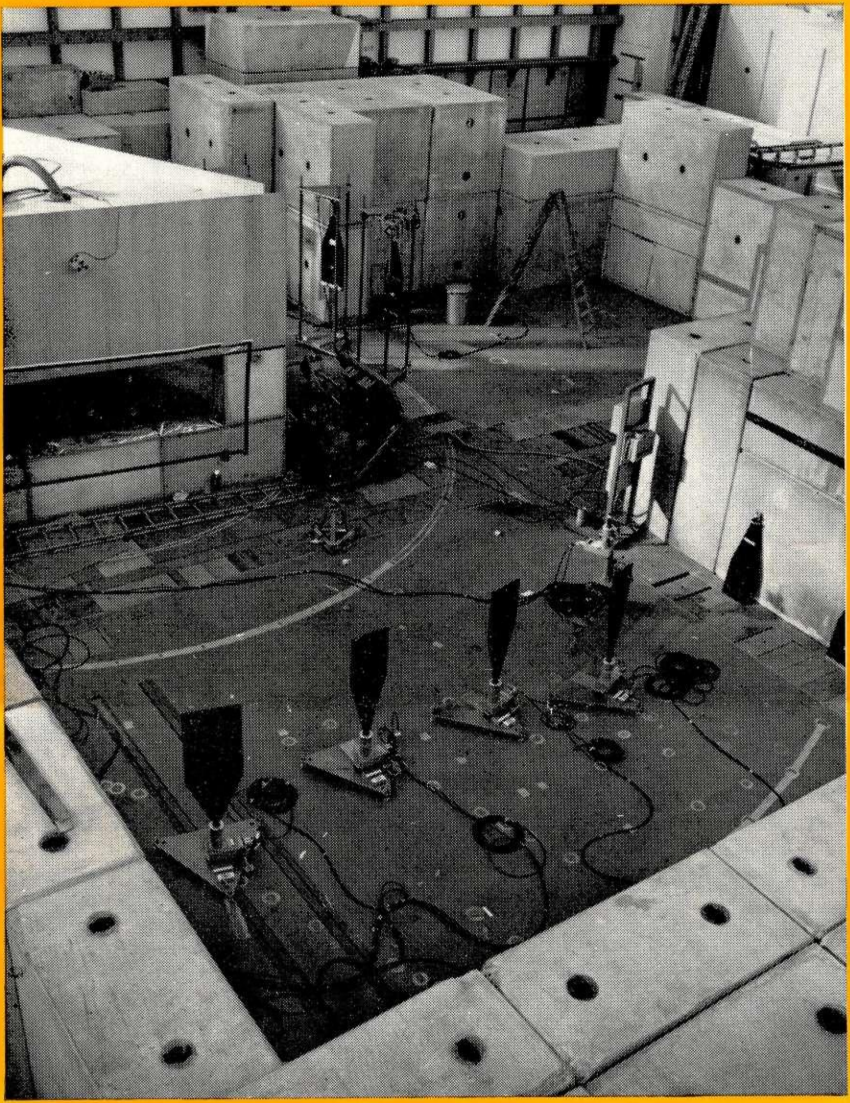
CERN COURIER



CERN/PI 103/264

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March 1964

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

The European Organization for Nuclear Research (CERN) came into being in 1954 as a co-operative enterprise among European governments in order to regain a first-rank position in nuclear science. At present it is supported by 13 Member States, with contributions according to their national revenues : Austria (1.96%), Belgium (3.85), Denmark (2.09), Federal Republic of Germany (22.86), France (18.66), Greece (0.60), Italy (10.83), Netherlands (3.94), Norway (1.48), Spain (1.68), Sweden (4.25), Switzerland (3.20), United Kingdom (24.60).
Contributions for 1964 total 107.2 million Swiss francs.

The character and aims of the Organization are defined in its Convention as follows :

' The Organization shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto. The Organization shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published or otherwise made generally available.'

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The cover photograph, taken in the North experimental hall of the CERN proton synchrotron, shows part of the counter experiment in search of a possible ' resonance ' in the reaction between a pion and a deuteron to produce two protons. Inside the blockhouse in the centre of the area, a beam of pions with momentum between 0.6 and 2.0 GeV/c strikes a target of liquid deuterium (heavy hydrogen). Unseen and unheard, the products of the interaction emerge through two long slits in the sides of the blockhouse ; no-one is allowed inside the outer wall of concrete blocks. Six pairs of detectors, large slabs of plastic scintillator mounted on photomultipliers, stand guard around the target. Four of them can be clearly seen. They relay information, to the physicists outside, on the angular distribution of the particles emitted from the target, and on the time (measured in thousand-millionths of a second) taken for each one to travel from the target to the detector.

CERN COURIER

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Last month at CERN

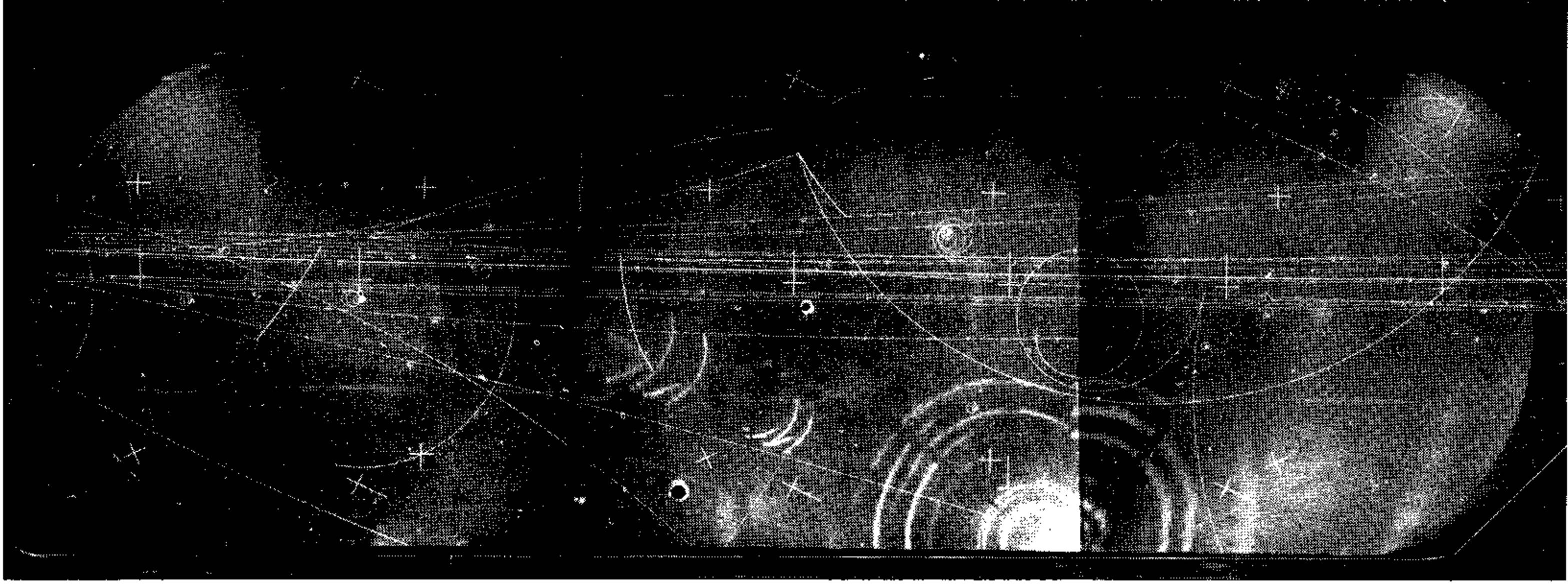
For most of the year at CERN, work goes on normally and, because few people are directly concerned, the fact that one or other of the experimental groups is at that moment discovering something new goes relatively unnoticed. In February, however, a number of events combined to provide the kind of excitement 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, U.S.A., 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 *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 repectively, 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 :



One of the early photographs taken with the British 150-cm hydrogen bubble-chamber at CERN. Protons with a momentum of 15 GeV/c enter from the left of the picture and some of them interact with protons in the chamber. The fineness of the tracks and the advantage of a chamber of this size for seeing all the stages of a complex series of events can be gauged from this example, though it shows nothing spectacular. One of the problems remaining is to reduce the general background of light and the unwanted reflexions that might make measurements difficult in some circumstances.

CERN/TC (PI 14/364)

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 between 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 centimetre 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/École 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. Morrison 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 École 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.

During all the excitement over aces and SU$_3$, other groups of physicists and engineers working at the **proton synchrotron** also had more immediate things to concern them. For the first time since last September the **fast ejection system** was to be used again for the proton

Continued on p. 34

WHO'S WHO IN CERN

Bernard GREGORY

Directorate Member for Research


CERN/PI 266/663

One of the decisions taken at the 26th Session of the Council, held last December, was to appoint Professor Bernard Gregory Directorate Member for Research. He takes over this post for the next two years and succeeds Professor Gianpietro Puppi, who had held it since September 1962.

Bernard Gregory was born in 1919 at Bergerac, in the west of the French 'Massif Central'. He soon left this sub-prefecture of the Dordogne, however, to 'go up' to Paris, where, after taking his 'baccalauréat', he prepared for the entrance examinations of the higher scientific Institutes of France.

In 1938 he sat the entrance examinations for the science sections of both the 'École Polytechnique' and the 'École Normale Supérieure'. Passing first in both examinations, he chose the 'École Polytechnique', which he entered at the end of 1938 — for barely a year.

The war which broke out in Western Europe in 1939 opened up a gap in his student career which was not closed until July 1945. These unproductive years saw Bernard Gregory first in the fighting forces and then within the confines of military prison camps. However, his efforts to profit from these long years were so successful that, on his return to France in July 1945, he was able to pass his final examination at the 'École Polytechnique'.

He then entered the 'Corps des Mines', which allows some of its staff to devote themselves to research.

By this time he had decided that his future lay in the direction of physics. Five years of captivity had given him ample time for meditation and study and helped him to crystallize his plans for the future. Physics seemed to suit the career he wished to follow in the related fields of education and research. Today it is amusing to hear the sardonic statement of a professor named Gregory, to the effect that 'physics leads straight to administration!'.

Such a thought may seem to smack of disillusionment. But in fact it probably reflects not only the state of mind of the 'chief', on whom falls the burden of making vital decisions concerning the future as much as the present, but also that of the contemporary research scientist. In experimental nuclear physics, the era of great discoveries made by a single person using primitive equipment is well and truly over. Since the War the emphasis has been on 'large-scale physics', using enormous machines costing millions to run. There are few of these machines, and it is all the more necessary to ensure their intensive exploitation with a minimum of lost time. For the physicist who is somewhat of an idealist by nature this means a sudden transfer to the planned atmosphere of the big laboratories where the relatively rigid organization may seem synonymous with administration carried to extremes... But we are forgetting Bernard Gregory. In September 1947 he obtained his engineering diploma and set off, under the auspices of the 'Corps des Mines', for the U.S.A. and high-energy physics.

He spent three years at the Massachusetts Institute of Technology. At that time, M.I.T. was passing through a period of transition: from a technical institution producing engineers it was to become a vast research establishment where scientists were to delve perpetually into the secrets of nature. Among the high priests of that scientific inquisition was Bruno Rossi, who was to be Bernard Gregory's mentor. In the absence of large particle accelerators, great hopes were at that time placed on cosmic rays and, in 1947, the most advanced detector of nuclear events was still the Wilson cloud chamber. Gregory co-operated in the running of this type of apparatus and then in the analysis of the thousands of photographs of nuclear events that were obtained.

He submitted a thesis to M.I.T. on the interactions of cosmic-ray protons in lead and aluminium screens in a cloud chamber, based on this work, and obtained his Ph.D. degree in 1950.

Back in France, Bernard Gregory entered the physics laboratory under Professor Louis Leprince-Ringuet at the 'École Polytechnique', and joined a team of high-energy physicists that included Charles Peyrou, André Lagarrigue and, later, Francis Muller. The detector constructed by the team was one of the most up to date at that time — a large cloud chamber with a capacity of twice 200 litres, composed of two parts one on top of the other. It was installed near the Observatory at the summit of the Pic du Midi de Bigorre. There at the same time was an experimental team from the University of Manchester, including Raphaël Armenteros, who soon joined the French group, all of whose members, we may mention in passing, now work at CERN.

Bernard Gregory continued working with cloud chambers until 1957, when he took his sabbatical leave at the American laboratory of Brookhaven.

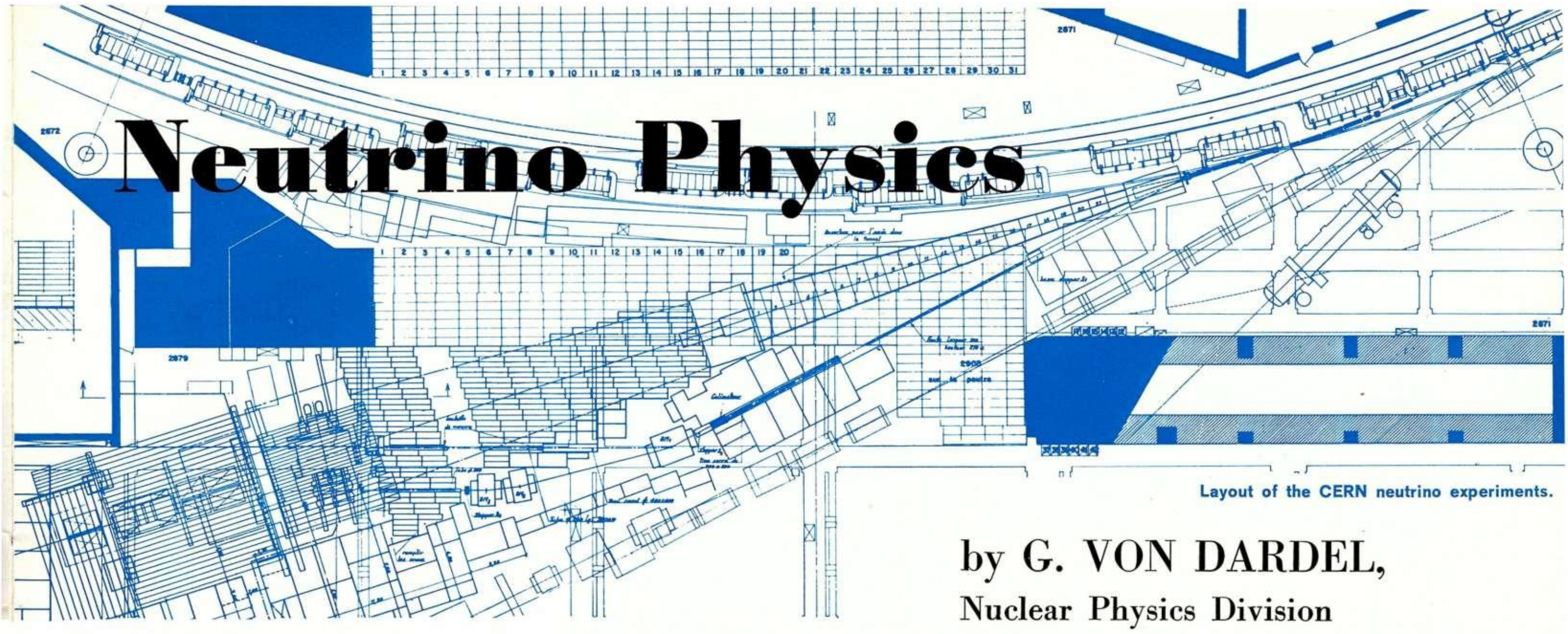
Back again, he took part, with a team from the French Centre for Nuclear Studies at Saclay, in the construction of the 81-cm liquid-hydrogen bubble chamber. This instrument was moved in January 1961 to CERN, where it has since proved of great value to European physics.

Ever faithful to his ideals, Bernard Gregory succeeded in combining with his research career the duties of a teacher. From 1953 to 1958 he was Professor of Physics at the School of Mines in Paris, and he has since been teaching at the 'École Polytechnique', from where he has been given leave of absence for the academic year 1964-1965.

Since 1961 Professor Gregory has participated in experiments at CERN, particularly as chairman of the committee of European physicists responsible for the track-chamber experiments carried out at CERN. In this capacity he has been a member, since 1960, of the Scientific Policy Committee, which advises CERN on its overall scientific policy. Thus Professor Gregory has had a marked influence on the experimental programmes for the bubble chambers at CERN. He will be a part-time member of the CERN Directorate until summer 1964 and then full time until the end of 1965.

As a physicist specializing in sub-nuclear particles and in the construction of machines for detecting their interactions, as an eloquent teacher blessed with a strong voice to balance his otherwise calm and relaxed appearance, Professor Gregory has only one hobby to occupy the brief moments of leisure allowed him by his professional activities: looking after his few acres of land not far from Paris ●

Neutrino Physics



Layout of the CERN neutrino experiments.

by G. VON DARDEL,
Nuclear Physics Division

As noted in the article by G. Vanderhaeghe in last December's issue of CERN COURIER, **the Training and Education Section is organizing a series of general information lectures on physics at CERN. The first of these, which was given (in French) on 4 December, 1963, by G. von Dardel, dealt with the physics of neutrinos, and gave the background to the current interest in these elusive components of matter.**

This article is basically the text of the lecture. It tells how the neutrino was first postulated to explain certain experimental results, shows how the neutrino is related to other fundamental particles and why it interacts so rarely, and relates how the existence of not only one kind but of two kinds of neutrino was proved. Finally, some of the implications for the future are discussed, including the problem of the so-called intermediate boson.

The author is responsible for co-ordinating the work of the bubble-chamber and spark-chamber groups studying neutrinos at the CERN proton synchrotron.

INTRODUCTION

There has been a great deal of talk about neutrinos at CERN during the last three years and I imagine there are few of you who have not at some time or another been affected by the programme of the neutrino experiment. I know that many of you have made a great contribution to this programme : by working overtime in the workshop to get the ejection components ready in time, by helping to position the thousands of tons of shielding, perhaps by scanning the photographs or by typing reports. For many others I know that the neutrino has been a nuisance, because you were not able to obtain your instruments or equipment from the workshop as it was too busy with work for the neutrino experiment. I think you all have the right to be told, therefore, what this experiment is about, assuming you do not know already.

If you do not know what a neutrino is, let me say first of all that we physicists are just as ignorant, because the neutrino is still one of the most mysterious of the fundamental particles discovered so far. It is, in fact, precisely this mystery which justifies the great efforts made at CERN and in the United States to find out more about the neutrino.

THE NEUTRINO HYPOTHESIS

The Italian word 'neutrino' means, if I am not mistaken, 'the little neutral'. We do not know much about its size, and maybe we should not even call it 'little' in relation to other fundamental particles. Its mass, however, is certainly much less than that of any other known particle, and it very probably has no mass at all. It is called 'neutral' because it is not affected by magnetic or electric fields. I should add that the masculine gender of the word in its original language is not to be taken too literally ; on the contrary, the neutrino is decidedly feminine in its behaviour.

How could the existence of this particle, with such elusive properties, ever have been suggested ? It was the outstanding theoretical physicist, W. Pauli, who first put forward the hypothesis of the neutrino's existence, in 1931, in order to explain certain observations concerning radioactivity. You no doubt know that some atomic nuclei have the property of being able to transform themselves spontaneously, with the emission of a negative or a positive electron ; in the course of this process a neutron in the nucleus becomes a proton, or vice-versa.

It was found that the total energy of the nucleus after the decay was less than before ; moreover the energy of the electron was not always the same and was always less than the energy lost by the nucleus. These facts could only be explained by the ordinary laws of physics by supposing that another particle was emitted at the same time as the electron and took away the rest of the energy. Such a particle, represented by the Greek letter nu (ν), would have to be neutral and have a very small mass, which might explain why it had not at that time been observed experimentally. On this hypotheses, then, the equation for the elementary radioactive decay described above is * :

$$n \rightarrow p + e + \nu.$$

FUNDAMENTAL FORCES

It was noticed at an early stage that the neutrino always occurred in reactions associated with an electron; it was also noticed that these two particles resembled each other in the sense that other fundamental particles acted on them only through the medium of very weak forces.

Let me remind you that the forces between particles may be of three types (apart from gravity) : 'strong',

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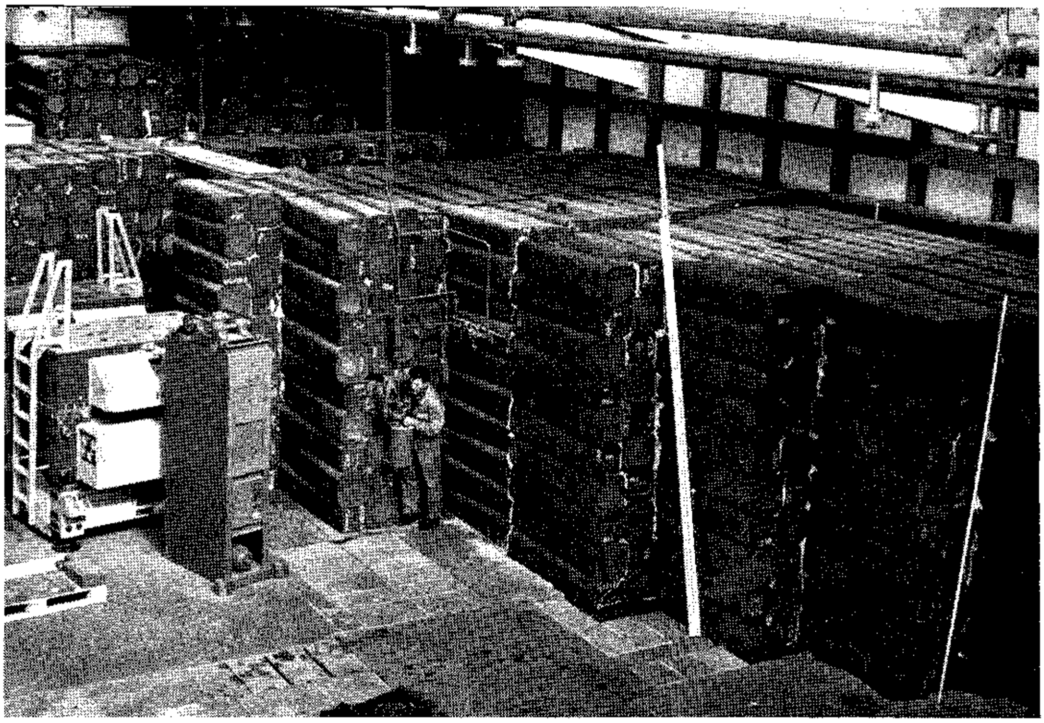
* For simplicity, no distinction is made at this stage between particles and antiparticles (but see later).



CERN/PI 48/463

Some of the thousands of tons of steel shielding placed between the PS target and the neutrino detectors for the CERN experiments. Although forming a solid wall 22-metres thick, this forms no obstacle to the passage of the neutrinos.

'electromagnetic' and 'weak'. The forces known as 'strong', such as those between protons and neutrons, are responsible for the stability of atomic nuclei. The 'electromagnetic' forces turn our motors. They are also responsible for the structure of atoms and for the bonds between them; together with the strong forces, they determine the structure of matter. Finally, there are the forces known as 'weak', which really are very weak compared with the two others. There are enormous differences between these forces: while strong interactions occur in periods of time of the order of 0.000 000 000 000 000 000 000 001 second (10^{-24} s), a weak interaction like the radioactive decay of a nucleus may take millions of years ($\sim 10^{13}$ s) to happen.

The electron and the neutrino have, as I have said, the same property of not being affected by the strong forces. This is not of great importance for the electron, because it has an electric charge and is affected by electromagnetic forces. As a result, this particle has become very popular in our time, and there is a whole branch of technology — electronics — devoted to it, the results of which we enjoy every day — when we watch television, for example. But the poor neutrino, with no charge, is only subjected to weak forces, which amount to almost nothing. In fact, once emitted during a radioactive transformation, the neutrino could traverse millions of millions of kilometres of iron without once colliding with an iron nucleus. Even the largest stars in the universe offer no obstacle to the passage of neutrinos. Therefore, once set free, the neutrino has played its part and it will presumably continue until the end of time to travel through a universe which must present a very empty appearance.

From the point of view of our everyday life, the greatest importance of the weak forces is perhaps the fact that they temper the (strong) nuclear reactions that cause the sun and the stars to shine. In the absence of the weak interactions (radioactivity) the earth would either be a cold and empty globe or would have disintegrated long ago in a furious blast from the sun. All the weak processes lead to the emission of neutrinos, which can thus be considered as a sort of smoke escaping from these cosmic furnaces. Like smoke, they remove a great part of the heat produced but, whereas in terrestrial furnaces the gases and smoke are at least reabsorbed by the vegetation and used again in the biological cycle, the neutrinos seem to be completely lost.

I have already explained that the neutrino has a very small mass or none at all. We are also familiar with another phenomenon that is due to a particle with zero mass: light. One of the foundations of Einstein's theory of relativity is that the speed of light is always the same, whatever its colour and in whatever 'system' (on earth or in a space ship) it is measured. The same is true for the neutrino; its speed is always constant and equal to that of light. Just as particles of light (photons) may have different energies, corresponding to different colours, so neutrinos may have different energies, but they always move at the same speed. In particular, the neutrino can never be at rest.

There is, however, a very important difference between the neutrino and light, which places the two in different categories. Light may be absorbed, for instance by a blackboard, without leaving any other trace than a slight rise of temperature, and it can be emitted by any body that is sufficiently hot. The neutrino, if it is absorbed, is bound to give rise to an electron (or, as will be explained, a muon), and it can only be created simultaneously with an electron or upon the disappearance of an electron.[*]

Another characteristic that the neutrino and the electron seem to have in common is known as 'leptonic charge'; the total amount of this should always remain constant in any reaction.

CLASSIFICATION OF FUNDAMENTAL PARTICLES

Fundamental particles can be classified, just as in zoology animals are classified into different families. There are first of all two big 'branches' of particles, corresponding to the vertebrates and invertebrates: these are the 'fermions' and the 'bosons' (see table below), named after the two physicists Fermi and Bose respectively. Light, for example, is classified as a boson, because it can be created or destroyed without leaving anything other than energy. Conversely, the

---

[*] Again neglecting the distinction between particles and antiparticles.

Fermions				Bosons	
Leptons		Baryons			
electron neutrino	muon neutrino	neutron	hyperons	light (photon)	pions
electron	muon	proton			
(and antiparticles)					

neutrino is classified as a fermion, because it cannot be destroyed without producing an electron, which is another fermion.

Among the fermions, there is another subdivision (in the same way as there are classes of fish and mammals) into leptons, which have little or no mass, and baryons, which are more massive particles. Several kinds of baryon are known, the most important being the neutron and the proton, the 'bricks' that make up nuclei. Baryons have a similar characteristic to that of leptons, in that they possess a 'baryonic charge'. The total value of this does not change in nuclear reactions; in other words, the total number of baryons in our universe has always been the same since its creation a few thousand million years ago. This is, of course, also true of the leptons. Neutrons may become protons neutrinos may become electrons, but the total number of particles in each class always remains the same. In order to make an accurate count, however, the existence of 'antiparticles' has to be taken into consideration. It is a general characteristic of the fermions that there exists a separate antiparticle for each particle (whereas the antiparticles of the bosons are not distinguishable from the particles themselves). When counting numbers of baryons and leptons, particles should always be added and antiparticles subtracted.

The antiparticle of the electron is generally called the 'positron', while the antineutrino has no more familiar name ; it is represented by the letter nu with a dash above it : $\bar{\nu}$.

SPIN

Another property of all fermions, including the neutrinos, is that they have a degree of internal freedom, called spin, which can be imagined as the rotation of the particle around its axis. As in the case of a gyroscope, this ensures a certain stability of the axis, which can only slowly change direction under the influence of external forces. Most fermions can spin in either direction, and until recently this was believed to be a universal fact. However, in 1957 Lee and Yang suggested that the neutrino was an exception to this law, and all the experiments done since have shown that the neutrino can only spin one way. It always turns in the inverse sense of a cork-screw around its direction of motion. Conversely, the antineutrino spins in the sense of an ordinary cork-screw. This 'sense of direction', left and right, makes the neutrino an exception among all fundamental particles. In fact, only a particle without mass can possess this faculty. Normally, if a particle appears to spin in one sense, the observer has only to travel away from it at a faster speed (hypothetically, of course) and then look back, in order to get the impression that it is spinning in the opposite sense. For a particle without mass, moving at the speed of light, this reasoning is not valid, because it is not possible to travel faster than light.

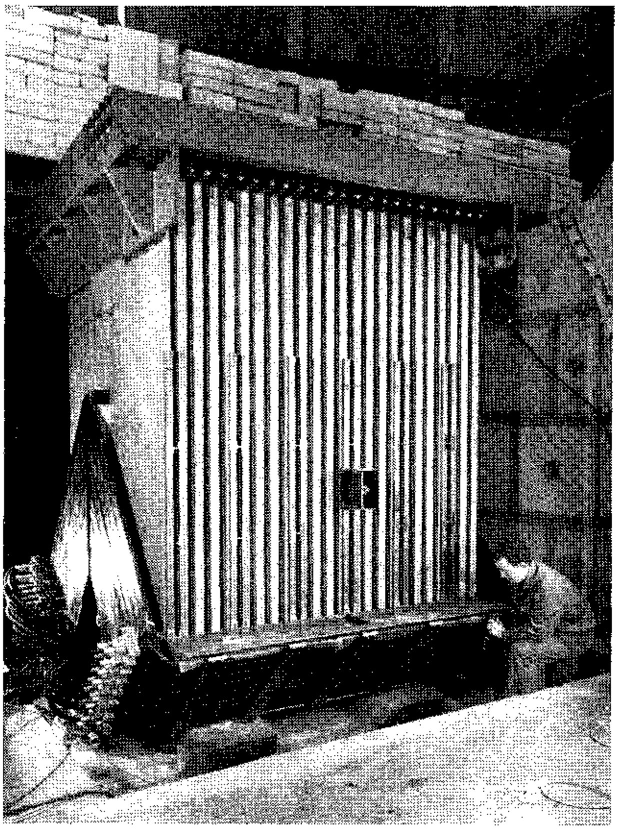
THE MUON

A particle which has been known for a long time is the mu meson (μ) or muon, examples of which constitute the majority of cosmic rays arriving at the surface of the earth. The muon behaves in every way just like an electron, except that it has a mass about 200-times greater. According to all the rules, therefore, it is not really a meson, but comes into the lepton family. Like the electron, in a weak interaction it can also give rise to a neutrino, or at least to something which has the same properties as the neutrino already discussed.

The muon could, in principle, be classed with the neutrino and the electron in a sort of 'ménage à trois'. However, in physics as in real life, this is not always very happy ; the theorists were, in fact, able to calculate that, as in the human parallel, there should be an interaction betweeen two of the partners (in this case the muon and the electron), changing each one into the other. But since this transmutation had never been observed experimentally, the hypothesis was put forward that perhaps the electron and the muon lived very respectable lives, each with its own neutrino, who were twins but not identical ones. In order to distinguish between them, each of these twins has been given the family name of its partner, and they are represented thus : ν_e and ν_μ .

REACTIONS WITH NEUTRINOS

The only way to verify this two-neutrino hypothesis with certainty is to study reactions both with the neutrinos produced at the same time as electrons (such as the neutrinos of radioactivity) and with those pro-



CERN/PI 81/1263

Neutrinos have no mass, but the same cannot be said for the equipment required to investigate their properties ! Here part of it, a complex electromagnet for use with large-area spark chambers, is being assembled for the second series of neutrino experiments at CERN.

duced together with muons. If the hypothesis is correct, the former will be involved only in reactions which give rise to an electron, and the latter only in reactions producing a muon. Otherwise, following the hypothesis of a ménage à trois with a single neutrino, electrons and muons will be produced in both cases, independently of the source of the neutrinos.

The study of neutrino reactions is extremely difficult, however, because of their rarity. Since the neutrino can pass through millions of millions of kilometres of iron without reacting, and since any detectors that can be designed and manufactured are only a few metres thick, some thousand million million neutrinos have to traverse the equipment to produce a single reaction. Nevertheless, such reactions were observed by Reines in 1957, in detectors installed near one of the big nuclear reactors in the United States. Such a reactor is an extremely intense source of neutrinos, which are produced in the radioactive processes that follow fission.

However, this type of experiment can throw no light on the question of the two neutrinos, since the energy of the neutrinos produced in reactors is quite inadequate for producing muons. You will recall that the particle mass has to be ' created ' from the energy of the neutrino, and that the muon mass is some 200 times more than that of the electron. Quite apart from any hypothesis, therefore, only electrons will be seen.

In order to solve the problem, it is necessary to have an intense source of neutrinos of much higher energy. This is only possible with accelerators, where neutrinos are produced mainly in the decay of the pi meson or pion (π).* The pion is an unstable boson which decays into a muon and a neutrino ; $\pi \rightarrow \mu + \nu$. If there are two neutrinos it should be a ν_μ that is produced. If the pion has a unit positive charge, the total charge after the reaction should also be one positive unit. Since the neutrino carries no charge, the muon must be positive. But the positive muon is an antilepton and the lepton rules tell us that it must be produced with a lepton, namely a neutrino. In the same way, the decay of a negative pion will produce a negative muon and an antineutrino :

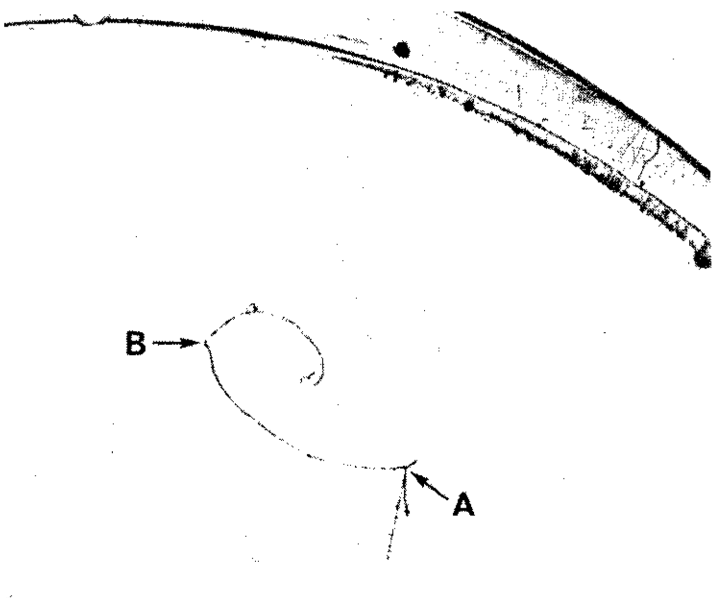
$$\pi^+ \rightarrow \mu^+ + \nu_\mu \text{ and } \pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$

If the hypothesis that there are two neutrinos is valid, nothing but reactions giving rise to muons should be observed in experiments near a high-energy accelerator. If not, there should be as many reactions giving electrons as there are giving muons.

NEUTRINO EXPERIMENTS WITH ACCELERATORS

This difference is the basis of the experiments first undertaken two years ago at CERN and Brookhaven, in which those at Brookhaven achieved results much more rapidly, partly owing to the more favourable geometrical construction of the accelerator there.

There are several factors in favour of accelerators. The first is that high-energy neutrinos react much more frequently. Most of the neutrinos created with CERN's 28-GeV synchrotron have an energy of between 1 and 2 GeV. At these energies they produce reactions not once every million million kilometres of iron, but once every thousand million kilometres. In other words, with a detector a few metres in thickness, a reaction will be produced if it is traversed by a million million neutrinos, while the experiments at the reactor required several thousand million million. Another favourable factor is that the neutrinos are all concentrated within a narrow cone in the direction of the original proton beam, whereas the neutrinos leave a reactor in all directions. Finally, with high-energy neutrinos the detectors can be made much bigger, since the particles produced in the high-energy reactions can travel a great distance before stopping.



CERN/NPA

Clues to one of the mysteries of the composition of matter : particle tracks from a neutrino interaction in the CERN heavy-liquid bubble chamber. At A the neutrino interacted with a neutron to produce a muon, which subsequently decayed to an electron at B. The struck neutron was bound within the nucleus of an atom, which disintegrated and produced the three proton tracks also seen radiating from A.

The combination of all these factors helped the Brookhaven team to observe several neutrino reactions per day in a detector consisting of 10 tons of aluminium. While 26 reactions were observed in which a muon was produced, not one electron was found with certainty. This was the proof that the two neutrinos partnering the muon and the electron are twins, but not identical.

STUDY OF WEAK FORCES

With this question solved, there remain many other problems to be studied in experiments with neutrinos. Most of these problems concern the weak-interaction forces. Neutrinos are particularly suitable for the study of these since, not having any electric charge, they are subject to weak interactions alone.

The reactions that can be studied are those in which a neutron forming part of an atomic nucleus is transformed into a proton, or vice-versa, by a neutrino (or antineutrino) which itself turns into a muon :

$$n + \nu_\mu \rightarrow p + \mu^- \quad \text{or} \quad p + \bar{\nu}_\mu \rightarrow n + \mu^+$$

Similar reactions are well-known in radioactivity, where the neutrinos ν_e and ν_μ are involved but these reactions concern low-energy neutrinos and thus correspond to interactions with a relatively great distance between the particles. With high-energy neutrinos it is possible to study reactions of this type under conditions where the neutrino penetrates much further into the proton or the neutron, whose internal structure as seen by neutrinos is not very well known. Using another analogy, to find out whether there is a stone in a cherry

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* These pions are produced by the (strong) interaction of the accelerated protons in a target.

it is necessary to use an instrument capable of penetrating the fruit ; high-energy neutrinos are just such an instrument for protons. These problems will be treated more fully by Michel Paty in a subsequent article dealing with the experiments carried out at CERN using the propane bubble chamber.

THE INTERMEDIATE BOSON

Another very important problem is the nature of the weak interaction itself. Do the neutrino and the neutron strike each other directly like billiard balls or is there a force which acts between them at a distance, for instance like the force between a magnet and a piece of iron ? Physicists generally tend to prefer the second hypothesis, which is that of action at a distance by a ' field ' — the magnetic field, for example. When there is such a field, according to the ' rules and regulations ' of physics, it can be associated with a particle. The magnetic field, for instance, and other electromagnetic manifestations are associated with the photon, the particle of light. In this interpretation the force between the magnet and the piece of iron is brought about by a continuous exchange of photons which go backwards and forwards between the magnet and the iron. These photons are generally only ' virtual ' and so cannot be directly observed. However, if sufficient energy is involved, free photons will be produced ; for instance, when a piece of iron is made to oscillate in a magnetic field, electromagnetic radiation can be detected at a distance.

This idea of considering forces to be due to fields has been widely accepted. It has been adopted for the forces between atoms (in a molecule, for instance), where it is the electrons that go backwards and forwards, and for the strong forces acting between neutrons and protons in a nucleus, where the pions play this role.

It is not yet known whether the weak forces are due to a field. If they are, the properties of the corresponding particle can be predicted : it must be a charged boson, which has been given the name of intermediate boson (W), and it should be produced when neutrinos of sufficiently high energy pass near a nucleus. A muon must also be produced at the same time. Symbolically the reactions are :

$$\nu_\mu \rightarrow \mu^- + W^+ \quad \text{or} \quad \nu_\mu \rightarrow \mu^+ + W^-$$

However, if it exists, the intermediate boson must have such a short life that it cannot even cover a distance of one micron (10^{-3} mm) before decaying into other particles. There is thus not much hope of seeing the boson directly, but it could be recognized from its decay fragments, among which there should be the products of the inverse reaction to that of production, namely :

$$W^- \rightarrow \mu^- + \nu_\mu \quad \text{or} \quad W^+ \rightarrow \mu^+ + \nu_\mu$$

In such a case, it would appear as if two muons were produced in the same reaction, together with one neutrino which would be invisible. Another possibility is for the intermediate boson to decay into an electron and its neutrino ν_e, in which event the reaction would appear as the production of a muon with an electron. Jean-Marc Gaillard will deal in another article with the fascinating hunt for these kinds of event in the spark-chamber experiments at CERN.

The intermediate boson may also decay into other fragments, and in particular into a certain number of pions. These decay modes are particularly interesting because, at least in principle, all the fragments can be observed and their energies determined. This would then enable the mass of the boson to be deduced if the particle exists.

In conclusion, it may be said that the physics of neutrinos presents many fascinating problems, which can only be solved with high-energy neutrinos. CERN is in a particularly favourable position from this point of view, because of the increase in neutrino intensity provided by the fast ejected proton beam of the synchrotron and the focusing of the pions before they decay by means of the 'magnetic horn'. These pre-requisites to last year's successful experiments and to those now in progress were described in an article in *CERN COURIER* last June ●

BOOKS

Sonnenenergie, by H. Rau, (Mainz, Krauskopf-Verlag, 1962 ; DM. 12.80).*

In its airy manner this delightful little book possesses certain attributes of a soufflé. While consuming it, one has that sense of well-being which only a tasty morsel can convey, and on finishing it, one is pleasantly replete. But one very soon develops a craving for more. So with this book : it acts as an apéritif without really answering all the questions.

The author is obviously endowed with the gift of being able to convey to the reader a relatively large amount of information, requiring the minimum of effort on his part to understand and to absorb. This is no idle compliment : we note that the book is written in German, a language more fitted for semantic acrobatics than for an exercise in simple expression. Mr. Rau had rightly decided to tackle his subject from the 'Ur-beginning' and to leave no fact untouched, however insignificant. The result is not only a formidable table of contents but also a tidily written book which it is a pleasure to read.

The opening chapter, not unexpectedly, discusses the need for new sources of energy. The next deals with existing 'stocks' of energy and on we go, relentlessly. A quick look at the mythology and what our ancestors thought of the whole affair, then a little physics of the sun, followed by the first pioneers who attempted to harness solar energy for other purposes but human sacrifice. (Curiously, the author does not mention the Mayas or the Aztects, who, after all, were *the* experts in this field. But that is unimportant). The technology and economics of solar energy, with all their ramifications, form the backbone of the book. Photobiology and the rocket strato-probe experiments are mentioned, and the book ends, inevitably, with an outlook on the future. All this information is carefully packed into some 170 pages, including some very fine illustrations, both photographs and line drawings, and a truly magnificent bibliography. Is one permitted to wonder whether the author has indeed read all the material he lists ?

Strangely enough it is just this extensive bibliography which is the main weakness of the book. The author had evidently decided that the reader for whom the book is intended would rarely if ever bother to look up one or the

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* We understand that Dutch, English, and Italian editions are also available, or will be shortly, and that editions in Croat and Arabic are in preparation.

Last month at CERN (cont.)

beam. A new central conductor, designed to increase the number of neutrinos produced at higher energy, had been put into the magnetic horn, and a completely new arrangement of spark chambers had been installed for further measurements on **neutrino interactions.** In the event, everything worked well, and very soon the scanners were busy again, picking out photographs of neutrino interactions obtained both in the spark-chamber array and in the CERN heavy-liquid bubble chamber. The spark-chamber set-up now includes one section of chambers interspersed with magnetized iron plates, intended to provide a good distinction between positive and negative particles arising in the interactions. Altogether, the arrangement contains more than 100 tons of material.

In the East bubble-chamber building, another centre of activity was formed by the **150-cm British bubble-chamber,** filled with liquid hydrogen again, cooled to —246° C, and producing high hopes of a good run. The decompression and recompression cycle was successfully put into operation, and the cycle time afterwards reduced to once every two seconds. After about 24 hours testing like this, particles from the o_2 beam were introduced into the chamber and conditions adjusted to give the best tracks. Later the magnetic field was turned on, and finally the automatic cameras tested. On 22 February several thousand photographs were taken with incident protons. But a number of small troubles made it less clear that the chamber would be able to run continuously for several days at a time and, rather reluctantly, the beam was switched to the 81-cm Saclay/École Polytechnique chamber for thé physics experiments scheduled.

This period was also of particular interest since, for the first time, a bubble-chamber experiment at the PS was being carried out simultaneously with the neutrino experiment. By using the '**rapid beam deflector**', a small part of the circulating beam was directed at the target serving the o_2 beam shortly before full energy was reached; this was then followed by ejection of the full-energy beam in the usual way.

Missing from last month's issue of *CERN COURIER* was the news that electrons had been successfully 'stacked' in the **electron storage-ring model, CESAR.** Towards the middle of January the circulating current from a single pulse of the Van de Graaff injector was accelerated slightly by means of the betatron core, so that it circulated on an orbit of larger diameter, but oscillations of the beam were building up to large values and soon causing it to be lost. With a shut-down for maintenance and alterations scheduled for 31 January, there was little incentive for a full investigation of the reasons ; instead, by manipulation of some two dozen different magnetic corrections around the ring, it proved possible to accelerate the beam to the full energy determined by the 7-cm width of vacuum chamber available. Whereas the betatron core accelerates all the particles circulating in the ring, the radiofrequency system accelerates only those electrons which have about the right energy. This system was then tried out, and 20 successive pulses were injected into the ring and 'stacked' into adjacent orbits. After this, measurements were made on the lifetime of the circulating current, for single turns in different positions and for multiple turns, and the second radiofrequency system, intended for phase-space analysis of the stacked beam, was successfully tested.

These preliminary experiments completed the 'running-in' phase of the storage-ring, and their success provides grounds for believing that CESAR will prove an extremely useful experimental device. During the subsequent shutdown, the 2-MeV Van de Graaff was completely dismantled and rebuilt, with many new components. Among many other jobs, the whole of the vacuum chamber also had to be dismounted, for modifications to the clearing-field electrodes, and several new targets for measurement of the beam position were added. Insertion of a new inflector tank should enable the pressure to be reduced for the first time to 10^{-9} torr or better, giving much longer beam lifetimes when experiments are resumed ●

other reference. As a result the amount of information concerning the source of most entries is rather sketchy and in more than one case ambiguous. What, then, is the point of such an exhaustive list ? The absence of an index, that perennial gripe of all reviewers, is less noticeable, since the table of contents, as we have said before, is rather detailed.

To return to the opening paragraph of this note : for whom exactly did Mr. Rau write this book ? For the scientist seeking information outside his own field, or for the layman wishing to gain some insight into a fascinating subject ? If the former is the case, the author has succeeded admirably ; if the latter, we are not so sure that Mr. Rau has not been led astray by his own thoroughness. The dose is perhaps a little too concentrated and may even lead to indigestion.

We wonder, by way of ending, whether Mr. Rau, since he would seem to have all the information in his possession, could not produce another book on the same subject, but this time for the expert, with all the details, technical information and calculations involved ?

St. L.

Knowledge and wonder — the natural world as man knows it, by Prof. V. F. Weisskopf, has now been published in paperback edition (Science Study Series ; New York, Anchor Books, Doubleday and Company, Inc.) and is available at the Geneva bookstalls ●

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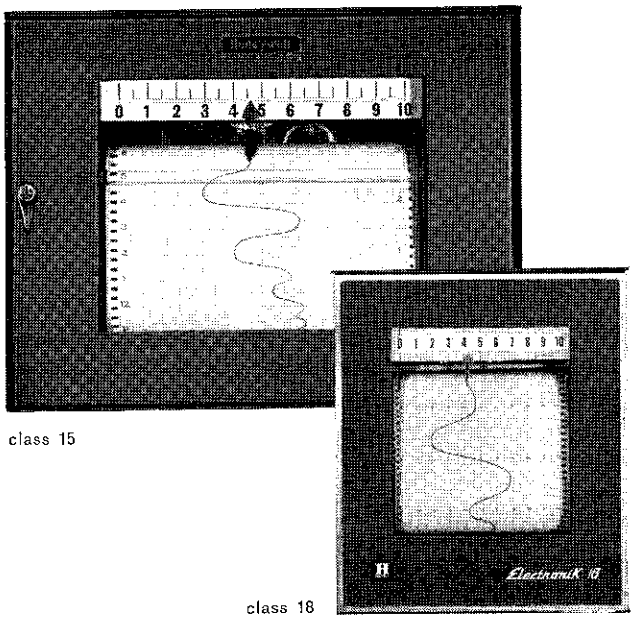
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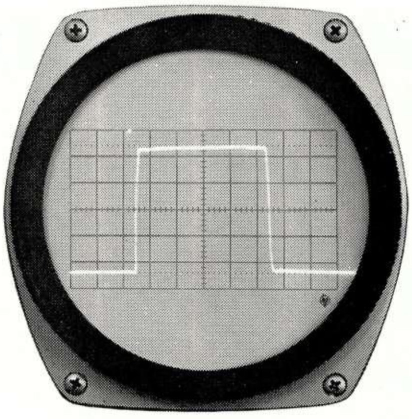

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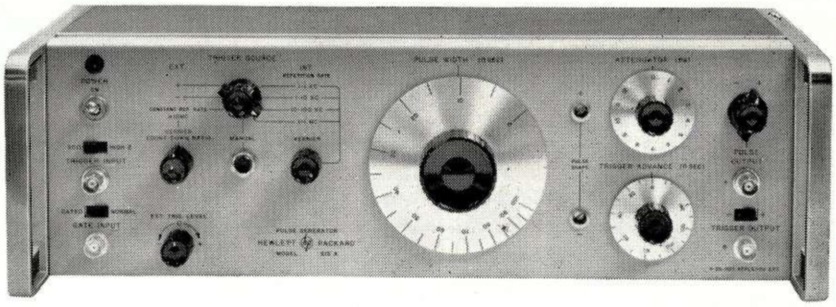

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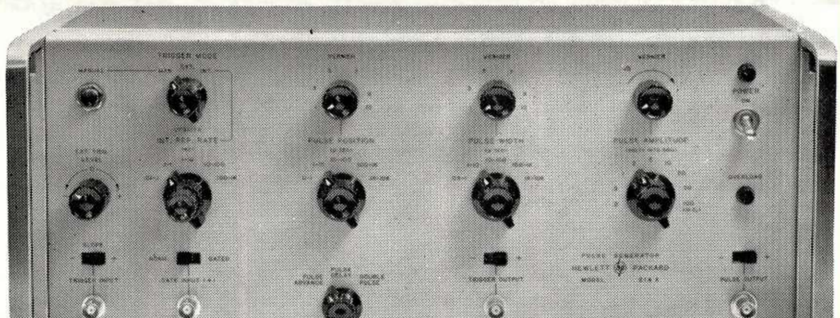

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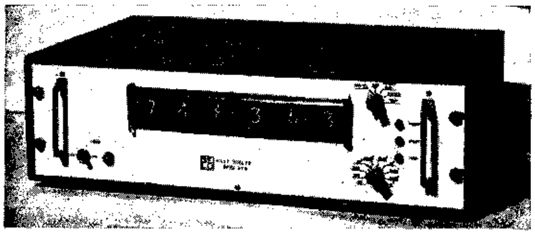

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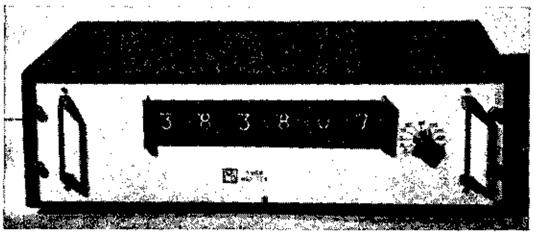

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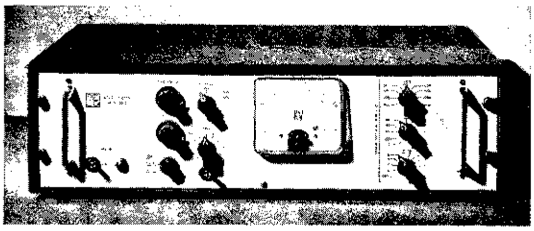

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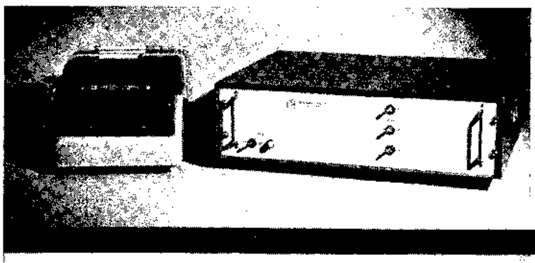

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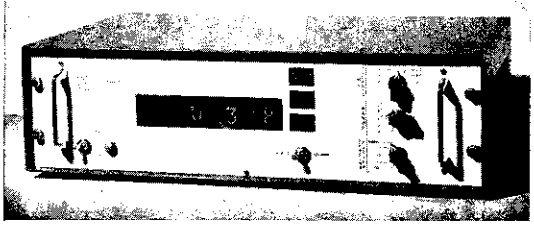

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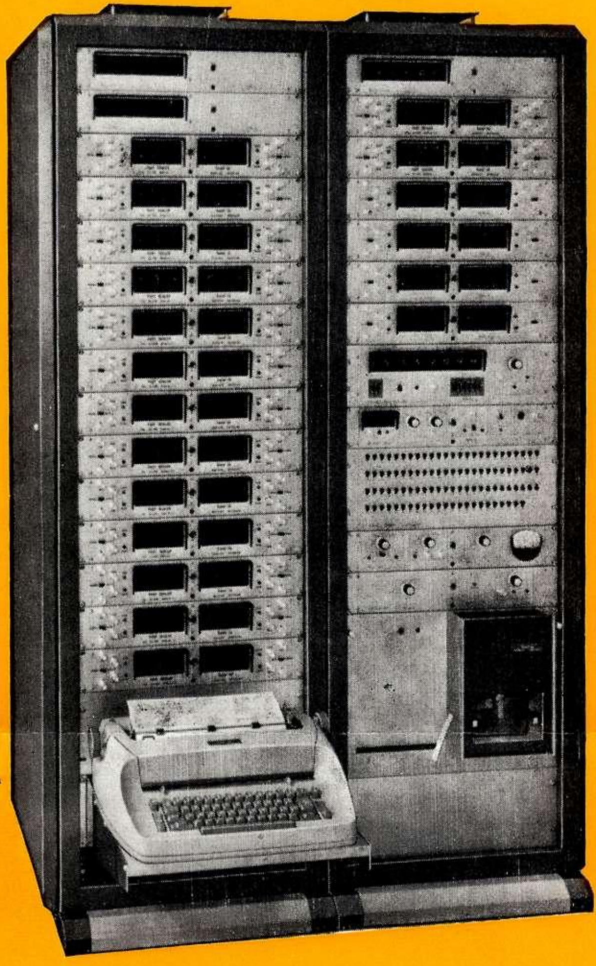

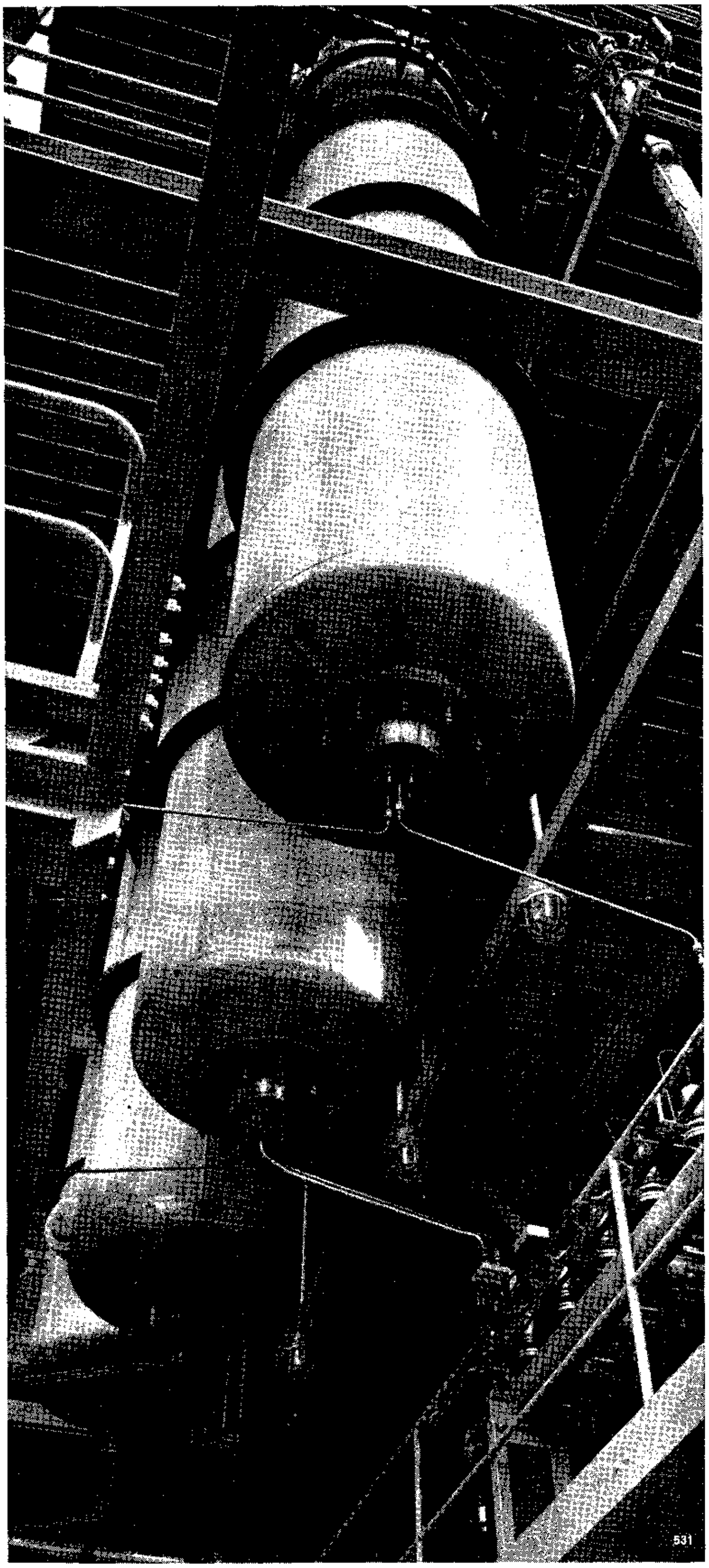
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