Nobel Prize for Physics, 1979

Physics' most prestigious accolade goes this year to Sheldon Glashow, Abdus Salam and Steven Weinberg for their work in elucidating the interactions of elementary particles, and in particular for the development of the theory which unifies the electromagnetic and weak forces.

This synthesis of two of the basic forces of nature must be reckoned as one of the crowning achievements of a century which has already seen the birth of both quantum mechanics and relativity.

Electromagnetism and the weak force might appear to have little to do with each other. Electromagnetism is our everyday world — it holds atoms together and produces light, while the weak force was for a long time known only for the relatively obscure phenomenon of beta-decay radioactivity.

The successful unification of these two apparently highly dissimilar forces is a significant milestone in the constant quest to describe as much as possible of the world around us from a minimal set of initial ideas.

'At first sight there may be little or no similarity between electromagnetic effects and the phenomena associated with weak interactions', wrote Sheldon Glashow in 1960. 'Yet remarkable parallels emerge...'

Both kinds of interactions affect leptons and hadrons; both appear to be 'vector' interactions brought about by the exchange of particles carrying unit spin and negative parity; both have their own universal coupling constant which governs the strength of the interactions.

These vital clues led Glashow to propose an ambitious theory which attempted to unify the two forces. However there was one big difficulty, which Glashow admitted had to be put to one side. While electromagnetic effects were due to the exchange of massless photons (electromagnetic radiation), the carrier of weak interactions had to be fairly heavy for everything to work out right. The initial version of the theory could find no neat way of giving the weak carrier enough mass.

Then came the development of theories using 'spontaneous symmetry breaking', where degrees of freedom are removed. An example of such a symmetry breaking is the imposition of traffic rules (drive on the right, overtake on the left) to a road network where in principle anyone could go anywhere. Another

Abdus Salam

Harvard Professors Sheldon Glashow (left) and Steven Weinberg at a news conference at Harvard after it was announced that they share the 1979 Physics Nobel Prize with Abdus Salam.

(Photo Photopress)

Abdus Salam with members of the collaboration which worked with the Gargamelle heavy liquid bubble chamber. It was this detector which first saw the neutral current interaction predicted by the electroweak theory.

(Photo 392.10.79)

example is the formation of crystals in a freezing liquid.

These symmetry-breaking theories at first introduced massless particles which were no use to anybody, but soon the so-called 'Higgs mechanism' was discovered which gives the carrier particles some mass. This was the vital development which enabled Weinberg and Salam, working independently, to formulate their unified 'electroweak' theory.

One problem was that nobody knew how to handle calculations in a consistent way. The way round this obstacle was shown by Gerard 't Hooft in the early seventies. With this, the initial ideas matured into a fully-fledged theory.

One by-product of the unification was a type of weak interaction which would not change the electric charges of the participating particles. For a long time all weak interactions were seen to shuffle electric charges around.

Then in 1973 came the discovery in the Gargamelle bubble chamber at CERN of the 'neutral current' of weak interactions, in which neutrinos interacted with target particles, but remained as neutrinos. This was the first vital piece of experimental evidence in favour of the unified electroweak theory. After this the remaining pieces of the puzzle soon fell together.

If there is a neutral current, it should be seen in other ways, for example the decay of a neutral kaon into a pair of muons. But this is only a very rare form of kaon decay. What inhibits the direct decay through the neutral current?

The exact answer had been provided by Glashow, who with J. Iliopoulos and L. Maiani, showed how the electroweak ideas could be fruitfully extended to cover quarks (the components of strongly interacting hadrons) as well as the leptons of the original theory.

In this picture, the basic particles (the quarks and the leptons) can in general spin either right- or left-handedly (the neutrino however appears to have no right-handed form). The left-handed particles can be grouped into fours, each four being composed of a pair of quarks and a pair of leptons.

One set of four basic particles — the 'up' and the 'down' quarks together with the electron and its neutrino, provides all the source material for our everyday world of atoms whose nuclei are made from protons and neutrons. But there were still more basic particles to use up — there was the strange quark, the muon and its neutrino. To get a second set of four basic particles required a new type of quark.

This was the heavy 'charmed' quark, which could account for the problem of the neutral kaon decays. However charm was to exhibit itself much more vividly. In November 1974 came the simultaneous discovery by the teams of Sam Ting at Brookhaven and Burton Richter at SLAC of a remarkably stable heavy meson, the J/psi.

This was explained as a bound state of a charmed quark and its corresponding antiquark, and the spectroscopy of charmed particles was unravelled in further experiments at SLAC and at DESY. Particle physics had entered a new age, and the discoveries made by Ting and Richter were recognized in the award of the Nobel Prize in 1976.

However there was still a lot of work to be done. In particular, physicists had to look at the detailed behaviour of the neutral current interaction to see if it followed the rules set out by the simplest electroweak theory, or whether some more elaborate version would be required.

While inevitably odd transient things appeared in the ebb and flow of experimental statistics which did not agree with the theory, it is impressive how all the results which stood the test of time have been in line with the simplest model of electroweak phenomena, as originally formulated by Weinberg and Salam.

Particular mention should be made of the remarkable experiment at Stanford which measured right-left asymmetries (parity violation) in electron-nucleon scattering. These tiny effects are the result of the delicate interference between weak and electromagnetic interactions and provide an acid test of the theory (see July/August 1978 issue, page 245). The agreement between experiment and theory is excellent.

In addition, results continue to come in from neutrino experiments,

Abdus Salam, the oldest of the three laureates, was born in 1926 in Jhang, now in Pakistan. He received his doctorate from Cambridge University in 1952. In 1957, he became Professor of Theoretical Physics at Imperial College, London, a position which he still holds. He was also one of the main movers behind the establishment of the International Centre for Theoretical Physics in Trieste, which he directs.
Sheldon Glashow was born in New York in 1932, obtained his doctorate at Harvard in 1959, and is now Professor at the Lyman Laboratory, Harvard.
Steven Weinberg was born in New York in 1933, and attended the same Bronx high school as Glashow. He obtained his doctorate at Princeton in 1957, and now holds the post of Higgins Professor at Harvard.

As well as their formulation of the electroweak theory, the three men have also made numerous other important contributions to the theory of elementary particles.

at both high and low energies, which display further the remarkable power of the theory.

But probably the greatest prediction of all remains untested. Just as Maxwell's formulation of the electromagnetic field had to await confirmation through Hertz' discovery of electromagnetic radiation, so the electroweak theory awaits the discovery of its own radiation.

The theory makes very exact predictions for the heavy particles which provide this radiation, but which today is out of reach of any Laboratory. The proton-antiproton collider project now under construction at CERN and scheduled to begin experiments in the early 1980s, will for the first time open up the energy range where this radiation is expected to be seen.

Another vital ingredient of the theory which remains to be tested are the Higgs particles of the spontaneous symmetry breaking mechanism. Here the theory is still in a volatile state and no firm predictions are possible. But this mechanism is crucial to the theory, and something has to turn up.

The great success of the electroweak unification has led many theorists to become more ambitious and look for ways to bring in the strong interactions, and possibly gravity as well, to achieve a 'grand unification' of the forces of nature.

However it is sobering to remember that a hundred years had to pass between Maxwell's synthesis of electricity and magnetism and the new electroweak unification. If this pattern is repeated, grand unification would be for the 21st century.

(A detailed account of the development and application of these gauge theory ideas to electroweak unification was published in our September 1977 issue, page 271.)

Second ICFA Workshop

From 4–10 October a second Workshop on 'Possibilities and Limitations of Accelerators and Detectors' was held at Les Diablerets in Switzerland with review talks at CERN on the final day on the work of the different groups. It followed a Workshop at Fermilab in 1978 (see November 1978 issue, page 389) and was promoted by the International Committee for Future Accelerators in the context of its very long-term thinking about the future of high energy physics. ICFA, which was set up under the auspices of the International Union of Pure and Applied Physics, is at present chaired by John Adams and has representatives from the various regions of the world involved in high energy physics.

The Les Diablerets Workshop was organized by Ugo Amaldi and divided its work into several topics — Very high energy electron-positron colliders (reported by A.N. Skrinsky), Many TeV proton accelerators and proton-antiproton colliders (Lee Teng), Extraction and external beams from a many TeV accelerator (Bas de Raad), Electron-proton interaction regions and experiments (Gus Weber), Extrapolation of experiments at electron-positron and proton-antiproton colliders (Barry Barish), Deep inelastic experiments with lepton beams of a few TeV (Guido Barbiellini), Hadron and photon experiments at fixed target machines (Yuri Prokoshkin) and Possibilities and limitations of detectors and data handling (Dave Nygren).

In working on higher energy electron-positron machines it became even clearer that in the future this physics would have to be done with colliding beams from linacs. The largest storage ring system considered at the Workshop had 260 GeV per beam and such frightening parameters as 29 GeV