Nature is not all that malicious

The proton is not decaying as fast as the simplest unified field theory — SU(5) — predicts. But this is no cause for despair: the search should be for something even simpler.

IT seems the whole world is delighted about the discovery of the intermediate vector bosons, the Ws and the Z^0, which seem to fulfil all the requirements of the "electroweak" gauge theory developed by Sheldon Glashow, Abdus Salam and Steven Weinberg to unite electromagnetic and weak forces in one field of force. But there is a cloud on the horizon: the most obvious extension of the theory to include the remaining fundamental force apart from gravity, the strong nuclear force called "colour", which acts between quarks, is beginning to be "difficult to maintain". The words are Weinberg's, but others agree with him. The theory is minimal SU(5). (The symbols refer to a set of operations — a group — under which the "charges" of the theory are symmetrical.) "It's too early to draw the most discouraging conclusion", says Weinberg. But the experimental auguries are bad.

The immediate problem is an experiment which shows that quarks in protons (which contain three quarks) do not decay fast enough into positrons (anti-electrons). All unified theories that include colour inevitably draw a link between leptons — such as the electron and the neutrino, which do not respond to the colour force — and quarks, which do; and since quarks are heavier than leptons, the theories expect the former to decay into the latter. The rate of decay is predicted to be very slow, determined by the enormous energy, some 10^{15} GeV, at which quarks and leptons should behave on an equal footing.

There are now four working experiments to detect nucleon (neutron or proton) decay, with others under construction, and there is some conflict among their results. All are deep beneath the earth, where they are shielded — more or less — from cosmic rays, whose most penetrating components are muons and neutrinos. The Tata-Osaka-Tokyo collaboration is running a 140-tonne detector at the Kolar Gold Mine, some 7,600 m of water-equivalent deep beneath south central India: they claim three contained decay events in the chamber, and three whose tracks pass through the chamber walls. The Frascati-Milan-Turin experiment 5,000 m (water-equivalent) under Mont Blanc, with a 150-tonne detector, has one event.

But the latest results come from the Morton salt mine, 1,600 m (water-equivalent) beneath Ohio. There the Irvine-Michigan-Brookhaven (IMB) collaboration, together with colleagues from Caltech, Hawaii, Cleveland and University College London, has put 8,000 tonnes of pure water under observation by 2,048 photomultiplier tubes. Measurement is restricted to the inner 3,300 tonnes — but this is still 20 times the mass of the other experiments. The tubes and associated electronics and software are arranged to collect flashes of Cerenkov light that would arise if a proton in the water decayed. But at least in the first 130 days' running none of the 230,000 flashes collected each day was from a proton decay. The events, say the team in a paper in *Physical Review Letters* (**51**, 27; 1983), are mostly cosmic-ray muons passing through or interacting in the chamber of cosmic neutrino interactions. This has pushed the proton mean lifetime (in this mode) to something longer than 10^{32} years at 90 per cent confidence, the collaboration claims. The SU(5) prediction was 4.5×10^{29} years, with uncertainty of ± 1.7 in the exponent.

This IMB result has cast doubt on the world's four other examples of nucleon decay in smaller detectors — even though they have much lower muon backgrounds (Kolar, 2 per day; Mont Blanc, 20 per day) — and physicists now appear to be taking the pessimistic view: they believe IMB, and dismiss the other results as flukes or misinterpretation. Moreover, although IMB has been looking predominantly at the pi-zero/positron decay mode predicted by SU(5), the experiment is also "sensitive to nearly every sensible decay mode" of the proton says Maurice Goldhaber, one of the team leaders. So an IMB search for decays into an alternative mode of K-zero/muon, for example, has put a limit on such decays at 1.4×10^{31} years, says Goldhaber. This begins to stretch another (more accommodating) unified theory known as "super symmetry", which attempts to link the description of matter with field. Supersymmetry predicts a dominance of K-decay modes.

Weinberg is naturally disappointed. "We had looked forward to happy years of exploring the phenomenology of proton decay. . . It would have been such fun to do all that." His view is that nucleon (proton or neutron) decay is likely to turn up some day, in the neighbourhood of 10^{31} to 10^{33} years, but this small range covers "the difference between instant gratification and years of subterranean labour". Assuming the latter holds, says Weinberg, "I think the only area where we're almost sure to see something decisively important" now is in multi-hundred GeV collision experiments, to seek the mechanism which "breaks" the symmetry of the Salam-Weinberg model. This mechanism is usually assumed to be a set of "Higgs fields" a new form of matter which would fill the Ws and Z^0.

Another thing to discover would be certain peculiar partners of the gauge particles and the fermions, called gauginos and sfermions, predicted by supersymmetric theories. Finding these would be even more exciting than proton decay, Weinberg believes, as supersymmetry is the most comprehensive of unified theories. However, "No-one so far has a model, nor a satisfactory picture of how supersymmetry is broken" says Weinberg. "If there were a candidate supersymmetry theory that didn't already disagree with experiment, that had naturalness and attractiveness, then I would say this is the most important thing, stop everthing; but there isn't such a theory." Abdus Salam, as you might expect, is less pessimistic: he believes the content of the theories is relatively little explored, and that complicated effects within them might yield the world we know. He compares the problem with nuclear (as opposed to particle) physics. The phenomena may be an essentially complicated manifestation of a simple underlying structure. The vacuum may be like the nucleus, and it will take time to calculate its properties from supersymmetry (broken by supergravity, in Salam's view).

But Weinberg and others believe something new is needed. Weinberg and Philip Candelas are turning to geometry — theories that add extra, curled-over dimensions to space-time. "These calculations are extremely difficult mathematically, and we can deal only with spheres", says Weinberg, "but it may be that the real manifolds are more complicated".

However, whether Weinberg, Salam or some other is closer to the truth, no physicist should now forget Einstein's remark that God may be subtle, but not malicious. To make SU(5) fit Nature, the Higgs parameters (and there are 29 Higgs fields in the model) had to be extraordinarily finely tuned — certain arbitrary numbers had to cancel (but not quite!) to twenty-six decimal figures, without explanation for the cancellation. The theory surely deserved to go! Nature is *not* malicious: if it is, physicists might as well stop work. Simplicity has always been the answer, and will be yet. **Robert Walgate**

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