**Instantons**

Many particle physicists are convinced that applications of gauge theory hold the key to further understanding. In the still short history of the subject, however, many people have been preoccupied with goldmining for new physics and have not spared much thought for the extra pure mathematics which might be needed to produce a workable theory. General relativity is one example of an area of physics where the use of new mathematical techniques has paid considerable dividends.

Whatever gauge theories might tell us about the behaviour of particles, it is already clear that there are deficiencies in our present methods of handling them. These methods usually turn to perturbation theory, where one hopes that a mathematical series can be found which gives, term by term, a closer and closer approximation to the correct result.

Although fine for electromagnetic and weak interactions, this approach does not work for strong interactions because of the large coupling constant involved. While gauge theory games continue with the limited mathematical techniques at our disposal, some theoreticians are standing aside from the mainstream activity to see if other mathematical ideas could be used instead. Although there has been no major breakthrough, some general deficiencies of the usual picture of gauge theory applications have been discovered.

By ignoring the conventional perturbation theory approach, A. Polyakov and collaborators and G. ’t Hooft have shown that the existence of peculiar new entities cannot be ruled out, and it was quickly realised that these new entities, called ‘instantons’, could, if they exist, play havoc with conventional ideas of quantum number conservation and selection rules. In addition, a number of mathematical specialists have tried to put the ideas of Yang-Mills gauge theories into a more general mathematical framework, so that these ‘instantons’ and other peculiarities can be described in a natural way.

The idea of a Yang-Mills gauge theory is to produce a mathematical picture which describes the required symmetry of particle properties and comes out naturally with the right conserved quantum numbers. Just as the theory of quantum electrodynamics exploited the symmetry of its interactions in four dimensional space-time, subsequent work has concentrated on finding the additional ‘internal’ symmetries of interactions which might have to be superimposed on our familiar space-time world.

In this picture, each point in space-time is supplemented by an internal space which describes the microscopic behaviour of a particle at that point. When we go from one space-time point to another by two different paths, we do not necessarily land up at the same point in the two corresponding internal spaces. The difference between these two internal points is not observable and this freedom, or arbitrariness, is exploited in the gauge theory approach to produce the required picture of the interaction.

But the mathematics of gauge theory can become clumsy and difficult to handle. Just as a Fourier transform which takes ordinary space into momentum space can sometimes greatly simplify a mathematical problem, so it has been suggested by M. Atiyah at Oxford that some of the difficulties of handling Yang-Mills theories could be overcome by transforming the problem into some other space.

The approach is analogous to the well known technique of representing two-dimensional rotations by a system of one-dimensional complex numbers. As well as reducing the number of dimensions of the problem, the technique means that the nature of the interaction becomes implicit in the algebraic geometry of the new space.

The different types of physical behaviour are then characterised by integer numbers (like quantum numbers) which describe the topology of the mathematics in the new space. One ‘simple’ type of behaviour corresponds to lines in the new space but to points (i.e. events) in space-time and these are the ‘instantons’ discovered mathematically by Polyakov and whose relevance for physics has been elaborated by ’t Hooft.

These considerations show that there can be more than one vacuum for each gauge theory picture. What does this mean? Naively, one empty space is much like another, but if there are invisible internal symmetries at work, then there might be residual internal directional effects still around when everything else is taken away. These directional effects could distinguish one vacuum from another.

A normal Yang-Mills gauge transformation should take one of these vacua into another. One mathematical result of this is that there should be something intermediate between the two vacua, which is itself gauge invariant, and therefore observable. These mysterious intermediate phenomena, which spend their time burrowing from one vacuum state to another, are the ‘instantons’. Although they are events rather than particles, this burrowing is analogous to the well known quantum mechanical tunnelling effect where particles can statistically seep through an obstacle even though they do not have enough energy to get over it.

The existence of instantons could give rise to all sorts of anomalous effects, and certainly the exponentially-decaying profile of a burrowing instanton is something which cannot be described by ordinary perturbation theory. The most interesting pos-
People and things

sibilities emerge if the instantons could get out of their trap between neighbouring vacuum states and become free. This would require a tremendous amount of energy and could have been possible in the 'big bang' which created the universe. There, the instantons could have wiped out our conventional rules of baryon number conservation.

Whatever the future may hold for instantons, the increasing collaboration between pure mathematicians and theoretical physicists should pay dividends.

Ken Green

Ken Green, Brookhaven scientist for the past 30 years, one of the leaders in the construction of the 33 GeV AGS and world authority on accelerator design and construction, died in August at the age of 66. After studying at Berkeley with the group headed by Ernest Lawrence, Ken Green arrived at Brookhaven after the war years to become deputy to Stan Livingston, who was then organising Brookhaven's first accelerator project, the Cosmotron. He went on to head the building of the AGS synchrotron which was completed in 1960. He headed the Accelerator Department for many years, participated in the design of the Isabelle storage rings and his last work was in connection with the electron storage ring for the USA National Synchrotron Light Source. Ken was one of the pioneers of accelerator building who contributed considerably to establishing accelerator technology as such a thoroughly understood discipline. He was absorbed by his work and projected his enthusiasms with great gusto. His colleague for many years, John Blewett, writes, 'We have lost a man of extraordinary talent... Ken was skilled as a physicist, both experimental and theoretical, as an electronic engineer, as a power engineer, as a mechanical engineer and as a civil engineer. Withal he was a man with whom it was a delight to associate. Brookhaven will not be the same without him.'

Energy Department

A Department of Energy has been created in the USA and is beginning operation under James Schlesinger. It takes over some 20000 staff and an annual budget of $10 600 million. Prominent among its component parts is the large Energy Research and