NOTES FROM ABROAD

The Hunting of the Quark

The European Organization for Nuclear Research, which represents the cooperative efforts of thirteen nations of Western Europe, will be ten years old this year. The CERN Laboratory near Geneva has, during its relatively short lifetime, become known as one of the world's great centers of physics research, partly because of its proton synchrotron and other advanced equipment, but also because of the enthusiasm and dedication of those who work there. For its value in reflecting some of the atmosphere and spirit of the laboratory and its staff, the following excerpt from a commentary on CERN activities during the month of February, which was originally published in the March 1964 issue of the *CERN Courier*, is reprinted below:

For most of the year at CERN, work goes on normally and, because few people are directly concerned, the fact that one or other of the experimental groups is at that moment discovering something new goes relatively unnoticed. In February, however, a number of events combined to provide the kind of excitement for the physicists that more than makes up for the long periods of monotony and to make the rest of the staff somewhat more aware than usual that interesting things were happening.

The clues to part of the excitement had, in fact, been available in the library for a week or two, in the form of "preprints" of two theoretical papers, one by M. Gell-Mann, of the California Institute of Technology, USA, and the other by G. Zweig, of the same Institute but at present a visiting scientist at CERN. Gell-Mann's paper was published in *Physics Letters* on 1 February; Zweig's, the more detailed of the two, is expected to appear later in *The Physical Review*. Produced independently, both papers put forward a possible new way of looking at the theory of "unitary symmetry" known as SU_3.

The application of this theory, notably in the particular form known as the "eightfold way", has enabled a considerable amount of order to be brought into the chaos created by the discovery of so many new, supposedly "fundamental", particles during the past few years. SU_3 itself is a particular branch of a whole set of related systems of algebra developed by the Norwegian mathematician Sophus Lie nearly a hundred years ago. The symmetry properties of fundamental particles and the rules developed for quantum-mechanical calculations have been found to be closely related to some of the Lie algebras and to SU_3 in particular. Specific properties of particles can be represented by certain quantum numbers which can take only certain values, and application of the algebraic rules to these numbers then groups all the strongly interacting particles in a definite way.

Unfortunately, the parallel between physically observed particles and mathematical theory is not exact; in particular, although in SU_3 all positions in the groups arise from a set of three fundamental entities, in physics even such old-established particles as the proton and the neutron can only belong to a set of altogether eight particles, forming one of the Lie groups. There seem to be eight basic particles instead of three. The suggestion of both Gell-Mann and Zweig was that fewer outside restrictions should be imposed on the algebra. They assumed that all known strongly interacting particles could in fact be made up from just three basic units, combined in different ways. They then worked out the properties that such units would have, and found that they would be similar to the proton, neutron, and lambda particle, except that their baryon number would be 1/3 instead of 1 and their electric charge would be 2/3, -1/3, and -1/3 respectively, instead of 1, 0, and 0 (in units of the electron charge).

It was this last property that caused the stir. From the time of Millikan's classic experiments in 1911 (repeated by generations of students since) it has been accepted that the charge of the electron is the smallest one possible and that all others are integral multiples of this unit (positive or negative). The new ideas had a basic simplicity that was very appealing, and difficulties that had had to be explained away in the former versions of the theory did not seem to arise this time, yet the idea of fractionally charged particles seemed quite preposterous. Even those who had suggested it seemed to share the doubts; Gell-Mann called his new particles "quarks", bringing together literature and science with a reference to *Finnegan's Wake*! Zweig turned to the field of card games for inspiration, and called his particles "aces", with their combinations "deuces" and "treys". At least one person found the whole situation too much, and the following contribution to the discussion appeared on the notice board of the Theory Division:

Oh, Horrible Thought

Think of the words that our subject is fraught with,
Words that old Webster would never be caught with,
Ladders and tadpoles and majorization,
Bootstraps and buddahs and peratization,
Hafnians, pfaffians, some think it's drollish,
Why, half of the world speaks Regge Polish!
Things are so bad that I must protest it,
From Joycean footnotes, please give us some respite!
Oh, horrible thought if in nature 'tis observed,
That the quarks and the aces,
Keep changing their places,
And charge seems never conserved!

Anon

From the experimentalist's point of view, the excitement lay in the prediction that at least one of the new particles would be stable. This quark, or ace, if produced in a reaction be-

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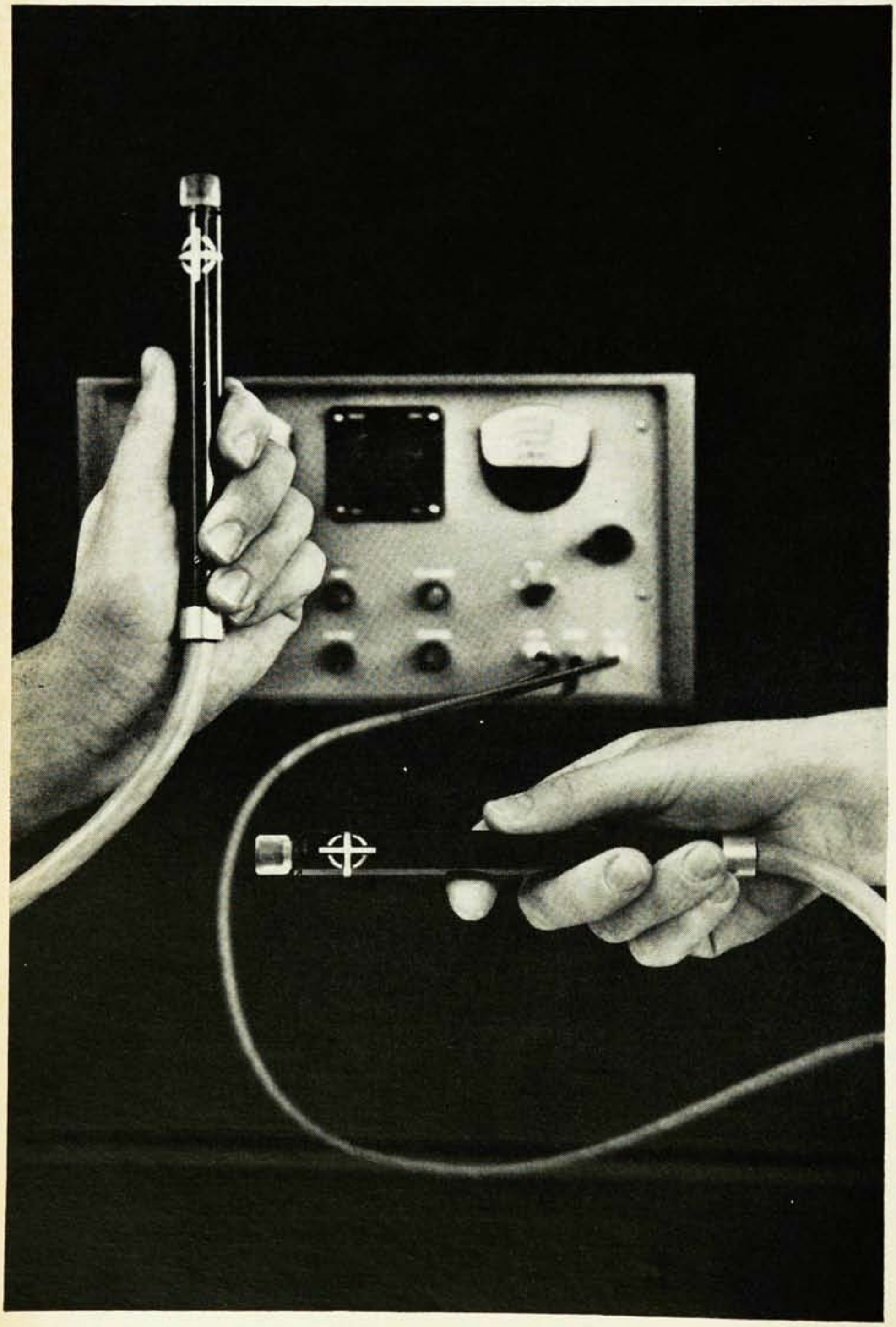

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tween high-energy particles, would behave like the known charged particles, but if its charge was only one-third that of a proton its ionizing power (and therefore the number of bubbles per centimeter along its track in a bubble chamber, for instance) would be only one-ninth, for the same apparent momentum. Of course aces might still be very rare, or their mass (which could not be predicted theoretically) might be too high for them to be produced with present-day accelerators. Nonetheless, the Electronics Experiments Committee, meeting on 11 February, decided that aces should be taken seriously, and that same afternoon the particles provided an unexpected subject for the weekly "Experimental Physics Discussion". Here G. Zweig explained his theory, and two proposals for experiments, from groups led by G. Cocconi and A. Zichichi, were described.

Some people felt that if aces existed then they ought to have been seen in at least one of the millions of bubble-chamber pictures already scanned for other experiments, though it was also reasoned that they could have been missed if the scanners were not looking specifically for them. In any case it quickly became clear that the combination of a bubble chamber and the O_2 beam in the PS East hall provided the quickest way of looking for the particles. Some time in March the PS will be run at almost its full energy and the O_2 beam (without the electrostatic separators) will be set to accept high-energy negative particles (mostly pions) from the internal target and direct them into the 81-cm Saclay/Ecole Polytechnique bubble chamber. The pions will provide the calibration tracks against which that of a quark, ace, or any other fractionally charged particle could be compared.

While working on this proposal, D.R.O. Morrrison realized that the same kind of bubble-chamber exposure had in fact been carried out with the CERN 32-cm chamber in 1960. The photographs were got out and a team of physicists and scanners looked through 10 000 of them in one night. No aces were found. Inspired by this search, the group working with the Ecole Polytechnique heavy-liquid bubble chamber then scanned a set of 100 000 photographs. Again the result was negative, leading to the conclusion that particles with charge 1/3 are produced at least a million times less frequently than antiprotons at the higher PS energies. The possibility was also raised that the aces might be formed in weak interactions rather than in the strong ones investigated in these two searches, in which case the arrangement of the CERN neutrino experiment would be ideal for their detection. Accordingly, the photographs of about 300 neutrino events in the CERN heavy-liquid bubble chamber were looked at again, but still no tracks with too few bubbles could be found.

The theorists, meanwhile, had not been idle, and by the end of the month H. Bacry, J. Nuyts, and L. Van Hove had produced a paper showing that if *two* sets of three particles were taken as fundamental building blocks, instead of only one set, then fractional charges were no longer a requirement. Zweig's aces and Gell-Mann's quarks may or may not be found, but obviously their ideas have triggered off a new series of moves in this search for an explanation of the occurrence of the so-called fundamental particles.

Adding point to the discussion was the news from Brookhaven in the middle of the month that two examples of the omega-minus particle had been discovered in photographs taken with their new 80-inch (200-cm) bubble-chamber. This particle, which has rather unusual properties, had been predicted by the "eightfold-way" theory and was the last one needed to complete a group of ten particles. Its discovery showed that the use of unitary symmetry to gain insight into the relationships between particles was indeed justified, and that further investigations would be well worth while. Of course, at CERN, the satisfaction of knowing that the omega really existed was tempered with a certain amount of disappointment, not to say envy, as two bubble-chamber runs last year and another one in January had been carried out here to look for the particle, but several hundred thousand pictures had so far provided no trace of it.