Physics at the frontier

Abdus Salam

Superforce: The Search for a Grand Unified Theory of Nature.
By Paul Davies.
Simon & Schuster/Heinemann: 1984. Pp.255. $16.95, £12.95.

Like many compelling images, it may turn out to be a mirage, but for the first time in the history of science we can form a conception of what a complete scientific theory of the world will look like. Paul Davies in *Superforce.*

THERE is no question but that there has been a transformation, during the past decade, in our understanding of the inanimate physical Universe — a "quantum" jump of the type which from time to time takes place in the history of science. It is this leap in knowledge that Paul Davies sets out to describe in his latest book.

Some eleven years ago, around 1973, the situation was this: we had just begun to believe that all matter in the Universe was made from quarks and leptons (electrons, muons and neutrinos). We believed then that there were four distinct forces controlling all interactions of matter — the universal force of gravity; the force of electromagnetism, acting between electrically charged quarks and leptons; and the two nuclear forces, the strong nuclear force, between quarks, and the weak nuclear force, between left-spinning quarks and leptons. So far as the cosmological structure of the Universe was concerned, observations supported a "standard" model of an expanding Universe; this model stipulated a Universe beginning with a mysterious big bang. We could trace the orderly evolution of the Universe — the formation and emergence of the familiar nuclei, atoms, stars and galaxies — with an epoch starting one-hundredth of a second after time began. But the earlier history was unknown.

The transformation which has taken place since that time lies primarily in the understanding of the nature of the four forces and a comprehension of the earliest history of the Universe. We believe today that the primary agents responsible for the four fundamental forces are the so-called "gauge particles". The prototype gauge particle is the quantum of light — the photon — which is the "gauge messenger" for the force of electromagnetism. During the past ten years, there has been experimental confirmation of the existence of gauge particles responsible for the strong nuclear force between quarks, and, even more dramatically, the discovery — in 1983 — of the gauge particles of the weak nuclear forces, the so-called Ws and the Z.

Even more important than the unveiling of these objects has been the experimental confirmation of a theory, first proposed in 1967, that the two seemingly distinct forces — electromagnetism and the weak nuclear force — share a common origin and are indeed aspects of a single unified force, the electroweak force. The clearest manifestation of this unification would need temperatures of the order of 10^{16}K or the laboratory provision of accelerator energies in excess of 100 Gev. Such an accelerator was built at CERN in Geneva in 1982 and the Ws and the Zs were duly created last year, with their theoretically predicted masses, in proton–anti-proton collisions.

So far as the history of the early Universe is concerned, we now believe that there was an epoch — lasting up to 10^{-12}s after time began — when temperatures in excess of 10^{16}K did obtain. During this epoch the Ws and the Zs shared with the photon a state of masslessness. A phase transition took place when temperatures fell below 10^{16}K, concomitant with the expansion of the Universe and its cooling. It was this phase transformation which was responsible for producing the distinction between electromagnetism and the weak nuclear force which we observe today. Before this epoch there was no distinction. With electroweak unification, we have thus pushed back the known life span of the early Universe by ten orders of magnitude.

So much for what is established and nonspeculative in the current thinking. With the success of these ideas however, the question arose: are the other two forces, the strong nuclear and the gravitational, also united with the electroweak? Are we dealing in the end with just one force? Twelve years ago, speculation began on this subject. As regards the unification of the strong nuclear force with the electroweak, an attractive version of such a "grand" unification suggested that perhaps another phase transformation did take place some 10^{-31}s after time began. This would extend our knowledge of the early Universe by another 20 orders of magnitude in time.

One hard consequence of such a second unification would be the prediction of the instability of the proton, which in this picture would have a half-life of the order of 10^{38}s. Experimental confirmation of this decay has been sought but not yet conclusively demonstrated. Yet, a phase transition of the type implied in this "grand unification" is not to be abandoned lightly, for this gives the best explanation of the otherwise mysterious predominance of matter over anti-matter as observed in the Universe today. Thus the search for proton decay is still on, and will remain so.

In a finely written book, Paul Davies takes us through all of these developments. He starts *ab initio*, assuming no prior knowledge of quantum theory or relativity theory, and gives a lucid exposition of these two earlier revolutions in our thinking. He then discusses the unification ideas I have mentioned above, and the relevance of the phase transitions in the early history of the expanding Universe, before moving onto the ideas currently occupying the centre of the theoretical stage which attempt to include the fourth force — gravity — in the scenario. Naturally, these ideas are highly speculative in nature. Among them is the postulate of a new type of symmetry — the so-called supersymmetry — combined with a postulate of extra dimensions of space, in what is known as the Kaluza–Klein framework. The synthesis of these two ideas gives rise to a discussion of the "superforce" of the book's title, a concept which draws together supermatter (quarks, leptons, gauge particles and their superpartners) into one unified whole with the force of supergravity (described by gravitons and their speculated superpartners, the gravitinos). The theory is not yet in any final shape, but it possesses a beguiling aesthetic attractiveness, particularly when formulated in 11 dimensions.

Davies also gives an account of the associated phase transitions in the earliest history of the Universe, including the recent ideas of its rapid inflationary expansion and the possible origin of the Universe as a "quantum fluctuation" of the vacuum, out of "nothingness".

This is new, heady stuff, professionally and accurately rendered. However, if I have one criticism of this eminently readable book, it is this. In the final part, one does not get the impression that the author is writing about material which is so highly speculative. The criticism applies also to a comment in the penultimate chapter:

The idea that non-causal, holistic order exists in the universe by no means originated with modern physics. Astrology, for example, is an attempt to discern a cosmic order in which the affairs of human beings are reflected in the organization of the heavens. The psychoanalyst Carl Jung and the quantum physicist Wolfgang Pauli proposed a non-causal connecting principle which they called synchronicity. They compiled evidence for a sort of pervasive order in which apparently independent events occur in conjunction in a meaningful way. Typical of such events are documented instances of extraordinary coincidences, well beyond the expectations of chance.

There are insufficient cautionary warnings to the reader that such thinking — about astrology and "coincidences" — is not the staple of physics. But this apart, unquestionably, Paul Davies has established himself as one of the most felicitous writers on physics at the frontier. □

Abdus Salam is Director of the International Centre for Theoretical Physics, Trieste, and a Professor in the Department of Physics at Imperial College, University of London.