

Physics monitor

Grand unification

'There is the scent of a new grand synthesis in the air.' These were the words of Murray Gell-Mann in his closing talk at the 1974 Stanford Accelerator Conference. Now, four years later, theories based on symmetry ideas have made further progress. With quantum chromodynamics maturing as a theory of inner hadronic interactions, and with the 'Weinberg-Salam model' almost ready for the textbooks as a unified picture of weak and electromagnetic interactions, the scent of 1974 must have ripened into an all-pervading aroma!

In quantum chromodynamics (QCD), the key idea is that while inter-quark forces are strong over relatively large regions of space-time (for example over the extent of a single nucleon), they get 'weaker' as the space-time region of the interaction gets smaller. It is this variation in the strength of the inter-quark forces which opens the door to further progress.

It means that the forces at work when high energy leptons pierce through to the deep interior of hadrons are much simpler than had previously been thought possible. Traditionally, strong interactions had been attributed with a cumbersome coupling strength which prevented any quantitative progress.

The new simplicity allows the techniques of perturbation theory to be used, quantum electrodynamics style, in new areas of physics and gives good predictions (see October issue, page 335).

The variation in the strength of the inter-quark force also means that out at an extremely high energy, these components of the 'strong' force may become comparable in strength to the electro-weak effects. Under such conditions, it is possible that there is some larger symmetry which encompasses those of both the strong and electro-weak worlds.

In the standard electro-weak theory, some of the available degrees of freedom in the ideal symmetry picture are 'frozen out', so that part of the symmetry is destroyed. The symmetry is said to be 'spontaneously broken'. Although vestiges of the full symmetry remain, the electromagnetic and weak interactions appear as different forces.

In the same way, a larger symmetry describing both strong and electro-weak effects could be spontaneously broken so that the strong and electro-weak components split. As well as having the aesthetic appeal of achieving a grand unification of three apparently highly different fields of force, this idea also produces important quantitative results which are unobtainable with separate theories of strong and electro-weak interactions.

In the standard 'Weinberg-Salam' formulation of electro-weak interactions, there is one free parameter — a mixing angle. This describes how the intermediate boson held responsible for the neutral current of weak interactions appears in the theory, fixing its mass and coupling strengths.

This parameter also dictates how the familiar description of electromagnetism is embedded in the larger theory of electro-weak interactions. This mixing angle is a free parameter which normally can only be determined from experimental results.

However the introduction of additional symmetry principles gives relationships between the coupling strengths of the component symmetries describing the individual forces, and allows the mixing angle to be calculated. Although there are a number of candidates for the overall grand symmetry, results from a number of calculations give acceptable values for the mixing angle. The fact that such a revolutionary idea gives results in broad agreement with experiment is certainly encouraging.

The basic particles in the grand symmetry theory are the pointlike quarks

and leptons. While having totally different properties in the everyday strong and electro-weak domains, the grand symmetry brings these particles together into common multiplets.

If the symmetry were exact, the masses of the quarks and leptons would be the same. However the symmetry breaking shifts the masses of the particles. Since the masses of the leptons are known accurately, the application of ideas from the renormalization group (see September issue, page 304) gives a handle on the spectrum of the quark masses.

The calculations agree with the observed thresholds for the production of heavy quarks with charge $-1/3$, such as the strange quark and the new heavy quark responsible for the ψ states.

The calculations seem to work best if there are six, or at the most eight, quark flavours. This is good news because six is the minimum number of quarks required to incorporate CP violation into the theory in a natural way, and also ties in with cosmological ideas on the permitted number of different massless neutrinos.

Any 'gauge' theory of a force field naturally produces vector (spin one, negative parity) bosons which mediate the force — photons for electromagnetism, intermediate bosons for the weak interactions and gluons for the inter-quark forces. So far, the photon is the only such particle whose existence cannot be doubted, and the immediate future of QCD and of the electro-weak theory rests on finding evidence for their respective vector bosons.

Introducing a grand gauge symmetry to unify all the other particle forces produces in turn its own force. This additional field would have its own set of bosons bringing about interactions between the basic particles — the leptons and the quarks.

Such a force would not differentiate between quarks and leptons and would convert quarks to leptons and

vice versa. Such a transmutability of quarks would show itself as an instability of hadrons, and the new force would apply equally to all hadrons, including the otherwise stable proton. While conservation of baryon number is well-entrenched in our thinking, there is no fundamental principle which dictates that the proton must be absolutely stable.

To ensure that the strong and electro-weak domains are well separated at currently available energies, their meeting point has to be at an extremely high energy. This implies that the bosons of the grand symmetry are very heavy, say in the range 10^{14} - 10^{16} GeV, and that the resulting force is very feeble.

While such a 'hyperweak' force would be masked by other effects in the decays of most hadrons, the proton would still be unstable, although only just. Methods can be brought in to restore stability to the proton, but they tend to spoil the general appeal of the scheme.

The history of modern physics is littered with attempts to unify the various fields of force. Some of the most heroic were those of Einstein and Weyl earlier this century, who did not have the benefit of our new insight into the possibility of electro-weak synthesis.

After the successes of the electro-weak theory, the way was clear to attack again the problem of grand unification. Most efforts centre on establishing a minimal overall symmetry which incorporates the different symmetries required for the strong and electro-weak worlds. Others propose different sets of particles, possibly even more fundamental than the quarks and leptons.

According to some formulations of the unification scheme, new phenomena are conceivable from a new generation of particle accelerators.

Whether present efforts are still

premature, only time will tell. However in the words of Howard Georgi and Sheldon Glashow, among the first to reattempt this unification, 'our hypotheses might be wrong and our speculations idle, but the uniqueness and simplicity of the scheme are reasons enough for it to be taken seriously'.

Hardware for the new Fermilab computer system being hoisted into place on the eighth floor of the Central Laboratory Building. The system consists of three powerful CDC CYBER 175 computers with a full set of peripherals. Initial operation started in November with the full system capacity scheduled to become available in the Spring of 1979.

(Photo Fermilab)

