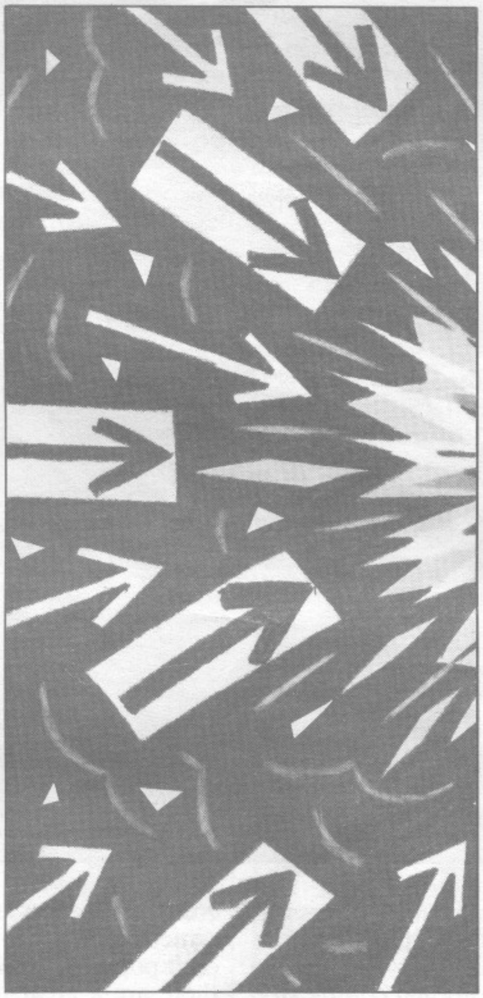
The eleven dimensions of reality

Theoretical physicists are beginning to piece together a unified theory of the Universe. But they picture a strange world in which force and matter are abolished and become merely knots and kinks in the 11-dimensional geometry of space-time

Paul Davies

AN AGE-OLD scientific dream is that the physical world might be reducible, ultimately, to pure geometry; that what we see as material bodies and forces are nothing but knots and kinks in empty space-time. The idea has an appealing economy to it—the concrete substantiality of the world whipped out of a frolic of nothingness.

The first serious step in the geometrisation of nature was taken by Albert Einstein in his general theory of relativity, published in 1915. In this historic work, Einstein abolished the force of gravity, replacing it by an enigmatic field of geometrical distortion, a warping, or curving, of space-time. According to general relativity, bodies are not pulled by forces of gravity at all, as Newton had claimed centuries before. They simply meander as effortlessly as possible through an underlying warped space-time. Viewed this way, the curvature of the Earth's orbit around the Sun is not really due to a force of gravity, but is a reflection of the curvature of space-time in the Sun's vicinity. (In spite of this, physicists still find it convenient to continue referring to "the force of gravity".)



The power and elegance of Einstein's geometrical description of gravity soon inspired a little-known Polish physicist, Theodor Kaluza, to look for a more comprehensive geometrisation of nature. In 1921 Kaluza published an extension of Einstein's general relativity in which he claimed that both gravity and electromagnetism could be formulated in geometrical language, provided they were united into a single field theory. Kaluza's was the first attempt at a unified field theory, and it seemed to be something of a mathematical miracle. Kaluza showed that electromagnetism can be regarded as a form of gravity—and here was the bizarre twist—the gravity of a fifth dimension.

The ordinary space of our perceptions is, of course, three-dimensional. Relativity links space and time, so physicists have traditionally thought of the world as four-dimensional, three dimensions of space plus one of time. Kaluza proposed that there exists yet another dimension of space—a fifth space-time dimension—that we do not see. According to this theory, what we interpret as electromagnetism is, in rough terms, gravity acting in this unseen fifth dimension. The theory abolishes electromagnetic forces, just as Einstein disposed of gravitational forces, and replaces them by warped geometry, this time five-dimensional geometry. In Kaluza's theory, an electromagnetic wave, such as a radio wave, is a ripple in the fifth dimension. The most remarkable feature of the theory is that Einstein's gravitational field equations, when extended to five dimensions, should reproduce *exactly* the laws of gravity and electromagnetism in the four space-time dimensions of direct experience.

The chief weakness of Kaluza's original theory is that we do not see this extra dimension of space which plays a central role in the description of electromagnetism. Where is it?

In 1926 the Swedish physicist Oskar Klein came to the rescue by suggesting that we do not see Kaluza's fifth dimension because it is shrunken to invisibility. The situation can be compared to viewing a hosepipe from a distance. What from afar looks like a wiggly one-dimensional line, on closer scrutiny, turns out to be a narrow tube. Every point on the "line" is, in fact, a little circle around the circumference of the tube. Klein proposed, analogously, that what superficially appears to be a single, structureless point in space, is in reality a tiny circle going around the fifth dimension. We do not notice the extra dimension of space because it has been "compactified", or rolled up on itself to a very small size. Calculations put the circumference of this "tube" of space at about twenty powers of ten smaller than an atomic nucleus—far too small for us to have discerned it directly, even in sub-nuclear particle experiments.

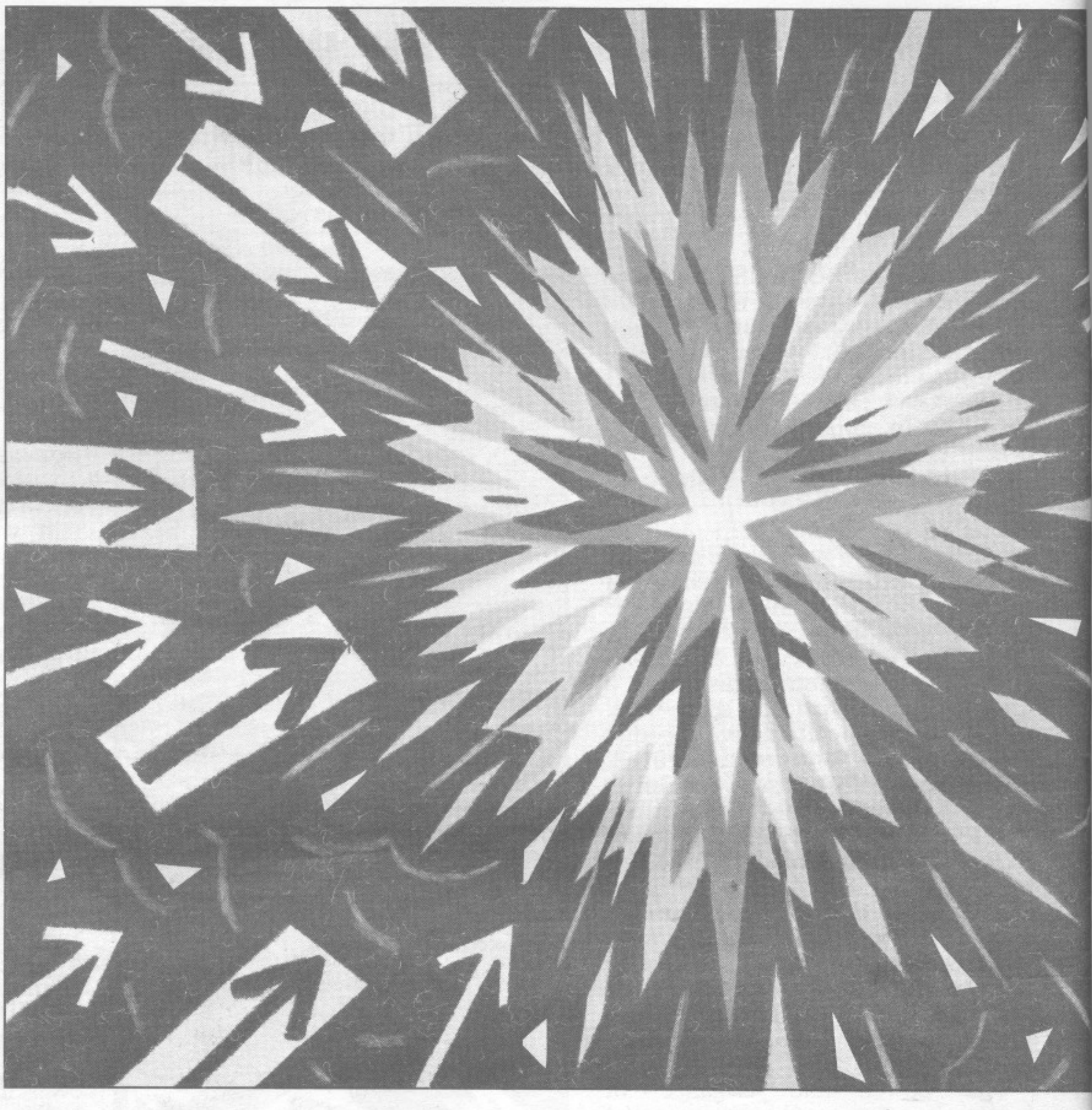
The Kaluza-Klein theory, though intriguing, remained little more than a curiosity for several decades. It was discussed in detail by Stephen Unwin in "Living in a five-dimensional world", *New Scientist*, 29 April 1982, p 296. Since then, there has been a surge of renewed interest occasioned by some spectacular recent developments in the search for a unified field theory.

Today, physicists recognise not two, but four basic forces of nature. In addition to gravity and electromagnetism, two nuclear forces, called weak and strong, have also been discovered. Any successful unified field theory would have to accommodate these two nuclear forces as well. Significant progress along this road was achieved in the late 1960s when Steven Weinberg and Abdus Salam found a mathematical description that weaves together electromagnetism and the weak force into a single conceptual scheme. Physicists consider this a major advance in our understanding of the relationship between the different forces of nature.

During the 1970s, suggestions for further unification came from Sheldon Glashow and others, in which the strong force is merged with the newly unified electromagnetic-weak force in what have become known as "grand unified theories", or GUTs for short. The aim of the GUTs is to provide a unitary mathematical framework in which three out of four of nature's forces emerge as closely related components. The theorist's ability to subsume three apparently very different sorts of forces under a single conceptual umbrella hinges on the discovery that these forces can all be described using so-called "gauge fields" in which certain abstract, but distinctive, symmetries occur in the structure of the force fields. The presence of these crucial symmetries already hints that some sort of hidden geometry is at work in the operation of the forces of nature. Only in the past couple of years has this geometry been made fully explicit—by appealing to the idea of further space dimensions once again.

In the Kaluza-Klein theory, electromagnetism was embodied within gravity by grafting a single extra dimension onto four-dimensional space-time. Extending their theory to incorporate the trio of forces—electromagnetism, weak and strong—demands still more dimensions of space.

The weak and strong forces are more complicated in structure than electromagnetism. For example, whereas the photon can be regarded as the "messenger" that transmits the electromagnetic force between electrically charged particles, the equivalent quantum description of the weak force demands both the newly discovered Z particle, which is identical to a photon in everything except mass, and two electrically charged messengers called W^+ and W^-. When it comes to the strong force, no fewer than eight sorts of messenger quanta (known as gluons) are needed. To accommodate all this additional complexity, the Kaluza-Klein theory has to be enlarged to involve a total of seven extra space dimensions, making 10 space dimensions plus time, or 11 space-time dimensions in all.



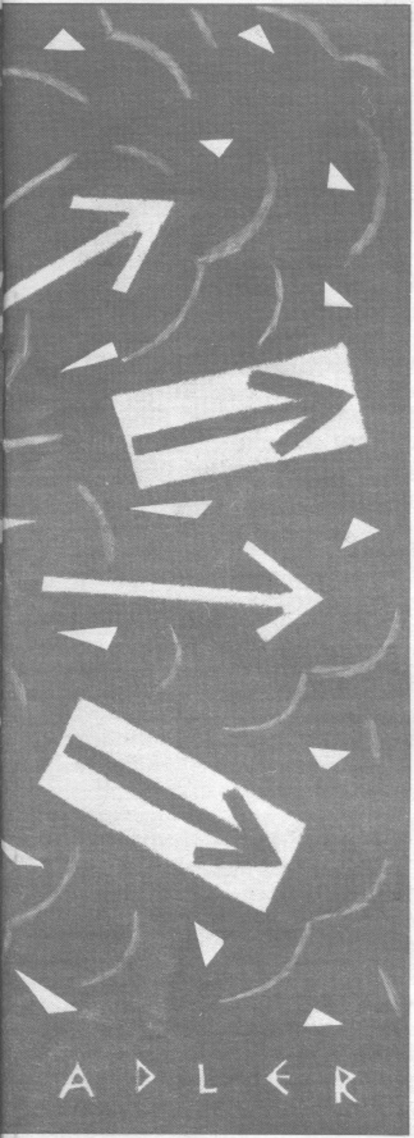
Is it conceivable that the Universe really is 11-dimensional, and that what we have always regarded as forces are actually the unseen seven dimensions at work? One man who thinks so is Michael Duff of Imperial College, London, who with his colleague Chris Pope has been developing the eleven-dimensional Kaluza-Klein theory for a couple of years. In this challenging task, intuition is of little help. Higher-dimensional spaces leave the imagination floundering. On the other hand, mathematics has no need of visualisation, and mathematicians routinely study all manner of multi-dimensional spaces for their interesting properties. One such was Elie Cartan, a French mathematician, who in the 1920s elucidated many of the geometrical properties of multi-dimensional spaces. Cartan's work, while conducted purely for its intrinsic interest, is turning out to have an unforeseen importance in the revitalised Kaluza-Klein theory.

As in the original version of the theory, it is necessary to assume that the extra dimensions are compactified, that is, rolled up somehow to a microscopic size. When only one additional dimension of space was involved, this compactification meant regarding each point in three-dimensional space as a tiny circle. In the extended theory, each point becomes a seven-dimensional compact space, and there are a great many different ways to compactify seven dimensions.

Remarkably, however, one particular choice stands apart. This is the seven-dimensional analogue of the sphere, known for short as the seven sphere. Cartan and other mathematicians had demonstrated that the seven sphere is possessed of a number of unique geometrical properties: and these, moreover, are precisely the properties required if the extra dimensions are to be interpreted as force fields.

A sphere is a highly symmetric shape, and a seven sphere embodies many additional powerful symmetries that reflect the all-important gauge symmetries on which our present description of the forces of nature hinges. However, one of the reasons it took so long for physicists to understand these forces is that, under most circumstances, the symmetries are hidden, or broken. This symmetry-breaking may be reproduced in the Kaluza-Klein theory by allowing the seven sphere to be slightly distorted, or squashed. The squashed seven sphere is emerging as the most favoured shape for the unseen dimensions of space.

The new Kaluza-Klein theory has proved so inspiring to theoretical physicists that they have been rushing to adapt all the laws of physics from 4 to 11 dimensions. One obvious problem to be tackled is to find a reason why an 11-dimensional space-time should arrange itself into four



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plus seven. The hope is that this configuration represents, in some sense, the lowest energy state of space-time. In physics, systems generally seek out a state of minimum energy, so it is possible to believe that when the universe was created, all 10 dimensions of space existed on an equal footing, but that somehow seven of them spontaneously decayed, curling up into a shrunken ball. If the idea is correct, it opens up a tantalising possibility. Perhaps the unstable seven dimensions remained active for long enough in the primeval cosmos to leave an imprint on the structure of the universe, an imprint that remains to this day?

The most spectacular such possibility is that the seven vanished dimensions will provide an explanation for the big bang itself. The ultimate cosmic mystery is the cause of the explosion which brought the physical Universe into being about 15 billion years ago. The only force known to us that can take control of the entire Universe is gravity, but in all our experience gravity is attractive—it is a pulling force. The explosive outburst which marked the creation of the Universe requires a pushing force of unimaginable power to blast the cosmic fragments apart and set the Universe on the path of expansion. Very recently, theorists have discovered that unified force fields naturally tend to produce just such a repulsive force under the extreme conditions expected in the big bang.

One conceivable scenario for the creation goes something like this: In the beginning, 11-dimensional space-time erupted spontaneously out of literally nothing, an event that is only explicable within the context of quantum physics, which permits the uncaused creation of physical structures. The shape of space need not initially have been specially ordered; it could have been chaotic and turbulent. In some regions, inevitably, the configuration would have been such that the competition of forces produced a huge repulsion. As a result, three space dimensions began to expand at an accelerating rate, while the remaining dimensions spontaneously rolled themselves into a seven sphere. If the outward driving force could sustain itself for long enough, the explosive violence characteristic of the big bang would be achieved.

At this stage such ideas can only be tested by calculation. Would the repulsive force have lasted long enough? Is it inevitable that three dimensions of space embark upon expansion while seven collapse, or could there be a different split, say, two plus eight?

It may be that even the number of starting dimensions is variable,and that 11 has been selected anthropically too. There is, however, some curious independent evidence that suggests the number 11 is unique. It comes from a branch of physics which sets as its goal the formulation of a mathematically consistent quantum theory of gravity. For some time, physicists have been greatly distressed that the general theory of relativity, whatever its intrinsic merits, clashes badly with the principles of quantum physics.The only way out of this impasse seems to be to embed general relativity in a more comprehensive theory of gravity which involves extra components— types of gravity we haven't yet seen. According to this philosophy, all the mathematical troubles with quantum gravity have arisen because physicists have been artificially isolating what is actually only a fragment of the full panoply of gravitational forces.

To achieve a complete theory of gravity—one which will be consistent with quantum physics—the gravitational force of familiar experience has to be fitted together snugly (in a mathematical sense) with the additional, as yet undetected, gravitational components. For the past decade, an army of theorists has been engaged on this daunting enterprise. Their work has centred on a key idea, called supersymmetry. This is an abstract mathematical concept related to the phenomenon of intrinsic spin found among subatomic particles. The technical details do not matter here. The point is that the most elegant formulation of a supersymmetric theory of gravity is one in which space-time has 11 dimensions!

Is this just an improbable coincidence, or does it point compellingly to a deep connection with the unified gauge theories of the other three forces of nature? Is the mathematics hinting at a fully unified field theory, in which gravity and other forces are merged into a single superforce? If so, then that age-old dream of building the world out of pure geometry could be close to realisation—but the geometry would be that of an 11 dimensional universe. ☐

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