CERN COURIER

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Contents

The cover photograph shows the reflector R2, one of the two large neutrino-parent focusing devices which are to be installed in the new neutrino beam line. After mounting the conical inner conductor (which was pictured in CERN COURIER, vol. 6, no. 4 (April 1966) p. 68) the reflector is being lowered to a horizontal position before being put onto its supporting structure. It is 5 m long and 2 m diameter and will be pulsed with a nominal current of 400 kA peak. It has already been tested successfully up to 300 kA peak, which is the maximum current possible from the power supply available at present.

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The European Organization for Nuclear Research, more commonly known as **CERN** (from the initials of the French title of the original body, 'Le Conseil européen pour la Recherche nucléaire', formed by an Agreement dated 15 February 1952), was created when the Convention establishing the permanent Organization came into force on 29 September 1954.

In this Convention, the aims of the Organization are defined 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.'**

Conceived as a co-operative enterprise in order to regain for Europe a first-rank position in fundamental nuclear science, CERN is now one of the world's leading laboratories in this field. It acts as a European centre and co-ordinator of research, theoretical and experimental, in the field of **high-energy physics,** often known as **sub-nuclear physics** or the **physics of fundamental particles.**

High-energy physics is that front of science which aims directly at the most fundamental questions of the basic laws governing the structure of matter and the universe. It is not directed towards specific applications — in particular, it plays no part in the development of the practical uses of nuclear energy — though it plays an important role in the education of the new generation of scientists. Only the future can show what use may be made of the knowledge now being gained.

The laboratory comprises an area of about 80 ha (200 acres), straddling an international frontier; 41 ha is on Swiss territory in Meyrin, Canton of Geneva (the seat of the Organization), and 39.5 ha on French territory, in the Communes of Prévessin and St.-Genis-Pouilly, Department of the Ain.

Two large particle accelerators form the basis of the experimental equipment:

— a 600 MeV synchro-cyclotron,
— a 28 GeV proton synchrotron,

the latter being one of the two most powerful in the world.

The CERN staff totals about 2300 people.

In addition to the scientists on the staff, there are over 360 Fellows and Visiting Scientists, who stay at CERN, either individually or as members of visiting teams, for periods ranging from two months to two years. Although these Fellows and Visitors come mainly from universities and research institutes in the CERN Member States, they also include scientists from other countries. Furthermore, much of the experimental data obtained with the accelerators is distributed among participating laboratories for evaluation.

Thirteen Member States contribute to the cost of the basic programme of CERN in proportion to their net national income:

Austria (1.90 %)	Italy (11.24 %)
Belgium (3.56 %)	Netherlands (3.88 %)
Denmark (2.05 %)	Norway (1.41 %)
Federal Republic of Germany (23.30 %)	Spain (3.43 %)
France (19.34 %)	Sweden (4.02 %)
Greece (0.60 %)	Switzerland (3.11 %)
	United Kingdom (22.16 %)

Poland, Turkey and Yugoslavia have the status of Observer.

The 1966 budget for the basic programme amounts to 149 670 000 Swiss francs, calling for contributions from Member States totalling 145 860 000 Swiss francs.

Supplementary programmes, financed by twelve states, cover construction of intersecting storage rings for the 28 GeV accelerator at Meyrin and studies for a proposed 300 GeV accelerator that would be built elsewhere.

The Ford Foundation Grants to CERN

by **R. N. Milligan**
Personnel Division

The financial support of the Ford Foundation, which has been of great help to CERN during its early years, comes to an end this month. This article describes the use that has been made of the grants and records the gratitude of CERN for all that it has made possible.

It was on the third of July 1956, when the CERN proton synchrotron was still on the drawing board and the synchro-cyclotron had not yet come into operation, that the Ford Foundation made its first grant to CERN. The purpose of the donation was specified in a letter from the Secretary of the Foundation, Mr. J. M. McDaniel jnr., to the Director-General of CERN, the late Professor C. J. Bakker, as follows:
'... to assist in strengthening ... co-operation with nuclear physics research ... in ... countries not members of CERN.'

In the ten years that have passed since then, 174 scientists and engineers from 24 different countries (mostly from the USA), have been able to visit the Laboratory to participate in our research programme, as a result of the generous assistance we have received from the Ford Foundation. The Foundation has made three grants to the Organization; the first of $ 400 000 covered four years from 1 September 1956, a further $ 500 000 was given for the next three years, and a final $ 250 000 was paid for the last three years. Thus, in all, it has contributed $ 1 150 000 — equivalent to five million Swiss francs — over a ten-year period.

From the very beginning, CERN had a completely free hand in the administration of the grant; the only obligation to the Ford Foundation authorities was to make an annual report on the uses to which the funds had been put, together with a statement of account. CERN could therefore choose its visitors purely for their scientific qualities. The fund was administered through the CERN Visiting Scientists Committee, which meets at regular intervals to consider applications for appointments and nominations of scientists to be invited to the Laboratory.

The visitors financed from the grants have made a contribution to the scientific work of the Laboratory, which has been out of all proportion to their number or their cost. Every first-rate Laboratory engaged in pure research needs to keep abreast of current thinking and of technical developments at the other centres which are engaged in the same field. With the Ford grant, CERN has been able to invite eminent scientists and engineers from Laboratories all over the world. Famous theoretical physicists, including for example Professors G. F. Chew, M. Gell-Mann, T. D. Lee, A. Pais, and C. N. Yang, have been a source of information and inspiration for our scientists. Eminent experimentalists such as Professors R. Adair, J. Ashkin, R. L. Garwin, L. Lederman, W. Panofsky, J. Steinberger and V. L. Telegdi, have made very valuable contributions in the development of our accelerators, the construction of experimental apparatus, and the carrying out and analysis of experiments.

At the same time, CERN has been able to play a role in the advancement of high energy physics in the less scientifically developed countries, where facilities such as exist at CERN are not available. Using the funds provided by the Ford Foundation, some of the more promising young scientists from these countries have been invited to collaborate in CERN's programme. They have done useful work at the Laboratory, and after their return to their countries, they used their experience for the benefit of their own scientific communities.

Early in 1963, the Ford Foundation notified CERN that their support for the Laboratory would terminate after the third grant. This move might almost be considered as a compliment to the Organization, for the Foundation's policy in allocating this type of grant is to provide large sums of money at the beginning of a venture, to be used for 'pump priming', and to withdraw their aid once the project has matured. In fact, since the programme bringing visiting scientists from non-member States to the Laboratory has shown itself to be extremely valuable, the CERN Council decided to maintain it on the regular CERN budget.

The last Ford grant was gradually phased out over a period of three years, while CERN began to allocate small funds from the contribution of the member States. Last year, the Council accepted a proposal by which 1 % of the overall staff budget is devoted to the support of non-member State visitors.

We should like to register our deep gratitude to the Ford Foundation for their confidence in our Organization, which they expressed with great generosity.

An experiment designed to measure the anomalous magnetic moment of the muon to a very high order of accuracy has completed a preliminary trial run at the CERN proton synchrotron. The run has already confirmed the results of an experiment, known as the 'g minus 2' experiment, carried out at CERN five years ago and more detailed measurements are now under way. This article describes the experiment and its relevance to the understanding of the most mysterious of all the sub-nuclear particles — the muon.

'Who ever ordered that ?'

Among the classes of sub-nuclear particles, there is a very small group — the electron, the muon and the two types of neutrino — called leptons (from the Greek word meaning 'thin' or 'small'). Their distinguishing characteristic is that they do not feel the most powerful of the forces which affect the behaviour of particles; they do not take part in 'strong' interactions. It might seem that, since there are only four particles involved in fewer interactions, they should be easier to understand than their many heavier relatives — the hadrons. But, although a lot of progress has been made in clarifying the complexity of the observations on the hadrons, there has been very little in understanding the leptons.

The most mysterious of them is the muon. This is a particle which has almost all its properties identical to those of the electron and yet is two hundred times heavier. Professor I. Rabi summed up the frustration of physicists confronted with this particle, when he said, 'Consider the muon. Who ever ordered that ?'

The muon was discovered in 1936 by C. D. Anderson and S. H. Neddermeyer from photographs of cosmic rays and, at first, it was interpreted as the particle, predicted by H. Yukawa in 1935, which carries the strong force binding the nucleus together. This Yukawa particle was calculated to have a mass about 200 times heavier than the electron and the muon seemed to fill the bill. But it was soon realized that the muon travelled too easily through matter to be the one involved in the nucleus, which must be easily emitted and therefore, easily absorbed. The true Yukawa particle, the pion, was eventually identified in 1947. (The masses are fairly close, the muon being about 207 times and the pion 273 times the mass of the electron.) We were thus left with the muon which fitted into no conceivable scheme of the particles.

Investigation of its properties showed that it exists in negatively charged and positively charged (the anti-muon) forms. It is a lepton subject only to the types of force called the electromagnetic and the weak. Its intrinsic angular momentum or spin is $1/2$ (expressed in the unit $h/2\pi$, where h is Plank's constant, given to particle spin). In all these properties it is identical to the electron. The mystery of the muon stems from the belief that the mass of a particle is a consequence of the interactions it undergoes. In this respect, the muon and the electron, as far as we know, are identical — they are subject to the same interactions. Where then does the difference in mass stem from ?

Anomalous magnetic moment

About 1960, experiments were carried out at CERN and elsewhere to find out whether there is any significant difference between the two particles in their 'anomalous magnetic moment'. If a difference showed up here, it could indicate that the muon does in fact experience some small force not felt by the electron and in this could lie the explanation of the difference in mass.

We have already said that the muon has spin. This does not mean that it is possible to observe an actual physical spin but that the particle has an angular momentum and behaves as if it is spinning. One of the properties of a spinning charge is that it sets up a magnetic field and associated with the muon spin, is a

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The team, carrying out the new experiment on the anomalous magnetic moment of the muon, seen grouped together at the muon storage ring. Left to right they are S. van der Meer (Netherlands), F. J. M. Farley (UK), M. Giesch (Federal Republic of Germany), R. Brown (UK), J. Bailey (Australia), E. Picasso (Italy) and H. Jöstlein (Federal Republic of Germany). One other contributor to the experiment, M. Tannenbaum (USA) is not with the group.

very small magnetic field. It is as if a tiny bar magnet lies along the spin axis of the particle.

The value of the magnetic moment is proportional to the angular momentum but it was found experimentally that, for elementary particles, the classical value has to be multiplied by a factor known as the gyro-magnetic ratio or g-factor to arrive at the correct value. One of the great successes of relativistic quantum theory worked out by P. A. M. Dirac about 1930, was to predict that for particles which have spin $1/2$, this g-factor should be equal to 2. The figure agreed very well with the results for the electron obtained at that time from atomic spectroscopy.

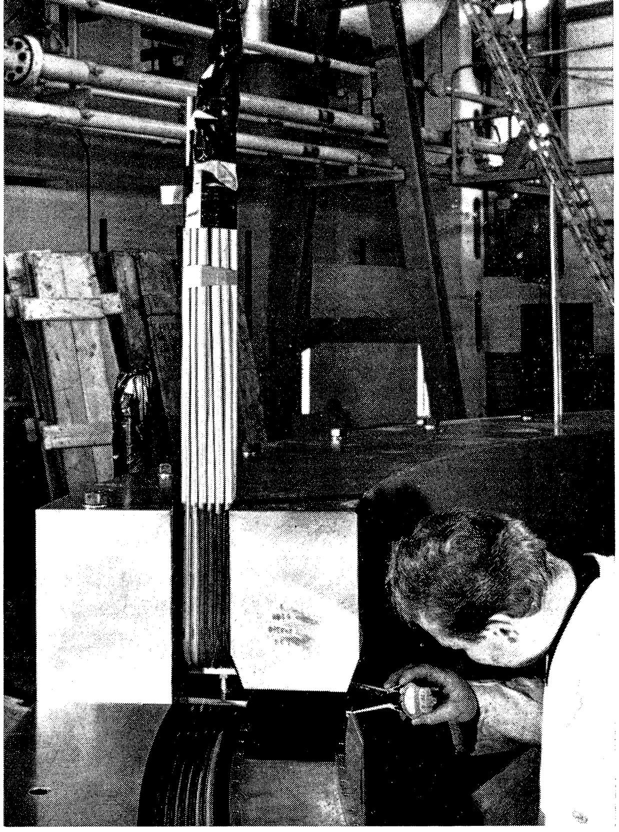
In 1947, more refined measurements of the atomic spectral lines revealed the so-called Lamb-shift which can only be explained by quantum field theory (quantum electrodynamics). This modified theory led to a small change in the g-factor for the electron, in other words a change in the theoretical magnetic moment of the electron compared with that derived from the Dirac theory. This change, which is of the order of one part in a thousand, is known as the anomalous part of the magnetic moment.

Virtual photons

The Nobel Prize in Physics for 1965 was awarded to J. Schwinger, S. Tomanago and R. Feynmann for their work in developing quantum electrodynamics. They succeeded in bringing quantitatively into the theory the fact that the existence of a charged particle such as the electron sets up an electromagnetic field and this electromagnetic field acts back on the electron itself causing small changes in its properties.

In quantum field theory, the classical idea of an electromagnetic 'field' is explained as being due to the existence of 'photons' which are the carriers of the electromagnetic force. Under undisturbed conditions these photons will not be observed and hence are called virtual photons but it is the continual emission and absorption of photons by the electron which sets up the field. And it is the fact that photons are continually popping in and out of the electron, so that some are in a cloud around the electron at any one time, that produces the small changes in properties as compared with what we can expect if we ignore this effect. Thus, the new theory says that the g-factor for the electron and the muon will be slightly different from the value of 2 giving a value for the anomalous magnetic moment of 0.001 159 6 for the electron and 0.001 165 for the muon.

It may help further to put across this rather difficult idea if we consider the proton. Here again we have a particle with spin $1/2$ and the Dirac theory says that the value of the magnetic moment will be found by using a g-factor of 2. But experiment reveals a g-factor of about 5.5. Why this very large change ? We said that the properties of our leptons, the electron and the muon, experienced small changes because of the electromagnetic field associated with them involving the emission and absorption of photons. But the proton is party to the strong interactions — it sets up a 'strong' field involving the emission and absorption of pions which are the carriers of the strong force. Having the rather thick cloud of massive pions around the proton, as opposed to the thin cloud of massless photons around the electron, causes a much more marked change in the properties of the proton.



CERN/PI 91.4.65

Manfred Giesch checks the magnet aperture during assembly of the muon storage ring. The eight sections of each pole were machined together on a large turntable at Linz in Austria, and reassembled at CERN. Careful design and construction and final correction by the addition of thin steel shims to the magnet poles, made it possible to establish the required field shape to an accuracy of a few parts in 10 000, on average. The field is stable to 50 parts in a million.

'g minus 2' experiment

A very successful experiment was carried out on the CERN synchro-cyclotron five years ago by a team consisting of G. Charpak, F. J. M. Farley, R. L. Garwin, T. Muller, J. C. Sens, V. L. Telegdi and A. Zichichi. They measured, directly, the deviation of the g-factor for the positive muon from the value of 2 (hence the name 'g minus 2').

With intricate apparatus providing high precision of measurement they obtained a value of 0.001 162 ± 0.000 005, which is in agreement with the theory. The result therefore says, to the order of accuracy achieved in the experiment (about 0.4 %), that there is no difference between the muon and the electron as regards the anomalous magnetic moment and the mystery of the existence of the particles remains unsolved.

The experiment also gave other information since it effectively investigated the laws of quantum electrodynamics down to very short distances. It had been suggested that the laws might break down at some point, just as classical dynamics, which is so successful in dealing with the behaviour of objects on a large scale, breaks down when dealing with sub-nuclear particles. No such effect was observed and it was possible to say that quantum electrodynamics holds good at least to distances as small as about a hundredth of a millionth of a millionth of a centimetre (10^{-14} cm).

A description of the experiment can be found in references 1 and 2 below and the results were presented in references 3, 4 and 5.

Muon storage ring

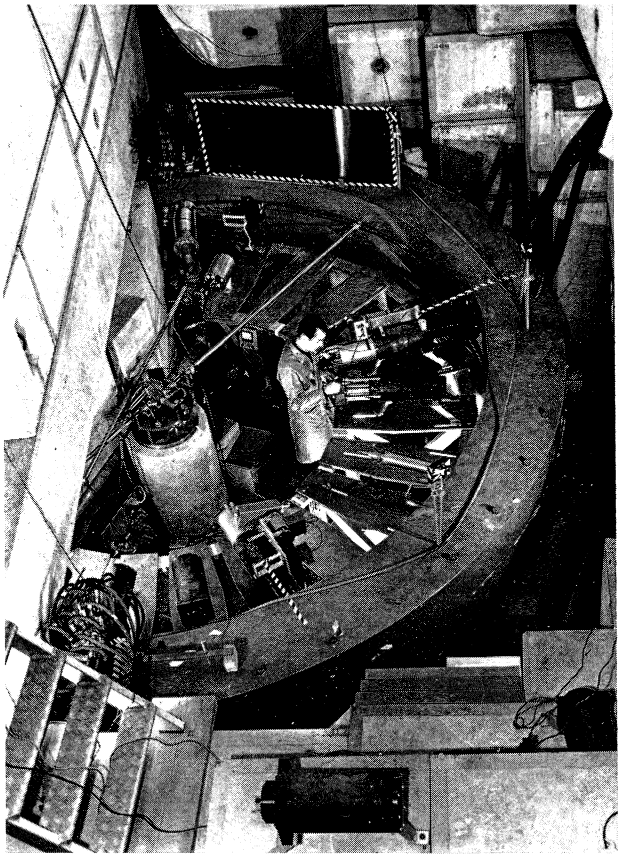
The present investigation at CERN uses an entirely different experimental set up to that of the previous experiment. The main item of equipment is the so called 'muon storage ring'. This device has a circular magnet five metres in diameter with an average field of just over 17 kG which is known to an accuracy of 0.005 %.

A beam of protons, of energy 10 GeV, is ejected from the proton synchrotron and guided onto a target inside the storage ring. About 70 % of the protons interact in the target producing a burst of particles including many negative pions some of which have the right momentum (about 1.3 GeV/c) to turn in the magnetic field so that they orbit the ring. The pions decay rather quickly and during the first turn in the ring a fifth of them change into negative muons. Some of these muons which are emitted at small angles to the direction of the pions have slightly lower momentum than the pions and therefore move to an orbit of smaller radius. In this way they miss the target as they complete the first turn and are stored orbiting in the magnet ring. (The remaining pions and the muons emitted at other angles are lost by collision with the target assembly or the walls of the vacuum chamber.)

In order to understand the next stage of the experiment, we need to recall that parity is not conserved in weak interactions. This means that in interactions such as the decay of the pion into the muon, Nature is concerned about the direction in which things happen. In this particular case, the decay results in almost every muon spin axis being lined up in the direction in which the muon is travelling. If parity were conserved, the spin axes would have every possible orientation with respect to the direction the muons are travelling. In the storage ring, practically all the muons at injection have their spin axes pointing along the path of the beam and the beam is described as 95 % forward polarized.

If the g-factor for the muon were exactly equal to 2, it can be shown that the spin axis would always stay lined up with the direction of motion, but the slight deviation from the value of 2 leads to the spin axis swinging round, or 'precessing', in the plane at right angles to the magnetic field so that after about 1 millionth of a second (1 μs) it is at right angles to the beam direction. After another 1 μs it points in the opposite direction, another 2 μs brings it back round to its initial direction and so on. This rate of precession is directly proportional to (g-2).

The muon is an unstable particle (though the most stable of the unstable) with an average life of 2.2 μs; in 2.2 μs half the muons in a beam will decay. The decay is into an electron, a neutrino and an antineutrino and, again because of the violation of parity in weak interactions, there is a specific direction associated with the electron coming from the decay. The negative muon likes to emit the electron in the direction in which the muon spin axis is pointing. This is the handle by which it is possible to get hold of the rate at which the muon is precessing. If we watch, from one position, the number of electrons which are thrown out from the muons, we should see the rate fluctuating with a frequency of about 4 μs. The rate will be highest when the muon spin axes point towards the detecting position and lowest when the spin axes point away from the detecting position.



CERN/PI 17.1.66

Checking the counters on the inside of the muon storage ring before a trial run. Concrete shielding can be seen surrounding the ring, and particularly around the target area, to reduce radiation in the rest of the South hall when the experiment is running. Shielding inside the ring itself protects the counters from the initial blast of radiation. The pillar in the centre provides a fixed pivot for magnetic field surveys. It can also support four rods (two can be seen in the photograph) which carry automatic NMR proton resonance magnetometers for continuous monitoring of the magnetic field.

In the experiment itself, this 'watching from one position' is done in a clever way. Electronic counters are set up inside the storage ring and are set so that they record only those electrons which have an energy greater than some fixed value. The type of counter used consists of a sandwich of lead plates 3 mm thick and plastic scintillator 10 mm thick. An electron passing through this assembly causes a tiny flash of light in the plastic scintillator. The flash is picked up by photomultipliers, converted into an electronic signal and passed to scalers, which record the time of arrival of the electron. By adjusting the electronics, the counter can be made sensitive only to electrons with an energy greater than say 750 MeV. To have so much energy, the electron has to be emitted in the forward direction — the direction in which the muon is travelling. Thus the detection system is equivalent to looking with a telescope pointing towards the direction of motion. We expect the counter to record a maximum of electrons emitted in this direction when the spin axes of the muons point along the direction of motion and a minimum when the spin axes point the opposite way. Therefore, the electron counts should show a regular fluctuation at the frequency at which the muon spins precess.

Time dilation

We stated above that the muon has an average lifetime of 2.2 μs and yet we have discussed observing the decay of the muon over a much longer time so as to see the 4 μs fluctuations. How is this possible ?

The answer lies in Einstein's relativity theory which says that the closer to the speed of light an object moves, the slower go its 'clocks' — a phenomenon known as 'time dilation'. In the previous g minus 2 experiment, measurements were made with muons produced in the decay of pions from the 600 MeV synchro-cyclotron. They had energies of about 25 MeV and their velocity was not close to the velocity of light. Their average lifetime remained about 2.2 μs and in fact the observation of the decays covered a time from 2 to 8 μs.

Making use of the much higher energies available at the 28 GeV proton synchrotron, the muon storage ring experiment examines muons of energy around 1.3 GeV when their velocity is very close to that of light. The muons, by their own 'clocks' (their own internal decay mechanism), still decay after an average life of 2.2 μs. But their clocks are going slower and relative to our clocks the average lifetime has increased to 27 μs. It has been possible to watch the muons for times extending beyond 100 μs and it is believed that the experiment has provided, by this observation, the first clear verification of time dilation in a circular or 'out and return' path.

Preliminary run

The experimental team are reporting in Nuovo Cimento in September the results of a preliminary run with the muon storage ring. They obtained a value for the anomalous magnetic moment of negative muons of 0.001 165 ± 0.000 003, which agrees with theory and with the result for positive muons from the previous g minus 2 experiment.

This preliminary result makes it possible to say something about the symmetry between the muon particle and antiparticle — as was already known, their average lifetimes are identical to better than one part in a thousand, their masses are identical to better than one part in ten thousand, and we now know that their g-factors are identical to better than one part in a hundred thousand.

More important is the fact that the muon storage ring is working as predicted and the team are now engaged in a run intended to achieve more accurate measurements. For the preliminary run, they used two of the twenty proton bunches from the proton synchrotron and one electron counter. They now take five bunches from the PS and use more counters, which should lead to a considerable increase in precision.

It is hoped in this way to take the accuracy of the measurement of the anomalous magnet moment an order of magnitude further. It may reveal a small deviation from the theoretical prediction. If a difference at this level of accuracy does show up, interpretation could prove difficult. It may mean that the muon is involved in some small force that the electron does not feel or alternatively that the limit of the laws of quantum electrodynamics has been reached. If no difference appears, the present muon-electron problem deepens still further and quantum electrodynamics will have been confirmed to shorter distances.

1. 'The Muon', by Sheldon Penman, Scientific American, July 1961.
2. 'g minus 2', CERN COURIER, vol. 2, no. 4 (April 1962) p. 3.
3. 'Measurement of the anomalous magnetic moment of the muon', Physics Review Letters, vol. 6 (1 February 1961) p. 128.
4. 'A new measurement of the anomalous magnetic moment of the muon', Physics Letters, vol. 1 (1 April 1962) p. 16.
5. 'The anomalous magnetic moment of the muon', Nuovo Cimento, vol. 37 (1965) p. 1241.

CERN News

What's on at the SC

The 600 MeV synchro-cyclotron began operation again on 11 July only a few hours behind schedule after a shutdown lasting from 8 May. The major items of work planned for the shutdown were all completed: the addition of extra shielding on the roof of the SC building, excavation work for the underground tunnel to take beams to the ISOLDE (Isotope Separator On-line Development) laboratory, modifications to the machine radio-frequency system, installation of new quadrupole lenses with remote-controlled positioning, and replacement of a variety of internal targets by a standard model.

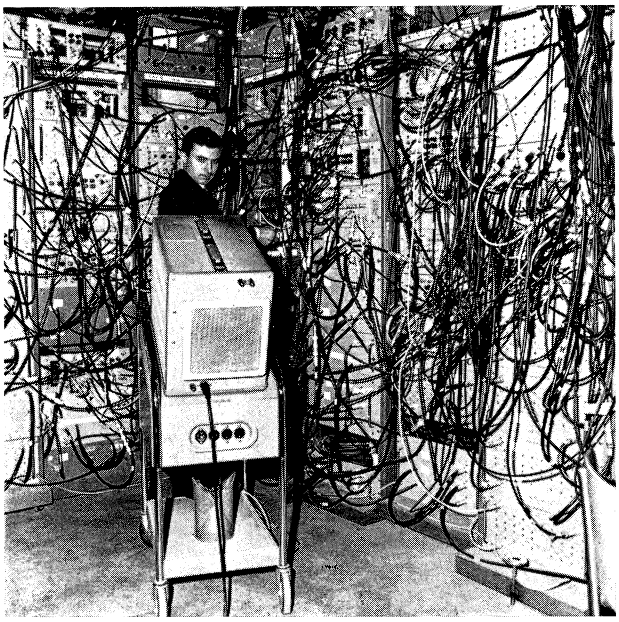
The experimental programme, planned for the remainder of the year, can be divided into two parts according to the type of problem being investigated — nuclear structure and weak interactions.

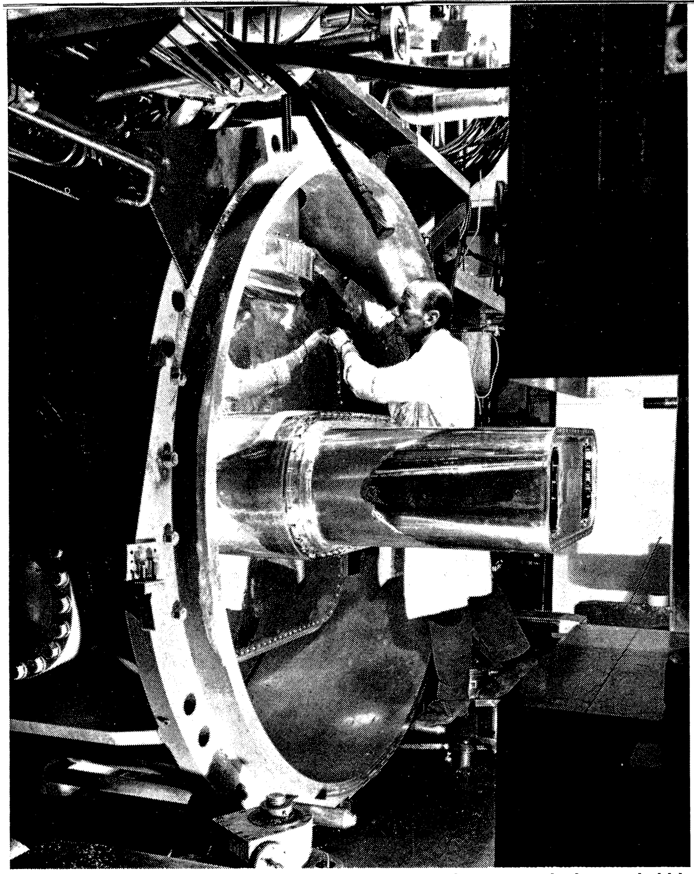
1. Nuclear Structure

A team, led by G. Charpak, is using a positive pion beam on to targets of light nuclei (such as lithium). The interaction studied is then $\pi^+ + N \rightarrow 2p + N^1$ and the energies and angles of the two emerging protons are measured. If, within the structure of the nucleus, a proton and neutron are bound, forming a quasi-deuteron, the incoming pion

The familiar bird's nest of wires associated with electronic-counter experiments at particle accelerators. This particular set of equipment is being used at the 600 MeV synchro-cyclotron in an intricate experiment to examine the weak interaction by observing the capture of the muon in gaseous hydrogen. A brief description of the experiment is given on page 157.

CERN/PI 209.7.66





CERN/PI 3.6.66

Work in progress at the beginning of June on the 81 cm hydrogen bubble chamber. The chamber, which has been in operation at CERN on loan from the Saclay Laboratory in France since 1961, became the responsibility of CERN from 1 August. Since the chamber arrived it has taken over seven million photographs.

Further news about bubble chambers from France concerns a very large hydrogen bubble chamber, called 'Mirabelle', now being constructed at the Saclay Laboratory. As part of the Franco-Soviet collaboration agreement, signed during the visit of President de Gaulle to the Soviet Union in June, this bubble chamber will eventually be transported to Serpukhov to be used by joint teams of Soviet and French physicists for experiments at the 70 GeV proton synchrotron which is nearing completion.

The finishing touches being given in the West Workshop to a mirror made from plexiglass. The mirror is part of a large area Cerenkov counter assembly to be used in an experiment, being carried out by a CERN-Munich group, to investigate the electromagnetic decay of particle resonances. The Cerenkov counter makes use of the fact that the passage of a charged particle through a transparent material at a velocity greater than the velocity of light in the material sets up a 'bow-wave' of light at an angle to the direction of the particle. The detection of this light selects particles moving with velocities in excess of some fixed threshold.

CERN/PI 293.6.66

can interact with this deuteron complex. Such an interaction is characterized by the protons emerging with a unique combined energy for a particular angle. If therefore, the experiment reveals sharp peaks in the combined energy distribution, gives information about the groupings of nucleons within the nucleus. The experiment is being performed with the aid of counters and digitized spark chambers. The team obtained interesting results before the shutdown and is now extending the measurements with improved equipment.

A second team, led by C. Cernigoi, is starting a related experiment using a negative pion beam where an analogous interaction leads to two neutrons and the combined energy of the emerging neutrons is measured.

Before the shutdown, a team led by G. Backenstoss started a series of measurements on pi-mesic X-rays using a negative pion beam which is stopped in a target. Normal X-rays are emitted when electrons in orbits around the nucleus fall to lower energy levels closer to the nucleus. Pions and muons yield X-rays under similar conditions. The energy levels associated with the muons have recently been measured at CERN and other Laboratories to high accuracy. Pi-mesic X-rays have been known for a number of years, but present day pion intensities and means of analysis, particularly the invention of the lithium-drifted germanium detector with its high energy resolution, make it possible to improve substantially the existing information.

The interpretation of pion X-rays is complicated by the fact that pions, unlike electrons or muons, experience 'strong' interactions with particles in the nucleus. This results in an energy shift and a broadening of the lowest energy levels compared with the corresponding levels for the muon and yields information about the pion-nucleus interaction. For the higher levels, however, where the strong force is not predominent, it is possible to compare the results of pion and muon X-rays on the basis of purely electromagnetic forces and thus to measure the masses of the two particles.

A further experiment on the same topic is being carried out by a team led by S. Nilsson. They are using a crystal spectrometer in an experiment designed to achieve very high accuracy. A recent pi-mesic X-ray experiment at Berkeley, USA, has yielded the accepted 'best value' of the mass of the pion. They hope to improve on the Berkeley value and also to learn something about other interactions affecting the pions.

A special beam has been set up (called the MSS beam after its designers R. Meunier, N. Spighel and J. P. Stroot) to give pion beams of very well defined momentum (± 1 MeV in 200 MeV). The beam will be used to bombard various nuclei and the energy spectra of the scattered pions will yield information about the energies which the pions give to the nuclei to lift them into higher energy states. Thus more knowledge about the excitation by pions of energy levels within the nucleus will be obtained. It is necessary to define the incoming pion beam with high accuracy and to observe the scattered pions with similar accuracy in order to differentiate between energy levels which are close together. The pion beam has now been developed to its final form.

A similar motivation, the desire to investigate the pion excitation of nuclear energy levels, is behind a series of experiments being done by a team from Oxford University led by N. W. Tanner, which concluded a first series of measurements before the shutdown. They also use a pion beam but, instead of looking at the energy spectrum of the scattered pions, they stop the bombardment and look at the β or γ rays emitted as an excited nucleus decays to a lower energy level.

2. Weak Interactions

Perhaps the most difficult experiment ever to be attempted at the SC is being carried out by a CERN-Bologna University collaboration led by E. Zavattini. The aim is to re-examine the weak interaction $\mu^- + p \rightarrow n + \nu_\mu$ where the μ^- is bound in a μp atom of total spin zero. The complications are many. In the first place the interaction happens only 1 in 1000 times as frequently as the muon decay interaction producing an electron; thus all the electron events have to be rejected. Secondly the 'muon capture' increases as the fourth power of the atomic number. Therefore, the slightest trace of heavier-element impurity in the hydrogen tends to hide the interaction that is being looked for. Thirdly, when the muon is captured by a proton it can form a μp atom which diffuses through the gas like a neutron; if it hits the wall of the vessel containing the hydrogen it can simulate a capture event. Therefore, a way has had to be devised of preventing the mu-mesic atoms, μp, from reaching the walls.

The interaction was investigated at the CERN proton synchrotron some time ago using a liquid hydrogen bubble chamber where capture of the μ^- was observed as part of a more complex system — a $p\mu p$ molecule. The present experiment uses a volume of very pure gaseous hydrogen at eight atmospheres pressure as the target and a very clean muon beam from the accelerator. There are electrodes arranged inside the target shielding the walls and acting as a counter. All events occurring in the immediate vicinity of the electrodes are rejected. Before the shutdown, some examples of muon capture in the hydrogen were observed.

The following experiments have been approved:

A further experiment on weak interactions involving the partial capture of muons in boron by a team led by P. Macq.

An experiment on pion-proton scattering at energies around 50 MeV by a team led by P. Waloschek. It is hoped that this experiment will yield information vital to the interpretation of an experiment on the proton synchrotron where a Λ hyperon decays into a pion and a proton.

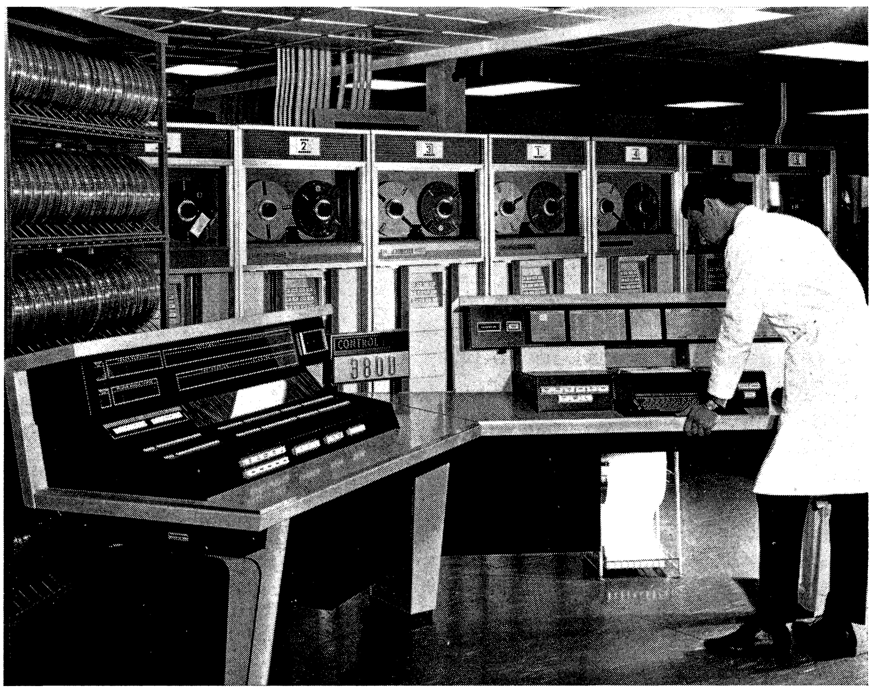
An experiment on the interaction between positive pions and deuterons proposed by E. G. Michaelis and D. F. Measdey.

Administered by Computer

The contribution of the computer to scientific research is well known. Sub-nuclear physics in particular could not have reached its present state or maintain its rate of progress, were it not for the parallel development of large scale computing facilities. CERN is the biggest computer centre in Europe and its computing capacity is still growing.

Computers are also playing an increasingly important role in other fields including various aspects of administration. In 1965, a study group was set up, on the instigation of the Director of the Administration Department, G. H. Hampton, to examine the main administrative procedures in CERN and to make recommendations for the future. The study group (W. Lock, G. Minder, N. Spoonley and M. Wenner) looked at such administrative operations as purchasing and accounting, salaries, stock control, manpower statistics, budgetary forecasting and planning...

A view of the CDC 3800 computer soon after its installation at CERN in July. The operating console is in the foreground and behind can be seen the eight magnetic-tape units.



CERN/PI 189.7.66

Their conclusions, presented in April 1966, start with the observation that the existing staff and equipment will soon be insufficient to carry the rapidly increasing load and that more staff or equipment is only a short-term solution. They therefore call for a long-term solution, involving the use of a computer, to cover the foreseeable requirements of the 1970's. This is now known as the ADP (Administrative Data Processing) project.

The present CERN computers are not appropriate for the needs of the administrative operations and 13 European computer manufacturers have been invited to submit suitable systems. Representatives of these firms attended a seminar at CERN from 25–29 July to learn of the requirements and to gather the necessary information for the design of the system. It is hoped that it will be possible to decide between the various proposals by 30 November and to install the machine in the spring of next year.

Anyone fearing for his status in this increasingly electronic age may take comfort from an opening remark in the report of the study group. While recommending the computer as essential if the administrative services are to keep pace with the ever-developing activities on the site, they maintain that 'a computer per se is not a panacea for all ills; there are certain operations involving human judgement and decision that cannot be performed by the computer, and consequently... attention must be given to all parts of the system' not merely those to be performed by the computer.'

In accordance with the agreements reached between CERN and CDC at the end of March 1966, a CDC 3800 computer arrived at CERN on 16 July. (For an extended discussion of the plans for computing facilities at CERN, see CERN COURIER, vol. 6, no. 5 (May 1966) p. 90).

CERN has said goodbye to its first computer which was installed on the site in 1958. This was a Ferranti Mercury which remained the only computer at CERN until the arrival of an IBM 709 in 1960. It is still not lost to sub-nuclear physics; it has been dismantled and sent to Cracow University in Poland where it will be re-installed and used for high-energy physics calculations.

Conference organizer extraordinary

If it is a European conference and the topic is accelerators or sub-nuclear physics, there is a high probability that the administrative organization will be in the hands of Miss Steel from the CERN Conference Secretariat. Her experience and ability in this field has, this year, received a considerable tribute from the USA; she has been invited to take part in the organization of the International Conference on High Energy Physics, at Berkeley (31 August to 7 September). This conference is the 13th in the major series of conferences in our field of research, known as the 'Rochester Conferences' since the first seven of them were held at Rochester in the USA. The organizing committee approached IUPAP and then CERN to bring in Miss Steel in the capacity of 'consultant'. She left for Berkeley on 6 August.

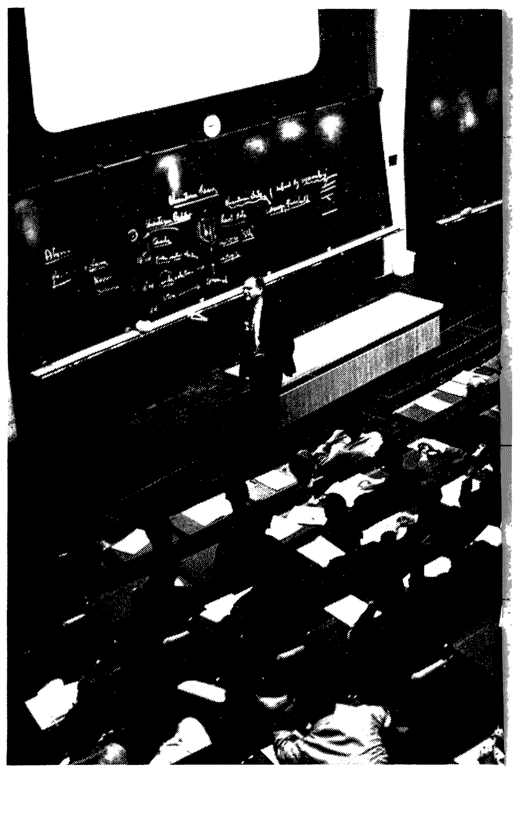
Miss Steel began work at CERN in 1955 as Divisional Administrative Officer in the PS Division and in 1956 was involved in the organization of her first conference — a symposium on high energy accelerators and pion physics held at CERN. At the beginning of 1961, the Conference Secretariat was set up and conference organizing became a full time occupation. In 1962, she was joined by Miss Henry and together they have built up a team with wide and detailed experience in the organization of conferences. The total of conferences organized has now reached 20 and, in addition, there have been 5 CERN Schools. This tally includes such major events as the two Rochester conferences held at CERN in 1958 and 1962, the accelerator conference in 1959, and the first two of the European series of elementary particle physics conferences in 1961 at Aix-en-Provence and in 1963 at Sienna.

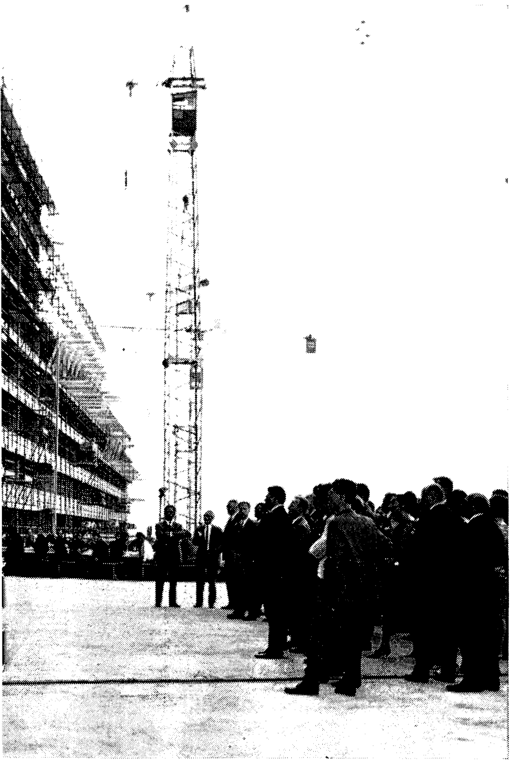
Correction

It will have been obvious to anyone who studied Figure 3 in the July issue very closely that, on one point, the ISR site layout did not agree with the figure caption and with the text. The figure showed the ISR tunnel expanded for experimental halls at beam crossing regions I4 and I5. This was a previous layout. The up-to-date figure which should have been used, shows the experimental halls at regions I1 and I4 as stated in the caption. We apologize for any confusion this error may have caused.

The scene at a ceremony to celebrate the completion of built in the housing development at Grand-Saconnex su from the improvised rostrum is Mr. Bloch, who spoke on ing was also addressed by Mr. Tieche (Manager of t Mr. Chavanne (Geneva Conseiller d'Etat).

Professor Weisskopf, Director General of CERN until t this year's vacation students. The lecture was a favou scientific research'. Professor Weisskopf, who has retu in the USA, arrived at CERN towards the end of June to 105 young scientists and engineers from 55 different unive selected, from over 300 applicants, to take part in the pants were sent to take part in the course by their home practical research experience in the groups to which th lectures has been arranged for them. The series cons programming, theoretical physics, experimental physics



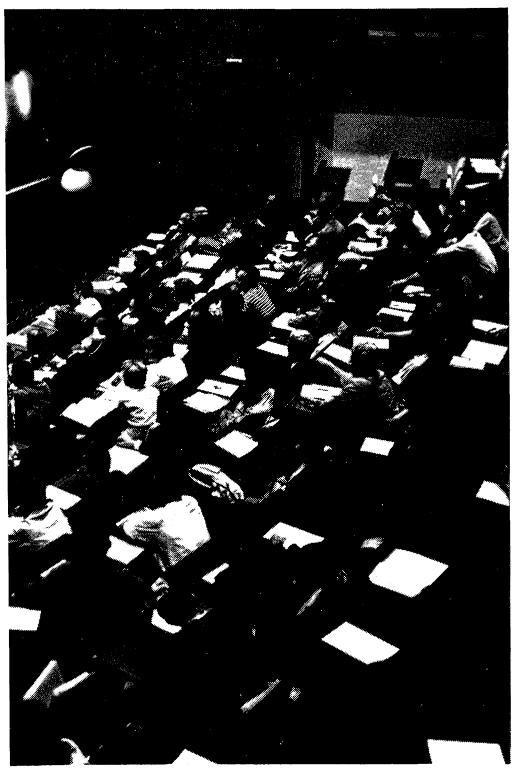


CERN/PI 208.6.66

ajor construction work on the first block of flats to be orted by the CERN Staff Insurance Scheme. The speaker half of the contractors engaged on the project. The gather- Staff Insurance Scheme), Mr. Jenny (the architect) and

end of 1965, giving an introductory lecture on 25 July to e topic of his — 'The place of high energy physics in modern ed to his post at the Massachusetts Institute of Technology end several months working here.

ties and equivalent institutes in the member States were cation students course this summer. Another nine partici- stitutes at the latter's own expense. The students gain are assigned at CERN. In addition, a special series of s of over 70 hours of lecturing time covering computer d engineering subjects.



CERN/PI 203.7.66

Rooms at the Top

On 22 June, a ceremony was held at Grand-Saconnex to mark the completion of major construction work on the first block of flats in the housing project undertaken by the CERN Staff Insurance Scheme. The basic structure of all nine floors in this long block, which will house 284 flats, is finished and it is hoped that the first of the flats will be ready for occupation at the end of autumn this year.

Work started on the site at Grand-Saconnex on 26 April 1965. There will eventually be 550 flats in four blocks and it is intended to allocate about half of them to CERN personnel and members of other international organizations, the remainder being available to Geneva families.

The project is part of a planned programme of investment of the Staff Insurance Scheme. The programme was described in the Annual Report of the Staff Insurance Scheme for 1964. The CERN Scheme has invested 50 % of the necessary capital for the construction of the flats and the other 50 % has been raised by the Scheme outside Geneva. In this way it is helping to ease the housing shortage in Geneva, without drawing on the limited capital available in the city for building.

The ceremony was attended by Mr. Chavanne (Conseiller d'Etat in Geneva and Swiss delegate to the CERN Council), Mr. Rivoire (Mayor of Grand-Saconnex), as well as Mr. Jenny (the architect of the project), G. H. Hampton and several other representatives of the CERN Staff Insurance Scheme.

News from Abroad

Stanford

It was announced on 30 June that the US Office of Naval Research has approved a $ 4.4 million modernization programme for Stanford University's Mark III electron linear accelerator. The Mark III came into operation 15 years ago. It has a peak energy of 1 GeV and the most notable work with the machine has been the investigation of the structure of the proton which gained Professor Hofstadter a Nobel Prize.

The improved version of the Mark III will have a beam intensity of 40 μA (as opposed to the present 2 μA) and a peak energy of 2 GeV. It will also have a longer duty cycle and better momentum resolution. The new machine will be built in an underground tunnel, 4 m in diameter and 200 m long, about 7.5 m below the existing machine. The earth shielding will then allow the accelerator to be operated 24 hours a day; at present, the Mark III can only be run at nights, week-ends and holidays because of the high radiation levels affecting the rest of the laboratory personnel.

A major item in the modernization programme is the construction of a very large spectrometer involving a magnet about 3.5 m radius. The spectrometer will be 12.5 m high and will be housed in an underground experimental area 60 m long, 22.5 m to 30 m wide and 18 m high. It will be possible to direct beams from the improved Mark III into this new experimental area or into one or other of the two existing areas.

An exciting prospect is that the new Mark III will be a superconducting accelerator — the first in the world. The Naval Research contract calls for further development of the research into superconductivity at Stanford and the possible application of its principles to the improved Mark III. Towards the end of last year, this research led to the acceleration of a beam of electrons in a small superconducting linear accelerator section for the first time (see CERN COURIER, vol. 6, no. 1 (January 1966) p. 15). If it can be applied successfully to big machines, it will result in higher energy for a given length of accelerator, in great savings in electrical power (though economically this will be offset by the cost of the refrigeration system), and, most importantly, in the ability to accelerate a continuous beam of particles instead of a pulsed beam. This last advantage could give a 10 000 foid improvement in the duty cycle of the Mark III.

Construction of the new machine still awaits official approval and is not expected to begin until the spring of 1968. Extensive studies of the problems connected with the underground tunnel will, however, begin at once. It is estimated that construction will take about four years.

BOOKS

'Irreducible Representations of the Space Groups', by O. V. Kovalev (New York, Gordon and Breach Science Publishers Inc., 1965) — translation from the Russian.

This book contains tables for one-valued and two-valued representations of space groups. The knowledge of these representations is necessary for the solution of problems in the physics of crystals in which microscopic symmetry is assumed.

The book starts with a list of elements of all 230 space groups which fixes the notations used later on, and then briefly explains the method of constructing the representations. This method applies to all space groups even if screw axes and glide planes are included. It makes use of loaded representations (or weighted representations depending on the translator) of certain point groups. The loaded representations were introduced into the discussion of crystal symmetries by G. Ya. Lyubarskii; they are dealt with in his textbook 'Group Theory and Its Application to Physics' (English translation from Pergamon Press).

If we call two momentum vectors equivalent when they differ only by a vector of the reciprocal lattice, the set of momentum vectors involved in a representation can be decomposed into equivalence classes. To each equivalence class, a stationary sub-group of the space group can be allocated. The representations of the space group can then be constructed simply by means of the representations, generally called 'small representations', of one of its stationary sub-groups. They are trivial and one-to-one related to loaded representations of the point group which corresponds to the sub-group.

Part two of the book contains tables of momentum vectors which characterize the equivalence classes and gives the corresponding stationary sub-groups. Parts three and four contain, respectively, single valued and, two-valued representations of the point groups in matrix form.

W. Rühl

New Foundations of Quantum Mechanics, by A. Landé (Cambridge University Press, 1965), is a lucid, demystifying and courageous attempt to sort out the jumble of pseudo-explanations, prejudices and valid ideas which underlie quantum mechanics and its teaching. The book is thoughtfully presented; at the end of each of the eight chapters there is a summary of its essential points. The style is lively and the book is pleasant to read.

The author's avowed aim is to solve what has for long been known as the 'Quantum Riddle', namely the derivation of quantum principles from the still more elementary foundations of pre-quantal physics without the aid of ad hoc assumptions.

While recalling that Einstein, in order to deduce his law of special relativity, had to apply invariance and symmetry postulates to a combination of mechanics and optics in which the velocity of light is the measure of space and time, the author deduces the different quantal rules as the necessary consequence of the application of general invariance and symmetry postulates to the structure of a metric of probabilities. This problem is dealt with in the chapters on 'Transition Probabilities' and 'Interference of Probabilities'. In these two chapters, Landé succeeds in overcoming his critical attitude to the unsatisfactory language used by the pioneers of quantum mechanics to express new ideas. In fact, he adopts (apparently involuntarily) a point of view already envisaged by Von Neumann on transition probabilities. Unlike his predecessor, he uses an extremely elementary mathematical formalism, which has the advantage of avoiding confusion while preserving the attractions of the method.

Let us follow the main stages of his argument. Starting with Leibniz's principle of continuity and the postulate that a test result is reproducible, he comes first to the theorem of two-way symmetry, which maintains that the probability that the state A of a system, certified by an A-meter, will change into a state B after measurement by a B-meter is equal to the probability of the opposite process. Then follows the non-quantal postulate that Nature prefers order to chaos; this leads him to construct a theorem of the interdependence of probability matrices (the so-called 'principle of superposition', which is too often used in text-books as a starting point, is then shown to be a special application of the theorem). Here he shows that a unitary transformation via probability amplitudes is the only possible way to connect the quantities P, positive probability and 'two-way symmetry'; in other words, unitarity is not the curious consequence of wave-particle duality, but the only possible way in which transition probabilities can satisfy an interdependence law.

The last step consists in showing that it is possible to derive the periodic form of the probability amplitude function and the need to use complex unitarity (and not real orthogonal transformations) from the postulate of the invariance of dynamics in relation to zero shift. It should be noted, however, that the author succeeds in demonstrating this highly intriguing point only for a pair of canonically conjugate variables by coming very close to the ad hoc procedure, and makes no general demonstration. Landé has then achieved his aim of deducing Planck's law on energy exchange and Sommerfeld-Wilson's law on the exchange of kinetic momenta from non-quantal considerations. It should also be mentioned that he rehabilitates, with a great flourish, Duane's rule concerning the variations of linear momentum in solids with spatial periodicity. This rule gives the author the opportunity to show that there is no need for 'wavicle' duality to explain the phenomena of diffraction by a crystal or a slit. He is, however, far from denying the practical aspect of wave formalism which, although it is not physical, can be used for many rapid calculations.

A large part of the book is devoted to a violent criticism of the philosophy of certain schools which, in Landé's opinion, try to reduce Science to a verbal exercise, paying no attention to the phenomena themselves but only to the way in which they are described. Among others, he quotes the Copenhagen school, for which the materiality of particles does not give an adequate description of phenomena, diffraction for instance. Heisenberg's probabilism, which he considers an excellent example of an idealistic conception of Nature, and the hydrodynamic models of Bohm, de Broglie and Vigier are also dissected. However, in the end, while rejecting the rigid attitude of Laplace's determinism, the author finds no way out of the empirico-critical impasse. The hidden purpose of the discussion seems to be Landé's desire to defend his method of approach to quantum mechanics, but this makes for heavy reading.

L.Dubal

Ionic Bombardment — Theory and Applications, International Symposium of the National Scientific Research Center, December 1962 (New York, Gordon and Breach Science Publishers Inc., 1964).

This book, which is of practical help to physicists engaged in the study of ionic bombardment in the energy range known as 'intermediate' (a few keV to 100 keV), is a collection of the papers presented by the most outstanding experts in this branch of solid state physics, at an international symposium organized in France by the C.N.R.S. at the end of 1962.

The research in this field can be divided into two categories:

— the first, experimental, is the study of how to produce and control ion beams of intermediate energy, and to use them to examine their physical and chemical effects on a wide range of materials, which may be divided into three types — metals, semi-conductors and insulators.

— the other, more theoretical, is the study of the fundamental mechanisms of the interaction of ions and matter, and particularly the energy exchanges between the incident ions and the crystal lattice.

An extremely well written introductory article provides the uninitiated with a clear and concise description of the main factors affecting the result of ionic bombardment of a solid surface, and of the effects of such bombardment and the ways in which they have been applied. These effects may be divided into purely physical effects, and chemical and physico-chemical effects.

Some of the applications based on the physical effects of ionic bombardment are: the cleaning of surfaces in a controlled atmosphere, or under vacuum or ultra-high vacuum, the preparation of very thin films, the study of recrystallization, crystal faults, sliding planes and diffusion between two metals. By using an ion beam which is also capable of reacting chemically with the atoms or molecules of the target material, one can for instance oxidize metal surfaces in a few seconds or neutralize certain metals to obtain a surface which resists oxidization (bombarding an aluminium surface with a helium beam gives a kind of 'alloy' coating which has great resistance to oxidization). The chemical effects of this type of ionic bombardment are also used to improve certain properties of textiles and synthetic fibres, such as resistance to wear, colour-fastness and dimensional stability.

The book also gives numerous results, unfortunately sometimes contradictory, concerning cathode-sputtering coefficients as a function of the type, energy and angle of incidence of the ion beam, and also some data on the energy spectra of the ejected atoms. The text is illustrated by some excellent photographs of surfaces subjected to various types of ionic bombardment, which make many of the articles easier to read. Every article is followed by a lively and sometimes very long discussion, which often throws more light on certain aspects of the problems.

To read this book, including the final remarks, is to realize that in the field of the solid state physics of surfaces, discoveries are still being made and that many of the phenomena are not yet understood.

From a theoretical point of view, the calculations are always based on models which are simplified representations of the supposed mechanisms of cathode sputtering. Numerous models have been proposed and all the resulting theories agree roughly with experiment, if one restricts oneself to a consideration of the general behaviour of the cathode sputtering coefficients as a function of the main parameters (such as the mass of the target atoms and of the ions, and the energy and angle of incidence of the ion beam). In no case, however, do the formulae give the absolute values of these coefficients. Experimentally there is still considerable disagreement over the results obtained. For example, in the case of the variation of the cathode sputtering coefficient as a function of the angle of incidence, a speaker reported that his results showed a very pronounced maximum at an angle of 75°. One of the audience objected that his own measurements showed that the coefficient increased continuously until grazing incidence was reached. The answer was simply: 'Our measurements were made every 5° from 45° to 85°'. No firm conclusion can therefore be reached at this stage.

To sum up, this book on ionic bombardment will give the uninitiated a good knowledge of the subject without too much effort, and give the initiated a more wary attitude to what he already knows.

R. Rohrbach

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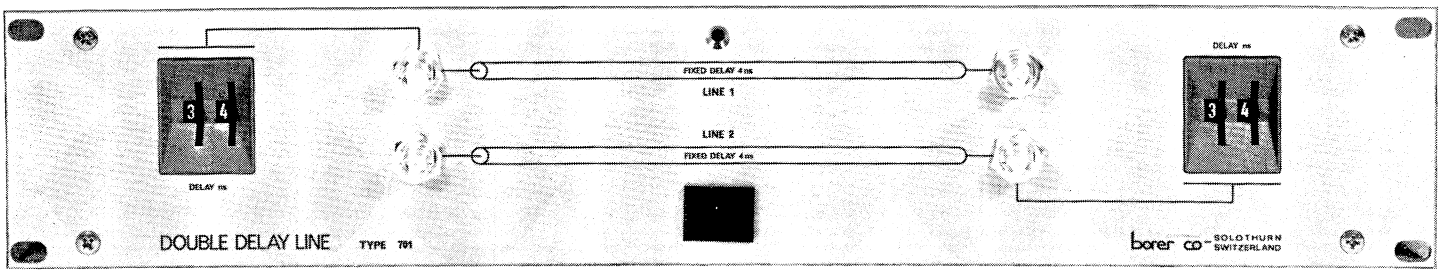

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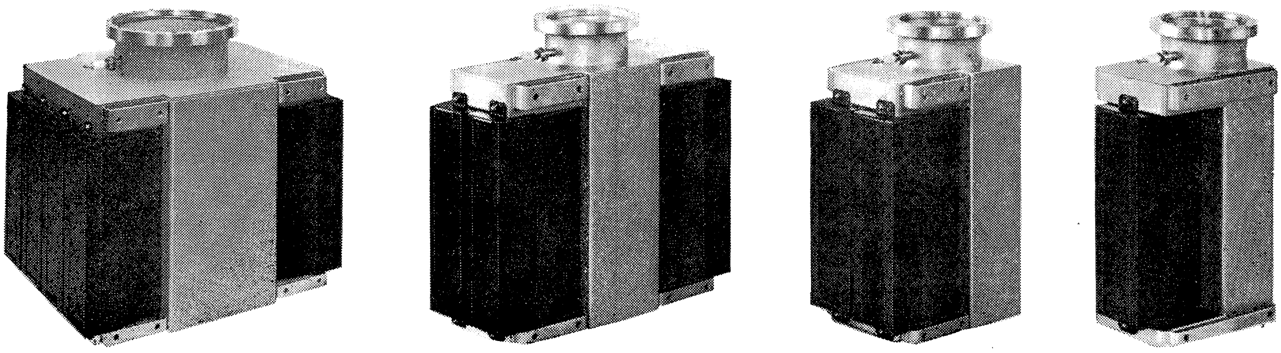

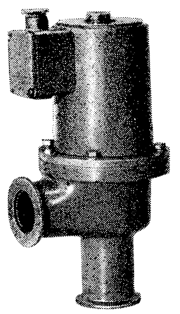

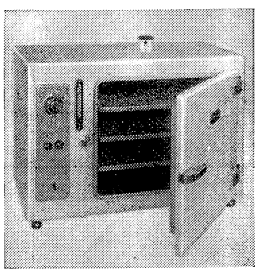

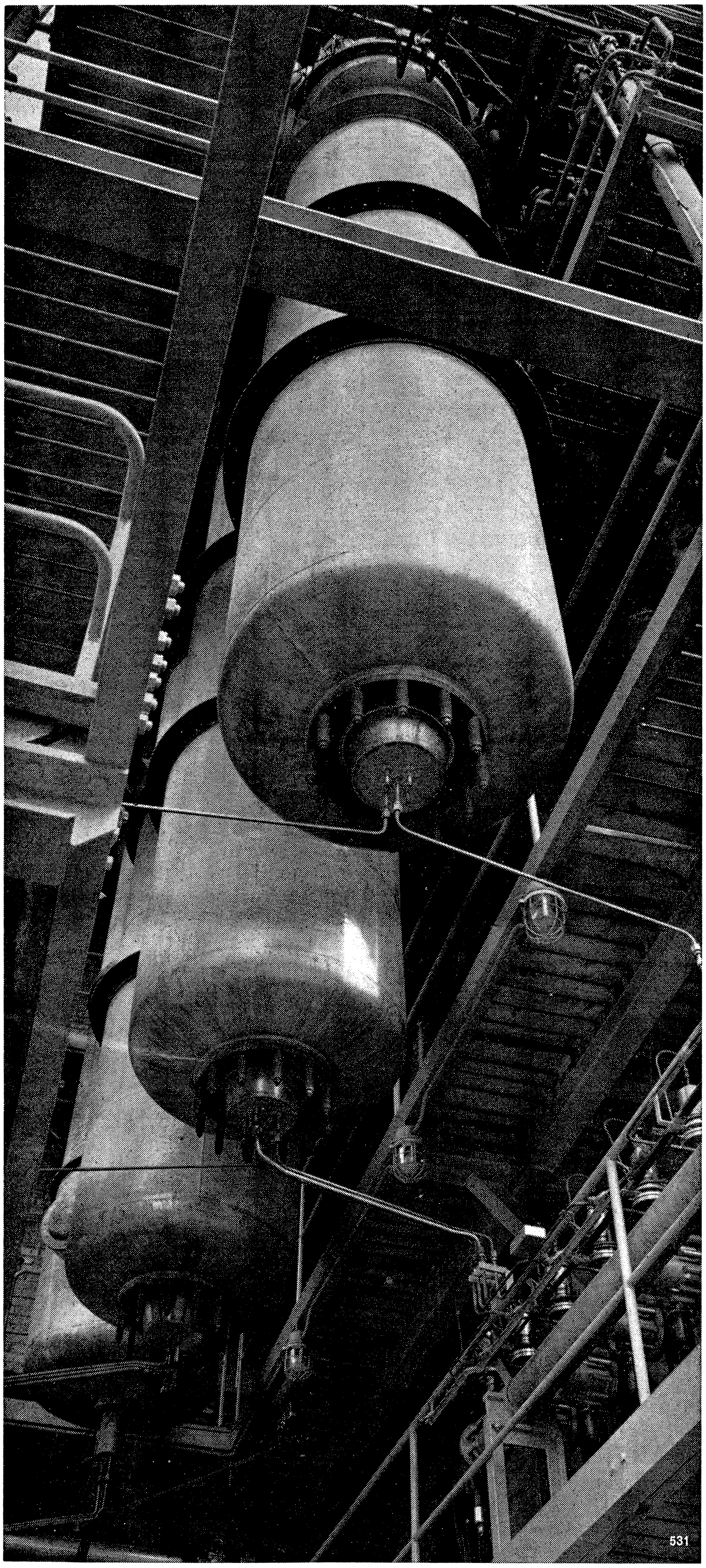

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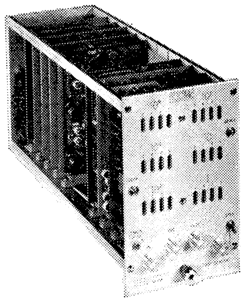

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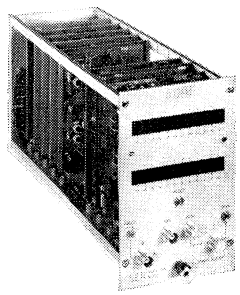

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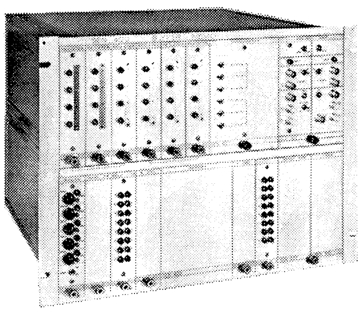

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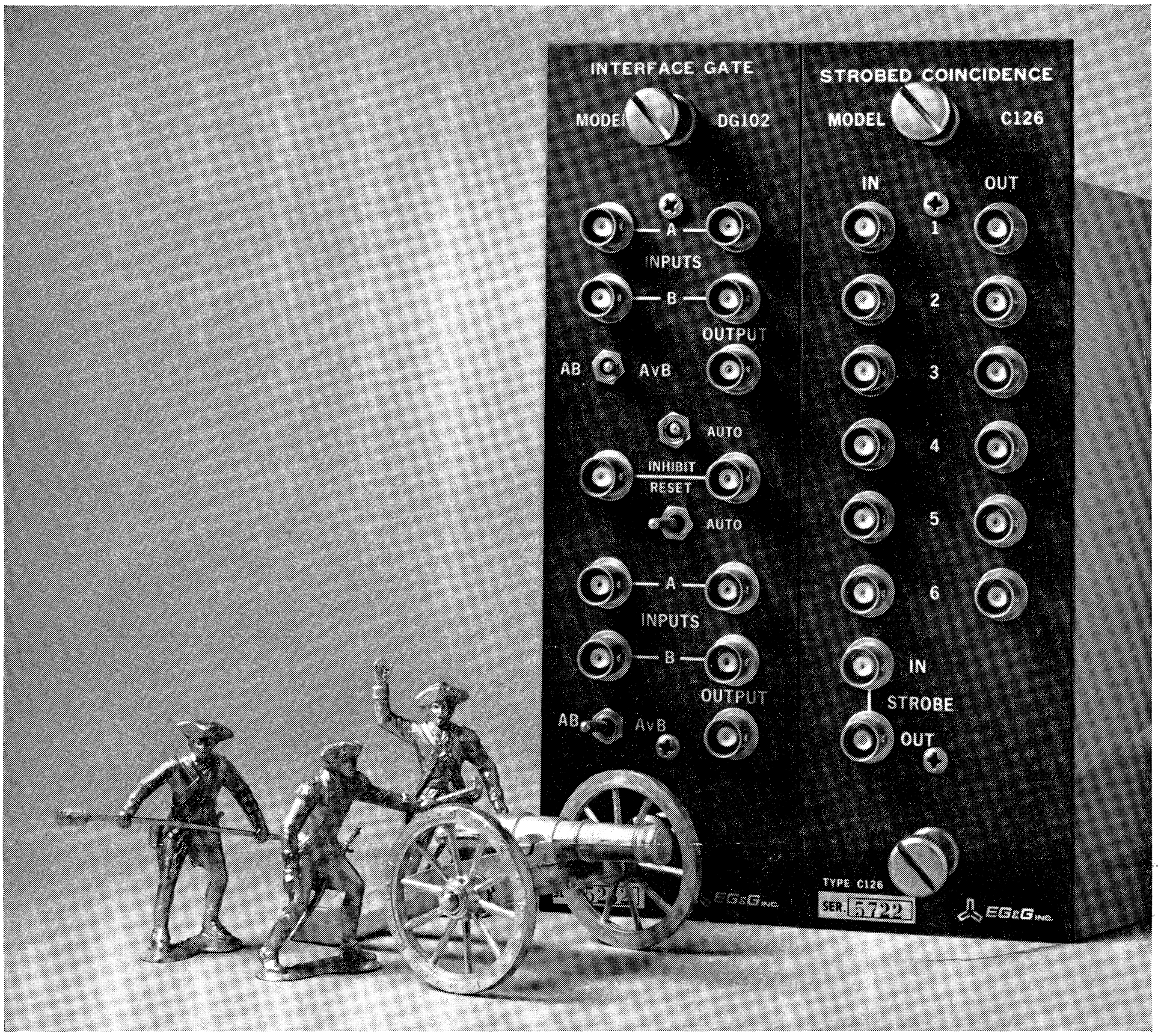

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