar\alpha$ and forms a harmonic series.

It is more sensible therefore to speak of a wave/particle identity in which frequency, wavelength, amplitude and phase are all related within their respective domains with orbital radius, circumference and period in a way which is consistent with classical mechanics. The duality exists between the two domains, hence there are two frequencies, one in the domain of the electron and one in the domain of the stationary observer and there are two orbital path lengths, one in the domain of the electron and one in the domain of the stationary observer. It is better to describe this as a wave duality and a separate but related particle duality.

In the case of the photon there are two different wavelengths, one observed by the stationary observer and one by the moving photon. In the domain of the photon the orbiting electron and positron each follow a circular path and there is no translational motion. The wavelength is constant and equates to the orbital circumference. As we have seen the orbital speed is close to that of light. The relationship between these three properties is exactly that we would expect and is consistent with classical mechanics. That is to say velocity is the product of wavelength and frequency.

For an external stationary observer the propagation velocity of the photon varies from a maximum when it has low energy to a zero when it has maximum energy. Hence the wavelength of the photon varies being long at low energies, at least in theory it could extend up to infinity, to zero at maximum energy. Once again the classical laws relating to waves still apply; velocity is the product of wavelength and frequency.

The current received wisdom places no upper boundary on the energy of the photon. Given the above it is easy to see why. Strictly speaking it is not the upper frequency or energy that is boundless, it is the wavelength that is considered to have no lower limit, and from the point of view of a stationary observer the wavelength does indeed extend all the way down to zero.

Measurement of the energy possessed by a single photon is a practical impossibility. The uncertainty principle prevents us from doing so. Instead what can be measured is the wavelength of a beam of photons and it is from this that the energy of the individual photons is then calculated. Effectively this means we are measuring the average wavelength of an indeterminate number of photons and it is from this that we can calculate the energy of the individual photons within the beam. The only wavelength that can be measured in this way is that observed by a stationary observer and this does indeed extend all the way down to zero.

It is easy to see why the upper bound for the energy of the photon is so obscure. Conventionally the energy of the photons in such a beam is taken to be, Planck's constant multiplied by the speed of light and divided by the wavelength. This is based on the implicit assumption that the speed of the photon is equal to the speed of light. Here however the speed of the photon varies with frequency and is equal to zero when the wavelength is zero.

This then leads to a discrepancy between the value measured in this way and the actual value of the energy. The fact that this discrepancy only occurs at extremely high frequencies, well into the gamma ray part of the spectrum is perhaps also to be considered.

## Maxwell's Equations

Maxwell's equations describe the photon as a pair of interlocking sine waves, one magnetic and one electrical and they sustain one another because of the properties of empty space. To endow empty space with such properties is, in effect, to reinvent the ether. All of the evidence however points to the fact that the ether does not exist.

Here the photon is composed of two discrete particles in orbit around one another and moving through space. This means that the source of the electric fields moves through space with the photon. The motion of these two particles then creates the oscillating magnetic field. The paths of the two particles have the form of two interlocking cycloids. Cycloids are created when a generating circle moves through space, whereas a sinusoid is generated as a projection of a circular motion where the generating circle remains stationary in space. This is why Maxwell's equations imply the existence of the ether, the circular motion of an otherwise stationary medium which causes the wave to propagate.

For most of the easily explored part of the spectrum the wavelength of the electromagnetic wave is very long compared to the diameter of the generating circle. Under these conditions the cycloid is an extreme form of what is termed a "Curtate Cycloid". Such an extreme curtate cycloid is practically indistinguishable from a sinusoid generated using similar parameters. What this boils down to is that Maxwell's equations are a good approximation for frequencies where the wavelength is significantly greater than the orbital diameter of the photon.

## The Fine Structure Constant

The Fine Structure Constant (Alpha) is a repeating theme throughout atomic and nuclear physics and yet it is until now one of the great unsolved mysteries of modern physics. Richard P Feynman, one of the gurus of quantum physics, said of the Fine Structure Constant:

*"It has been a mystery ever since it was discovered more than fifty years ago, and all good theoretical physicists put this number up on their wall and worry about it. Immediately you would like to know where this number for a coupling comes from: is it related to pi or perhaps to the base of natural logarithms? Nobody knows. It's one of the greatest damn mysteries of physics: a magic number that comes to us with no understanding by man. You might say the "hand of God" wrote that number, and "we don't know how He pushed his pencil." We know what kind of a dance to do experimentally to measure this number very accurately, but we don't know what kind of dance to do on the computer to make this number come out, without putting it in secretly!"* [vi]

It is frequently described as *Coupling Constant*, an appropriate epithet in the light of what we have discussed, since it couples a measurement of distance in the domain of the moving electron with that of time measured in the domain of a stationary observer.

There is nothing mysterious or special about the fact that the Fine Structure Constant is a pure number, lacking units or dimensions. It simply means that it derives from the ratio of two values which have the same dimensions, in much the same way as $\pi$ is dimensionless because it is the ratio of two lengths.

Bohr was able to solve his equations in order to match the energy levels of the Rydberg formula and as a consequence was able to derive an analytic formula for the Rydberg constant. When Sommerfeld linked the Bohr velocity to the speed of light he opened the door to allow the Fine Structure constant to be expressed in terms of other known physical values, but the reason why it should have that particular value remained a mystery.

The introduction of Relativistic Velocity solves the mystery and shows that it is indeed the ratio of two quantities. We can think of it as the ration of two lengths, although it is equally valid to describe it as a ratio of two times or even two masses. In terms of length, it is the ratio of the orbital circumference measured by a stationary observer to that measured by the moving electron in the hydrogen atom in the base energy state. It also occurs in each stable energy state as one of the multivalued orbital circumferences that occur due to the phenomenon of aliasing.

We can also think of Alpha as being the ratio of two times, the period of the orbit as seen by the stationary observer and the period as seen by the moving electron in the base energy state. Similarly we can view it as being two frequencies, the orbital frequency as seen by the stationary observer to that seen by the moving electron in the base energy state.

Alpha occurs again in the photon, only this time the ratio is equal to 4/Alpha, rather than simply Alpha. The 4 comes about because the while the orbital radius is the same for both the electron in the hydrogen atom and the electron and positron in the photon. They are diametrically opposed in the photon and hence the electrical force is less by a factor for due to the nature of the inverse square law.

## Force

Relativity is unique among physical phenomena in that there are always two versions of any physical measurement be it based on length, time or mass. So for example the distance between any two points or the time taken to travel between two points will depend on whether they are measured by a stationary observer looking at the situation from outside or by an observer moving in the same reference frame as the moving object. Relativity therefore naturally contains a certain duality and it is that duality which is manifest here.

Relativity creates a duality that applies to distance, time and mass and we have seen that this also extends to velocity in certain circumstances. Certain orbital velocity terms are seen to be affected by relativity and so there exists a duality of velocity between the various reference frames. This relativistic velocity is such that it straddles the two reference frames, that of the moving object and that of the stationary observer. Within each of these two domains both distance and time are affected equally by relativity and so the velocity is invariant between them. However Relativistic velocity affects interactions between the two reference frames and is formed as a sort of hybrid involving the distance measured in one domain to the time measured in the other.

Quantum theory asserts that force is 'mediated' by particles, each force has an associated particle (except gravity), so the electromagnetic force is said to be mediated by the photon and the strong nuclear force is mediated by a type of Meson called the Gluon. It is never quite explained how this process takes place.

Clearly, if the photon is composed of an electron and a positron in mutual orbit, it is not possible for it to be involved in such a process. In any event, it has never been explained just how the photon can cause an attractive force when it carries momentum and is therefore only capable of pushing things away, as for example with the solar wind. However the energy carried by the photon is kinetic energy. It is a similar story with the Gluon, which is after all a hypothetical entity. The attractive force between protons within the nucleus is a modified version of gravity caused by the effects of relativity and so the Gluon disappears from the lexicon of particles. Hence the energy associated with binding the protons together within the atomic nucleus is mechanical in nature. It is a similar story with the force binding the orbiting electron to the atomic nucleus. This too is mechanical in nature. Thermal energy and chemical energy are also seen as being mechanical in nature meaning that all types of energy are ultimately forms of kinetic energy.

This idea of duality can be extended to encompass force.

Historically it is argued that there are four fundamental forces, the electro weak force, the strong nuclear force, electricity and gravity. There have been various attempts to unify these four forces into a single force and there has been some success with the strong, weak and electric forces. Gravity on the other hand remains elusive.

Were it not for relativistic velocity the centrifugal force acting on the electron within the hydrogen atom would be too large to hold it in a stable orbit. It is the reduction in this force due to the effects of relativistic velocity that allows the electron to enter a stable orbital state around the atomic nucleus. Although it is not strictly the case, we can think of this as equivalent to a reduction in the centripetal force created by the electric field acting between the electron and the nucleus; a sort of weakened electric force that exists by virtue of relativity. Between this and the conventional electrostatic force there is a sort of dual relationship, similar to that between distance, time or frequency measurements. The force is reduced by the same factor Gamma and the atom is stable whenever Gamma is an integer multiplier of 1/Alpha. So it is this same mechanism of relativity that leads to an apparent weakening of the electric force.

This idea of a duality of force can be extended further to include gravity as well as the electrostatic force, only this time it serves to increase the force rather than reduce it. For atoms other than hydrogen the atomic nucleus contains more than one proton. Protons have a positive electric charge and positive charges repel one another. Being very small means that the forces, which are subject to the inverse square law are very large which begs the question as to what force can possibly overcome the repulsive forces created by these positive charges in order to bind the nuclear protons to one another.

Relativistic velocity acts in such a way that it serves to reduce centrifugal force acting on an orbiting body as the velocity gets close to that of light. There is no limit to the extent of this reduction and so at a high enough velocity the force will be effectively reduced to zero. At the same time as the velocity increases ever closer to that of light the mass of an object increases for an observer located at the orbital centre. There comes a point where the gravitational attraction between the increased mass of the protons is sufficient to match the electrostatic repulsion caused by the charges on the protons. At this point the nucleus will be stable.

Hence the strong nuclear force can be thought of as a sort of dual for gravity brought about by the effects of relativity in much the same way as the weakened electric force was a dual for the electrostatic force. It can be said to exist by virtue of relativity.

This means that we can reduce the number of forces of nature from the currently conceived four forces to two fundamental forces; electricity and gravity, and two further virtual forces, one for electricity as a weakened electric force and one for gravity as a strengthened gravitational force.

This combination of attraction and repulsion is the fully subscribed set of forces for two bipolar static forces. Any additional such forces would only ever add to or detract from these two forces.

| **Gravity** | | |
|---|---|---|
| + | + | Attractive |
| + | - | Repulsive |
| - | + | Repulsive |
| - | - | Attractive |

| **Electrostatic force** | | |
|---|---|---|
| + | + | Repulsive |
| + | - | Attractive |
| - | + | Attractive |
| - | - | Repulsive |

Table 5-1 Forces of attraction and repulsion

## Energy

We are taught in school about the various different types of energy. There is kinetic energy, electrical energy, chemical energy, thermal energy and so on. Later on we may learn that there is energy associated with the atom, so called binding energy and similarly with the atomic nucleus. Some of these various different energy types have been unified, most notably with the kinetic theory of thermodynamics. Relativistic velocity and all that it implies allows us to complete this process and unify all types of energy to be kinetic in nature.

We have seen that the energy of a photon is carried as kinetic energy by the orbital rotation of its constituent particles acting as a flywheel. Given that the energy is mechanical in nature it follows that the conversion of energy into matter and matter into energy as represented by Einstein's famous equation is a mechanical process. The strong nuclear force is also seen as a mechanical force amplified on a nuclear scale by the effects of relativity and so the energy associated with this force is kinetic. As we list the other forms of energy that we encounter in nature these too are all seen to be kinetic, including heat and mechanical energy itself.

The idea of duality extends to the wavelength of light, since there are two ways of measuring it. We can measure the distance in the direction of propagation or we can measure the distance travelled by the individual particles along their respective trajectories. In both cases the classical equations of the wave apply. In the former the wavelength is the distance between successive peaks measured in the direction of travel and is given by the velocity of propagation divided by the frequency. In the latter the wavelength is the distance traversed by the electron or the positron as it follows a cycloid path for one complete cycle and is given by the speed of light divided by the frequency.

From this it is evident that the transformation of energy into mass and mass into energy as represented by Einstein's equation e=mc2 is itself a mechanical process.

## The Ether

Quantum theory is rather wedded to the idea of the ether, although the need for and belief in the ether dates back to antiquity. Over time there have been various attempts to eliminate it, but every time it has been reinvented, often with a different name, so Huygens and Decartes referred to it as the Plenum, then it became the ether, more recently we have had the Fabric of Space time and Quantum Foam. Despite the name changes and some subtle changes in the way it is supposed to work these are all really just euphemisms for the ether.

Relativistic velocity and the associated model for the photon do away with this need completely. The photon, being composed of discrete particles which have a physical presence can travel across empty space. It does not need a supporting medium. Its wavelike characteristics derive from the orbital motion of its constituent particles. It differs from Maxwell's model in that the locus of the charges follows a cycloid path rather than a circular one and it is this that causes the speed of propagation to decrease with increasing frequency.

This means that empty space is just that, completely devoid of anything save the concept of mass length and time within a reference frame. Such a space has no properties. Properties such as permittivity and permeability exist only by virtue of the juxtaposition of particles. All material substances and energy are composed of particles and combinations of particles of either matter or antimatter.

In a sense space is defined by the inverse square law and relativity. The concept of space is linked to the idea of a reference frame, a set of co-ordinates which defines the space. In order to construct such a set of co-ordinates it is necessary to have a measure of distance, a unit of length. Ultimately the only way we can establish such a reference distance is by virtue of the forces acting between them, and these are subject to the inverse square law. Even if we adopt the current strategy for establishing a standard length based on the wavelength of light emitted by a certain atomic transition we find that this too is intimately connected to the inverse square law.

## Hypothetical entities

There are a number of other casualties of concepts and hypothetical entities contained within the current theories that this new theory implies.

The Copenhagen interpretation and subjective reality, which seeks to suggest that a particle exists in some sort of nether state as neither a particle nor a wave until it is measured at which time it "collapses" into one or the other according to what is being measured. Here however the particle exists as a real physical entity, it does not need to, nor does it collapse when observed. It exists objectively.

It is a similar story with Schrödinger's cat, which can finally be laid to rest and given a decent burial. Schrödinger devised his thought experiment as a criticism of the Copenhagen Interpretation. The cat, you may recall, is sealed in a box with a device that may or may not kill it with a 50% probability and is said therefore to exist in a state of being both alive and dead and neither alive nor dead at the same time. When the box is finally opened, the history of the cat during this entire experiment suddenly, and as if by magic, comes into existence to reveal whether it died or not.

Relativistic velocity means that particles are objectively real. The cat is either alive or dead at every instant in time throughout the experiment, it is just that we cannot determine which, simply because the box is sealed.

The currently held view is that quantum theory is correct as far as it goes, but incomplete. As a result there have been various attempts to fill in the supposedly missing blanks. It is argued here that this is not the case and that quantum theory is fundamentally flawed and always has been and that the principle reason for this is that it relies on the invalid assumption that angular momentum is quantized. Over the years there have been various attempts to complete quantum theory. These have got ever more fanciful and far-fetched as time goes on. They include string theory, brane theory, multiverse theory, the anthropic universe, variations in the fundamental constants over time in particular the fine structure constant but also the gravitational constant. All of these and whole plethora of other such theories can be cast into the dustbin of history where they belong.

## The Uncertainty Principle

While there are undoubtedly casualties caused by this new theory, there are some aspects of the current thinking which are decidedly not casualties. Paramount among these is the uncertainty principle.

When Heisenberg first discovered the uncertainty principle he proposed that the uncertainty derived from the fact that the object being measured was of the same order of magnitude to the tool used to measure it. In this case when one parameter is being measured, it necessarily alters other related parameters and so, for example, it is not possible to measure both position and velocity at the same time. This was and is a valid explanation of the phenomenon. It was only later that he changed his mind to argue that uncertainty was an inherent property of the particle or photon, in line with Bohr's ideas.

Uncertainty is unavoidable, especially here where the photon is seen as being composed of an electron and a positron. It is therefore very definitely of the same order of magnitude as an electron and so there is bound to be a trade off to the accuracy with which measurements can be made.

The fact that there is bound to be uncertainty with which we can measure on the scale of the atom, the electron and the photon, means that we are forced into using statistical methods and probabilities on this scale. Such techniques are the bedrock, not of quantum theory, but of quantum mechanics, much of which therefore remains valid.

Very little of quantum mechanics is reliant on quantum theory and the models it contains. For example if we look at Einstein's paper on the stimulated emission of radiation, which laid the groundwork for the maser, the laser, the led and a host of other devices, it owes nothing at all to quantum theory, but everything to the discoveries by Fraunhofer, Angstrom and Kirchhoff and to the Rydberg formula.

## Schrödinger's Wave Equation

Schrödinger based his wave equation on Louis de Broglie's idea of the particle existing as a wave. In this the wavelength is not the orbital circumference, but is instead an integer fraction of the orbital circumference. The equation and de Broglie's model are both based on the assumption that angular momentum us quantized in units of Planck's constant. The wave equation is readily derived by taking the canonical form of an undamped second order differential equation and coercing it to reflect this quantization. The result is an equation which contains an energy term which has to be expressed as containing both kinetic and potential energy. This latter potential energy is the same as is expressed by the change of radius in the quantum leap. In other words, Schrödinger's wave equation intrinsically assumes that there is a quantum leap.

With the introduction of Relativistic Velocity, the need for a quantum leap disappears. The electron is seen as a point particle having deterministic properties. In the resulting atom the electron always orbits at the same radius, equal in fact to the reduced Compton wavelength. There is no change in potential energy with change in energy level.

It is necessary therefore to draw up a different wave equation, similar to that of Schrödinger, whose solution is this type of wave. In fact there needs to be two such equations, one for the wave as experienced in each of the two reference frames.

## Other Phenomena

The fact that antimatter has negative gravitational mass has important implications not only on the atomic scale, but also on a cosmic scale. Our knowledge of the universe is intimately associated with the photon. Almost everything we know about the universe is known because the information is carried to us by photons.

For each type of particle there is an alter ego, an antiparticle equivalent and the antiparticles are subject to exactly similar processes and forces as are particles. So for example a positron is capable of orbiting an anti-proton to form anti-hydrogen. And if it is true for hydrogen it is true for all of the other elements as well, so there must exist anti-helium, all the way up to anti-uranium. All of the chemical, atomic and nuclear processes that take place in matter have equivalents in anti-matter. However all of these elements and the corresponding compounds would have negative gravitational mass. The photon on the other hand is its own antiparticle.

It is therefore impossible to determine whether a photon arriving here on earth originated as a result of a process which took place in matter or the equivalent process taking place in antimatter. This means that we have no way of knowing whether a distant object is composed of matter or antimatter. Clearly all of the stars within an individual galaxy are composed of the same type of substance otherwise it would not have gravitational integrity.

However there is no reason to conclude that other galaxies are made of the same stuff. It is equally likely to be predominantly antimatter or predominantly matter. This has important implications when we look at the origin, size and age of the universe. It means we have no way to determine the overall mass of the universe, this in turn means we cannot determine whether it is geometrically flat or geometrically curved. It means that all of the mathematics around dark matter and dark energy is subject to doubt and will require re-examination. And it means that we cannot readily determine the age of the universe.

## Conservation

If, when matter is transformed into energy, it is the result of particles combining with antiparticles to produce massless photons. The individual particles are not destroyed, they do not evaporate, they continue to exist as part of a compound particle. Similarly when energy is transformed into matter it is the constituent particles of the photon which separate to continue their existence as particles rather than as components of a photon. In other words particles are conserved throughout these transformation processes. This applies equally to both matter and antimatter and so we can extend our ideas about the laws of conservation to include a law of conservation of particles.

Particles can neither be created nor destroyed, they may combine with one another to form matter, antimatter and energy in such a way that the sum of the energy is equal to the sum of all the masses multiplied by the speed of light squared.

$$\sum e = \sum mc^2$$

## Multiverse

We saw in Chapter 2 that Multiverse theory asserts that there is more than one universe and that we are constrained to exist in just one of these many universes. In some versions of the theory universes are spawned at every interaction of every particle, leading to an unimaginable number of different universes. However the duality brought about by relativity provides us with an alternative and far more prosaic answer.

Earlier we saw that within its own reference frame every photon is identical and within that reference frame it is stationary and orbits at its maximum possible frequency, $\omega_{max}$. We see the photon from a different reference frame and as a consequence time in our reference frame runs at a different rate. This means we see the photon as having a different, lower, frequency than does the photon itself. This is a manifestation of the dual nature of the frequency of the photon as a result of special relativity. We can use this in a simple thought experiment to explain just how the multiverse comes about.

Consider the case of a photon and a hydrogen atom in its base energy state, somewhere in empty space. We have seen that duality means that the photon will be perceived as having two frequencies. Within its own reference frame the photon always has a frequency of $\omega_{max}$ or $7.76345184*10^{20}$ radians per second. If the photon is such that it appears blue to the hydrogen atom it will have a lower frequency, as far as the hydrogen atom is concerned. The frequency of blue light is roughly $4.71*10^{15}$ radians per second. Of course the hydrogen atom cannot literally see the photon, but if it could then it would perceive it as being a blue photon with this frequency.

The photon's perception of the hydrogen atom is also affected by this duality. The hydrogen atom is in the base energy state and so seen from within its own reference frame it has an orbital frequency of $7.76324511*10^{20}$ radians per second. The velocity of propagation of a blue photon is such that Gamma is roughly 16500. Relativity affects frequency and so the frequency of the orbiting electron in the hydrogen atom is seen by the photon as being multiplied by Gamma, which means that the photon would see the orbital frequency of the hydrogen atom as being increased by this factor, or in other words an orbital frequency of $1.28*10^{25}$ radians per second.

Supposing now the photon had an interaction with some other particle, perhaps a collision as might happen as a result of Compton scattering. The outcome of this collision as far as the hydrogen atom is concerned is that the photon is red shifted and so loses some energy. Internally however the photon is unchanged; within its own reference frame it continues to have a frequency of $\omega_{max}$. However the photon's perception of the hydrogen atom will have changed. Suppose that the extent of the collision is such that the photon now appears red to the hydrogen atom. The velocity of propagation of the photon will have increased (red light travels faster than blue light) and therefore so will the factor Gamma. For a red photon the velocity of propagation is such that Gamma has a value of 33000. The result is that the photon will appear to the hydrogen atom to have a frequency of $2.35*10^{15}$ radians per second and that the hydrogen atom will appear to the photon as having an orbital frequency of $2.56^{25}$ radians per second.

In this simple example we have only considered the effects of duality on a single photon and a single hydrogen atom but the change in perception caused by the photon's interaction with a particle will affect the way it perceives every other particle in the universe which is not in its own reference frame. Prior to the interaction there each such particle will have an associated value for Gamma which changes as a result of the interaction.

We have only considered the effect of duality and changes in Gamma on the perceived frequency, but relativity affects all measurements, not only time and frequency. It also affects distance and mass. This means that any interaction affecting a particle will alter not only its perception of the frequencies of all other particles, but it will alter the entire geometry of the universe as far as that particle is concerned. As far as the photon is concerned the entire universe has taken on a completely different perspective.

The particles that are most affected by this are those traveling at close to the speed of light, so photons and other massless particles, but the same logic applies in principle to all particles. Whenever a particle interacts with another particle causing a change in its velocity then its perception of the whole universe changes as a result. The changes that come about depend on the change in Gamma, which for most everyday objects are negligibly small and so the changes are insignificant.

The term Multiverse is something of a misnomer since in reality there is only one universe but every reference frame within that universe sees it frm a different perspective. Perhaps the term *Virtual Multiverse* would be more appropriate, since all of the different perspectives exist by virtue of relativity. It encompasses everything that exists everywhere.

However every particle has a different perspective on the universe and that with every interaction that perspective changes. These changes are a consequence of the dual nature of reality and that dual nature is in turn the consequence of special relativity.

## Occam's razor

Occam's razor suggests that where there are two or more competing theories, then the one which makes the fewest assumptions is most probably correct. So it is worth comparing the assumptions made here with those of the current standard model.

Here there are just two assumptions. The first is that antimatter has negative gravitational mass. Nobody has ever successfully weighed antimatter, which means that the assumption is at least plausible. The second assumption is that certain velocity terms should be considered as being affected by relativity. Again the idea has never been tested and given that it provides a solution which is consistent with all of the other laws of physics as we understand them, then it is also at least plausible.

When it comes to such assumptions there are dependencies, which sometimes imply further assumptions. Here there are none, apart from the assumptions themselves, the conventional laws of physics apply and these are well known and well proven on all other scales.

When it comes to the current quantum theory, then the list of assumptions and implied assumptions is almost endless. The first and most obvious and fundamental assumption is that angular momentum is quantized. Not only does this violate the tenets of the scientific method, but it also leads directly to a number of absurdities or implied assumptions.

These include the quantum leap or whatever euphemism is used instead, wave particle duality, collapsing wave fronts, intrinsic uncertainty, action at a distance, the absence of synchrotron radiation without any reason. The list goes on. All of these supposed phenomena must exist if angular momentum is quantized and they all require that we abandon our understanding of how physical systems work.

## The Great Debate

During the 1930's and 1940's physics divided into two rival camps. On one side were the likes of Niels Bohr, Paul Dirac, Werner Heisenberg who supported the idea of subjective reality and the Copenhagen interpretation. On the other side were the likes of Albert Einstein, Louis de Broglie and Erwin Schrödinger who reasoned that reality had to be objective. In the intervening years physics has drifted towards the point of view of Bohr and his cohort. The ideas proposed here overturn that view in favour of the Einstein camp. Reality is objective, the universe is far more prosaic than subjective reality would have us believe. Einstein was right.

## Conclusion

The assumption that angular momentum is quantized makes a complete mockery of the scientific method. It leads directly to the absurdity that is the quantum leap. The wave particle duality attempts to get around this, but in doing so it introduces a new type of wave, a hypothetical one based on Planck's constant rather than being based on total angular momentum as happens everywhere else. Such a wave has no physical significance, nothing to wave and no substance. Schrödinger developed an equation to describe such a wave and in doing so is forced to introduce a potential energy term, reflecting a change in orbital radius with change in energy level, effectively re-introducing the quantum leap via the back door but with a different name. Like a house built on sand, everything else in quantum theory stems from these suspect foundations. Later the Heisenberg uncertainty principle, which had a perfectly rational explanation as a problem of measurement, was hijacked by the advocates of quantum theory in an attempt to circumvent the quantum leap. But even with uncertainty de Broglie's standing waves are merely a euphemism for the quantum leap, a way of describing it without using the words 'quantum' or 'leap'.

There have been numerous attempts to validate the theory, in effect to bridge the gap between classical mechanics and quantum theory, so called 'unification'. They have all failed. Any attempt to validate quantum theory based on the theory itself is doomed to failure. Such self-referring proofs have no validity in logic. The only way to validate such a theory, or for that matter to devise a new one, is by starting on the classical side and proceeding from there.

If we try to do so simply by writing Newton's equations to describe the dynamics of the hydrogen atom, we obtain a single solution. Such an atom would have constant energy and would therefore be incapable of emitting or absorbing energy at different levels. There is clearly something wrong with Newtonian mechanics, some shortcoming or missing factor. This exactly what Niels Bohr attempted to suggest with his assumption that angular momentum is quantized, but that was an incorrect assumption, which means we must look elsewhere.

There is one obvious oversight in Newtonian mechanics, which was only discovered in 1905 and that is the effects of special relativity. Einstein showed that mass, length and time depend on the reference frame within which they are measured and that when such reference frames are moving with respect to one another time runs at different rates, distances appear to be different and so does the mass of an object.

The Rydberg formula is an objective description of the behavior of the atom, telling us the energy levels of the absorbed or emitted electrons. If the quantum leap is a physical impossibility then it follows that the orbit of the electron cannot change with energy level. Restricting the Rydberg formula in this way reveals an atom in which the electron orbits at near light speed and the variable of quantization is Gamma, the Lorentz factor. The unit of quantization is then found to be the reciprocal of the Sommerfeld fine structure constant.

The atom can only achieve dynamic balance if the centrifugal force is moderated by relativity, which leads to the postulate that orbital velocity is also affected. If orbital velocity is assumed to be based on the distance traveled by the electron subject to, and foreshortened by, relativity, divided by the orbital period measured by a stationary observer then not only do the forces come into balance, but aliasing of the such a velocity term causes all of the various energy levels to be stable states of the atom. Such a hybrid velocity term addresses the issue as to why synchrotron radiation does not cause the electron orbit to decay. It also addresses issues such as zero point energy and the wave nature of the particle which derives directly from its orbital motion and finally solves the riddle of the fine structure constant.

Turning to the photon: photons are observed to decay into pairs of particles, an electron and a positron. Under different circumstances these particles in turn can combine to form a photon. It is reasoned here that the photon is therefore composed of such a pair of particles, locked in mutual orbit and traveling together like conjoined twins through empty space. There is no such process as annihilation, more one of combination, equally particle pairing is a process of decomposition into the photon's constituent particles. The dynamics of such a system are very similar to those of the hydrogen atom, both being examples of a so called two body problem. By applying the same assumption that orbital velocity is affected by relativity the dynamics of such a photon come into balance. The individual particles are traveling at near light speed along a cycloid path and the whole is propagating through space at somewhat less than the "speed of light". Hence the photon and its component parts are subject to the limits of the "speed of light" and not the cause of it.

The photon has zero aggregate mass because the positron is an antimatter particle and it is postulated here that antimatter has negative gravitational mass.

Taken together the models for the hydrogen atom and the photon described here do away completely with the need for the invention of the ether and all of the other fanciful notions that quantum theory implies, they address the issue as to how light can travel through otherwise empty space as well as settling the issue of the nature of reality.

The concept of duality is all pervasive. It affects everything from the scale of the universe right down to the scale of the atom, and most likely beyond. Its effects are most manifest on the scale of the atom where objects are moving relative to one another at close to the speed of light. It not only affects mass, distance and time but also frequency, wavelength, velocity and force. It is the mechanism which brings about stability within the atom and it confers the atom with its various stable energy states. It provides the mechanism that underpins the dynamics of the photon. The driving force behind this duality is relativity which provides us with its cause.

It is perhaps a fitting tribute to the genius of Albert Einstein that every single atom and every single photon in the universe depends for its existence on the effects of Einstein's Special Relativity.

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[i] Bailey, H.; Borer, K.; Combley F.; Drumm H.; Krienen F.; Lange F.; Picasso E.; Ruden W. von; Farley F. J. M. ; Field J. H.; Flegel W. & Hattersley P. M. (1977). *Measurements of relativistic time dilatation for positive and negative muons in a circular orbit*. Nature 268 (5618): 301–305

[ii] Dyson F.W.; Eddington, A.S., & Davidson, C.R. (1920). *"A Determination of the Deflection of Light by the Sun's Gravitational Field, from Observations Made at the Total Eclipse of May 29, 1919"*. Phil. Trans. Roy. Soc. A 220: 291–333. doi:10.1098/rsta.1920.0009.

[iii] From <u>*Nobel Lectures,*</u> *Physics 1922-1941*, Elsevier Publishing Company, Amsterdam, 1965

[iv] Planck, M. (1901) *On the Law of Distribution of Energy in the Normal Spectrum* Annalen der Physik vol. 4, pp 553

[v] Einstein, A (1905) *On a heuristic point of view concerning the production and transformation of light* Ann. Phys., Lpz **17** pp 132-148

[vi] Feynman, Richard P., (1985) *QED: The Strange Theory of Light and Matter*, Princeton University Press, p. 129.