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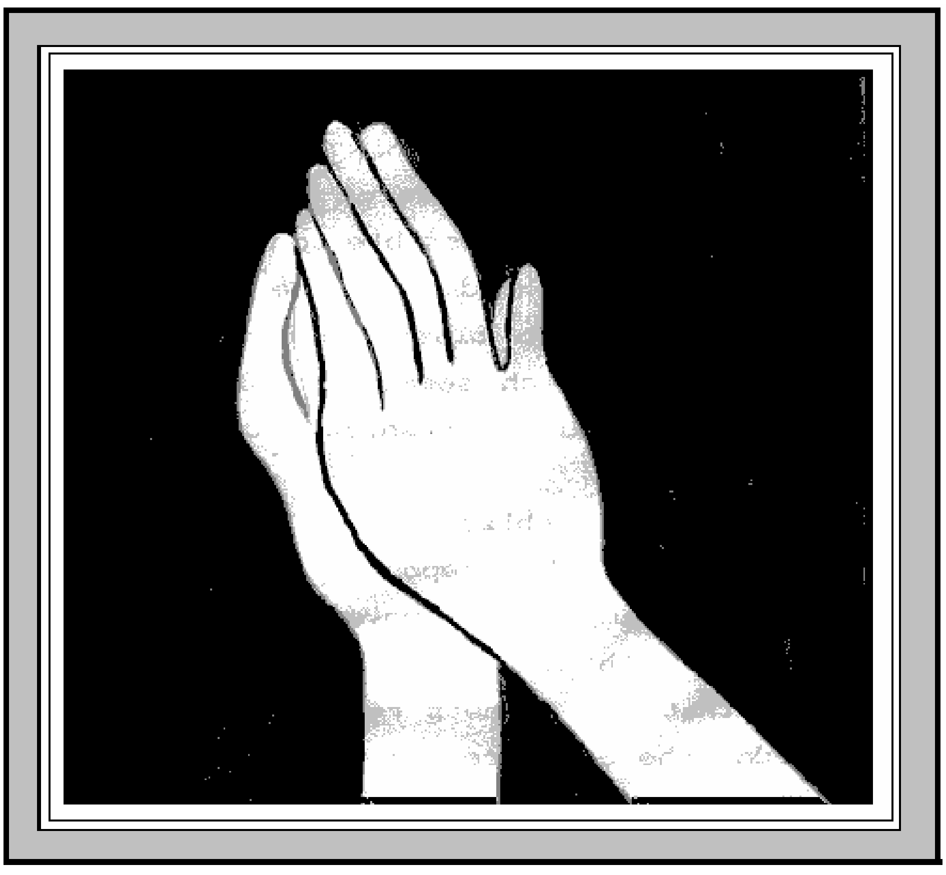
STAGE 2

There is a Solution

Ask, and it shall be given unto you;
seek, and ye shall find.
Jesus Christ



Help!

THE SCIENTIST HAS GREAT FAITH. He believes that sensible questions will have meaningful answers. Unwavering confidence in this, together with the doctrine, attributed to Francis Bacon around 1600 that there can be no final claim to scientific knowledge until a proposition has been subjected to experimental verification, has led to rapidly accelerating progress in science and technology since the time of Newton, about three hundred years ago.

The fundamental theoretical discoveries of Newton published in 1687 led DIRECTLY AND INDIRECTLY, over the following hundred and fifty years, to dramatic developments in large and small scale engineering; to steam engines (1700), steam pumps (1705), steam ships, railway trains (1814), reflecting telescopes and pendulum clocks, as well as to better bridges, microscopes, guns, locks and keys, pumps, pulleys, weighing machines, nuts and bolts, ball bearings, spectacles, spinning and weaving machines, musical instruments and all kinds of tools and manufacturing processes. It might even be possible to argue that Newton was responsible for ensuring the dawn and relentless rise of the Industrial Age which rested firmly not only on blast furnaces but also on the *mechanical philosophy* which seems to follow naturally from Newton's physics. He even had a mechanical *corpuscular* theory of light.

Galileo Galilei in 1632 published work which greatly offended the Church. He reported his observations by telescope of, for example, the movements of Sun spots, which led him to agree with the opinion of Nicholaus Copernicus, published 1543, that the planets revolve around the Sun: the Earth goes round the Sun once a year and about its own axis once a day. This shattered the Aristotelian world view which had been adopted by Christianity since the time of Saint Thomas Aquinas around 1265. However Newton's mechanical theories did not cause an immediate split with the Church. Newton's own ardent Protestant theology evoked a *God of the gaps* to justify the apparent action at a distance of gravitation, and he believed in a theological division between *matter* and *powers*. This was accepted as sufficiently consistent with Christian and Platonic ideas not to be heretical. Perhaps the Church did not protest because the clergy did not understand the unprecedented radical significance of the first truly dynamical deterministic theory which was expressed mathematically using Newton's new and difficult *calculus*. Also pure idealism had already been tempered by the mind-matter dualism of the devoutly Catholic René Descartes in 1637.

The discovery by Sir Charles Darwin, published in 1859, that all life EVOLVED from a common origin fitted in well with the mechanical philosophy. "All living things are as they are because their forms have undergone a long process of evolution from simpler ones." Soon after, in

1865, Gregor Mendel published his laws of heredity which reinforced Darwinian ideas. However Darwin's theory *flatly contradicted* the biblical account of the creation of man. This immediately provoked uproar and a furious conflict between the evidence of science and the dogma of religion.

In the seventy years between 1800 and 1870 the world changed more than it had in the previous thousand years. Much of this was due to the mathematical theories of Newton which formed a precise rigorous and accurate foundation to the mechanical understanding of the world thus allowing it to be interpreted, moulded and conquered by science and engineering. There is a solid solution. Mechanics.

Adding to the clamour of the mechanical revolution came the electrical revolution, initiated by Alessandro Volta, Charles Coulomb, Jean-Baptiste Biot, Félix Savart, André-Marie Ampère and Michael Faraday, and crowned by Maxwell in 1873. This quite literally gave a new (electromotive) force to the accelerating pace of change in the shrinking planet Earth. Again, having a firm mathematical foundation to their understanding, inventors began to produce a shower of spectacular new undreamt-of applications and appliances.

Within a hundred years the world had been shrunk by a revolution in communications; by the telegraph (exploited by Morse 1844), the telephone (Alexander Graham Bell 1876), wireless (Guglielmo Marconi 1899, popularised from 1939) and television (John Logie Baird 1925, popularised from 1950). It had been lit with electric light bulbs (Thomas Eddison 1879) and brought to life with bells, buzzers and electric motors. Homes were being powered by electricity generating stations leading to a flood of revolutionary domestic appliances such as room heaters, electric kettles, vacuum cleaners, refrigerators, electric toasters, record players, sewing machines, electric razors and washing machines. Business and industry also received a considerable boost from a host of other new tools, such as dictaphones and automatic assembly lines, to improve business efficiency and speed up repetitive manufacturing processes. The petrol motor car (Karl Benz 1885) and aeroplane (first flight Wilbur & Orville Wright 1903) combined both mechanical and electrical expertise. The mathematical equations of Maxwell were a huge success and have now affected in one way or another almost everyone on our planet. There is a solution. Electromagnetism.

In the last fifty years some consequences of the profound new *quantum revolution* have taken visible shape and are beginning to influence every corner of our lives. Quantum mechanical devices, upon which many modern gadgets, gear and gismos are based, include transistors (1947), integrated circuits and very large scale integrated circuits (VLSICs), fluorescent tubes, laser beams (used for holograms, fibre optics and laser gyroscopes), ultrasound scanners, superfluids, superconductors, superconducting quantum interference devices (SQUIDs) and quantum fridges.

Quantum theory first found mathematical formulation in the works of Heisenberg and Schrödinger who independently, around 1926, found a quantum version of Newton's mechanics, called quantum mechanics. This *modern* mechanics was immediately imported into chemistry and soon into molecular biology making many discoveries possible from plastics (1933) to the double helix of deoxyribonucleic acid (DNA) (Francis Crick and James Watson 1953). Without the quantum mechanical revelations concerning new principles behind the physical world many of the recently growing industries would hardly be conceivable; microelectronics, transputers, high speed data communications, precision robotics, computer aided design and manufacture (CAD/CAM), modern pharmaceuticals, genetic engineering, space exploration, modern scientific instrumentation, radioactive material application and the very new micro-robotics and nanotechnology. There is a new solution. Quantum mechanics.

Prior to the advent of quantum mechanics, Einstein found that Newton's mechanics and Maxwell's electromagnetism were mutually *inconsistent* in their account of motion. This he rectified in 1905 with his theory of special, or restricted, *relativity* which simply but profoundly adjusted mechanics to incorporate the velocity of light as an ABSOLUTE CONSTANT for all observers irrespective of their state of rectilinear motion. In so doing Einstein revealed that *mass is a form of energy*. Just how much energy can be extracted from a small mass was demonstrated most conclusively by the atomic bombs used on Japan in 1945 and later by nuclear powered electricity generating stations and submarines.

Apart from these awful and awesome examples, special relativity has had little impact on everyday life. It is essential in explaining high energy processes like that responsible for the Sun's radiation but it has not *yet* led directly to inventions for low energy home use. However, the possibility, for example, of travelling *forwards* in time at different rates has been established definitively by a pair of identical atomic clocks, one flown right round the world and the other kept stationary on the ground. The clocks were synchronised at the start and were DIFFERENT at the end of the flight by the predicted amount. The theory has also been verified in many other places where Newton's classical mechanics manifestly fails. There is another new solution. Special relativistic mechanics.

While none of these scientific theories is entirely satisfactory, they have supplied mankind with ever more sophisticated equipment with which to fulfil his needs and satisfy his desires. And while there is very good reason to be concerned about the uncontrolled accelerating pace of change and the new potential for destruction, caused by technical advances, themselves for the most part made possible ultimately by the advances in theoretical physics, one important factor behind the astounding success of fundamental science is the entrenched belief that *every sensible question has a meaningful answer*; *every real problem has a comprehensible solution*.

At a time when rapid changes are taking place all around us, more than ever requiring responsible technological and orderly social progress, there is a solution; faith in QUANTUM PHILOSOPHY. We are in the throes of an almighty potential catastrophe. Science got us in. Philosophy *can* get us out.

❶ Answers: reduction to self-evidence

THAT MAN HAS THE CAPACITY TO ANSWER difficult questions is a wonderful treasure indeed. How exactly it is possible to induce deep original generalities from particulars by means of a creative leap of imagination is not at all understood by science. It is only clear that without conscious mind such guessing power would be almost inconceivable, if not completely meaningless.

But man can answer questions of a most penetrating kind and can demonstrate the validity of his arguments with, in some cases, fantastic precision. His scientific conclusions are not usually held to be ultimate, absolute truths which are unassailable by all future generations of thinkers - although Euclid's geometry and Aristotle's logic have been considered as such until relatively recently. Nevertheless, in the last three hundred years there have been a few scientific theories which answer with considerable elegance and comprehensibility a tremendous number of questions about nature.

Physicists realise that all the theories which they currently recognise and accept as the best they have have problems associated with them making it highly unlikely that any of them is final. Nevertheless these theories must encapsulate something of essential truth because of their startling success in giving us power over nature through exact understanding. Those who argue that the current scientific theories are not too important because they will eventually be refuted and replaced by others considerably mislead. Current theories are exceedingly important both to science and to society. Their importance cannot be overstated. The modern world cannot be understood without them. They form the new rational basis of our modern culture.

In the last hundred years, millions of man-years of thought have gone into making a huge web of rigorously solid and thoroughly tested scientific theories. Any attempt to improve upon that structure is considered dispassionately and installed only after being subjected to careful experimental verification. Anyone attempting to criticise or debase this structure as a whole must replace it with something at least as useful, or else show themselves up as unable to appreciate its massive importance to us all.

It is necessary to be able to suspend dogmatic judgements and preconceptions in the pursuit of science. However it is also vital that those theories which are found to work are given the weight and credit they deserve. It is possible to apply scientific theory in the wrong direction, to take the power of science and use it selfishly, or to disrespectfully degrade the insights of many great thinkers without bothering to understand what they actually meant. For example, most interpreters of quantum theory try to fundamentally change the theory according to their prior predilections. Instead, scientists and non-scientists alike ought to place great faith in those theories which are shaping the world around us at breakneck speed.

A crucial aspect of the methodology of science is the demand that everyone can, at least in principle, confirm all the experimental evidence supporting a theory. It is the lack of reliable repeatable evidence for ghosts, clairvoyance, psychokinesis and telepathy which has led the scientific community to denounce and completely disregard the subject of parapsychology. While there is probably too much haste in the dismissal of this field of study because claims to evidence tend to be ruled out pre-emptively since they do not sit well in the current classical paradigm, there is nothing like seeing the evidence with your own eyes.

Most people do not feel the need to validate in detail the assertions of experimental scientists whom they implicitly trust not to be intentionally fraudulent. Nevertheless it can be argued that by switching on and viewing your television you are indirectly verifying quantum mechanics yourself since the rationale behind the construction and function of a transistor relies substantially on the validity of quantum mechanics as applied to silicon or germanium crystals. It is very hard to see why a transistor should ever have been constructed without the theoretical justification. Neanderthal man should not have made an electronic computer nor should the proverbial monkeys have written 'A Midsummer Night's Dream'. The real progress comes through *understanding*.

If you ought strongly to believe theories which are known to have only limited application, like classical relativity which does not apply at microscopic scales, or non-relativistic quantum mechanics which does not apply at very high velocities, then how much more strongly ought you to believe a general philosophy which seems to have unlimited application. This relativistic *quantum philosophy* is different from a theory. One can take a theory and *quantize* it. For example classical mechanics, when subjected to a quantization procedure which turns functions that act on variables into operators that act on functions, becomes quantum mechanics and classical electrodynamics, when subjected to a rather more elaborate but essentially similar quantization procedure, becomes quantum electrodynamics. Indeed all quantum theories considered until very recently started as classical theories which were then quantized. Quantum philosophy prescribes the *type of mathematics* to be used, not necessarily the detailed form of the theory which still has to be teased from nature.

There is something essentially correct about classical mechanics but, as with every other physical theory, it has to be viewed now with quantum philosophy in which, for example, a measurement must of necessity have an essential influence on that being measured, as opposed to mechanical philosophy where the disturbing influence of a measuring instrument can be reduced without theoretical limit, and hence removed in classical principle.

A major effect of moving from a mechanical to a quantum philosophy is that the very concept of *explanation* itself shifts in meaning. One has fully explained something when one has managed to reduce it to self-evident propositions. In the mechanical philosophy it was sufficient to give a mechanical model or analogy to be satisfied. If one can picture the process then further justification is hardly necessary because ‘familiarity breeds self-evidence’. But in quantum philosophy outcomes generally do not follow deterministically from initial states, however well specified, so that there are some things which, from the old point of view, *can never have an explanation*! On the other hand from the new quantum point of view it is self-evident that a particle in a box can not have zero kinetic energy. This understanding is incomprehensible in the mechanical paradigm.

The ultimate goal of any scientific theory is that it constitutes a SELF-EVIDENT explanation of the relevant facts. Science has adopted a very successful iterative approach whereby the current best theories are acknowledged to be partial and yet greatly respected. While it can be argued that science is diversifying all the time and expanding rapidly in all directions, the complement is also true that science is rapidly leading to a unification of all interactions and a UNIFICATION OF ALL IDEAS.

❷ The Standard Model: a great achievement

IN COMMON CIRCUMSTANCES special relativistic mechanics gives almost exactly the same predictions as classical mechanics which itself has come to be seen to mirror common sense. At HIGH ENERGIES relativity makes very different predictions and it is the predictions of relativity that are borne out by experiment. Schrödinger therefore first set out to obtain a *relativistic* wave equation for matter. This equation, now called the Klein-Gordon equation, did not give correct predictions for the behaviour of electrons in hydrogen. Schrödinger realised that the *non-relativistic* wave equation gave rough agreement with observation and so published the non-relativistic one in 1926.

It was not until 1928 when Paul Dirac published his relativistic quantum theory that the reason why Schrödinger's relativistic equation did not work became clear. In Dirac's theory the electron has an intrinsically quantum property called *spin* which has no classical analogue and which is still not entirely understood. The magnitude of the electron's spin is exactly half of Planck's constant. Although experimental evidence for the existence of electron spin had been accumulating from certain experiments since 1922 and from Wolfgang Pauli's *exclusion principle* proposed in 1925, Schrödinger had not taken these into account.

Dirac's equation gives a more detailed understanding than Schrödinger's equation of atomic fine structure and the periodic table of chemical elements. Chemical bonding and crystalline solids can now be described extremely accurately from a quantum point of view. The reductionist ambition to rest chemistry firmly on physics is beginning to be realised. As quantum chemistry came to account for more, the whole of biology reoriented to a functional as well as a mechanical approach. This organic story has still a long way to go, but it is already clear that in some important and highly significant sense biology *can* be reduced to chemistry and chemistry to quantum physics.

Another new consequence of the Dirac theory concerns the existence of negative energy solutions. These are interpreted as indicating a new manifestation of matter called ANTIMATTER. In 1931 Dirac predicted the antielectron or *positron*. The existence of the positron was not believed by Bohr or Pauli until it was experimentally observed by C.D.Anderson in 1932. Since, according to relativity, mass is a form of energy, it should be possible to convert a photon of sufficient energy, at least the equivalent of two electron masses, into an electron plus a positron since their charges are exactly equal and opposite and therefore cancel. This is the cornerstone of *quantum electrodynamics*

One of the greatest successes of the quantum philosophy was the quantization of electrodynamics in 1948. It took 20 years to obtain a fully predictive quantum theory of photons and electrons. The *number* of massive particles is no longer constant. To accommodate this new *dynamical* observable of number, the Dirac wave or *state function* describing the noumena was re-expressed in terms of creation and annihilation operators acting on a vacuum state or noumenal nothingness. Electrons and photons were thus put on a similar footing to one another and wave-particle duality was thereby made more manifest. Thinking purely in terms of a particle interpretation of noumena, Richard Feynman enumerated all the possible classical-type particle interactions noumenally involved behind some particular phenomenon. He found an *infinite number of types* of processes each with an *infinite number of processes* involved. As with an electron passing an obstacle, every classical possibility has to be added together to obtain the quantum prediction. This led to predictions of INFINITY for the mass of the electron and INFINITY for the charge on the electron, which are obviously nonsense from an experimental point of view.

To understand the conceptual origin of these infinities, consider an implication of the uncertainty principle when the number of electrons and photons is variable. What might happen to an electron in an exceedingly short interval of time? According to Heisenberg's uncertainty principle, *the product of the uncertainty in the time of an event, times the uncertainty in the total energy of an event, is greater than or equal to Planck's constant*. Therefore, during a very short time interval the classical principle of conservation of energy does not apply so that the energy of the electron is very uncertain which means that it would be possible for it to emit a high energy photon as long as the photon is reabsorbed *within* the implied short time interval. In this way the electron has to be regarded noumenally as being surrounded by a seething bundle of *virtual* photons, virtual because they are noumenal and therefore unobservable in quantum principle. This potentiality produces the electron self-energy which turns out to be infinite when calculated by quantum electrodynamics. Similarly a photon can spontaneously change into an electron-positron pair for an instant so long as they quickly recombine to form the photon again. This produces a seething bundle of virtual electrons and positrons causing a polarisation effect of the vacuum which makes the electron charge theoretically appear infinite.

Despite this mathematical impasse, in 1947 Hans Bethe surmised that if one replaced the infinite constants with the corresponding *experimental values* of mass and charge wherever they appear in the theory then the theory might yield *finite* results which could then be compared with experiment. This procedure of *renormalization* was developed principally by Feynman and Julian Schwinger, and resulted in a theory which is in excellent agreement with experimental facts such as the scattering of photons off electrons, or the 'Lamb shift' observed in atomic spectra, or the 'anomalous' magnetic moment of the electron. Calculations in quantum electrodynamics are very hard though. For example if the supposed particle interaction involved say eight individual interaction vertices then this would lead to almost nine hundred Feynman diagrams to be calculated. The number can be reduced to eighty six by symmetry arguments, but this still results in twenty thousand mathematical functions each of which has to be integrated over ten dimensions.

Elementary Field Physics

The study of *particle physics*, which should really now be called *field physics*, can be said to have started in 1897 when J.J.Thomson discovered the electron. By 1930 three fundamental particles, the *proton*, the *electron* and the *photon*, were recognised as elementary. In 1932 James Chadwick distinguished the *neutron* from the proton in atomic nuclei and in the same year Anderson found the *positron*. From then on every material particle was presumed to have an antimatter counterpart, as required by the Dirac equation. In 1937 a heavy electron called a *muon* was discovered entirely unexpectedly. It is still not actually predicted by any theory. In 1947 a number of other unexpected particles called π, κ, Λ, Σ and Ξ were discovered in cosmic rays.

After the second world war, really huge particle accelerators were built which led to the discovery of a profusion of other new particles. In 1953 the *electron-antineutrino* was discovered. It had been predicted by Pauli in 1933 in order to remove energy, momentum and angular momentum discrepancies in the decay of a neutron into a proton plus an electron. In 1955 the *antiproton* was observed. By 1957 the number of known fundamental particles had increased to about thirty. In 1962 a new type of neutrino, the *muon-neutrino*, associated with the muon rather than the electron, was found. By 1964 the number of known particles had increased to about a hundred. None of these new particles had been seen earlier because most of them are more massive than the proton and so require a large amount of energy to produce. Also they are highly unstable, decaying extremely rapidly into lighter particles.

A hundred different particles could not really all be embraced as fundamental building blocks of matter. Plato had a few geometric solids and Aristotle only had FOUR essences; earth, fire, air and water. From attempts to develop a theory explaining why so many new particles should exist emerged a few utterly new quantum properties of matter: *baryon number* from βαρυs meaning heavy, *lepton number* from λεπτοs meaning light, *isotopic spin* relating for example neutron to proton, and *strangeness* which is zero in all but a few of the new particles. These were the true (quantum) hidden variables.

In 1964 Murray Gell-Mann and George Zweig independently proposed a classification scheme based on these quantum numbers into which all particles with zero lepton number, except light, could be placed. The scheme introduced three new particles called *quarks* and, of course, the corresponding three antiquarks. Every known particle, except the leptons (electron, muon, neutrinos, and their antiparticles) and the photon, which are exceedingly well described by quantum electrodynamics, was shown to be made up of either a quark and an antiquark or three quarks or three antiquarks. The scheme is based on a deep symmetry exemplified by the set of *Special* (i.e. determinant one) *Unitary* (i.e. inverse equals complex conjugate of transpose) *3* by *3* matrices, called SU(3) symmetry. The symmetric scheme predicted that there must exist an unknown particle called Ω. The Ω was sought and found in 1964. Suddenly the abstract mathematical theory of *groups* had found a new and profound application in physics.

Despite this predictive success the quark model was not taken very seriously by most physicists who considered that it was only a classification system and not a dynamical theory. Even after 1968 when evidence of quark-like constituents of the proton was found in high energy electron-proton collisions, the preferred approach to a dynamical theory was not SU(3) theory but *Scattering matrix theory*. Although having only limited success, the ultimate goal of this S-matrix theory was really very ambitious indeed. Its foundation is the democratic notion that *all* particles may be composites of other particles, none of them being any more elementary than any other. In this way the whole set of particles would *hold itself up by its own bootstraps*. The bootstrap approach is not necessarily misguided and may yet be resurrected in a future theory, but it has not supplanted quarks.

Quantum Chromodynamics

The original quantum field approach has held the day. Each quark is assigned a new unseen quantum number called *colour* which can be labelled red, green or blue. By analogy with addition of visible coloured filters, red plus green plus blue is colourless (black). Also antired (cyan) plus antigreen (violet) plus antiblue (yellow) is colourless, as is a colour plus its anticolour. Postulating that all observed particles have to be colourless accounts for the existence of all the observed baryons.

Can a quantum theory of colour charge be devised by analogy with quantum electrodynamics, the hugely successful quantum theory of electric charge? In quantum mechanics all observables can be calculated in terms of the modulus of the complex wave function. This means that the wave function can be multiplied by a complex phase factor without affecting any observable quantity. The most general way of constructing quantum electrodynamics is to look for a theory which is invariant in the case where this single complex phase factor is allowed to be any arbitrary function of space-time position. This is called U(1) local gauge invariance. The U(1) symmetry is directly associated with conservation of electric charge. Imposing this invariance on the electron field *forces* one, in a bootstrap sort of way, to introduce the photon field. This is a very satisfactory unifying consequence.

For different coloured quarks to stick together in baryons, the mediators of the force must themselves be coloured. They must carry colour and anticolour, and since there are three colours, there must be nine possible types of these *gluons*, one of which is colourless and consequently has no observable effect. In this case, to account for conservation of colour charge, one can introduce an SU(3) symmetry describing local phase transformations of the three colours. Imposing this symmetry on the quark fields forces one to introduce eight gluon fields exactly as required. Quarks imply gluons and gluons imply quarks. They 'bootstrap' one another into existence.

The resulting theory of *quantum chromodynamics*, discovered in 1973 by Harald Fritzsch, Gell-Mann, H.D.Politzer, David Gross and Frank Wilczek, is renormalizable although significantly more complicated than quantum electrodynamics because gluons can interact with other gluons whereas photons can not interact with other photons. In particular, in a very short time interval a gluon noumenally can turn into a virtual quark and antiquark pair which recombine to give a gluon again. As in the case for a photon, this causes vacuum polarisation effects. However the gluon can also turn into two other gluons which recombine again to give a single gluon within the implied instant of time as required by the uncertainty principle. This new potentiality has a much stronger reverse polarization effect on the vacuum. It causes the colour force to be very short range because the total effect is that the colour force *increases rapidly* with distance unlike the electric force which is long range and *falls off slowly* with distance. The great strength of the colour force means that it becomes easier to create new particles than to stretch the colour field lines. This accounts for the *jets* of particles seen by large detectors emanating back to back from very high energy collisions. They are the remains of quarks.

Electroweak Theory

Quantum chromodynamics and quantum electrodynamics together explain very well, in principle, almost all observable physics with just a few unexplained constants such as the various particle masses. But so far we have not considered interaction between quarks and leptons, nor the observed weak decay of neutron into proton plus electron plus electron-antineutrino, nor the violation of parity (or mirror symmetry), first observed in 1957 by T.D.Lee and C.N.Yang, nor quark mixing which is needed to suppress certain unwanted strangeness changing decays.

The quantum theory which does account for these particular phenomena was pioneered by Enrico Fermi in 1933 to explain radioactive decay. It was finally constructed in renormalizable form by the efforts of Sheldon Glashow in 1961, Steven Wienberg in 1967 and Abdus Salam in 1968. The *electroweak theory*, sometimes called quantum flavodynamics, is again based on a local gauge invariance but this time the theory contains a number of unsavoury conceptual complications.

First an attempt was made to describe neutron decay in terms of an SU(2) local gauge invariance. This introduced three new W fields to mediate the interaction between neutron, proton, electron and electron-antineutrino. The model was improved by Glashow who introduced an extra U(1) local invariance making $U(1)\times SU(2)$ invariance. This allowed quantum electrodynamics to be incorporated in a natural way. The U(1) had an associated B field. The photon field is then formed by a superposition of the B and the neutral W. The remaining orthogonal superposition of B and neutral W makes a new neutral Z field. The two remaining charged Ws, the Z and the photon become the mediators of the new electroweak force which unifies quantum electrodynamics with the theory of weak interactions.

In order to explain nature's lack of left-right symmetry, the left handed and right handed spin projections of some fields have to be treated differently. Indeed, right handed neutrinos are usually completely omitted from the model as they have never been observed. Because left and right handed components of neutrinos behave differently, it is not possible to introduce non-zero masses for any of the particles and retain the $U(1)\times SU(2)$ gauge invariance which is necessary for renormalization. This problem was solved independently by Wienberg and Salam who applied an idea devised in 1964 by Peter Higgs to break symmetry and hence, in this case, allow fields to 'acquire' a mass. The resulting theory was shown to be renormalizable in 1972 by Gerard 't Hooft and Martinus Veltmann. Higgs' mechanism retained the underlying symmetry of the theory but *broke the symmetry of the vacuum state*. By introducing a Higgs field into the vacuum to which other fields in the theory can couple, these other field can consequently have mass.

Electroweak theory predicted some new hitherto unknown interactions by way of the new neutral Z field. Some of these interactions were observed in 1973. The theory also predicted very precisely what the masses of the W and Z fields should be, but there was no accelerator large enough to produce and detect them. In 1973 there were only three *flavours* of quark involved in quantum chromodynamics; up, down and strange. However, electroweak theory suggested that quarks, like leptons with their corresponding neutrino field, should come in pairs. A fourth *charmed* quark had already been proposed in 1970 by Glashow, John Iliopoulos and Luciano Maiani in order to cancel out certain flavour changing processes which were not observed. The charmed quark was discovered experimentally in 1974.

In 1975 a new unexpected lepton, heavier than the muon, called *tau*, was found. This spoilt the symmetry between the number of lepton doublets and the number of quark doublets. This new tau lepton is assumed to form a doublet with a *tau-neutrino*. Neither the tau-neutrino nor the tau-antineutrino have been observed directly yet. To redress the balance, a new third generation of quarks forming a pair of new flavours called *truth* and *beauty* (often called top and bottom) was proposed. In 1977 the beauty quark was identified in the form of a beauty-antibeauty pair. In 1983 accelerators became large enough to generate W and Z fields. Amid much excitement, W and Z were both found at the predicted energy levels.

In 1989 a new large £1billion electron-positron collider started operating in Switzerland. To date this machine has verified with great accuracy the description given by the *standard model*; of quantum chromodynamics plus electroweak theory. This 1 2 3 theory based on the internal symmetry group U(1)×SU(2)×SU(3) accounts, in principle, for all the observed phenomena of micro physics right down to the scale of a thousand trillionths of a millimetre, where a thousand million is a billion and a thousand billion is a trillion. This is a great achievement which will doubtless eventually have unbelievable technical applications causing a revolution at least as profound as the electrical revolution and probably generating a third and fourth wave of nanotechnology miniaturisation, the second wave having already started to produce atomic and molecular devices such as single atom transistors, nuclear gyroscopes, bistable switches sensitive to the motion of a single atom, and quantum fridges.

There is now an unprecedented situation in science. There are essentially *no* outstanding totally mysterious experimental results in physics. Everything terrestrial which is known is consistent with the standard theory of particle physics. There is no *experimental* evidence of a limit or flaw in this theory. However, the standard theory has twenty one free parameters, including the quark and lepton masses, the various interaction strengths, the quark mixing angles and the Higgs particle mass. So the theory could be more tightly constrained than it is. And there are a host of other unexplained facts about the form of the theory, such as why *fractional* electric charges on quarks. Nevertheless just about all results from experiments are in terrific agreement with the predictions of the standard model. Also there is evidence from cosmology that there are no more than three types of neutrino in the universe. This evidence suggests that the three generations of quarks and of leptons in the standard model comprise the complete set of fundamental matter fields to be found in nature.

Nature is believed to be composed materially of three pairs of quark flavours; up and down, strange and charmed, truth and beauty. And three pairs of lepton flavours; electron and electron-neutrino, muon and muon-neutrino, tau and tau-neutrino. Each quark flavour comes in three different colours. These together with their associated antifields account for the material constitution of the entire observed universe. The fact that all the commonly observed matter in the universe is composed solely of up and down quarks and electrons raises a deep question of why nature chose to include two extra generations of matter fields. “Who ordered that?” said Pauli.

As well as the matter fields, there are the fields associated with the different types of force or interaction. For quantum chromodynamics we need eight differently coloured gluons. For electroweak theory we need one photon, one neutral Z and two oppositely charged W fields.

From these ingredients *all* the many hundreds of observed particles, including the proton and the neutron and all the atoms, are believed to be generated and all their known properties are believed, in principle, to be exhaustively predictable. This is a glorious theoretical triumph. While the above description is just the tip of the iceberg of the full explanation of the standard model, it does indicate how firm is the grip of modern physics on reality as we know it, albeit quantum reality.

❸ Theory of Everything: required improvement

THE STANDARD MODEL OF ELEMENTARY PARTICLES is very impressive and very comprehensive and hundreds of detailed experiments agree with its predictions, but it is *not beautiful enough*! Physicists believe that nature is simple and beautiful and that everything comes from next to nothing. All of nature can already be explained in terms of just a few basic principles and a few special fundamental constituents. But this standard model still has too many arbitrary unexplained features and is generally too complicated to apply in practice. It has been estimated recently that it could take ten years for theorists to calculate some particular number from the theory, and it could take twenty years for experimentalists to measure the number!

Although based on a rather beautiful 1 2 3 symmetry, written by mathematicians as U(1)×SU(2)×SU(3), the theory can not be described as self-evident. The job of the scientist is not finished until the whole of nature is understood intuitively. It is necessary, but not sufficient, to have a means of predicting all reproducible experimental results. There should be no arbitrary parameters, unless one is needed in principle to set the scale of things. There should be no more than one type of fundamental entity, unless matter and force are distinct, in which case two, and *everything should be obvious*.

There have been many attempts to improve upon the standard model, using aesthetic criteria in the absence of any recognisable anomalous experimental clues. For example, there was an attractive attempt based on U(1)×SU(3)×SU(3) to build all quarks, leptons and interaction fields from just TWO *rishons* having fractional electric charges, any of three colours and a new property called hypercolour which comes in three varieties. An alternative approach has been to search for a *grand unified theory* in which the symmetry group U(1)×SU(2)×SU(3) is a subgroup of a larger symmetry such as SU(5), but no new predictions of any of these theories has been confirmed to date.

Space-Time-Matter

And anyway, what about gravity? In all this discussion about unification of the forces why have we not mentioned the obvious force of gravity? How does that fit into the standard unified scheme? The answer is that it does not fit in at all because nobody knows how to quantize it properly. Physicists have been trying to solve this puzzle for the last sixty nine years, with ever growing clarity and zeal. This is without doubt the greatest, the deepest, and the most exciting problem in science today. Apart from the intellectual satisfaction of possessing a unified description of nature, the technological repercussions of such understanding could be totally astounding making most science fiction (which is actually based on real science) seem elementary. For example, it may be possible to travel instantly across vast tracts of space-time through a *wormhole*. It may be possible to shoot an imploding *'seed bomb'* straight through the Earth toward a city on the far surface. As the seed slows it will gulp in more mass. If it is projected at the correct velocity, just as it leaves the far surface it will take with it an exponential cone, including the entire city!

The deepest theory of gravity found to date is based on Einstein's general theory of relativity, published in 1916. If you ever find yourself in free fall towards Mercury, which has only an extremely tenuous atmosphere, you might notice, if you are content to reflect calmly, that you are almost completely *weightless*. It is as if your acceleration towards Mercury cancels out its gravity. On the other hand if you are spinning on a merry-go-round you will feel a centrifugal force, very much like an outward gravitational pull, caused by the acceleration involved in the circular path. Einstein's special theory of relativity restricted itself to uniform *linear motion*. Einstein realised that if his theory was generalised to include *acceleration* then the result might be a theory of gravity.

An *imaginary* number is one which, when multiplied by itself, gives an ordinary *real negative* number. No ordinary number multiplied by itself can give an ordinary *negative* number. What then could be the square root of a negative number? In 1908 Herman Minkowski showed that, by treating time as an imaginary number, special relativity could be viewed as describing paths in a *flat four-dimensional space-time*. The whole theory can be derived from the simple geometrical principle that nature chooses the shortest possible path for particle trajectories in four dimensional space-time. All this suggested to Einstein a geometrical approach to gravity.

In 1827 Carl Fredrick Gauss showed how a surface can have *intrinsic curvature*. This is a curvature which can be defined from within the surface itself, rather than the more familiar concept of *extrinsic curvature* which is associated with the embedding of a surface in a higher dimensional space, for example a soap bubble in ordinary space. If the surface of the bubble is considered not as an embedding in three dimensional space but entirely on its own, without reference to an outside, then 'straight lines' on the surface will close on themselves leading to the conclusion that the surface has some intrinsic curvature.

In 1861 G.F.B.Riemann developed the study of two dimensional intrinsic geometry and provided an exact mathematical measure of the departure from flatness of such a non-Euclidean surface. This measure was generalised to any number of dimensions by E.B.Christoffel in 1869. Einstein and Marcel Grossmann guessed that matter intrinsically curves space-time and in 1915, after an incorrect guess, Einstein found the simplest possible relativistically consistent equation directly relating matter distribution to curvature, saying in some sense that *matter is geometry*. The constant of proportionality was found by requiring that, in the limit of weak gravitational forces and with velocities small compared to the velocity of light, Einstein's equation must reduce precisely to Newton's gravitation theory, whose predictions are known, by optical astronomy, to be very accurate.

By means of his equation, Einstein showed that light should appear to bend in the vicinity of matter. This was verified by Sir Arthur Eddington looking at starlight passing close to the Sun during a total eclipse in 1919. General relativity also gave the correct magnitude for the precession of Mercury's elliptical orbit round the Sun for which the prediction of Newton's theory was too slow by about one hundredth of a degree per century. Many other tests have now been performed and they all confirm the predictions of general relativity. Recent observations of *pulsars*, which are neutron stars rotating sometimes very many times per second, show that general relativity is also valid in *strong* gravitational fields and at velocities at least up to a thousandth of the speed of light.

In 1929 Edwin Hubble observed that the spectrum of light emitted from remote galaxies is systematically shifted to the red end, and that the amount of the shift is proportional to the distance of the galaxy from us who live in the Milky Way galaxy. According to general relativity this means that all the matter in the universe, and therefore by Einstein's equation, the fabric of space-time itself is not in static equilibrium as had always been implicitly assumed. Some sort of *big bang* explosion of space-time-matter in the distant past, about fifteen billion years ago, caused everything to fly apart. The rate of expansion of space-time is slowing down because of gravitational attraction. It is not known whether there is enough matter in the universe to eventually stop the expansion and cause it to recollapse because not all the matter in the universe gives off detectable radiation, so it hasn't all been identified yet. The contribution of the neutrino relic from the big bang is a case in point.

Stephen Hawking and Sir Roger Penrose showed in 1970 that the initial matter density, and therefore the initial curvature of the universe, was necessarily infinite, according to general relativity. This really means that general relativity is unsatisfactory as a theory to describe the universe before a certain very early time. However general relativity does give a very plausible cosmological description right back to the first trillionth of a second of the life of the universe as a whole.

Evolution of the Universe

The very first second of the life of the universe has been called the golden age of particle physics because during that second the universe was extremely hot and dense and field interactions, which these days require an accelerator to induce, were commonplace. Using arguments based on the standard model, before about the first trillionth of a second, quarks and leptons behaved similarly to each other and were in equilibrium with photons, Ws, Zs and gluons, which also behaved similarly to each other. Then photons, Ws and Zs began to become distinguishable. Quarks also distinguished themselves from leptons. After about the first millionth of a second, quarks combined into pairs or triplets, forming mostly neutrons and protons. Within a few minutes primordial nucleosynthesis finished, having made isotopes of hydrogen, helium, small quantities of lithium and beryllium and minute amounts of some heavier nuclei. After a year of expansion, neutrinos ceased to interact much with other matter and decoupled. After about one hundred thousand years, the photons, which are by far the most numerous type of particle in the universe, decoupled leaving a photon 'relic' background which was first predicted in the late 1940s by Ralph Alpher and Robert Herman and was happened upon by Arno Penzias and Robert Wilson in 1965.

The photons decoupled because the universe had cooled sufficiently for electrons to combine with nuclei to make electrically neutral atoms. After another ten million years these atoms clumped together under gravitational attraction to form galactic nebulae, and then stars within galaxies.

A star starts life as a large nebulous ball of atoms, mostly hydrogen. The star contracts under gravitational pressure until the temperature in the centre rises to about a thousand million degrees when nucleosynthesis can take place. Nuclei within the star combine, forming shells of heavier and heavier elements - iron being a particularly stable core end point.

If the mass of the star is more than about one and a half times the mass of our Sun then, according to general relativity, gravitational collapse will continue indefinitely because the internal pressure will never be able, by any known means, to resist the inexorably cumulative gravitational pressure. According to standard astrophysics, at a certain point in time, in a process taking only one second, stellar electrons will combine with stellar protons to form a single massive atomic nucleus a few kilometres across made mostly of neutrons. The centre of the star is thus a single atom of atomic weight about one thousand million trillion trillion trillion. At this point the core loses elasticity and the imploding outer layers strike it and rebound under the shock. These layers are thus ejected into outer space in a *supernova* explosion leaving a neutron star, or gigantic atom, behind. This phenomenon is visible to the naked eye about once every thirty years in our galaxy: one happened in 1987.

According to general relativity, collapse of this nucleus will continue beyond the point where electrons or even photons can escape the gravitational field. Photons become trapped when the local curvature of space-time is so great that it curves right round in a circle to form a *horizon*. Inside is a *black hole*. None has yet been identified for certain, although Cygnus X1 could be one. There is also mounting evidence of a black hole of about two million stellar masses, perhaps accompanied by another of about five hundred stellar masses, at the centre of our galaxy which is three hundred thousand trillion kilometres in the direction of the Sagittarius constellation.

A direct attempt to quantize Einstein's gravitational field equations leads to an impasse because any number of *gravitons*, the hypothetical quantum of the gravitational field, can theoretically interact with each other at any point. This makes the theory unrenormalizable. Nevertheless there have been many attempts to introduce quantum ideas into general relativity. In quantum gravity one expects the very geometry of space-time to be subject to uncertainty.

In 1919 Theodor Kaluza proposed a brilliantly simple classical way of unifying general relativity with electromagnetism. He wrote down Einstein's gravitational field equations in FIVE dimensions instead of four and then proposed that the fifth dimension is rolled up tightly into a very small loop so that any observer attempting to penetrate the fifth dimension will almost instantly find himself back where he started. He then demonstrated that Maxwell's equations were satisfied by a field which was naturally associated with the fifth dimension, but he made no new predictions. Although Einstein was fascinated by the theory he delayed publication of Kaluza's paper for two and a half years because he felt the theory required more work. In 1926 Oscar Klein took Kaluza's theory and wrote down a five dimensional version of Schrödinger's relativistic wave equation. He then showed how to interpret the solutions as waves of gravitational and electromagnetic fields moving in four dimensional space-time, but again no new predictions were forthcoming. Anyway we would now want to use the Dirac equation and include the other known interactions as well.

Another worthy approach to a quantum mechanical understanding of gravity was made by Hawking in 1974. He showed that near the boundary of a black hole virtual pairs of particles could be created from the vacuum. One particle could fall into the black hole leaving the other to escape by quantum tunnelling. In this way *Hawking radiation* could be *emitted* from a black hole. Small 'primordial' black holes created in the early days of the universe could be slowly loosing their mass by this mechanism and when almost all their mass has gone they could pop out of existence with a huge explosion leaving nothing but flat empty space behind. No such evaporating black hole has yet been identified.

Here is another quantum parable. Since close to a massive body the energy of a particle is, in a sense, less than the energy of the particle when further away because work has to be done to take it away due to the attractive nature of gravity, and since a particle's energy can thus theoretically become *negative* inside the horizon of a black hole, it is conceivable that the universe began with a total energy *almost exactly equal to zero*. According to the uncertainty principle, a very *small* amount of energy can spontaneously appear out of nothing for a relatively *long* period of time, say eighty thousand million years. This is a quantum theory of the creation of everything *ex nihilo,* from nothing!

Matter-Force Supersymmetry

In 1974 Julian Wess and Bruno Zumino made a wonderful discovery which has had a major influence on the practitioners of quantum gravity. Wess and Zumino introduced physicists to a new kind of anticommuting number first defined by H.Grassmann in 1844. This kind of number has the property that the sign of the result of multiplying two of these numbers together is reversed if the order of multiplication is reversed. This implies that the square of a Grassmann number is identically zero. Thus ordinary numbers commute while Grassmann numbers anticommute. In a quantum field theory, the force fields satisfy commutation relations while the matter fields satisfy anticommutation relations. Wess and Zumino introduced *superspace* in which some of the dimensions represent real lines and others represent Grassmann lines. A point in this superspace is represented by a *supernumber* which has a *body* of ordinary numbers and a *soul* of Grassmann numbers, analogous to the real and imaginary parts of a complex number.

A *superfield* is a function ranging over supernumbers. Wess and Zumino showed how a superfield can be used to represent *both* the anticommutation relations of matter fields *and* the commutation relations of force fields, *both at once*. They showed how a *supersymmetry* transformation in superspace can change force fields into matter fields or matter fields into force fields. Thus it became conceivable, although not yet actually achieved in practice, that quarks may be related directly, by a rotation in superspace, to gluons in a supersymmetric generalisation of quantum chromodynamics. In 1977 Wess and Zumino demonstrated how to give a geometrical formulation of *supergravity* in superspace by introducing a local space-time supersymmetry. There is no experimental evidence in favour of supersymmetry and the theory of quantum supergravity is unrenormalisable but the basic idea is still very appealing to theoreticians.

Quantum Geometry

In 1984 Michael Green and John Schwarz proved that a particular supersymmetric string (*superstring*) theory in ten dimensional space-time is renormalisable. This caused great excitement amongst theoretical physicists. String theory had begun in 1970 during the period of interest in scattering matrix theory when Yoichiro Nambu, T.Goto, Holger Nielsen and Leonard Susskind suggested a kind of rubber band model of the strong force holding quarks together. With the advent of quantum chromodynamics interest in this new string theory, wherein nature minimises the area of the string world sheet, rather than the length of a particle world line as in general relativity, diminished considerably. However around 1974 Jöel Scherk and Schwartz demonstrated that unbelievably tiny quantized string loops can be interpreted consistently as gravitons. The theory can be quantized in twenty six space-time dimensions and contains no matter fields. Such strings are about a trillionth of a trillionth of a trillionth of a millimetre long.

In 1985 David Gross, Jeffrey Harvey, Emil Martinec and Ryan Rohm managed to combine string in twenty six dimensions with superstring in ten dimensions making a quantum theory of closed string loops in which waves travelling in one direction round the string are waves of the twenty six dimensional kind, and waves in the other direction are waves of the ten dimensional supersymmetric kind. This leaves sixteen dimensions which could be wrapped up and interpreted as internal dimensions, like Kaluza's fifth dimension. Sixteen internal dimensions give more than enough space in which to fit the standard model internal symmetry group of U(1)×SU(2)×SU(3). Many physicists have set to work to try to find a natural way of *compactifying* the free dimensions and breaking the unobserved supersymmetry in order to obtain the standard model ontology. Many different alternatives have been tried using *symmetric* and *asymmetric orbifolds*, *lattices*, *twists* and *shifts* but nobody has yet managed to find a natural way to obtain the standard model material requirements. Nor has anyone found any testable consequences from this highly mathematical theory.

It had been argued that this string theory was in some sense *unique* since it was the only real contender for a theory of everything, which obviously must include gravity. However a number of modified string theories have recently been suggested. A very interesting alternative was proposed by A.M.Polyakov in 1986. He showed that it is possible to generalise the original version of string by incorporating extrinsic curvature as well as intrinsic curvature into the theory. This gives string a lateral rigidity which opposes string world-sheet bending making it a rather more realistic model since the original theory could not distinguish between a smooth world-sheet and an arbitrarily creased world-sheet of the same area.

In 1989 I showed mathematically how to tie knots in rigid string and proposed that simple knots, like the left and right handed trefoils in loops of string, account for the elementary fields. One might further speculate that the universe is gradually becoming more knotted, and the observable stable structure, from individual electrons to galaxies, which we see around us, is associated ultimately with the stability of knots in string. Knot theory has now become a major area of study for theoretical physicists. Would an electric current through a wire with a knot in it emit a toridal photon from the essential singularity? Aerial theory might take a quantum topological leap.

In 1983 W.Siegel found that a supersymmetric particle (*super-particle*) has a new and rather mysterious symmetry called κ-symmetry. In 1986 Ed Witten extended superstring theory to incorporate this κ-symmetry. The Green-Schwarz-Witten superstring was then extrapolated mathematically to *supermembrane* by Eric Bergshoeff, Ergin Sezgin and Paul Townsend in 1987. The idea of a fundamental membrane theory had been introduced originally by Dirac in 1962 in a partially successful attempt, prompted by the inexplicable discovery of the muon, to classically model an electron and muon as different quantum states of a closed spherical membrane. With the popularity of string, rather than point particles, as a serious model for fundamental quantum fields, it was natural to generalise the notion of extensibility to a membrane theory, especially since the membrane could be wrapped into a tube by the Kaluza-Klein method, immediately giving a string theory by *dimensional reduction*. One particularly attractive feature of supermembrane in eleven dimensions is that the constraints on the torsion of superspace, required for κ-symmetry of the supermembrane, are exactly equivalent to the constraints implied by the equations of motion of eleven dimensional supergravity. This establishes an intimate connection between foreground world-volume geometry and background space-time geometry; a sort of membrane generalisation of Einstein's equation.

The next natural generalisation from points to strings to membranes is to *lumps*. A lump is a three dimensionally extended object embedded in a higher dimensional space-time. In this case the dynamical theory can be derived from the principle that nature acts to minimise the four dimensional volume of a lump's world-path. These and other generalisations are collectively called *p-branes* where *p* is a whole number specifying the dimensionality of the spacial extension; zero for particles, one for strings, two for membranes, three for lumps, etc. In 1987 Anna Achücarro, Jonathan Evans, Townsend and David Wiltshire showed that the Green-Schwarz-Witten theory could be extrapolated to twelve *super p-brane* theories; from superstring in three dimensions, through super-membrane in eleven dimensions up to super 5-brane in ten dimensions. All other possible κ-symmetric theories can not be made supersymmetric.

Quaternions were introduced by Sir William Hamilton in 1843 as a generalisation to four dimensions of the two dimensional complex plane of real and imaginary numbers. Minkowski space-time is so similar to *quaternionic space* that very significant progress in mathematical physics would doubtless occur if a deep quaternionic equivalent of complex analysis were to be discovered. Complex analysis is a theory credited to A.Cauchy in 1821. It can be regarded as the necessary foundation for the mathematical completion of Newton's calculus. Early unsuccessful attempts to define quaternionic analysis led Maxwell eventually to abandon the real part of quaternions and use only the vector part for the *vector analysis* which he used to present his electromagnetic theory. Quaternionic analysis is not these days regarded by most physicists or mathematicians as a particularly hopeful pursuit. However, SU(2) *is* a symmetry associated with unit quaternions, special relativity *can* be formulated succinctly using quaternions and quaternions, like the observables of quantum mechanics, do not commute. Therefore quaternions are not without precedent in modern physics.

The last member of the series of numbers real, complex, quaternion - with the characteristic property that the modulus of the product of a pair of them is equal to the product of the modulus of each - was found in 1859 by A.Cayley and called an *octonion* because it had *eight* elements. It is therefore particularly interesting to find that superlumps in eight dimensions are amongst the list of allowed super p-branes because they might be interpreted as a supersymmetric embedding of quaternions in octonions.

In 1990 I discovered the first theoretical examples of lumps in eight dimensions. At the same time I found a completely new beautiful theory of LUMPS IN OCTONIONIC SPACE. Unlike all other contenders for a theory of everything, this new theory is not based on a geometrical minimum world-path principle but on an algebraic principle minimising the non-associativity of octonions - that is the amount of difference there is when multiplying three octonions together when starting with different pairs of the trio. The equations of motion have not yet been derived from the action functional because it is based on an SO(8) invariant rank four tensor about which not much is known.

However, there are three aspects of this new theory of lumps which make it appear significant. Firstly it dispenses with a square root which is ultimately the reason for the distinction between the Dirac and the Klein-Gordon equations, and hence the distinction between matter and force fields. Thus the need for supersymmetry might be obviated. Secondly the theory had its origin in the *instanton* sector of a previous theory which was discovered by Ed Corrigan and me in 1987 and independently by Marek

Grabowski and Chia-Hsiung Tze in 1989. This sector is entirely attributed to quantum transitions between stable topological structures. Thus the theory might have a natural quantum interpretation. Thirdly, although not yet mathematically proven, the new theory of *associative lumps* might be interpreted as a dynamical theory of the embedding of four dimensional quaternionic lumps in eight dimensional octonionic space-time. This leaves four space-time dimensions to be compactified. Four dimensions is just sufficient room to incorporate a slightly streamlined version of the standard model internal symmetry group.

The standard model has got a number of inelegant features. There have been many marvellous attempts to improve on the model and one day someone will make further verifiable progress. Maybe someone will even stumble on the beautiful theory which explains, in quantum terms, everything. Physicists and mathematicians seem to be getting very close to the ultimate analytic statement, a succinct mathematical expression from which an account of everything known can be drawn. Even as they are, the standard model plus general relativity can explain, *in principle* (the reductionist principle upon which the scientific approach is based), all observations in particle physics, all nuclear and atomic physics, all molecular theory (chemistry), all macro-molecular theory (biology, physiology, neurophysiology), all geology, astrophysics and just about all cosmology! What of psychology, sociology and politics? Nothing?