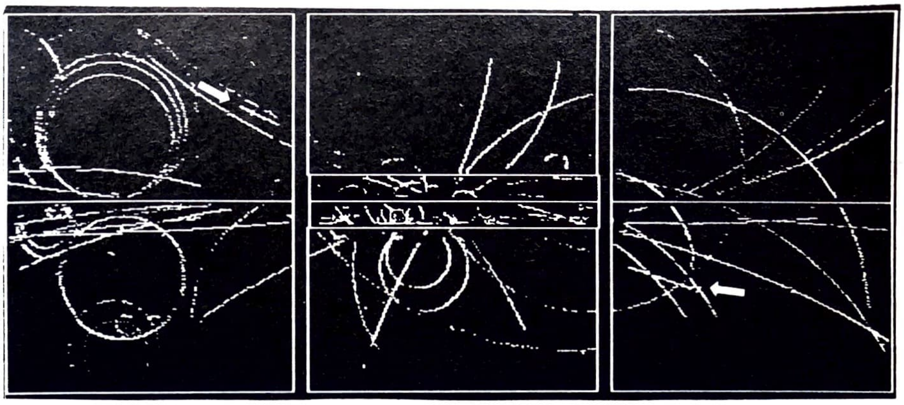
INSIGHT



The Physics of Reality

In the beginning the universe seemed simple. Just three fundamental particles – the electron, the proton and the photon – were enough to describe the world. Then confusion arrived and continued to sway as physicists unearthed more and more elementary particles. Today, four kinds of particles – the "up quark", the "down quark", the "electron" and the "electron neutron" – and a theory that attempts to unify the forces of nature, have brought some order back to the chaos. It seems that we swim, like fish, in a n-dimensional space. But, as **Robert Walgate** explains, the apparent order has been achieved at the expense of a coherent philosophical outlook. The Theory of Theories, the ultimate *zikr,* the key to the physical universe, lies not in pragmatic efforts to stitch the theories of physics together, but in contemplating and seeking beauty in the results that have been obtained so far

WHAT is the nature of the physical world? That is the question that lies behind the most fundamental of all sciences, elementary particle physics. And at last the question is nearing an answer, 2500 years since the first Greek philosopher, Thales, began it all by claiming everything was made of water.

However, what will it mean to "understand the nature of the world"? Already, physicists now know the components, the building blocks, of all visible matter on Earth and in the visible universe. The list is short: matter consists of just four kinds of particle: the "up quark", the "down quark", the "electron" and the "electron neutrino". Physicists also know the four basic forces by which these components interact: in order of increasing strength, they are gravity, the "weak interaction", electromagnetism, and the "colour force". All four forces are now described by clear, mathematical theories which within experimental error appear to be exact.

We now know that there are four particles, and four forces, all more or less exactly known. So what more is there to do? Do we not now understand the world, at least in its material content? Well, no. The physicists are not yet content – because their picture is not yet simple enough. And the lesson of physics has always been, as Einstein put it "God may be subtle, but he is not malicious".

But contentedness may not be far off; and subtlety is close at hand. Physics is moving so fast that man will soon be able to say with some confidence not only that he knows the components of the world – as he does now – but that he truly "understands the nature of the material Universe". Probably it will be by the end of this century that we shall be able to contemplate the formula, the Mantra of the world – even though, no doubt, its true meanings will be difficult to comprehend.

The imminent discovery of this Theory of Theories will be an extraordinary, millennial event. But now in this last quarter of the century the mood of the physicists does not quite match their historic situation. Physicist have become, on the whole, pragmatic beings with pragmatic theories. This is not really the best philosophic condition in which to face Unity.

We could debate the many social and economic forces outside physics that have led to pragmatism in the 20th century. However, there have been forces inside physics too. The road to the Theory of Theories has been extremely hard. And in taking this desert road, physicists have had no time for fine philosophies.

The desert began when physicists exposed "cloud chambers" – devices in which the paths of particles could be revealed as evanescent tracks of steam, little droplets of water – to cosmic rays, the natural radiation of particles that bombards the Earth from space. The collisions of the cosmic rays with atoms in the cloud chambers began – we now understand – to produce members of the higher families of quarks and leptons (see below). Matter appeared to multiply. Instead of getting simpler, everything was getting more complicated.

First the muons (see table 3), then "V-particles" (now understood as particles containing a "strange" quark) were discovered. And then, to explore such phenomena in a more controlled way, physicists began to produce artificial "cosmic rays" with which to bombard targets: in other words, they began to build accelerators. (The first powerful such machine, the Berkeley cyclotron, began life in California in the early 1950s). And as accelerator energies rose, and more and more particles began to be discovered – these were the hadrons which now with hindsight we know to consist of quarks in many combinations and orbits. But further understanding seemed to require yet higher energies; where was the spectrum of new particles going to end?.

Accelerators became ever more vast, and experiments ever more complex and lengthy. Theory appeared to fall behind the plethora of confusing results, and doing physics became in experiment a business, and in theory a series of bandwagons mostly leading nowhere. For a starting student in the mid 1960s, as I was then, it was a disillusioning time. And to survive in such difficult times, physicists learned to be pragmatic. Even the more philosophical had few lines to guide them, and wandered off in unconstrained and unproductive directions (Only a few ideas of these times proved durable, and it was very difficult at the time to predict what those ideas would be). And since these conditions lasted more than a generation, pragmatism in experiment and numerical "model building" in theory became the accepted way of doing physics.

Table 1

fermoin	approximate mass (MeV/c)	electric charge	colour charge	weak charge
first family				
up quark	350	+2/3	r,g, or b	+1/2
down quark	350	−1/3	r,g, or b	−1/2
electron-neutrino	›0.000046	0	0	+1/2
electron	0.511	−1	0	−1/2

The four fundamental fermions out of which the matter of the universe is composed. They form the first of three closely related families of fermions (see tables 3 and 4). The charges shown link, or "couple", the fermions to the corresponding fields; if a charge is zero, this means the particle does not respond to or produce the corresponding field. The labels r, g, and b under colour charge signify that each quark can come in three "colours": "red", "green" and "blue". If quarks with these three colours were joined, the resulting composite particle would be colour-neutral. This is how protons and neutrons, the components of the atomic nucleus, are formed.

Einstein used to talk of "concepts"; particle physicists were reduced to "models": structures of ideas in which no one truly believed or they would have been graced with the term "theories". This was the desert that physicists had to cross, because nature was keeping its ultimate components deeply hidden.

At least, it kept them hidden until 1969. Then an experiment firing electrons at protons at the Stanford Linear Accelerator Laboratory (SLAC) in California showed that protons apparently contained something: pointlike objects: components.

With that, one of the pragmatic models of the 1960s suddenly revealed its true content, and it became a theory. Seen in the light of the new experiment, this theory (which had been dubbed SU(3), or "the eightfold way)" could be interpreted as saying that protons and other hadrons were composed of "quarks" (indeed its originator, Murray Gell-Mann, and another physicist, George Zweig, had suggested the possible existence of quarks, but no one – including himself – appeared to take them seriously. I personally remember once doing so in a seminar around 1967 and being rudely told "nonsense – quarks are merely theoretical tools)"

But by 1970, given that the nuclear world appeared to be composed of quarks, suddenly other things began to fall into place. The plethora of hadrons which everyone had been trying to explain as fundamental entities were clearly interpreted as composite entities, consisting of just a few types of quark (three were known then – six now) in different states of motion around each other. But that picture did not really solidify until five years later, when in November 1974 (a time since dubbed the "November revolution") a particle now called the J/psi was discovered at SLAC and at the Brookhaven National Laboratory in Long Island.

The J/psi proved (after yet another year or two) to be composed of a new (fourth) kind of quark called a "charmed" quark (see table 4), combined with its antiparticle (the "anti-charmed-quark"). And although otherwise just one particle among others, the J/psi had two fundamental impacts on the history of physics.

On the one hand, because the charmed quarks were heavy and interacted only slightly, study of the J/psi made it possible to calculate the exact orbits of the quarks and predict the excited states of the particle. The consequent predictions and observations finally confirmed the truth of the quark model – and of the theory of interquark forces, originated around 1971, called quantum chromodynamics, or "colour" (of which more later).

And on the other hand, the existence of the charmed quark itself, and its precise decay properties, confirmed another neglected theory which had been lying around since 1967, the "Weinberg-Salam-Glashow" model – which unified the weak and electromagnetic forces into one model (the "electroweak force"). This theory (described further below), to explain certain decay data discovered in the 1960s, required the existence of a fourth quark with exactly the properties discovered in "charm".

I remember talking to a physicist who had helped discover the J/psi. "At last we are doing real physics!" he exclaimed.

At last indeed! And still not quite yet. The point is this: the road from early thirties to 1974 was extremely hard for particle physics, and it took its philosophical toll. While aware that they were on the threshold of a great discovery, particle physicists in the 1980s don't seem entirely sure how to react. The theories which work still, on the whole, smack of model-building rather than understanding, and there is still a quality of paper-and-paste about the models.

That's why physicists can talk glibly of GUTs and TOEs: they hold the leg of the elephant, but are not yet prepared to dare a look at the whole elephant. Few physicists are seeking the special kind of beauty that Einstein called a "physical concept", a unifying idea that as he himself put it would be "simple, and easily explained to anyone". Thus even the most imaginative of current theories – a theory in which particles are strings in 10 dimensions – has, as one observer described it, the character of "phenomenological mathematics", in which in a real sense the practitioners do not

Table 2

gauge bosons	corresponding field of focus	comments
graviton	gravitational	the weakest force, but always additive
W, W, and Z	weak	the "transformer": the stellar switch
photon	electromagnetic	dominates matter on the atomic scale
the eight gluons	"coloured"	the force between quarks: the nuclear force

The fundamental "gauge bosons" are exchange between the fundamental fermions (tables 1, 3 and 4) to create the four fundamental fields of force to which matter is subject. These four fields may also be described in terms of a "curvature" of spcae-time (for gravity) or a space beyond space-time (for the other forces.) The particles in this table may be considered to carry "parcels" of this curvature.

know what they do. Physicists, as an inevitable consequence of their recent history, have lost their philosophical balance, and the balance must return before the unity of physics is achieved.

But before we seek unity and infinity: here is what the world is made of, according to the recipe for the universe discovered – and somewhat randomly labelled – by physicists during the crossing of the desert.

Fundamental particles, the objects that we now believe are the real components of matter are shown in table 1. Together these particles are called the fundamental "fermions". They consist of the "up" quark, the "down" quark, the electron and the electron neutrino. These four particles are by far the major and most prominent components of the whole visible and tangible universe.

The particles are distinguished entirely by their "charges"; and their charges determine what forces they feel. Charge is a very fundamental concept in modern physics. A similar example of charge at work is a magnet (such as a compass) in a magnetic field (such as that of the Earth). The magnetic field, spreading through space, is what turns the magnet. The ends of the magnet have magnetic "charge", which "couples" to the magnetic field – as if by a hook – and consequentially feels a force. The magnetic charge is the magnet's connection to the field; if the magnet were magnetically neutralized (demagnetised) it would not couple to the field and would feel no force – just as if the field were not there. This is why a piece of wood will not point north: it cannot be given a magnetic charge.

Equally, a charge not only *reacts* to the field to which it hooks, or "couples" – it also *produces* the same kind of field. Thus a magnet itself produces magnetic field, which can affect other magnets.

Thus charge, by means of the field it produces, and the field to which it reacts, is the source of the force between particles.

Just four fundamental kinds of charge – and the four corresponding field of force – are recognized. Different fundamental particles carry different charges, and each reacts only to those of the four fundamental forces to which they have corresponding charges.

Consider first mass (or more strictly, energy-momentum density) which is the "charge" that produces and couples to gravity. Gravity is by far the weakest of the forces, a thousand trillion trillion trillion times weaker than electromagnetism, but it is always and incessantly attractive – whereas all the other forces can be both attractive and repulsive. Thus over large masses in which the positive and negative forces caused by the other charges tend to cancel out, gravity begins to dominate, so that gravity becomes the most familiar force in the astronomical world, where masses are vast.

Consider next the electromagnetic (or for short "electric") charge which couples to the electromagnetic field. The corresponding electric and magnetic forces, much stronger than gravity, dominates the world on a smaller scale – the world of atoms. Each atom of matter consists of an electrically positively charged nucleus (which also carries most of the mass of the atom, incidentally) surrounded by an exactly balancing negatively charged cloud of (almost massless) electrons. Thus each atom is electrically "neutral" – an important property which means "no net charge". It is this neutralising of the electromagnetic charge at the atomic level that allows gravity to dominate at much larger scales.

Incidentally, the temporary breaking down of this neutrality, and the separation of atomic electric charges, is the phenomenon we call "electricity". But the separation involved is only very slight, amounting to a breaking of only one in millions of atoms.

For if all the electrons in a gram of water (a thimbleful) were separated from all the nuclei, and if the electrons were placed in New York and the nuclei in London – nearly 6000km apart – the electrical attraction between them would still amount to over 60,000 tons weight! This indicates both how strong the electromagnetic force really is and how perfectly neutral matter is most of the time.

However, from close up atoms can interact electrically. A parting of the electron clouds here and there creates unbalanced electromagnetic forces – which cause the chemical attraction and repulsion of atoms and molecules. Chemistry and the properties of materials are in this sense a result of the electromagnetic force so finely balanced within atoms.

Consider next the third and strongest charge, "colour", coupling to the colour field of force (it is an *entirely different* thing from visible colour, despite the confusing name). The force corresponding to the charge "colour" is the force that hides in the nucleus of the atom. As we've seen, electromagnetism is strong; but colour is stronger: it lies behind the ferocious power of the atom bomb and the heat of the Sun.

In everyday matter the two quarks, "up" and "down", each carry colour. Colour has a triality about it so that three quarks can combine to make a colour-neutral object [here is the analogy with true colour, in that the three primary colours red and green and blue mix (as lights) to make white. However this is a physiological phenomenon and the analogy is weak].

The most familiar colour-charge-neutral objects made from three quarks are called "protons" and "neutrons". Protons contain two up quarks (each of which also carries electric charge +2/3, in units in which the electron has charge −1) and one down quark (electric charge −1/3), making an object of total electric charge +1. Neutrons similarly contain one up quark and two down quarks, making a total electrical charge of zero.

Protons and neutrons are colour-neutral, just as atoms are electrically neutral. But they combine (like atoms combining in chemistry by local variations in electric balance, but this time by virtue of local variations in the colour balance) to make atomic nuclei.

The forces in the nucleus between proton and neutron used to be called the "strong" nuclear force, but now it is seen to be a derivative of the more fundamental colour force between quarks. The strong force is to colour as chemical forces are to electromagnetism.

Weak charge, coupling to the weak field, results in a force much stronger than gravity but around 100-fold weaker than electromagnetism.

The weak force is also peculiar because it is a "transformer". It changes the nature of particles. The fundamental fermions fall into pairs: and the weak force "flips" members of a pair into one another (these pairs are indicated in table 1). Thus the weak force transforms up quarks into down; and electrons into neutrons.

The behaviour of the weak interaction may seem exotic. Indeed it is. But this magical transformer, the weak interaction, plays a crucial role in stars – where it enables hydrogen, the principal component of the universe to turn into helium, the process by which stars burn and shine.

It happens in this way. Most of the universe – and most of the mass of stars – consists of hydrogen, which has atoms in which the nucleus is a simple proton. But the "chemistry" of the strong force results in the most tightly bound of all nuclei – the bottom of the hill of nuclear transformation – being not hydrogen, but helium, whose nucleus contains two protons and two neutrons. This is the case because the strong force between the neutrons helps overcome the electrostatic repulsion between the protons.

But the quark content of these two systems is different. A proton contains two up quarks and one down. A neutron contains one down and two up. Thus four hydrogen atoms contain 12 quarks, consisting of eight up quarks and four down quarks. But one helium atom, though also containing 12 quarks, has the recipe of six up quarks and six down quarks. To transform hydrogen into helium, releasing the energy we see in starlight and sunlight, two up quarks must be transformed into two down quarks.

This is exactly the transformation that the weak interaction achieves, allowing a nuclear transmutation from hydrogen to helium that releases immense amounts of energy.

The weak force, therefore, behaves like a switch that turns on the light, by allowing the stellar nuclear transformation to take place. Without the weak force, the night sky would be dark and the sun would not bathe us with light.

Another stellar phenomenon, just as significant to us, is that stars (with the help of the weak interaction) also forge other heavier nuclei such as oxygen and carbon – in fact the whole periodic table of elements. These are blown into interstellar space by stellar winds and explosions, and eventually recondense into second-generation stars and planetary systems.

The Earth and our very bodies are composed of such debris: we are composed, quite literally, of star-dust.

The fundamental fermions are divided according to the force they feel, and therefore the charge they carry.

The *quarks* have everything: mass, weak charge, electric charge, and colour. They couple to all the forces.

The *electron* has mass, weak charge, and electric charge, but is colourless. It cannot react to the colour force, which is why, in the atom, it does not bind strongly to the nucleus but flies free like a cloud above the Earth.

The *electron neutrino* is probably massless (experiment can determine only upper limits), but couples to gravity through its energy and momentum; and it has weak charge. But neutrinos have no colour or electromagnetic charge, so they couple to ordinary matter very poorly, and fly through the universe like ghosts.

Together, the electrons and neutrinos are called "leptons" [they do not feel the strong (or colour) force]; and the quarks and the particles they compose (which do feel colour) are called "hadrons".

There are other particles than those we've mentioned, the majority of them composed of quarks. But these "baryons" and "mesons" are no longer thought of as fundamental entities.

Other than these composite particles, however, there are the "gauge bosons": but these do not make the components of "stuff", of matter that you can hold in your hand. The bosons *are* particles, but – in the theory of the motion of matter called "quantum mechanics" – they are exchanged, like money, between charges to create what we have previously described as the "fields of force" of gravity, electromagnetism, colour and the weak force.

These fundamental bosons are quickly listed (see table 2): for the gravitational field, we have the (unobserved) graviton; and the exchange of gravitons we observe as gravitional forces. For electromagnetism, the corresponding "field particle" is the well-known photon; for the weak interaction, the recently-discovered W and Z particles; and for colour, a collection of eight particles called "gluons".

These then are the forces and the particles: each well-described and now well-known, each with predictable properties. This is modern physics' recipe for the universe, and in a pragmatic way it works. But how far do we *understand* this recipe?

There are still weaknesses in our understanding of the recipe this is why

Table 3

fermoin	approximate mass (MeV/c)	electric charge	colour charge	weak charge
second family				
charmed quark	1500	+2/3	r,g, or b	+1/2
strange quark	500	−1/3	r,g, or b	−1/2
muon-neutrino	›0.51	0	0	+1/2
muon	106	0	0	−1/2

The second family of fundamental fermions. These particles are closely related to the first family (table 1) out of which matter is composed, but are not present in ordinary matter. They are created during energetic collisions between members of the first family.

we need to unify and improve these ideas; and because our description of it is not yet elegant, as a true Theory of Theories must certainly be.

The first weakness is with our understanding of the particles; and the second with that of the forces.

The problem with the particles is that our first family of fundamental fermions, consisting of the up and down quarks, the electron and the neutrino (see table 1) – is not alone. That is to say in all ordinary and visible matter from the earth to the stars it *is* alone. But when disturbed at the immense energies of particle accelerators, in which matter is thrown at matter at velocities approaching the speed of light, a new family comes to light, in all respects similar to the first family except in mass.

Thus we get the exotic second family of fermions: the "charmed quark", "strange quark", "muon" (a heavy electron), and "muon neutrino" (see table 3).

And more recently a third even more exotic and heavier family has been discovered, consisting of the "top quark", "bottom quark", "tau lepton" (an even heavier electron), and "tau neutrino" (see table 4).

There are indications – from cosmology where the number of neutrinos affects observable properties of starlight – that these three families are the only ones. But their existence – though fleeting, as with the exception of the neutrinos they all decay rapidly into their lightest partners – indicates that we don't understand something about the first family. How can the first family, the family of ordinary matter, be excited by collision to form the second and third families? Why these repetitions? What is the real difference between an up quark and a charmed quark? Or between an electron and a muon? Clearly the existence of these differences is telling us something profound about the nature of matter, but their message has not yet been interpreted.

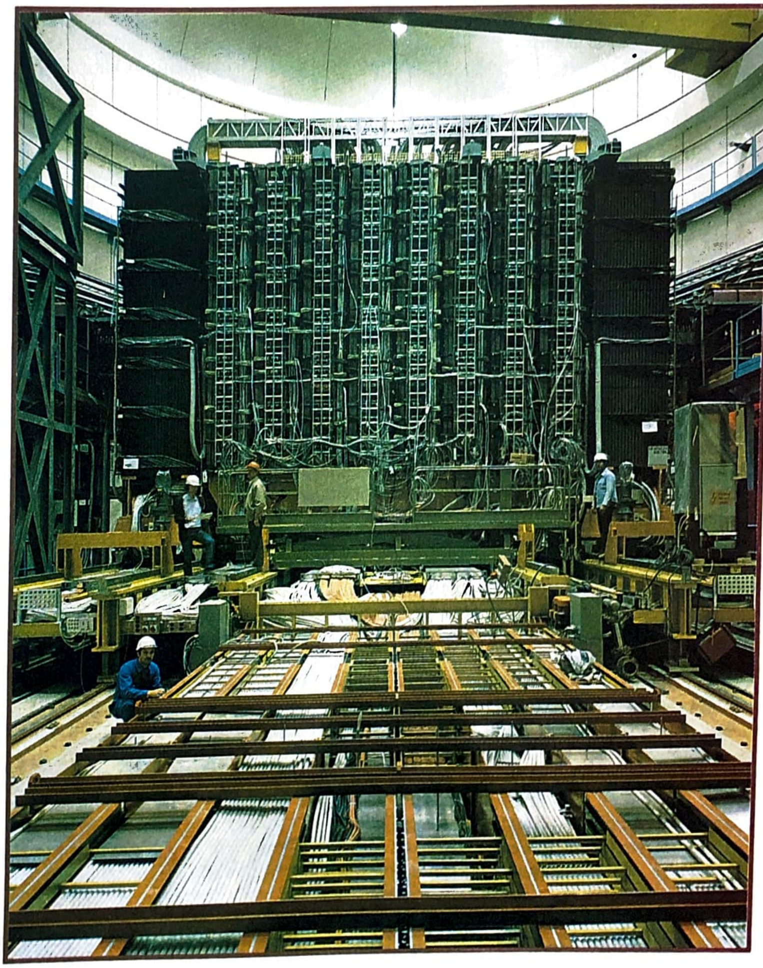
The puzzle is starkest in the case of the neutrinos. The only role of the neutrino in each family appears to be as the transformed partner into which the weak interaction converts the electron-like particle of the family: thus the weak interaction converts electron to electron-neutrino, muon to muon-neutrino, and tauon to tau-neutrino. Although otherwise apparently identical, the neutrinos refuse to transform to or from the "wrong" partner (such as electron to muon-neutrino, for example). The neutrinos carry some kind of record of where they came from, but of what that record consists, we have no clue.

Some pragmatists may take the view that since these exotic states are so rare – or even "artificial", whatever that means – there is no point in worrying about them. But to that there is a pragmatic answer: in the Big Bang with which cosmologists tell us the Universe came into being all these states were certainly created, as the temperature was infinitely high. We, this universe, are the result of matter having passed through these exotic states. So if we do not understand the higher families, we understand nothing.

And as for the forces, it is inelegant and certainly wrong that each force should have a different theory, a different mechanism, and a different charge. The whole history of physics has been the discovery again and again that the many are the one: that the immense variety of the world is really a manifestation of underlying unity.

There is a simple example: the "magnetic charge" we mentioned earlier as an example of charge was discovered, as early as the 19th century, to be simply an electrical charge in circular motion: thus what were originally two charges, electric and magnetic, were discovered to be merely different aspects of one.

But so it must be with all the forces



The giant 'UAI' particle detector, built to straddle the proton-antiproton colliding beams at the European Organisation for Nuclear Research (CERN) near Geneva. This device detected the W and Z particles, the carriers of the weak nuclear force, for the first time, and won the designer of the apparatus (and the colliding beams), Italian Carlo Rubbia, a Nobel Prize. Some zoophysicists were required to build and operate UAI

of nature, and the search must be for a beautiful hypothesis which unites, as different facets of a crystal, the four forces.

At present, this unification of forces appears tantalisingly close; and it seems increasingly likely that with that unification will come also an understanding of the three families of particles.

It is in this deep sense that physics is close to understanding the nature of the world – not in the more obvious sense that we can now, more or less, calculate most phenomena in the universe using the particles and forces we know, but that that ability tells us we must be closer to some yet deeper truth.

The modern "unified field theories", the first steps towards the final Theory of Theories, have all, more or less, been based on the example of one successful model: the Weinberg-Salam-Glashow (WSG) model, developed by Americans Steven Weignberg and Sheldon Glashow and Pakistani Abdus Salam, which unites the weak and electromagnetic forces into one theory.

The WSG theory was first written down in its entirety in 1967, and found its final practical confirmation – a proof that it really works – with the discovery of the so-called W and Z "intermediate vector bosons" at the European Organisation for Nuclear Research, CERN, near Geneva, in 1983-4.

The WSG model is an example of a "gauge theory". And it involves something called "spontaneous symmetry breaking". Both of these concepts are fundamental to most attempts at further unification.

A "gauge theory" describes exactly how a "charge" creates a force on another "charge" at a distance. It thus explains the existence of the four fields of force, and relates the nature of the forces to the nature of the charges.

Gauge theory has strong analogies to general relativity, Einstein's theory of gravitation. Both gauge theory and gravitation involve the concept of "curvature". In both theories, a kind of curvature constitutes the "field of force" between particles, and the "gauge bosons" which are the force "carriers" exchanged between charges effectively cairy pieces of curvature around with them.

But why curvature? Briefly, the idea in both gauge theory and gravity is that particles always follow the shortest possible paths in some space. In a flat (uncurved) space, such paths are straight lines. Since particles only move in curves when they are subject to forces, motion along shortest paths in a flat space represents force-free motion.

But when is a curve curved? It all depends how you look at it. For example, a great circle path on the Earth's surface, the shortest path from A to B on the surface of a sphere, looks like a straight line to someone who cannot move from the sphere's surface. But stand outside the sphere and the path looks curved. Similarly, the curved paths particle take under the actions of forces may actually seem to be straight paths when seen as part of another, curved space.

Einstein showed that the curved paths created by gravity – the orbits of planets or the path of a ball thrown in the air – can be explained simply and beautifully as a curvature of four-dimensional space-time. The curvature we see as 'gravitational field', created by the presence of mass.

Equally, guage theory says that the curved paths created by, say, the electromagnetic field acting on an electric charge, are caused by the curvature of yet further dimension; colour by yet others, and so on. This extra space, inaccessible to us, is called 'gauge space'. But whereas in gravity the whole of space-time is curved, in gauge theory it is only necessary to curve the extra dimensions. Space-time is left alone in guage theory. The effects of the gauge forces appear like shadows cast by the unseen world of the curved gauge space on our space-time down below.

Such "gauge spaces" to be added to ordinary spaces are called "internal spaces", as we appear unable to travel into them, and because they appear to have their effect only as "internal" properties of the particles: their charges and the forces to which they respond.

Now each of the four forces in the recipe is described by some form of gauge theory. And such theories, of course, where each force has its respective limited space above space-time, casting its shadow on our visible world, cries out for unification; clearly all such spaces must be aspects of one space, and the goal of physics must be to find out what that space is.

However most current theories attempt to unify the gauge theories (in other words, the internal spaces) of the weak, electromagnetic and colour forces first, and only then consider space-time, rather than attempting an earlier, more intimate integration of all the internal spaces with space-time. There is a good reason for this. The force caused by space-time curvature (gravity) is so much weaker than the other forces it might seem that integration should first be done with the gauge fields and only then with gravity.

But such a piece-meal approach to what must ultimately be a complete unity may be misguided.

The WSG theory integrates a gauge theory of the weak and the electromagnetic force, ignoring gravity. But WSG theory also needs another very significant trick, which almost all subsequent unified theories have also employed. The trick entered as a solution of a technical problem, but may prove ultimately to have been a profound discovery.

Experimentally, the electromagnetic force has long range, and the weak force short range; and theoretically, two forces of different ranges were

Table 4

fermoin	approximate mass (MeV/c)	electric charge	colour charge	weak charge
third family				
top quark	30-50,000	+2/3	r,g, or b	+1/2
bottom quark	4,700	−1/3	r,g, or b	−1/2
tau-neutrino	›49	0	0	+1/2
tau lepton	1,784	−1	0	−1/2

The third and probably final family of fermions, listed above, is closely related to the first and second families (tables 1 and 3). But like the second family, these particles are created only in energetic collisions created by cosmic rays impinging on the Earth, or in accelerators. The energies required to create the third family are much larger than those needed to create the second family.

Particle tracks detected by the UAI detector at CERN. In the centre a proton has collided with an antiproton and produced – among other things, a Z boson, a carrier of the weak nuclear force. This decays almost instantly into an electron (orange track left) an its antiparticle the positron (orange track right). A measurement of the energies and momenta of the electron and positron allows physicists to calculate the mass and other properties of the Z particle

incompatible. Theories combining them in a simple way just did not work, producing irremovable infinities. For a time it seemed that the weak and electromagnetic forces, despite having close similarities in other respects, were too different to combine.

Until, that is, it was discovered that such a combined theory of short and long-range forces needed more than just a gauge space beyond our space-time, but also a vacuum full of invisible matter.

Perhaps this is to pile too many extraordinary ideas on top of one another, but WSG theory says empty space is not empty. In WSG theory the vacuum is certainly invisible, and normally insensible, but it is not empty.

What may be said to happen in WSG theory is that some natural symmetries of the larger gauge space break down, and it curls and collapses into our space-time. This phenomenon – called "spontanteous symmetry breaking" – fills the vacuum with a material called "Higgs field" (after one of its inventors, Scots physicist Peter Higgs).

Higgs field, in WSG theory, is assumed (without explanation) to be electrically neutral, but to carry some of the charge of the weak interaction. Thus the weak force – the curvature of the weak gauge space – is affected by the vacuum. And it works out that the weak force cannot penetrate such a vacuum very far. It turns out to have short range, even though the intital theory had both forces of long range.

Thus WSG theory effectively combines the weak and electromagnetic gauge theories by extending the effective dimensions of space-time, and by filling the vacuum with Higgs field. And, very significantly, it has been largely confirmed by experiment, including the discovery of the massive IVB particles, the Ws and the Zs, with all their predicted properties.

In other words, WSG theory – while still not the Theory of Theories – works, and probably teaches us two profound lessons: that we can unify forces by combining spaces beyond space-time; and that ordinary space-time is not empty.

We swim, WSG theory tells us, like fish in a n-dimensional sea.

There has been further unification beyond the WSG linkage of the weak and electromagnetic forces: there are theories called GUTs: the "grand unified theories" that attempt to find a unified gauge space for the weak, electromagnetic and colour forces. But here the picture begins to get a little ragged.

By analogy with WSG theory, GUTs also involve a filled vacuum to unify now three rather than just two forces. There are two classic GUTs: one, called SU(5), introduces a 5-complex gauge space, and the other closely related theory introduces a 10-real space, both to be added to space-time. Effectively, both theories require a space-time-gauge space of 14 real dimensions.

But in such large spaces, there can be many more kinds of curvature – or forces – than we observe. In particular, we get not only colour, but a force that can destroy colour and convert quarks into leptons. But if this force were commonly at work, matter would decay into positrons and electrons, and we would all have gone up in a puff of photons long ago. So, these colour-destroying forces must be suppressed – and they can be, if Higgs fields with the right charges are assumed to be present in the vacuum to make the forces of incredibly short range, just as the weak force is "weakened" in WSG theory by the introduction of the WSG Higgs field. Then in practice particles would just hardly ever get near enough one another for the colour-destroying forces to take effect.

This, then, is the role of Higgs fields in GUTs – to suppress the unstitching of matter. But in such GUTs matter will come unstitched eventually, at an incredibly slow rate, and experiments are actually underway in sensitive detectors buried under the Earth from India to the USA to detect the first decay of a proton. So far, however, no unequivocal such decay has been detected, and there is beginning to be some suspicion that the simplest GUTs are wrong.

However, even these simple GUTs are already pretty complicated, like large machines whose many knobs and buttons must be turned and pressed in exactly the right order to make them work. In particular, the Higgs fields they must assume – the stuff they place in the vacuum like dust brushed under the carpet – is so complex (and unexplained) that the theories would appear to be only exchanging one problem for another: the problem of visible matter for one of invisible matter.

So it would appear that the route of "gauge theories with spontaneous symmetry breaking" has been pursued as far as it will comfortably go. And the questions become: what to preserve from them a likely elements of a deeper theory; and what should that deeper theory be?

The very latest concept is that the particles may not be particles – in the sense of pointlike objects – at all, but infinitesimal, spinning strings. It will not surprise the reader by now that these strings exist not in four dimensions but in ten; and that somehow six of these ten dimensions collapse and curl up to make a kind of Higgs-like background in our usual four-dimensional space-time.

The great advantage of strings is that they include and mix both gravitational and gauge forces in one theory – all the curvatures are mixed up in one total space – and that they appear to solve many serious technical problems that beset a full quantum theory of gravity. These are the first such theories to achieve that degree of unification.

Moreover, string theories have another extraordinary property. When the six dimensions curl up to make the "Higgs background" they leave many (six-dimensional) holes. And fields can wrap around these holes making different configurations – like knots. And different knots can behave like different families of fermions! So it seems that in these theories there is room to provide for both a unification of forces and an explanation of the trio of particle families.

However the string theories – now becoming the theorists' bandwagon – still face many technical difficulties (in particular in these theories matter unfortunately decays instantly!), and they may still not be the final Theory of Theories.

What then will that theory be? We must wait and see, but that theory, the final *Zikr*, the key to the physical universe, does seem so close that it must now be time to forget some of the more pragmatic efforts to stitch our theories together, and to sit quietly – contemplatively – and seek beauty in our theories.

This it seems to me, many physicists have forgotten to do in the hectic competition for success and favour in the modern western academic world. It may be time now to pause a little in the senseless race of accelerators between the United States and Europe, to make less haste and more speed.

And thus, in a contemplative mood, I would like to offer these ideas about the Theory of Theories that is to come.

Physics has told us that the world is multidimensional, with a dimensionality greater than four and perhaps as much as ten. What we call physics will turn out to be the geometry of this vast space, which we see in section just as a page is only part of a book.

Physics has also told us that the geometry is probably folded and involuted, with the extra dimensions rolling around one another to make the structure that we see as "Higgs field".

And, in the partial success of the strings, it has also certainly told us that the "particles" which live in this space are not points, but extended objects. So it will turn out that not only are the particles more than points, or even strings, but that they are whole portions and knots of the geometry itself; and that therefore we do not have to add "matter" to "space" at all.

This concept of "space without particles" is not anarchic or crazy, but has strong foundations in physics, in that it has always been possible to treat particles – charges – as if their only content was the field which they create. And if that field is geometry, what need of the particle?

This may be a simple step in physics. But it will have enormous philosophical implications. For, you may legitimately ask, what then is reality? If all is geometry, what then is the stone I kick? We are used to placing matter in space like actors on the stage. But if there is only the stage? What is a distance, if there are no rulers? It will be as if Euclid's triangles do not have to take any form, but float out of the mind into reality. And if all is abstract geometry, is there not very little distance, philosophically speaking, between the existence of things and our contemplation of them? Will the Theory of Theories willy nilly lead us at last to some philosophic union between subjective and objective? It seems not impossible.

Philosophically, we will be turning back from Democritus (who conceived of the world as atomic and particulate) to Plato and his Muslim followers like al-Farabi, ibn Sina and even al-Ghazzali (who conceived of the world as one of Ideas). The world will seem much less concrete. And such a fundamental, potentially *mystical* shift in consciousness is bound to have profound philosophical and even social, historical and religious consequences: such deep changes in ideas always do.

And for physics all that remains to be done to reach that state is to find that geometry, the geometry of the universe.

Experiment has already taken us close to it.

I am certain that when we find this geometry it will be simple and extraordinarily beautiful. Its true expression will be the Universe itself. Its interpretation will be as vast and incomprehensible. Its beauty will be the *Zikr* which we seek, and – if we are patient and seek well – will be the *Zikr* which we soon shall find. It is this search and nothing else that makes particle physics worthwhile.