CERN COURIER

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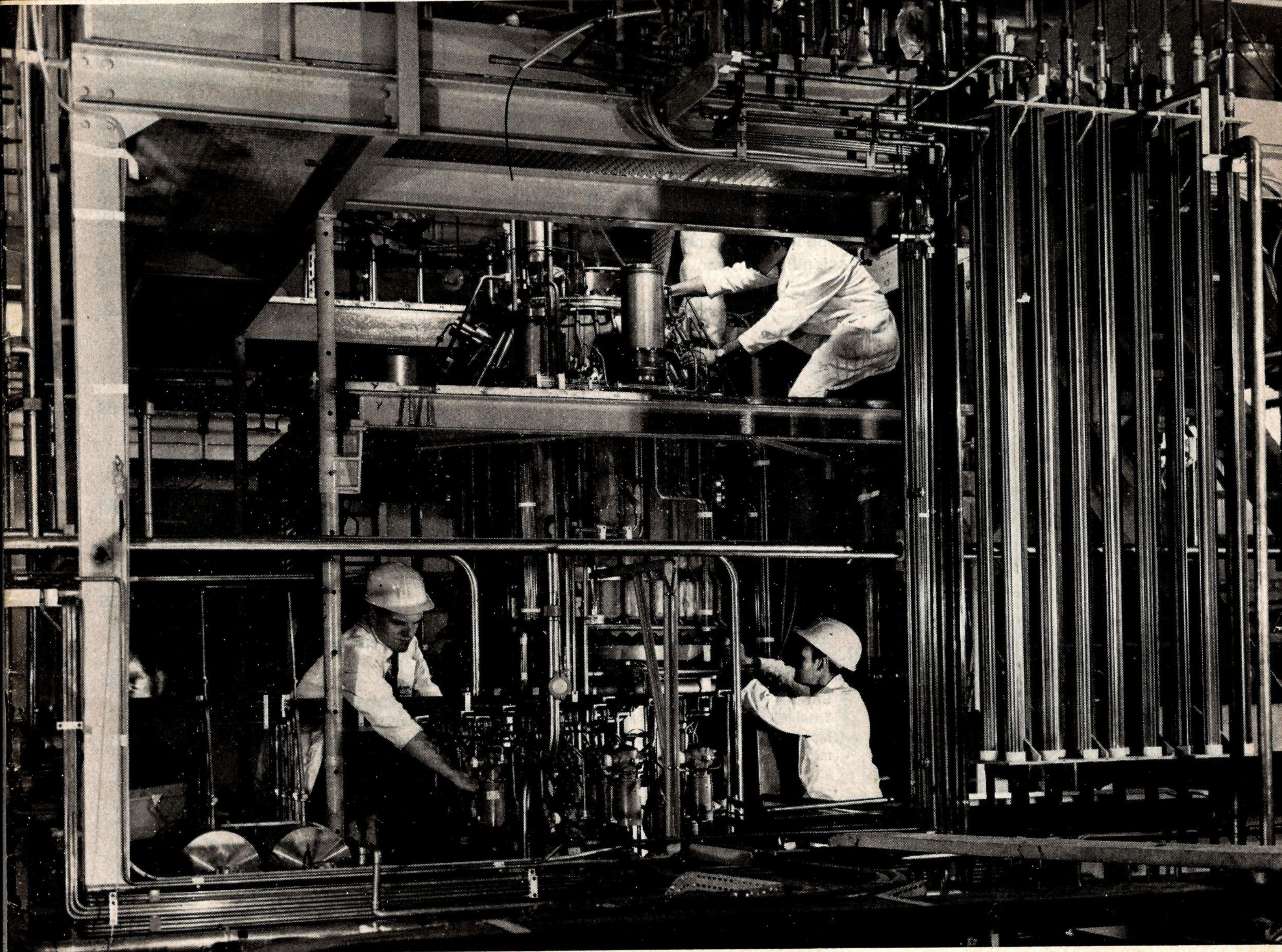
European Organization for Nuclear Research



CERN, the European Organization for Nuclear Research, was established in 1954 to '... provide for collaboration among European States in nuclear research of a pure scientifice and fundamental character, and in research essentially related thereto'. It acts as a European centre and co-ordinator of research, theoretical and experimental, in the field of sub-nuclear physics. This branch of science is concerned with the fundamental questions of the basic laws governing the structure of matter. CERN is one of the world's leading Laboratories in this field.

The experimental programme is based on the use of two proton accelerators — a 600 MeV synchro-cyclotron (SC) and a 28 GeV synchrotron (PS). At the latter machine, large intersecting storage rings (ISR), for experiments with colliding proton beams, are under construction. Scientists from many European Universities, as well as from CERN itself, take part in the experiments and it is estimated that some 1200 physicists draw their research material from CERN.

The Laboratory is situated at Meyrin near Geneva in Switzerland. The site covers approximately 80 hectares equally divided on either side of the frontier between France and Switzerland. The staff totals about 2650 people and, in addition, there are over 400 Fellows and Visiting Scientists.

Thirteen European countries participate in the work of CERN, contributing to the cost of the basic programme, 235.2 million Swiss francs in 1969, in proportion to their net national income. Supplementary programmes cover the construction of the ISR and studies for a proposed 300 GeV proton synchrotron.

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Comment

In 1935 Julian Huxley was elected Secretary of the Zoological Society of London, a post which gave him responsibility for the London Zoo. For the next seven years his reign was distinguished not only for the quality of the scientific research centred on the Zoo (which was well within his province as an eminent zoologist), but also because he opened the doors of the Zoo to the public. He was driven by the conviction that in animal behaviour there is fascination and beauty which is accessible to all.

Exhibitions and lectures were multiplied. Books and pamphlets were prepared. A 'Zoo magazine' was started rising to a circulation of 100 000. A Public Relations Officer was appointed and a Press Conference was held every morning so that hardly a day went by without some story of the London Zoo animals in the papers. Artists and photographers were encouraged to make full use of the Zoo.

The aim was to make the Zoo 'the centre and focus of popular interest in every aspect of animals and animal life — scientific, artistic, literary'. The success can be judged in several ways. An immediate effect was that the number of visitors rocketed (and so did the money from entrance fees made available for research). The Zoo became part of national life. Less tangible, but probably of deeper significance was the effect on public opinion. The policy of Huxley helped to generate an awareness and love of animals which may well have been vital in providing a climate of opinion in which conservation schemes to protect wild life could be promoted and could get political backing.

Huxley's policy did not go unopposed. The more conservative zoologists resented the public interest in animals and the intrusion into what had been virtually exclusively their domain. They finally succeeded in manoeuvering Huxley out of power in 1942 but by then the doors of the Zoo could not be closed. (However, they did serve to release Huxley to bring his touch of genius to the first two formative years of UNESCO (1946-48) as Director-General.)

On page 70, Yuval Ne'eman opens the

Contents

Cover photograph : Servicing the one-metre model. The model has been in operation since June of last year to test several features of the design of the large European Bubble Chamber. Experiments are being carried out on thermodynamic properties, on bright-field illumination, and on a laser beam system of fixing fiducial marks. (CERN/PI 97.10.68) doors of the Particle Zoo in an excellent article on 'the strongest force'. Particles are not as accessible as animals but it is possible to get across much of the fascination of particle physics.

Particles are not the exclusive property of high energy physicists. On the contrary, there exists almost a moral obligation to open the doors of the Zoo to the people who are paying for the research. But perhaps a more telling argument is one of self-interest.

There are indications of a widespread and growing disenchantment with science at present. The best documented measure of this is the rapid drift away from science among young people selecting the field for their further education. Science is losing its appeal. Another sensitive sign is the declining amount of space given to science topics by the newspapers. Editors are judging that science is of less and less interest to the public. Political decisions and budgets often reflect situations like this fairly rapidly.

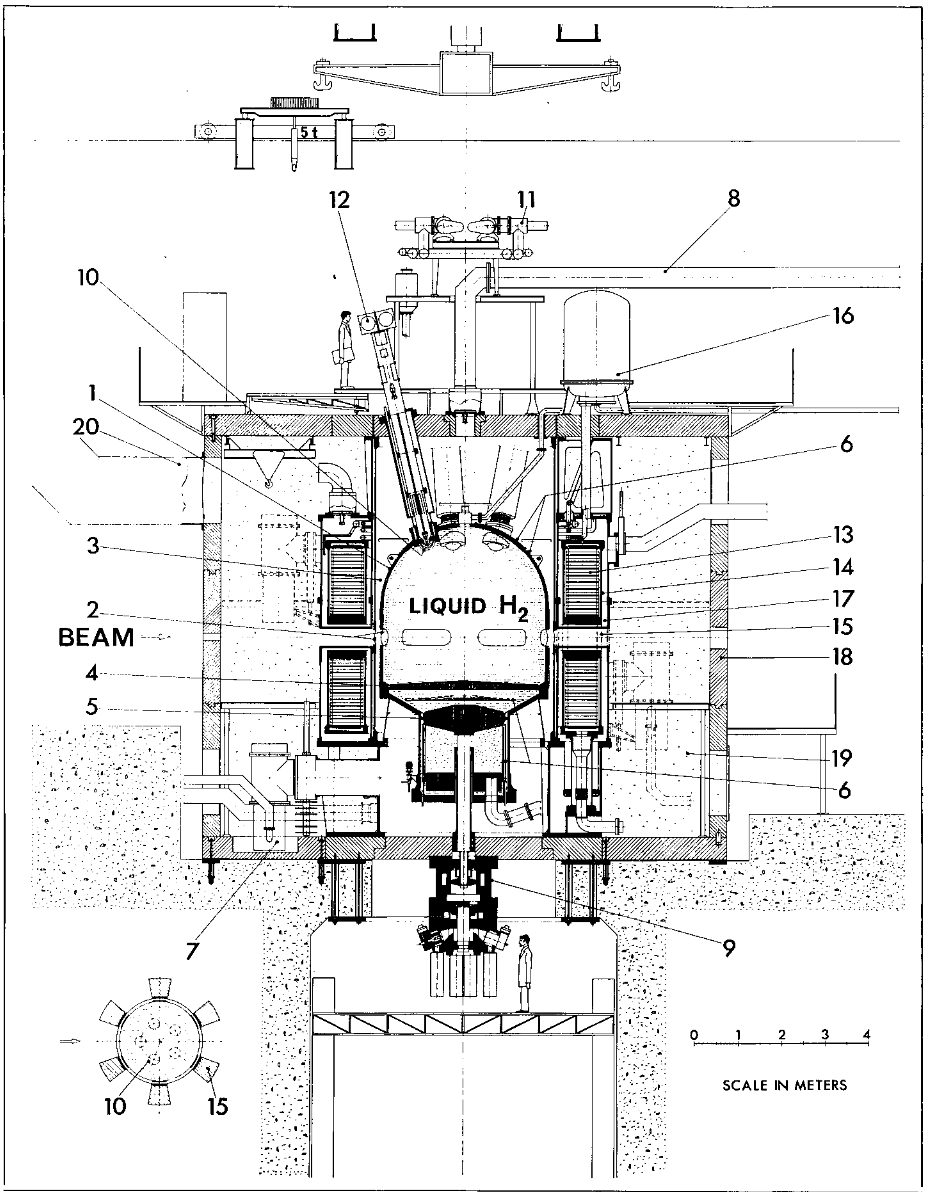
Unless scientists are prepared to come out of the ivory tower onto the soapbox they may find too late that the foundations of the tower are crumbling.

BEBC Progress

In June 1967 the CERN Council approved the proposal to construct a large hydrogen bubble chamber for use at CERN. It became known as the large European Bubble Chamber (BEBC), the project being carried out jointly by the Federal Republic of Germany, France and CERN.

The initial proposal was for a 3.5 m diameter chamber having a volume of 30 m^3 (20 m^3 of 'useful' volume) with a superconducting magnet to produce a field of 35 kG. Later, certain minor changes were made to the design and it proved possible to increase the diameter to 3.7 m, thereby giving a total volume of 33.5 m^3 (21.5 m^3 of useful volume).

For more than a year final design work was done and at the end of 1968 the main parameters were 'frozen'. Invitations to tender for the major components were sent to potential suppliers and the adjudication of contracts took place at the Finance Committee meetings on 4 February and 11 March. This seems therefore an appropriate time to up-date the information carried in the previous CERN



The final design of the 3.7 m d'hydrogen bubble chamber :
1) chamber body
2) beam windows
3) vacuum tank
4) separation disc
5) piston
6) exchangers
7) secondary vacuum pumps
8) vacuum chamber vent
9) expansion motor
10) fish eye
11) fish eye pumps
12) film magazines
13) superconducting coils
14) cryostats
15) coil spacers
16) helium buffer volume
17) magnet vacuum enclosure
18) magnetic shield
19) nitrogen
20) magnetic shield vent

Samples of superconducting strip

— Sample	1	2a	2b	3	4	5	6
— Stabilizer	Al+Cu	Al+Cu	Cu	Cu	Cu	Cu	Cu
— Cross-section of superconductor (mm^2)	0.059	0.035	0.03	0.032	0.09	0.44	2
— Number of strands	79	260	260	224	116	54	18
— Weight of superconductor (g/m)	28	51	42	43	67	156	235
— Current density in superconductor at nominal current (A/mm^2)	1500	780	730	790	550	240	160
— Cross-section of stabilizer (mm^2)	130	160	157	177	172	159	143
— Resistance of stabilizer in zero field and no stress (10^{-8} Ω cm)	0.6	1	1	1.16	0.6	0.9	1.33
— Weight of conductor (g/m)	673	840	1600	1620	1600	1580	1515
— Total length of conductor (km)	52.5	52.5	65.5	65.5	65.5	65.5	65.5
— Length of strip without welds (m)	1560	1560	1560	780	180	130	200
— Critical current in parallel field of 51 kG and perpendicular field of 38 kG (kA)	8	8	6.45	6.45	6.45	6.45	6.45

1.	CGE	Centre de Recherches de la Compagnie Générale d'Electricité (F.)
2a, 2b.	CFTH	Compagnie Française Thomson-Houston (France)
3.	SSW	Siemens-Schuckert-Werke (Federal Republic of Germany)
4.	BBC	Brown-Boveri (Switzerland)
5.	IMI	Imperial Metal Industries (United Kingdom)
6.	SUP	Norton International Supercon Division (USA)

Left : A table of parameters of the seven types of superconducting strip considered for the magnet of the 3.7 m chamber.
Right : A photograph of the samples showing the disposition of the superconducting filaments in the stabilizer.

COURIER article (the project was described in detail in vol. 7, page 143) and to mention the work carried out using Braracourcix (the magnet test assembly) and the 1 m bubble chamber model.

To recap very briefly the main features of the design : The chamber itself is a vertical cylinder 3.7 m in diameter and about 2 m high with a rounded dome on top where four cameras look through fish-eye lenses. At the bottom of the chamber is the piston and expansion system which produce the voulme changes needed for the formation of bubbles in the tracks of charged particles.

The chamber will be filled with 33.5 m^3 of liquid hydrogen and surrounded by a vacuum tank. Outside this is the superconducting coil to give a magnetic field of 35 kG at the centre of the chamber. It is immersed in a cryostat containing liquid helium to achieve the very low temperature at which the coil is superconducting. Surrounding this whole assembly is a magnetic screen which shields the high stray magnetic field coming from the coil.

Design Changes

One of the important changes concerns the vacuum tank which surrounds the bubble chamber. It has been extended at the top so that it forms a cylinder reaching to the magnetic screen on the floor and ceiling. This has resulted in more convenient access to the dome of the chamber and in fewer apertures into the tank.

Another change is the decision not to ventilate the space between the magnetic screen and the vacuum tank, but to fill it with nitrogen which further helps to reduce the explosion hazard. An operator, specially equipped, can enter the space for exceptional work.

A third change concerns the emergency evacuation system for the 33 m^3 of liquid hydrogen in the chamber. Part of the liquid will be heated and fed into inflatable balloons.

A hybrid solution has been selected for the refrigeration systems rather than having two separate classical refrigerators — one for the hydrogen of the chamber, the other for the helium of the magnet. Instead, the helium system has been increased in capacity and the hydrogen cooling will be achieved in a heat exchanger through which liquid helium is circulated. This novel solution will probably cost less than the classical solution and has the particular advantage that the hydrogen plant is reduced in size and complexity which further reduces the risk of explosion.

Contracts

Four major contracts have been awarded by the Finance Committee.

1. Superconducting strip

65 km of superconductor is required to wind the coil. Superconducting filaments of niobium-titanium alloy are embedded in a copper strip (61 X 3 mm^2) to carry a current of about 7000 A.

The contract is being divided between Siemens (Federal Republic of Germany) and Thomson-Houston (France) ; the characteristics of the strip supplied by each of the manufacturers being identical.

The total value of the contract is 7.7 million Swiss Francs (3.65 MSF to each firm) and delivery will be spread over the period September 1969 to June 1970.

2. Stainless steel vessels

This contract concerns the supply of the various tanks of the chamber involving 350 tons of steel. It has been divided into two parts

- the body of the bubble-chamber and its vacuum tank
- the cryostats for the superconducting coils and their vacuum tank.

The tanks measure between 3.7 m and 6.5 m diameter and are up to a height of 5 m. The tolerances on machining and surface finish are particularly stringent, to ensure that the tanks are leak-proof with liquid hydrogen and helium. Welding of thick stainless-steel plates presents some difficulty to manufacturers. At low temperature, the weld seam must have a high mechanical strength and good ductility in order to withstand the stresses which arise from the pulsing of the chamber. Furthermore, the maximum ferrite content of the welds has to be restricted to less than 2 % to avoid perturbing the magnetic field.

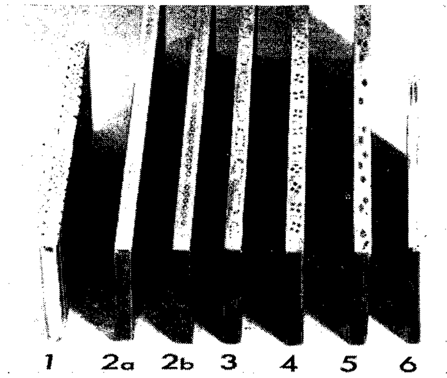
A contract worth 2.7 MSF for the chamber and vacuum tank has been awarded to Thyssen (Federal Republic of Germany) and another worth 3.3 MSF for the cryostats and vacuum tank, to Alsthom-Neyrpic (France). Delivery will be phased between April and November 1970.

The welding processes proposed by these firms are not identical : Thyssen's is automated whereas Alsthom-Neyrpic's is manual. In both processes the welds are subjected to an on-line X-ray or ultrasonic inspection. Alsthom-Neyrpic is at present developing a process for welding very thick components by electron bombardment. This is much faster (1 m per minute, compared with 1 m per 25 hours) and neater than the manual process but calls for considerable accuracy when machining components before the weld. This process will be used if perfected in time.

3. Refrigeration plant

The plant is required for :

- purification and liquefaction of the helium and the hydrogen for the magnet and the chamber
- cool-down of the magnet and chamber from room temperature to operating temperature
- steady-state refrigeration



— warm-up of the chamber and magnet.

The contract has been awarded to Sulzer (Switzerland) at a price of 5.02 MSF. The plant is to be ready for operation by 31 October 1970.

4. Magnetic shield

The magnetic shield consists of nearly 2000 tons of cast steel to contain the stray field of the superconducting coil.

The contract was awarded to CAFL (France) for 3.74 MSF. Delivery will be phased between January 1970 and February 1971.

Superconductor tests

The superconducting magnet for the chamber is the largest of its type yet to be built, both in magnetic field intensity and in size. The coil has no iron core and will produce a field of 35 kG in the chamber. (A superconducting magnet of similar size with an iron core, producing a field of 20 kG, is now being brought into operation at Argonne.)

A conventional magnet could have been used for the chamber but power considerations have been the determining factor in the selection of a superconducting magnet. A conventional magnet would have required 57 MW of power (twice CERN's present electricity consumption !) including 1.2 MW for cooling ; the superconducting magnet will need less than 1 MW, almost entirely for cooling since losses in the superconductor, and its connections and leads, will be only 200 W.

The comparison of 56 MW against 200 W speaks for itself. Although a superconducting coil is more expensive to manufacture, this is soon offset by the reduced consumption ; 5 000 hours operation of a conventional magnet would cost 17 MSF, whereas the superconducting magnet will cost 0.6 MSF.

In May 1968, the first specification for the strip was issued.

In the light of the replies, received in July 1968, it was decided to reduce the cross-section from 88 X 3 mm to 61 X 3 mm to lessen the coil-winding problems. A second invitation to tender was sent in October 1968. CERN received seven samples of superconducting strip two of which were aluminium-stabilized and the remainder copper-stabilized. Most of these samples were tested at CERN in the 60 kG BRARACOURCIX magnet test assembly (see CERN COURIER vol. 8, page 23). The table on page 64 gives the basic details of the seven samples considered.

Important criteria for selection of the strip were :

1) a minimum number of welds per 'pancake' i.e. per 1600 m of strip wound into a flat coil ;
2) the Nb/Ti alloy must be isotropic as far as the magnetic field was concerned (wires with a circular cross-section were best in this respect) ;
3) the bond between conductor and copper must be good ;
4) the mechanical strength must be high. (Owing to the magnetic field, the forces on each turn of the pancake winding are very great. The tensile load on the strip at the most highly stressed points is about 10 kg/mm^2. The vertical force of attraction between the two halves of the coil will be 9 000 tons.)
5) cost

The winding configuration has been based particularly on studies done at Brookhaven on which CERN did some further research, and on research done by two European firms, l'Air Liquide (France) and British Oxygen (UK). These studies were concerned, in particular, with the influence of the winding configuration on the dissipation of heat.

The development of satisfactory superconducting strip has required some major research in European industry and CERN has benefited from excellent cooperation with the firms who responded to the challenge of the specification.

The 1 m model

Experiments with the 1 m model of the large bubble chamber, which has many of the features of the final design (except for the magnet) have been under way since June 1968 (see CERN COURIER, vol. 8, page 129).

A great deal of information has been obtained, most of the proposed methods have been confirmed and, in a few cases, better methods have been found. A rapid survey of the various investigations follows:

Use of Scotchlite : all doubts concerning the clarity of particle tracks when Scotchlite is used with a considerable depth of hydrogen have been removed.

Bubble formation : photography against a bright background means that pictures cannot be taken until the bubbles have reached a size of at least 600 μ as against about 300 μ in conventional chambers. The longer growth time increases the likelihood of drift and prejudices the accuracy of measurement. However, by operating with a lower hydrogen temperature (25° K rather than the normal 26° K) the rate of bubble formation is increased.

Most of the photographs in the model were taken at 25° K and the period before bubbles measuring 600 μ were obtained was 2 to 3 ms.

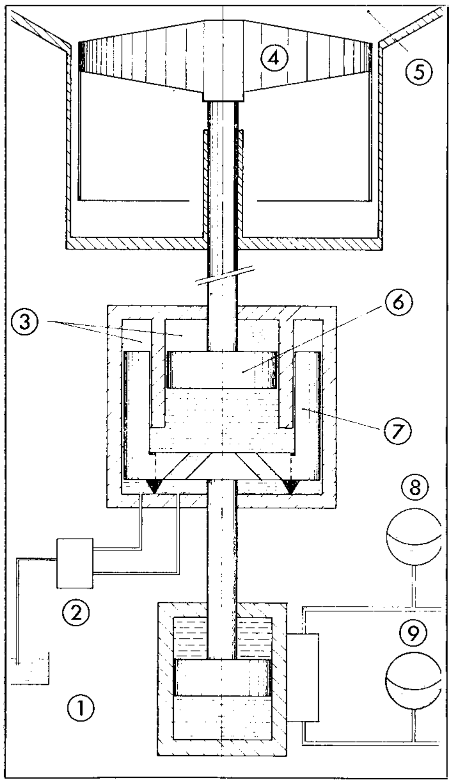
Refrigeration : operation at these low temperatures was made possible because of the excellent operation of the heat exchangers, of the configuration of the chamber, and of the proper sealing of the piston which reduced the formation of parasitic bubbles. The experiments on the model show that it will be possible to operate the large chamber with a reasonable refrigerating capacity, even with a relatively slow expansion (40 ms or more) and a high repetition rate (2 Hz or more).

Turbulence : thermal properties were studied using measurements of the deflection of a laser beam with thermal gradients in the model, and photographs of the laser beam and of a straight line on the bottom of the chamber.

It was noted that thermal turbulence was very slight during the expansion, and appeared only after 40 ms (well after the photograph would be taken).

Fish-eyes : after a long series of static tests, the hemispherical windows (fish-eyes) were fitted to the chamber for the first time. The joints, secured with an epoxy/aluminium adhesive, remained perfectly sealed and this simple method will be adopted for the large chamber.

There was slight difficulty from a minor leak in the external piping which allowed traces of nitrogen to enter. These condensed on the inner surface of the fish-eye giving rise to some parasitic diffusion of the light. This type of deposition on the fish-eyes is one of the occupational hazards of those working with bubble chambers. It is usually necessary to



Schematic diagram of the expansion system :
1. Energy make-up system
2. Lock up
3. Gas springs
4. Cold piston
5. Chamber
6. Driving piston
7. Counter-weight
8. Accumulator (high pressure)
9. Accumulator (low pressure)

evacuate the chamber and heat it to get rid of the deposit.

Advantage was taken of this incident to try a method of fast cleaning. The fish-eyes are connected to a vacuum system separate from that of the chamber. It is thus possible to fill the space between the fish-eyes with gaseous helium without breaking the main vacuum and without evacuating the chamber. All that is necessary is to lower the level of the hydrogen to just below the fish-eye so that a current of warm helium can evaporate off the condensed nitrogen. The operation took fifteen minutes at the most.

Other systems : experiments with the model have also confirmed the usefulness of mounting the piston at the bottom, and have served to perfect the main components of the expansion, monitoring and remote-control systems.

Finally, experiments on the model have helped to familiarize the team with some of the novel features of the large chamber; the experience gained will be invaluable when the 3.7 m is brought into operation.

Expansion system

Experiments on a reduced-scale prototype of the expansion system will begin in May. They will serve in particular to test the features of the system which differ from those in use on the currently operating chambers.

The dynamic forces generated by the movement of the expansion system of a bubble chamber at each pulse can cause considerable vibration because the masses involved (piston and liquid) can be considerable and because the cycling times are very short (of the order of 40 ms). In the 3.7 m chamber, the moving masses amount to close on two tons, added to which the stroke of the piston is 145 mm to produce the required 1 % change in volume of the liquid hydrogen, with a pulse duration of about 40 ms. This will produce a dynamic force of 345 t.

Special measures have to be taken to reduce the effect of forces of this magnitude. A system, rather similar to that in a recoilless cannon, will be used. It involves using a counter-weight equal in mass to the piston, which is hydraulically connected to the piston via a volume of oil so that it follows any movement of the piston travelling parallel to it in the opposite direction. There is then no dynamic force due to the piston-counter-weight system transmitted to the surroundings. The remaining dynamic force will be about 140 t, due to the movement of the mass of liquid inside the chamber itself. This is an acceptable figure.

The hydraulic equipment, many parts of which are being supplied by outside industry, will be assembled at CERN. The main components are scheduled for delivery in April 1970 and testing will begin towards the end of that year.

Construction

Construction of the buildings for the BEBC is well advanced. The connecting hall between the large West experimental hall and the bubble chamber building itself is almost complete and will be used as from the beginning of May for the installation of the equipment to wind the coils of the superconducting magnet. The office and laboratory building is scheduled for completion in July so that the group involved in the project can move across to accommodation near the bubble chamber building ready to work on components as they arrive. Construction of the bubble chamber building and the buildings to house the refrigeration equipment is in progress.

The chamber is scheduled to come into operation in 1971.

CERN News

Council meeting cancelled

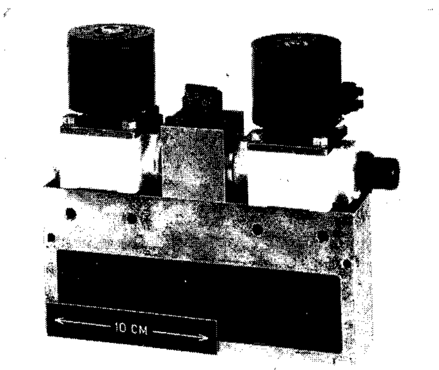
The Council meeting scheduled for 12, 13 March was cancelled. It has proved necessary to re-organize the programme for the outstanding decisions on the 300 GeV project. Since the decisions have to be rephased there was no need for the special Council meeting in March. The next Council meeting will take place as usual in June (19, 20).

2 m double pulsing

On 13 March the 2 m hydrogen bubble chamber was operated twice during a single cycle of the proton synchrotron for the first time. This new possibility in the operation of the 2 m chamber will enable some experiments to collect their data more quickly.

9 GeV pions were used in the tests. They were produced by 15 GeV protons from the synchrotron, taking one proton bunch for each bubble chamber pulse and after feeding the 2 m bubble chamber, the synchrotron energy was raised further to supply particles to other experiments (see diagram). Following the modifications which have been carried out on the chamber and its ancillary units, it could pulse four times per accelerator cycle but, with the present operating conditions, this would mean that the bubble chamber would be the sole user of the machine.

Preparation of the chamber for double pulsing began in June 1967 and the necessary modifications in the chamber itself took place during the 1968 annual shutdown of the synchrotron. Other modifi-



CERN/PI 126.3.69 1.

1. The new film transport unit in use for double pulsing the 2 m chamber. It enables film to be advanced twenty times faster than before so that pictures can be taken at 85 ms intervals. The black cylinders shield the pneumatic units from the magnetic field.

2. The magnet cycle of the PS during double pulsing of the 2 m chamber. The two bursts of protons are extracted at 15 GeV on the first 'flat-top'. The field is then increased to 19 GeV to feed the heavy liquid bubble chamber and finally to feed electronic experiments.

3. Protons, coming from the synchrotron on the left, pass through the target, where about 20 % of them interact (in the particular case of the e5 beam). The remaining protons go off to the right to feed other experiments. The solid lines represents the paths of the proton beam and the thin lines the paths of the secondary beams (the angle between them has been exaggerated for clarity). The continuous thin line is the path of the beam of negative secondary particles (now being used). The thin dashed line indicates the path of positive secondary particles, though positive secondary beams have not yet been called for.

cations were completed recently. They included :

1. A new film transport system which advances the film from one frame to another in 85 ms. The film movement is achieved using a block 25 mm thick pierced by many tiny holes through which a suction of 0.8 kg/cm^2 is applied to the film. This block is made by welding together hundreds of tiny hollow glass tubes, then cutting a slice through them and polishing. This method of construction enables the suction to be applied over 40 % of the surface compared with the usual 3 %.

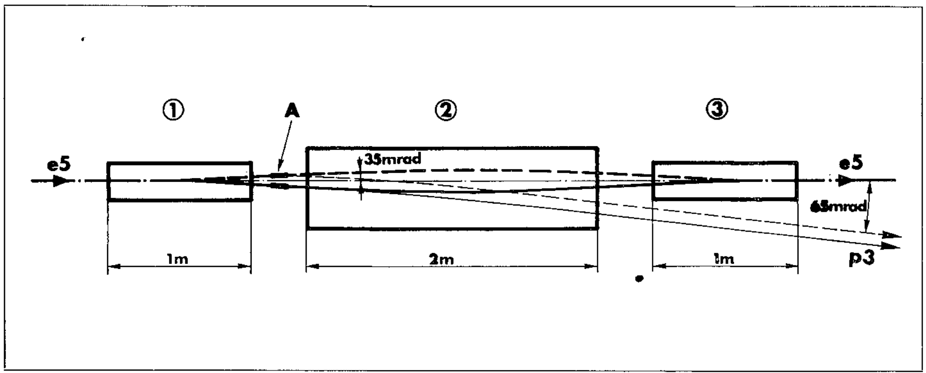
Another change in the film system is that the size of the reels has been doubled so that the rate at which they are changed remains the same.

2. Tests carried out in 1967 showed that the existing flash-tubes could be used to illuminate the chamber during fast cycling. It was necessary however to modify the electrical system powering the tubes (for operation after an interval of 80 ms), to add fins to cool the tubes and to cycle the gas (argon-helium) in the tubes for cooling and for filtering off evapoured tungsten from the electrodes.

3. New electromagnetic valves and new control circuitry have been fitted to the expansion system.

4. More powerful heat exchangers have been installed to reliquify the hydrogen bubbles without altering the percentage volume change in the chamber by increasing the movement of the piston. (Other multiple-pulsing chambers have increased the piston movement.)

During the double pulsing tests the on-line computer in the bubble chamber control room was in use (see CERN COURIER vol. 7, page 181). It served to monitor the parameters of the chamber and of the beam feeding it, to keep watch on safety conditions and to log data. The computer also helped to control the quality of the photographs by controlling parameters of the pressure cycle in the chamber.



3.

Wobbling orbit

A simple method of deriving a secondary particle beam from a target part way along an ejected proton beam-line is being used on the slow-ejected beam e5 in the East experimental hall. The beam collides with target A where a secondary beam, p3, is produced and then continues to bombard two other targets positioned further into the hall.

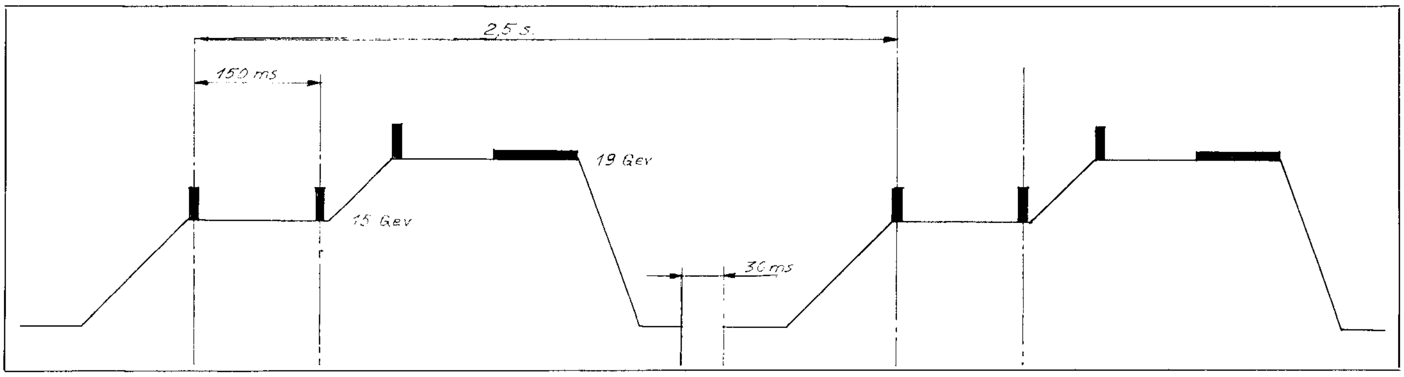
The advantages of the method (known as the wobbling orbit since the path of the proton beam is 'wobbled' through a system of three magnets) are simplicity, production of high energy secondaries in the forward direction or at small angles, good angular acceptance (there is a quadrupole close to target A), and high efficiency in the use of the accelerated protons.

The method involves positioning the target between two magnets as indicated in the diagram. The first magnet deflects the proton beam so that the secondary particles produced in the target have already a forward direction tending to take them out of the direction of the primary beam. This is supplemented by the effect of the second magnet while the remaining component of the proton beam is restored to its former direction by the effects of magnets two and three. Depending upon the sense of the fields in the magnets a positive or a negative beam of secondary particles can be drawn off.

The wobbling orbit method is currently yielding negative particles for the p3 beam-line while the proton beam continues to yield four further secondary beams.

Transforming currents

One of the most popular ways of measuring beam intensities in particle accelerators is to use a 'beam current transformer'. In

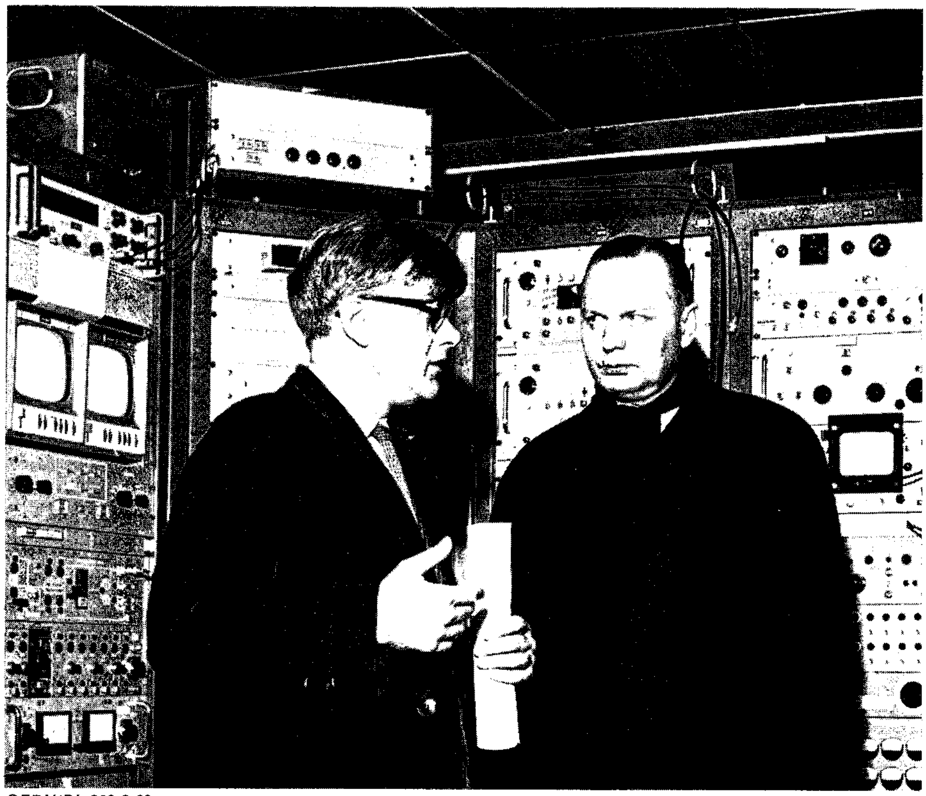


2.

Visitors to CERN during the past month included : Top photograph — Dr. G.H. Veringer (right), the Minister for Education and Sciences of the Netherlands with the Director-General Professor B. Gregory (centre) and Professor H.B.G. Casimir.

Bottom photograph — Ambassador J. Boyesen, (right) the new Norwegian delegate to the CERN Council with Dr. K. Johnsen, Director of the ISR Construction Department.

CERN/PI 55.3.69 2.



CERN/PI 282.2.69 3.

these devices the particle beam passes through the centre hole of a toroid of high permeability acting like a single-turn primary winding of a transformer. A signal proportional to the beam intensity can then be obtained from a secondary winding, usually of many turns, wrapped round the toroid. This type of beam monitor has the advantages that it does not interfere with the beam, can be easily calibrated (with an additional calibration winding on the toroid) and is capable of high accuracy.

The beam current transformer is basically a very simple device but in its simple form it has severe limitations. It is not very sensitive and will respond only in a restricted frequency range. To overcome these limitations, electronic circuits of considerable sophistication have been developed for use with the transformers. CERN has probably put more effort into these techniques than other Laboratories and some excellent results have been obtained.

At the CERN proton synchrotron beam current transformers are in use on the injector, on the main ring, on ejected beams and are planned to be used on the intersecting storage rings.

In principle, the transformers respond to *changes* in current (they are a.c. devices). Thus on the injector there is basically no problem because they are required to monitor bursts of protons a few microseconds long. Transformers have recently been incorporated in a method to monitor energy spread in the 50 MeV beam from the injector (see CERN COURRIER vol. 9, page 7). Problems are introduced however by the need for high sensitivity.

On the synchrotron ring the requirement is more stringent — the transformers should be capable of monitoring rapid changes in intensity (requiring high frequency response from the electronics) and of giving a measurement of the beam intensity over the duration of the acceleration cycle of the order of a second (requiring low frequency response).

A monitor which can cope with frequencies of 30 MHz for rapid fluctuations and also with frequencies up to a time constant of about 4 hours, very much longer than the pulse duration, has been developed by K. Unser. It has two channels, one for high and one for low frequencies, each with its own beam current transformer, and the channels are coupled in such a way that there is an automatic and continuous transition between the two to cover the whole range.

Beam current transformers for monitoring fast ejected beams have been developed by S. Battisti and R. Bertolotto. (At the synchro-cyclotron, R. Hohbach and S. Mango have achieved monitors of high sensitivity — down to about 0.5 μA — for the extracted proton beam.) The particular problem with ejected beams is the low beam current and an accurate device for slow ejected beams with a long spill-time has not yet been operated.

More difficulties come in when faced with the problem of monitoring the beam in storage rings. The aim is to provide a monitor for the ISR which will be capable both of measuring the total stacked beam current (with values up to 20 A circulating for many hours) and which will also be sensitive to small changes, so that the addition of an extra pulse (say 50 mA) from the PS during the stacking process can be monitored, and so that any beam losses can be detected. A paper on this work by Unser entitled 'Beam Current Transformer with D.C. to 200 MHz Range' was read at the 1969 Particle Accelerator Conference at Washington on 7 March.

The response of the monitor is extended to the d.c. condition (to measure the steady stacked beam in the ISR) by adding a magnetic modulator to the system already used on the PS (which measures the rapid changes). It consists of a pair of toroids which are excited by an auxiliary oscillator in opposite senses so that their signals, in a winding around both toroids, cancel. When a beam passes through, it introduces an asymmetry giving an output signal proportional to the current.

A prototype has given very encouraging results. It has been tested up to currents of 20 A and over a wide frequency range down to d.c. The accuracy was about 0.01 %.

The Strongest Force

This article by one of the co-discoverers of 'the eightfold way' of classifying strongly interacting particles, first appeared in 'Science Year 1968' and is reproduced here by kind permission of the publishers.

Yuval Ne'eman

When that visionary, Jules Verne, described the launching of the first manned space flight in his science fiction novel 'From the Earth to the Moon' in 1865, he calculated the height of Captain Barbicane's monstrous gun, the 'Columbiad', at 880 feet. When the gunpowder that filled a quarter of this gun was ignited, the space capsule, in an earth-shattering blast, shot instantly to the 36 000 foot-per-second velocity required to escape the earth's gravity. It was a jolting beginning to a remarkable lunar voyage.

In 1968, Verne's prophecy has become reality. Men of another century were constructing the Saturn V moon rocket, the most powerful machine ever built, to send an Apollo spacecraft soaring to the moon. To overpower gravity's enormous resistance, the Saturn's engines burn almost 4 000 gallons of fuel and oxidizer every second.

Man has thus learned how to overcome gravity — the gross force of all the earth's atoms. But within each small atom, there is a much larger force — electromagnetism. Imagine that tiny rocketeers living within an atom wished to launch a negatively charged electron against the electromagnetic pull of its positively charged atomic nucleus. They would need 10 000 times more fuel than the amount needed to lift a single electron from the earth to the moon. To further illustrate the strength of this force, imagine that a Space Age imp had removed all the electrons from only one-tenth of a cubic millimeter of the Apollo capsule's metal skin and had carried them down to the launch pad. The electromagnetic force now attracting the positively charged capsule to the electrons on the ground would be so overwhelming that, at blast-off, the 7 500 000 pound thrust of the Saturn's fiery engines could not budge the spacecraft. The imp, to the bewilderment of the astronauts, would have matched the gravitational force of the whole earth with only a millionth of a gram of electrons.

Within the nucleus of the atom there is a force even stronger than electromagnetism. Scientists have known of this force for just over 30 years, and, today, the search for an understanding of it is the greatest challenge in physics.

At Serpukhov, Russia, on the other side of the earth from the Saturn's base on Merritt Island, Florida, is the world's largest proton accelerator. Its proton beam acts like the first stage in a multi-stage rocket. But each proton in the beam is boosted to 50 million times the energy it would take to lift it to the moon. It has 76 000 million electronvolts (76 000 MeV) of kinetic energy. Remembering the Saturn's energy needs, it is obvious that physicists studying this stronger force, needing so much more energy, must settle for an extremely small payload. When a small bunch of protons strikes a metal target, the collision produces a multitude of tiny new particles called pions, kaons, and antiprotons. These are separated and collected in secondary beams, which are sent to destinations located deep within the nucleus of the atom.

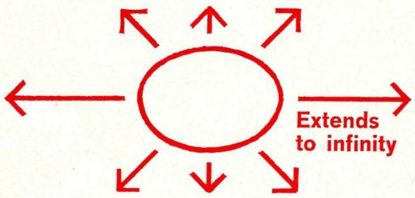
Even as man explores the moon, so will particles in those secondary beams explore a new world — the world of the strong nuclear force. Physicists call it the strong interaction. It binds together neutrons and protons in atomic nuclei. Its pull, particle for particle, is more than a hundred times stronger than electromagnetism, and a hundred followed by 35 zeros times stronger than gravity.

These forces — gravitation, electromagnetism, and the strong nuclear force (plus a little-understood weak nuclear force) — cause all of the variety, change, and beauty in the universe. Without them, objects would never be aware of one another. They would never attract or repel, and they would not collide, but would effortlessly pass through each other. How do forces, which somehow act through what seems to be empty space, account for this? One of the great theoretical achievements in physics tells us the answer, and allows us to see how the strong nuclear force — the strongest force — behaves.

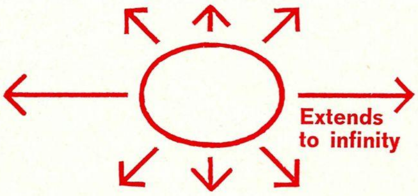
When electrons violently collide, as they do in the sun or in the hot filament of a light bulb, small bundles of kinetic energy are knocked free. The electrons slow down, due to dispersion of some

Nature's Quartet of Forces

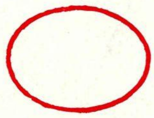
Gravitational force



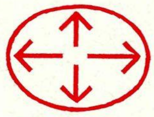
Electromagnetic force



Weak nuclear force



Strong nuclear force



We can detect a proton only through its forces. It is the sum of four effects. The gravitation force, surrounding all matter in all directions to infinity, controls the stars and galaxies. The much stronger electromagnetic force cancels out at long range, since there are equal numbers of positive and negative charges in the universe. It controls the world of atoms and molecules. The weak nuclear force is known to exist, but its carrier has not yet been detected. The strongest force — the strong nuclear force — controls most effects in the compacted nuclear and sub-nuclear world.

of their kinetic energy. These energy bundles, called photons, carry the electromagnetic force that moves electrons in your eye — and you can see.

Photons, then, should also carry the force that exists between two charged particles even when neither is moving. Although the static charge on a too-easy-to-charge nylon shirt often is a nuisance, it is scientifically illuminating. For the charge is not moving and can have no kinetic energy, yet it does emit photons. I know of them because they make the hair on my arm stand up. I cannot see these photons, however, even when I am using the finest laboratory instruments.

A powerful principle of physics, the principle of uncertainty, explains why we can observe some photons as lumps of energy but not detect the energy of other photons at all. A photon is the smallest amount of energy that we can measure. We must wait for all its energy to pass by us or see none of it. A definite amount of time, then, depending on the energy of the photon, is needed to detect it. The principle says, for example, that a single photon of green light, 2 x 10^{-6} MeV of energy, can be observed only if it exists longer than a million-billionth (10^{-15}) of a second of time. When this photon exists for a shorter time, it cannot be detected.

No photon having measurable energy can be emitted by a static charge on my shirt, but unobservable photons can freely emerge from it at the speed of light and act on a hair. Thus, a stream of 'virtual' photons — so called to distinguish them from the 'physical' photons that we can observe — carries the charges' attraction or repulsion. The less energy a virtual photon has, the longer the time it can act. Thus the farther apart two charges are, the longer the virtual photons take to leap between them, the smaller the energy the photons can possess, and the weaker the force they transmit. The electromagnetic force has an infinite range ; infinitely weak virtual photons reach out from each charge to the very horizon of the universe.

This also holds for the gravitational force. Its action is transmitted, also at the speed of light, by particles of energy called gravitons. Though virtual when simply binding the earth to its orbit around the sun, they are, according to theory, emitted physically whenever matter is accelerated. Gravitons must be exceedingly feeble. They have never been observed.

The principle of uncertainty neatly explains the repulsions and attractions between charged particles and the gravitational attraction between all masses. But when the neutron was discovered in 1932, it soon became clear that still another force must bind them to other neutrons and protons in the nucleus. The neutron carries no electric charge, and gravity is far too weak. In 1935, Japanese physicist Hideki Yukawa suggested the new force, based upon the observation that its range is extremely short. Indeed, the pull of the nuclear force comes to an abrupt end at a distance of only 1 *fermi* (a 10-trillionth of a centimeter) from the centre of both neutrons and protons — the two varieties of the *nucleon* (the heavy particle that makes up all atomic nuclei).

Recalling that virtual photons carry electrical forces, Yukawa conjectured that the nuclear force carrier should be a massive particle. He first assumed that the new force could not spread faster than light, which was not proved experimentally until 1967 by Seymour Lindenbaum at Brookhaven National Laboratory. A photon moves 1 fermi in 10-trillionths of a trillionth (10^{-23}) of a second. Yukawa then used the uncertainty principle to calculate the minimum energy of a virtual particle that can act only this very short amount of time. He found it to be about 100 MeV, roughly one-ninth of the energy — and thus one-ninth of the mass — of a nucleon. This hypothetical force-carrying particle was called a meson.

Scientists could hope to check Yukawa's theory by producing physical, rather than virtual, mesons in violent collisions between nucleons, just as physical photons emerge from collisions of electrons. With their sizable mass, the new mesons should, in fact, be easier to observe. Further, when scientists had bombarded nuclei with neutrons, they found the force that scattered the neutrons had turned some of them into protons, leaving the corresponding nuclei with one less positive charge. Yukawa's force-carrying meson, it seemed, could carry an electric charge as well. A charged meson would expose a photographic emulsion, leaving a characteristic track, or it would leave a trail of droplets behind it as it passed through a cloud chamber. Physicists hurried to study cosmic ray collisions, since protons arriving from outer space would have enough kinetic energy to materialize mesons.

It took 14 years, though, to confirm Yukawa's prediction. First, a particle was discovered that had very nearly the predicted mass, 106 MeV. This particle, called a mu-meson, or 'muon', was thought to be Yukawa's particle for a number of years. But in 1949, Soicho Sakata and Tokuzo Inoue in Japan and Hans Bethe at Cornell University and Robert Marshak at the University of Rochester explained that the muon simply did not have anything to do with the strong force. It was not really a meson. Shortly afterwards, the right particle, the pi-meson, was found. This 'pion' had a mass of 140 MeV, somewhat heavier than Yukawa's prediction. Further, the pion materialized in three states — positively charged, negatively charged, and neutral. Three states were necessary to explain why the strong forces between two protons, between two neutrons, and between a neutron and a proton are equal. The light (in weight) particles, called leptons (electrons, muons, neutrinos, and photons) do not 'feel' the pion's strong force. The pion and all heavier particles, which sense its strong force and interact through it, have been named hadrons.

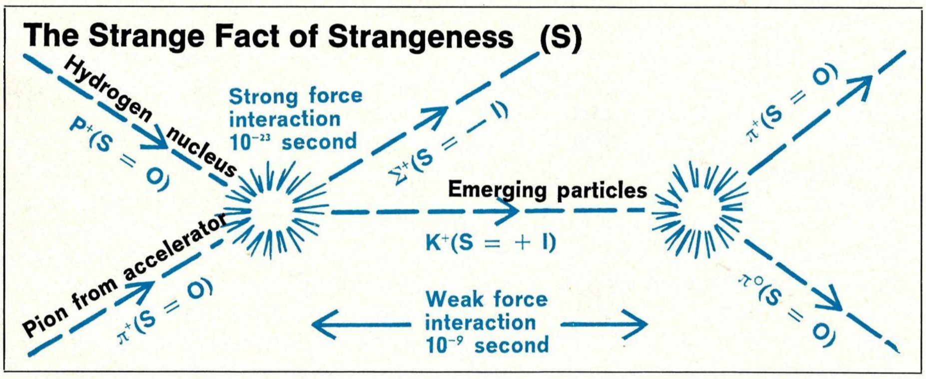
The pion story did not develop without inflicting a few wounds. It is said that Baron Ernest C. G. Stueckelberg Breidenbach, a Swiss physicist, had had the same idea as Yukawa in 1935. He checked it, however, with the renowned Austrian physicist Wolfgang Pauli, who ridiculed it. Pauli apparently tended to be too critical of ideas that were not his own. In any case, Stueckelberg did not publish his idea — and thus did not share the Nobel prize in physics that was awarded to Yukawa in 1949.

Another sequel relates to the muon-pion error. Because of World War II and the lack of scientific communications that followed it, the West had not noticed the Sakata-Inoue paper, and singled out Bethe and Marshak as the scientists who pointed out the mistaken identity. This created bitterness in Japan where it mixed with pro-Communist leanings and resentment over the wartime defeat. The bitterness exploded at a conference held in 1965 at Kyoto, Japan, to commemorate the 30th anniversary of Yukawa's theory. Mitsuo Taketani, one of the most respected of Japanese physicists, nursing personal and political grudges against the United States and its scientists, came out openly with an accusation of plagiarism. This was countered by Marshak in an intelligent and touching answer. The entire exchange was published in the conference proceedings. Hopefully, this freeing of inner tensions in the scientific body will have cleared the atmosphere.

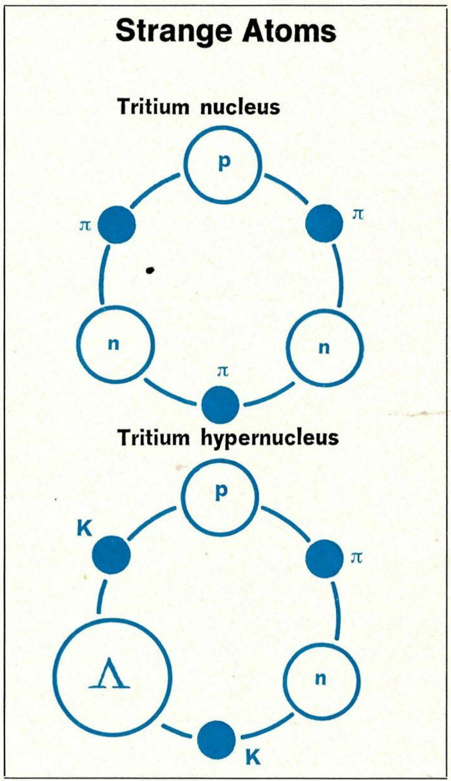
One might have thought that with the discovery of the pion, the strong force had yielded its secret. But the uncertainty principle tells us that other mesons having higher masses may lurk unobserved deep within the nucleon. The pion turned out to be just a beginning, in keeping with a 'law' of nature. Each time a major advance is made and a mystery solved, we are quickly confronted by a new mystery. Thus, shortly after the discovery of the three pions seemed to completely explain the strong nuclear force, scientists were shocked to discover four heavier mesons. These K-mesons, or kaons, at 500 MeV, were also produced by cosmic rays.

At about the same time, other new particles, similar to protons and neutrons, were discovered in cosmic ray tracks. Called baryons, they were heavier than the nucleon, and decayed into nucleons and pions, or nucleons and leptons. Strong-force decays always occur in roughly the lifetime of virtual pions, about 10^{-23} second. Kaons carried the strong force just like pions, gluing nucleons to the new baryons but not to nucleons. But these new particles all lived 10^{-10} second, more than a trillion times longer than the strong force would take to decay them.

This was a real puzzle. Why were kaons, rather than pions, virtually emitted by the new baryons? And why do they live so long? The behaviour of these particles, matter that seemed to have no reason to exist, was explained in 1953 by Murray Gell-Mann, then at the University of Chicago, and, independently, by Kazuhiko Nishijima in Japan.



When a high-speed pion strikes a proton, many new particles emerge. Since the K+ meson, for instance, physically exists longer than its expected life of 10^{-23} second, it must possess a new property, called strangeness, that prevents its strong-force decay into two nonstrange pions. The weak interaction permits the decay, but takes 100 trillion times as long.



Strange K-mesons can bond strange baryons in ordinary nuclei to make hypernuclear atoms. In tritium, scientists have replaced a neutron with a lambda particle.

The new particles must have a new characteristic that is not affected by the strong force. Gell-Mann called it strangeness. The new baryons, he said, each had one unit of strangeness, and were thus unable to virtually emit, or decay into, familiar nonstrange particles in 10^{-23} second. The weak nuclear force apparently allowed strangeness to change by one unit at a time, permitting these strange particles to decay. Its weak accelerations slow the decay rate, however, and the particles live 10^{-10} second, long enough to leave tracks in film or in a cloud chamber.

Strangeness had just managed to explain the role of kaons when experiments carried out by Robert Hofstadter at Stanford University and Robert Wilson at Cornell University provided the next mystery. Yukawa had said that a nucleon should be surrounded by a cloud of virtual pions out to a distance of 1 fermi. Hofstadter and Wilson hoped to observe the cloud by seeing nucleons in atomic nuclei deflect high-energy electrons. Although electrons cannot sense the strong force carried by a negatively charged pion that is virtually emitted by a neutron, they should sense the virtual photons from the pion's electrical charge.

The electron probes did find a cloud, but one that Yukawa's theory could not wholly explain. Yoichiro Nambu, a Japanese physicist working at the University of Chicago and one of the deepest thinkers in particle theory, showed in 1957 that virtual pions could be decay products of yet another virtual meson having entirely different features. This parent meson, called the rho, would have about five times a pion's mass and would decay into two pions deep within the nucleon by the strong interaction. Nambu showed that if the rho was spinning, the two pions, which cannot spin themselves, would have to come out orbiting around each other. Their orbital motion would solve the mystery of the Hofstadter-Wilson cloud.

The spin of the rho tells us something more. A particle's rotation around its axis — spin — can have only specific values. The electron, nucleon, and certain nucleon-like particles are considered to have spins of $^1/_2$ units. Some heavier nucleonlike particles have spin $^3/_2$ or spin $^5/_2$. Force-carrying mesons have a different kind of spin 0, 1, 2, 3. Which spin they have determines the nature of the force they carry. For instance, the force between identical particles is always attractive if the spin of the exchanged meson is even. The pion has spin 0. The best example of a pionlike force is simple Newtonian gravitation. It does not carry any twisting force ; two masses are simply pulled closer together along a straight line between them. Albert Einstein, in his 1916 theory of the gravitational force, better known under the mystifying name of the general theory of relativity, showed, however, that gravity is really carried by a spin 2 particle, the graviton. Attraction is only one aspect of gravity. The graviton's spin creates other effects : centrifugal force, formerly explained by inertial mass, now known to be the same as gravitational mass, and the coriolis force that holds a bicycle upright when its wheels are spinning.

Electromagnetism is transmitted by a spin 1 meson, the photon. This force, carried by an odd-spin meson, is repulsive between identical particles. The whole of magnetism — the twisting force around a moving electron that causes an electric motor to turn — is due entirely to the photon's spin.

The spin 1 of the new rho-meson would imply that it, too, exerts a twisting force similar to magnetism. And the force that it carries between similar hadrons would be repulsive, as in the case of electric forces. This would explain why neighbouring nucleons in a nucleus, pulled toward each other by virtual pions, do not fall into each other. Their central cores of virtual rhos prevent it. Nucleons and their opposite equivalents, antinucleons, however, are attracted together by the pions, and, being opposites, are attracted by the rhos as well. They annihilate themselves.

In 1961, Nambu's theory was confirmed when researchers using particle accelerators found indirect but certain evidence of a physical rho meson. Several other spin 1 mesons were similarly detected.

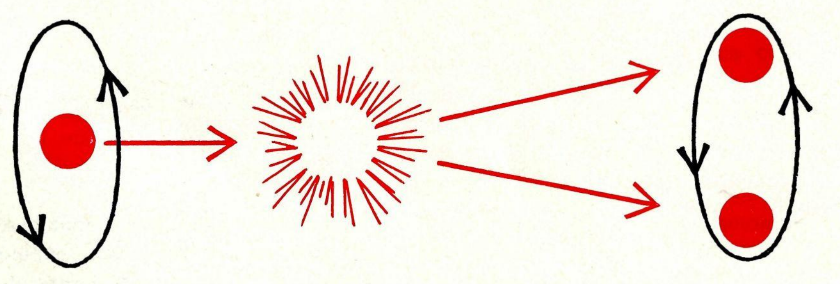
Attempts to measure the strength of the strong force still deeper in the nucleon turned, during the 1960s, to the high energy domain — the region where more massive virtual baryons and mesons should be materialized by cosmic rays and, perhaps, by beams from powerful new accelerators. Mesons having two units of spin were discovered between 1962 and 1964. The strong force, about $^1/_{10}$ fermi from the centre of a nucleon, is dominated by these heavy spin 2 mesons, even stronger in their attractive force than the pion.

I sometimes wonder at the fantastic promise of the strong force. The whole of present technology — chemical, electrical, and mechanical engineering — is based upon only two relatively weak forces, electromagnetism and gravitation. Now we see that the strong interaction has, at various ranges, all these effects and more. We shall further see that these forces all come in eights — eight simple attractive potentials, eight complex forces resembling electromagnetism, eight times a gravitation-inertialike force. What richness when someday engineers will be able to exploit the regions under one fermi. Can this prospect be more remote than Jules Verne's vision of space travel a century ago ?

The high-energy studies have shown, as well, that as the energy goes up, the chance of two nucleons scattering each other steadily goes down. Will it, at infinite energies, take a limiting value, perhaps corresponding to the geometrical 'size' of the nucleons themselves ? Or will the chance of collision vanish altogether and the particles become completely transparent to each other ?

The most recent studies show that at the very highest energies, the strong force is dominated by a meson named for Isaak Ya Pomeranchuk, a Russian physicist who died in 1966. The nature of this 'pom-

Decay of the Spinning Rho



The single unit of spin of the rho-meson, left, is conserved, forcing the two spin 0 pions into which it decays, right, to spin around each other. The detection of orbiting pions first indicated the existence of the rho.

eranchukon' is a mystery. It could be a spin 2 meson, the lightest among them, called the f°, at 1250 MeV. It could, however, be a different effect, perhaps the attraction due to the virtual emission of mesonlike proton-antiproton pairs, or other particle-antiparticle pairs emitted and reabsorbed at distances smaller than $^1/_{10}$ fermi.

Whether the pomeranchukon is this special object, or the f°, will have important implications for future space travel. According to relativity theory, as a spaceship nears the speed of light, the astronauts' bodily processes imperceptibly slow down. They could make hundred-year trips to stars a hundred light-years away in what to them would be just a few years. At these speeds, however, the ship would constantly encounter hydrogen atoms floating sparsely in interstellar space. If the pomeranchukon is the special object, two protons moving toward each other would always have a chance to collide, even at the highest energies. Hydrogen in space would hit the ship extremely hard, like cosmic rays, and this intense radiation could be one of the strongest reasons against the hope of travelling to the stars.

If, instead, the pomeranchukon is the f° meson, the chances of protons colliding would diminish with every increase in their energy. At infinite energy, the strong force would vanish, and the protons would never collide. A spaceship and its occupants could cruise extremely close to the speed of light and be unaware of the hydrogen gas passing harmlessly through them. The question of which is the correct view is one of many that will be answered by two giant accelerators to be completed in the 1970s, one by the U.S. Atomic Energy Commission at Batavia, Ill., and the other by the European Organization for Nuclear Research (CERN) in Europe.

While measurements of the strong force gradually advance, another approach has brought a much needed order into our picture of the nucleon. The situation is similar to that of natural history. Charles Darwin's theory of evolution emerged only when the animal kingdom had been sufficiently classified. Noting similarities and regularities, Darwin could trace descents. Sir Isaac Newton's theory of gravitational and inertial forces could come only after regularities and similarities in the motion of planets and falling objects had been discovered by Johannes Kepler and Galileo Galilei.

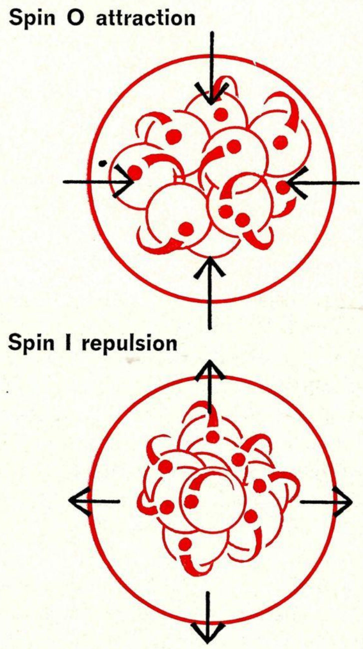
Early in 1961, Murray Gell-Mann and I independently suggested a scheme that classified strongly interacting particles into family groups. Previous attempts had failed. All the hadrons simply did not fit. One scheme had come close to success, however. It was based upon an idea of Sakata's, in 1956, that the proton, the neutron, and a strange particle, the lambda baryon, plus their antiparticles, were the basic building blocks of all particles, and thus of all matter. In 1960, Yoshio Ohnuki in Japan and Walter Thirring in Austria uncovered a 19th century mathematical technique known as SU (3) — for Simple Unitary group of transformations in 3 complex dimensions. This SU (3) is an especially good tool for manipulating groups of three basic objects. They found that by combining Sakata's charged particle, neutral particle, and strange particle in various ways, all the known properties of hadrons could be explained.

The scheme predicted that mesons having the same spin should arrange in groups of eight. Thus, the seven known spin 0 mesons — the three pions and the four strange kaons — should have an eighth companion. At the University of London, in 1961, Abdus Salam and John C. Ward extended Ohnuki's eightfold prediction to the spin 1 mesons as well, and suggested that the rho, if found, should likewise have seven spin 1 companions.

Baryons, however, not having the whole-number spins of the mesons, fell into 3-, 6-, and 15-member groups. Because Sakata had assumed that certain baryons, the neutral xi, for instance, were made by adding together three spin $^1/_2$ baryons, they were predicted to have spin $^3/_2$, and a more complicated structure than the nucleon.

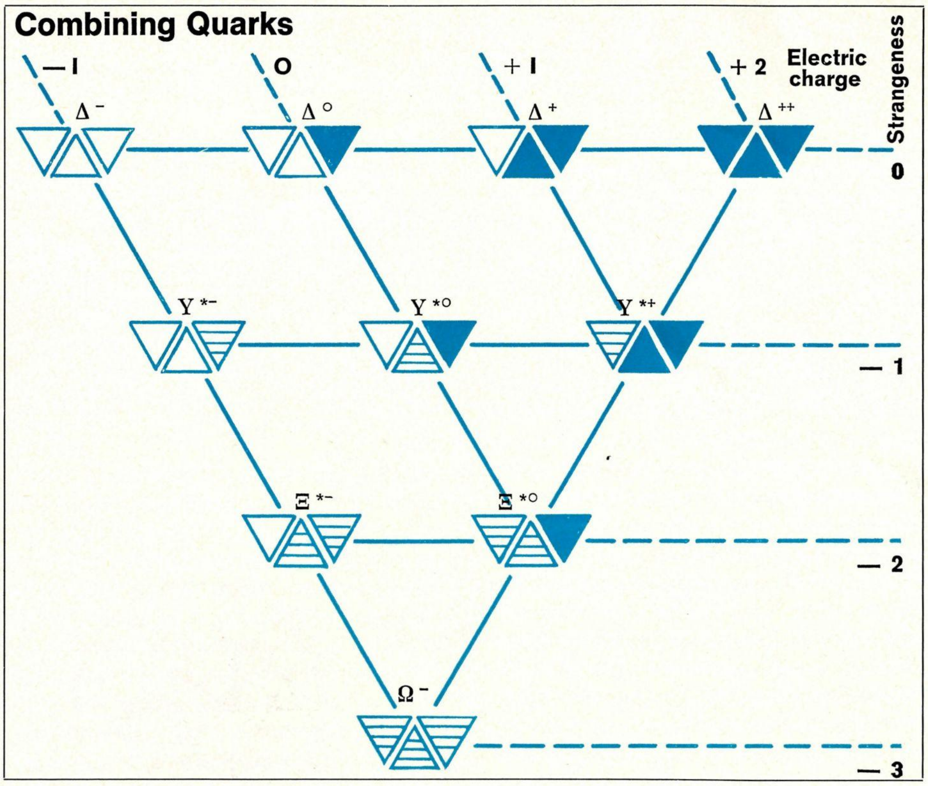
At about the same time, and without knowing of Sakata's theory, I was looking into the same problem. I hit upon the adequacy of the eightfold scheme as the simplest mathematical structure that could classify the strong interactions. The same

The Pulsing Nucleus



Forces carried by pions and rho-mesons alternately attract and repel nucleons in an atomic nucleus. Spin 0 pions keep the nucleus from flying apart ; spin 1 rhos keep it from collapsing.

The discovery of the spin 2 f° meson hints that if nucleons could be squeezed beyond the resistance of the rho forces, they would attract each other with enormous force. This would not only release staggering amounts of usable energy, but should also produce a new kind of matter. The rho's repulsion, however, does not weaken fast enough to allow this attraction except when two nucleons glance off each other at high speed.



Three kinds of objects, shown as coloured triangles, can be arranged into ten possible groups of three. In The Eightfold Way, each combination of three fictitious objects, called quarks, makes a different baryon.

idea occurred to Gell-Mann, at the California Institute of Technology (Caltech). Neither of us had any notion, however, of using known particles as fundamental 'bricks', as in the Sakata model. We both felt free to arbitrarily arrange the existing particles in various patterns, without concern for their building blocks, and see which pattern best fit the observations.

We thus found, unlike Ohnuki and Thirring, that, of all mathematically possible structures, the arrangement of the eight then-known baryons into one family best explained the facts. Mathematically, this meant that we had used three fictitious objects as the building blocks, and made all the baryons, including the nucleon, from various combinations of the three types. In our 'synthesis', then, the xi would be no more complicated than the nucleon and would have the same $^1/_2$ spin. Our theory also predicted the existence of eight spin 0 and eight spin 1 mesons. I published this, and so did Gell-Mann, early in 1961.

Within just a few months, the eighth spin 0 meson was discovered. The eight spin 1 mesons were also found in 1961. In 1964, the spin 2 mesons were found, and arranged themselves neatly into the same kind of octet.

Up to that point, it was not clear which theory was correct, the Sakata model — the more popular one — or 'The Eightfold Way', as Gell-Mann had named ours. Eight-member meson families had been predicted by both models. The spin of the xi was found to be $^1/_2$ in 1963 and seemed to indicate we were right, but the relative simplicity of Sakata's scheme still attracted many physicists.

One clear-cut difference could be drawn. If our scheme was right, baryons having spins of $^3/_2$ should exist as a 10-member family. Four had been discovered by Enrico Fermi in 1950. Another three, each with one unit of negative strangeness, were reported in 1961. And, at the 1962 CERN conference, held in Geneva, Switzerland, a pair with two units each of negative strangeness was reported. Their spins were not known. If these nine really made up a family, the 10th member should have three units of negative strangeness. Moreover, all nine decayed by the strong interaction in 10^{-23} second, and could be identified only by complex analyses of the decay products. Their 10th companion, though, could decay only by the weak nuclear force, as its mass would be smaller than any decay products having the same strangeness. It should thus live about 10^{-10} second and leave a track in a bubble chamber.

All the properties of the missing particle could be predicted from our theory. Gell-Mann went to the blackboard during the CERN conference and explained exactly what the experimenters should be looking for. I had made a similar suggestion the day before in a letter to Gerson Goldhaber and his late wife and collaborator, Sulamith Goldhaber. An experiment with negative results that they had reported just two days earlier had provided the last needed clues, and I was trying to convince them to look for the missing tenth piece of the puzzle.

In February, 1964, Nicholas Samios and 32 collaborators at Brookhaven National Laboratory found it — the first omega-minus particle. Since then, only 20 or so omega-minus particles have been observed. They have the right mass (about 1,680 MeV), charge, strangeness, and also, I hope, the right spin, since this has not yet been measured.

Thus, The Eightfold Way worked. Since then, many other predictions of The Eightfold Way have come true, so that the theory has been adopted by most physicists. From a particle's position in its family pattern, we can predict the relative strengths of the force between it and the various hadrons. The scheme even goes beyond the strong force, explaining their weak force and electromagnetic interactions, too. But we still do not know why The Eightfold Way should hold. Today's Newton has not yet appeared.

In 1964, Gell-Mann and Georg Zweig at Caltech suggested checking whether the three fictitious particles we had used as elementary really exist as virtual or physical particles. Gell-Mann called them quarks. In four years of searching, however, they have not been found, and the chance that they exist seems to be dwindling.

My own feeling is that the final theory of matter and its strongest forces will not have the naive simplicity of three truly elementary particles obeying the rules of The Eightfold Way. Nature will be more clever. Indeed, if quarks are ever found, I am sure that we shall be faced with an even deeper mystery. In 1968, a colleague who has lived through the entire history of elementary particle physics told me that the first two high energy accelerators — the Bevatron at Berkeley, Calif., and the Cosmotron at Brookhaven, N.Y. — both broke down shortly after they began operating in 1954. Six months went by before the experiments could be continued. The Creator probably had given himself time to put some complexity into this smallest of worlds that men were beginning to explore. Let us not underestimate the sophistication He will be using next.

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SACLAY
600 MeV Linac

On 19 February a 600 MeV electron linear accelerator was inaugurated at Saclay by the Minister for Research, Mr. R. Galley. The accelerator is intended for nuclear structure research, complementing the existing facilities of the French Commissariat à l'Energie Atomique (CEA). As indicated below it will be a fruitful source of pions and muons in addition to electron, positron and photon beams. The machine is situated at the Physics Laboratories of 'L'Orme des Merisiers', several kilometres from both Saclay and Orsay.

The usefulness of a powerful electron accelerator for nuclear physics research was pointed out in the Nuclear Physics Division at Saclay as long ago as 1959 by C. Tzara. Support for the project came in 1964-65 and construction was assigned to the firm CSF. The machine was commissioned in December 1968 and its performance is exceeding expectations.

The main features are :

1) High energy — several hundred MeV will allow distances of the order of the inter-nucleon distances to be investigated
2) High intensity — the accelerator can yield electron beams with an average power of over 200 kW (for example, 600 μA et 420 MeV)
3) Long duty cycle — this is perhaps the most distinctive feature of the machine ; the percentage of time for which the machine supplies electrons is much higher than usual from linear machines. Usual figures are up to 0.2 % ; the Saclay machine gives 1 to 2 %. At a maximum energy of 600 MeV the duty-cycle is 1 % (pulses 10 μs long, 1000 times per second) ; at 420 MeV this can be increased to 2 % (pulsing 2000 times per second)
4) Good energy definition — a near mono-energetic beam (the width of the energy distribution is only 0.3 to 0.5 % at half-height) and high long-term stability (0.6 % drift in peak energy over 24 hours) is achieved.

The accelerator is about 200 m long. It is of the travelling-wave type (wavelength 10 cm) with 30 sections fed by 15 klystrons and eight modulators. Using a modular construction for the sections it has proved possible to reach a peak current of 60 mA without any sign of beam break-up which is a common phenomenon in long machines.

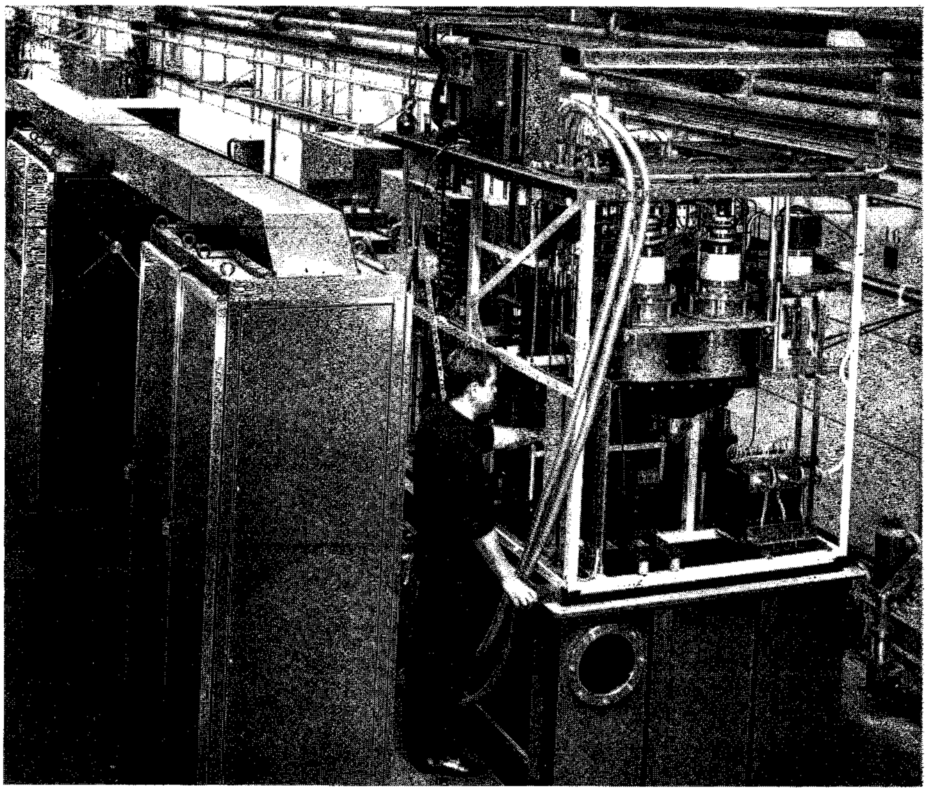
A positron beam can be produced at an electron energy of 80 MeV and further accelerated along the machine. A positron beam of 0.2 μA has been accelerated to 470 MeV and measured on a target placed 35 m from the output end of the machine. A maximum positron intensity of 24 μA has been recorded with an energy spread of 1.35 % at half-height. It is hoped to improve these figures further.

Estimates of secondary beam intensities (with a duty-cycle of 1 %) indicates the usefulness of the machine :

The estimated intensity (per second) of annihilation photons at 400 MeV (± 1.5 MeV) is 2 x 10^8.

The estimated intensity (per second) of bremsstrahlung at 200 MeV (± 1 keV) is 10^8 to 10^9.

The estimated relative intensity of stopped



A view of one of the eight double modulators in the r.f. power system of the new Saclay linac lifted from its container.
(Photo CSF — Jean-Claude GEORGEL)

At the inauguration ceremony on 19 February : (left to right) the Minister R. Galley, A. Abragam, F. Perrin, A. Messiah, F. Netter and C. Tzara.
(Photo Saclay)

The large superconducting coil (BIM) which is being operated at Saclay to gain experience in superconductivity techniques.

pions (per gram per cm^2) is 200 times that presently achieved at the CERN 600 MeV synchro-cyclotron (before the improvement programme). The 800 MeV LAMPF at Los Alamos, which is scheduled for completion in 1972, will be capable of an estimated relative intensity 5000 times the present CERN figure.
The estimated relative intensity of stopped muons in a target of a certain thickness is 150 to 15 000 (depending upon the beam transport system) times the present CERN figure (LAMPF will yield 3000 times).

Superconducting coil

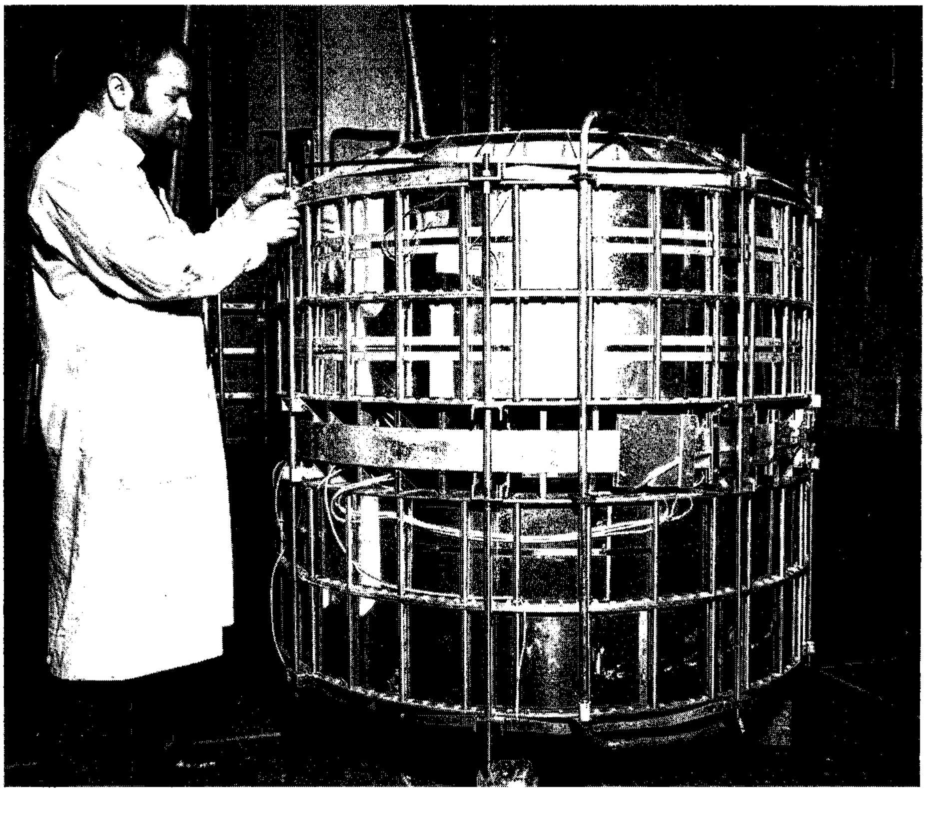
At the end of February a large superconducting coil (called BIM) was operated at Saclay. The coil has been constructed as part of the studies on the application of superconductivity — it may eventually be incorporated in some experimental equipment, but its initial purpose is to confront the problems of construction and operation of large superconducting coils.

The main parameters of the coil are as follows : The coil is in two halves each 0.4 m high, with internal diameter 1 m and external diameter 1.3 m, separated by a gap of 0.2 m. The superconducting ribbon is made of niobium-titanium filaments (about 0.25 mm in diameter) embedded in copper. The dimensions of the ribbon are 10 mm wide by 1.8 mm thick. The ribbon is coated with epoxy 50 μ thick to withstand 1500 V while still allowing good heat conduction.

Manufacture of the superconductor was assigned to two firms in Europe — Thomson—Houston (France) and IMI (UK). The two firms worked in collaboration with the Département Saturne at Saclay where the group who have designed and operated the coil is led by G. Bronca.

The coil is designed for a critical current of 1750 A. At a current of 1500 A the magnetic field at the centre of the coil will be 40 kG corresponding to 54 kG at the coil itself. The stored energy is then 10 MJ.

During the tests which began at the end of February, the current was raised without problem to a value of 1360 A corresponding to a magnetic field at the centre of the coil of 36.5 kG and a stored energy of 8.5 MJ. At this current a low resistance appeared in a section of the coil (involving about 30 m of the ribbon). This 'normal' zone did not spread to the rest of the coil and the superconducting state could be completely recovered by slightly reducing the current. Further tests are under way to correct the fault and to push the performance higher.



BATAVIA
Accelerated protons

On 20 January protons were accelerated for the first time at the National Accelerator Laboratory, Batavia ; an ion-source test stand gave a proton beam at an energy of 60 keV. The maximum current extracted from the source was 300 mA and the preliminary emittance measurements indicated that the beam quality more than meets the requirements of the machine design.

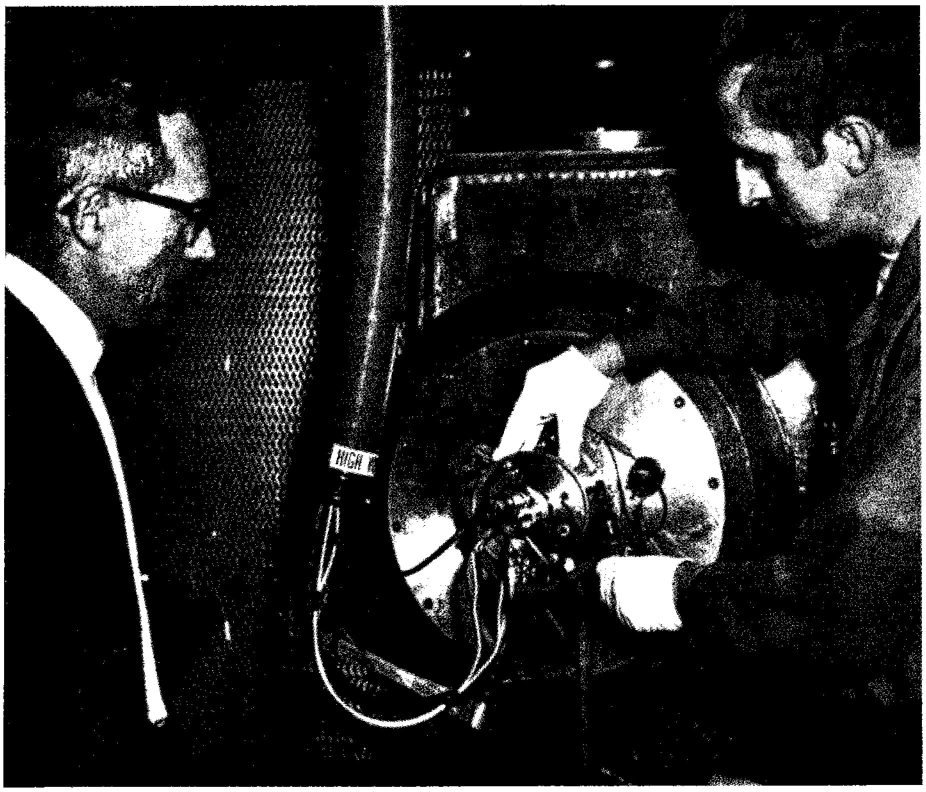
The design calls for a beam of 220 to 300 mA at 750 keV to be fed to the linac for acceleration to 200 MeV. The pulse length is 30 to 100 μs at a repetition rate of 15 pulses per second. Assembly of the accelerating column was completed in February and voltage conditioning began. A 750 kV high voltage supply from Argonne is in use.

Civil engineering work is going well to schedule. Excavation for the linac building was completed in February. Construction of the booster tunnel began in the same month.

Training programme

In the early discussions concerning the selection of Batavia as the site for the 200 GeV Laboratory, the question of civil rights was a major point of contention. In line with Director R.R. Wilson's declared determination to meet civil rights issues head-on, it was announced on 10 February that 22 young negro men had been selected by NAL to train for skilled jobs at the Laboratory. Nearly all the men are from Chicago which is about 50 km east of the Laboratory site.

The men are following a training programme under a Training and Technology Project (TAT) carried out by the Atomic Energy Commission at Oak Ridge, *The duoplasmatron ion source which has given Batavia its first accelerated protons.*



Tennessee. NAL has not yet built up training facilities itself.

URA New Members

Two new members have been elected to The Universities Research Association Inc. which operates the National Accelerator Laboratory. They are Case Western Reserve University (Cleveland) and State University of New York (Stony Brook). This brings the total number of members to 50 (49 in the USA and 1 in Canada).

A group of Canadian high energy physicists, under the chairmanship of E.P. Hinks, are urging greater participation from Canada in the 200 GeV project. They accept that the number of high energy physicists in Canada does not warrant the expenditure needed to build a national machine on a scale which would be interesting for high energy physics. They therefore propose to the government involvement in the 200 GeV project to the tune of a grant of $ 4 million per year initially for five years beginning in April 1970. In addition, Canadian groups carrying out experiments at the machine would need home support rising to at least $ 2 million in 1974-75.

Reports from the USA have mentioned the possibility of financial participation from the Federal Republic of Germany also in the construction of the 200 GeV machine. This would be as part of a broad plan of investment in science and technology in the USA, to help off-set US expenditure in the Federal Republic. Presumably the intention is that German scientists would then have access to the machine. This has not yet reached the stage of discussion among the high energy physicists in the Federal Republic.

STANFORD (SLAC) Radiation Conference

The 2nd International Conference on Accelerator Dosimetry and Experience will be held at the Stanford Linear Accelerator Centre on 5-7 November 1969.

Papers are invited in the field of accelerator radiation protection on such topics as —
Radiation protection around electron and proton accelerators ; problems of the new higher beam power accelerators; dosimetry of high energy photons, hadrons, leptons, etc ; health physics experience associated with accelerators below 100 MeV ; Radiation alternation measurements and calculations, particle yields, neutron spectra transmission through various shields, problems from bremsstrahlung radiation and cascades initiated in the human body by high energy particles.

Abstracts of 400-600 words should be submitted by 30 April to R.H. Thomas (Chairman of the Programme Committee) at the Health Physics Department, 67 Encina Hall, Stanford University, Stanford, California 94305.

CERN people requiring more information can contact J. Baarli (telephone 2151) who is Conference Vice Chairman.

RTI MOSCOW Cybernetic model

The ideal extent to which computers can usefully be integrated into the control of accelerators is still a subject of debate among accelerator specialists. During the past few years computers have been taking over an increasing number of functions in control rooms but these functions have been predominently those of monitoring and condensing the growing volume of information coming from accelerator systems of growing size and complexity. Only rarely have the functions extended to the next stage of using the information to control the accelerator. This remains the prerogative of the human operator.

Since the early 1960s, however, a group led by A.L. Mints at the Radiotechnical Institute of the USSR Academy of Sciences has committed itself to the computer all the way in pursuing the idea of a cybernetic accelerator. A paper by Mints including information on the performance of a 1 GeV model, which is designed to test the cybernetic principle, was read at the Washington Conference on 5 March.

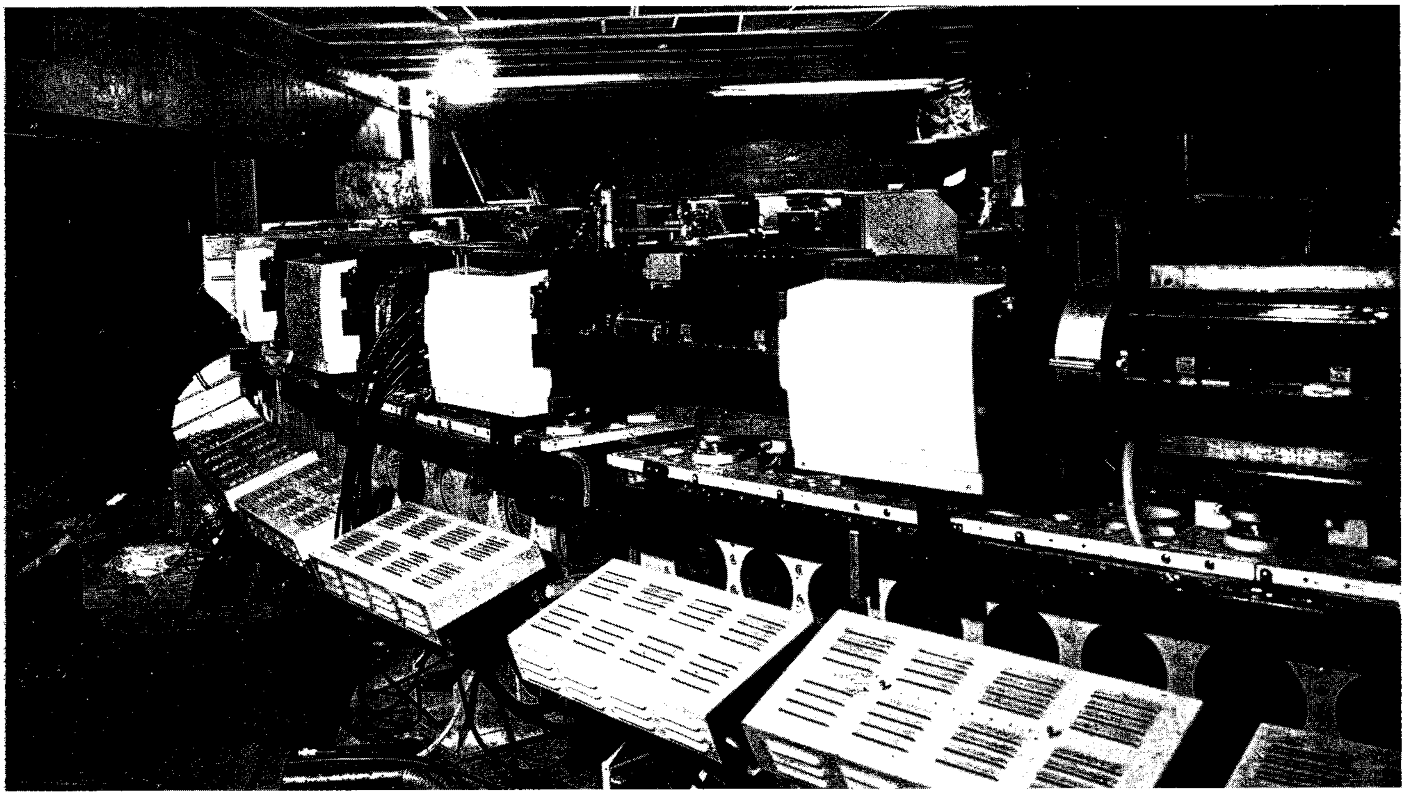
The idea is to build a computer into the accelerator so that it not only receives information on the machine performance but also uses it to give fast, refined beam-control. In particular, the computer receives signals about the beam position from a sequence of pick-up stations distributed around the ring. It calculates what are the deviations from the optimum position and returns signals to the power supplies of magnet lenses to establish better magnetic field conditions. The pick-up stations observe the effect of the changes and further changes could then be calculed and applied by the computer if necessary.

The interest of the Soviet scientists in such a system is in the context of thinking about very high energy machines. If extremely precise beam-control were feasible using a computer, it would be possible to have a smaller aperture for the vacuum vessel in which the beam travels with consequent savings in magnet cost. On the other hand a more elaborate beam detection system, control computer and field correction system than on conventional accelerators would be needed.

A study of parameters for a 1000 GeV cybernetic accelerator has been done and a few of its features are — three stage acceleration (linear to 800 MeV, booster to 18 GeV) ; diameter of large ring 5.4 km, vacuum vessel cross-section 40 x 66 mm^2 ; 264 pick-up stations round the orbit ; 528 correction magnets.

To test the principle, a 1 GeV model has been constructed at the Radiotechnical

The 1 GeV proton synchrotron at the Radiotechnical Institute in Moscow. This accelerator is serving as a model to investigate the idea of cybernetic accelerators where computer control of machine operation is carried much further than in conventional accelerators.
(Photo RTI)



Institute in Moscow. A lot of ingenuity has gone into the design and construction of this model, which produced its first beam in 1967. The main parameters are — diameter 17 m, injection from a 1 MeV Van de Graaff into a field of 250 g, 100 combined-functions magnets, 20 pick-up stations ; 40 correction magnets and 20 special non-linear correction magnets which can be excited in several ways (as quadrupoles or sextupoles, for example) ; vacuum vessel aperture 21 x 16 mm^2 ; vacuum pressure 5 x 10^{-7} torr ; 15 acceleration stations giving 3 keV per turn.

Computer correction of the particle orbits has been demonstrated over the first turn. The operation was not yet truly cybernetic though it could be made so. Information from the pick-up stations is fed to the computer and can be printed out. With initial deviations of about 3 mm from the ideal closed orbit, corrections can be worked out and applied via the magnet power supplies in about 2 minutes to bring the maximum deviation down to less than 0.5 mm. The losses of the injected beam then fall below 5 %. Computer correction is now being tried during acceleration.

TOKYO
40 GeV not supported

The Scientific Affairs Council of Japan which advises the Japanese government on science policy has not supported the proposed 40 GeV accelerator designed at the Institute for Nuclear Studies in Tokyo.

The Council under the chairmanship of S. Kaya decided that the total expenditure of $ 83 million for the project was likely to reduce too severely the amount of money available for research in other areas of science. They recommended that a total of $ 21 million be made available but this is unlikely to be acceptable to the physicists interested in particle research. It would involve scaling down the accelerator, perhaps to 10 GeV, and operating a research centre much less well equipped and staffed. Such a centre if it came into operation at the date planned for the 40 GeV (1973) would be unlikely to make a significant contribution to high energy physics research.

On 17 March, Ambassador Y. Nakayama, Japanese representative to the international organizations in Geneva, visited CERN. He was particularly impressed by the success of international cooperation at CERN and hoped that collaboration between scientists in Japan and at CERN could be further strengthened.

ILLINOIS
Superconducting Microtron

At the 1969 Particle Accelerator Conference at Washington on 7 March, the design of a 600 MeV superconducting microtron for the University of Illinois was presented. The machine is intended for nuclear physics research and involves several novel features.

Construction will proceed in two stages. The first stage, which received the support ($ 0.5 million) of the National Science Foundation last year, concerns a 30 MeV superconducting electron linac. It will replace a 25 MeV betatron which has been in operation at Illinois since 1941. (The

A schematic diagram of the 600 MeV race-track microtron. The two boxes, one at each side, represent magnets bending the electrons back to pass a total of twenty times through the 30 MeV superconducting linac represented by the long thin rectangle at the bottom.

A.O. Hanson (left) and P. Axel, leaders of the microtron project at the University of Illinois, with a test section of the linac. Hanson holds a lead-plated cavity while Axel supports the container assembly which surrounds the cavities with liquid helium, liquid nitrogen and vacuum heat shields.

(Photo Illinois)

betatron was invented at Illinois by D.W. Kerst in 1939 ; a 340 MeV betatron is also in operation at the University since 1950.) It is hoped to have the linac in operation in the summer of 1970.

The reasons for pursuing superconducting linear accelerators were discussed fully in the article on the work of Stanford University High Energy Physics Laboratory (CERN COURIER vol. 8, page 239). For the purposes of physics experiments, the main advantage is the high duty-cycle (the percentage of time for which the machine is providing particles) which becomes possible since the power consumption drops dramatically in superconducting machines. Compared with a conventional linac duty-cycle of about 0.2 % Illinois will have 100 %. The duty-cycle is one of the parameters that determine which experiments can be done and it is in some cases more important than beam intensity.

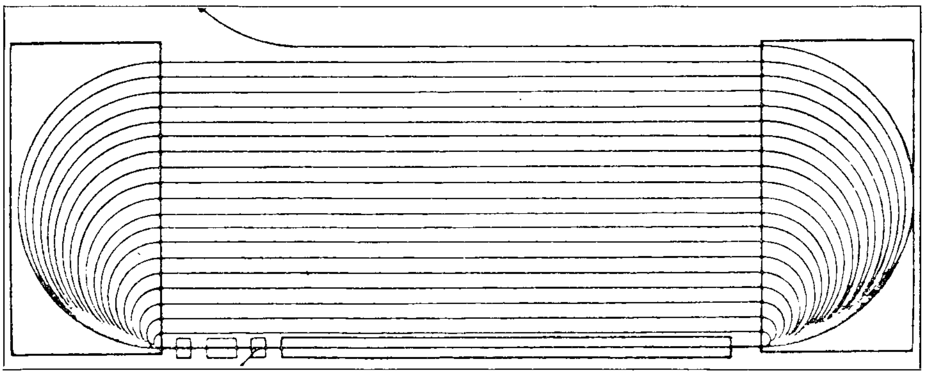
The linac will have niobium or lead-plated microwave cavities operating at a frequency of 1.3 GHz in a tube 4.9 m long and 0.9 m in diameter. This tube is then surrounded by liquid helium (from a 200 kW refrigerator) to establish the low temperature at which the cavities are superconducting, a vacuum heat shield, liquid nitrogen and another vacuum heat shield, giving a total assembly of size 5.2 m long and 2.7 m in diameter. The design beam current is 10 μA and when microtron operation begins there will be 20 beam traversals, as explained below, so that the total beam power is 6 kW (10 μA x 20 x 30 MeV). The input r.f. power will be 30 kW.

Tests are underway with single lead and niobium cavities to find a satisfactory method of fabricating and assembling superconducting cavities into a linac. This work is not on the scale of the Stanford effort and the Illinois group is in close touch with progress at Stanford. The decision between lead or niobium for the cavity material has not yet been taken though niobium with its better basic properties will be selected if the fabrication problems can be overcome.

Purchase of some of the conventional components — electron gun, chopper system, 1.8°K cryostat for a 2.5 m section — is going ahead and it is hoped to install these in summer to operate at least a 3 wavelength section of the waveguide.

Part 2 of the project will incorporate the 30 MeV linac in a 600 MeV microtron — the system being shown schematically in the diagram. Two large magnets about 7 m apart will bend the electrons accelerated in the linac back through 180° so that they make a total of 20 passages through the acceleration stage. The magnets will be about 3 m wide and have slots of a few centimetres aperture between the polefaces where the beams travel. A magnetic field of 13.67 kG will give a spacing 14.7 cm between adjacent beams.

Work on this second stage has been particularly concerned with studying particle trajectories in the racetrack microtron to ensure that the necessary beam stability can be achieved allowing for variations in input beam quality, in magnetic field uniformity and in power supply stability. The results of the calculations indicate no major difficulties. It is estimated that the microtron could follow two years behind the linac (that is in 1972) at an additional cost of $ 1.25 million.



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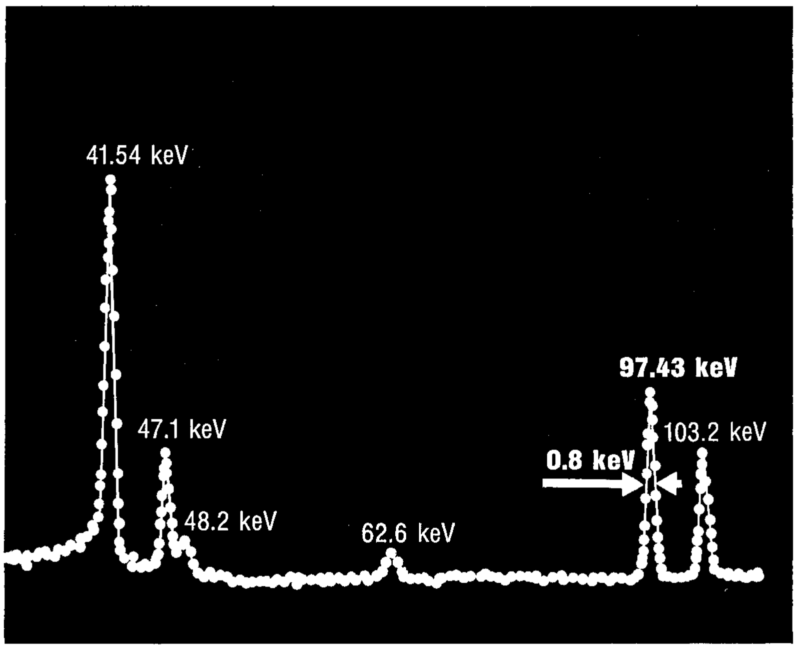
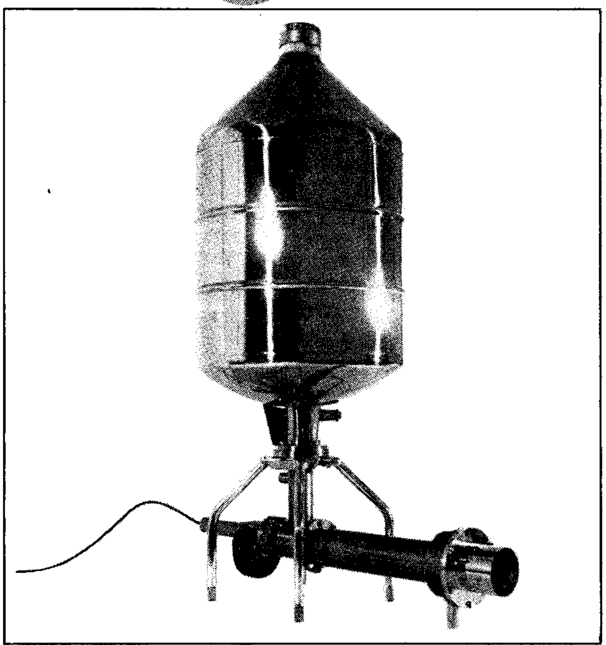
0.8 keV





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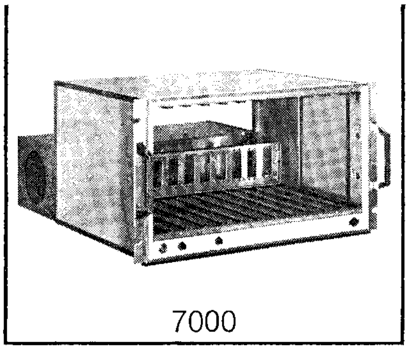
électronique rapide en standard NIM



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7012 Single channel analyzer
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7015 Time-to- amplitude converter
7016 Dual amplifier
7018 Dual discriminator
7019 Dual 2-fold coincidence veto
7023 4-fold mixer
7024 Octal linear gate
7020 4-fold coincidence veto

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Pattern unit 7030
Fast linear gate 7033

Other modules:
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Converters:
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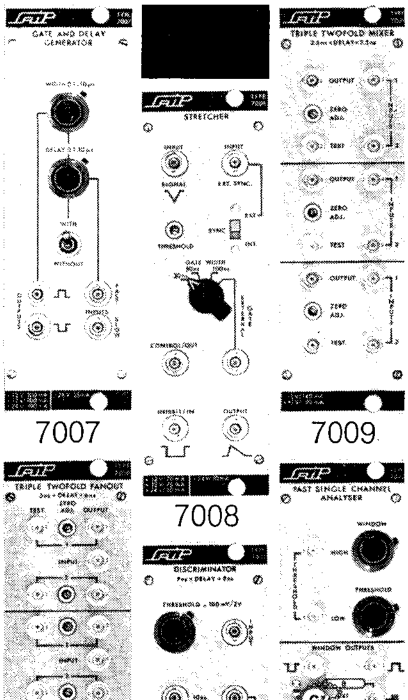
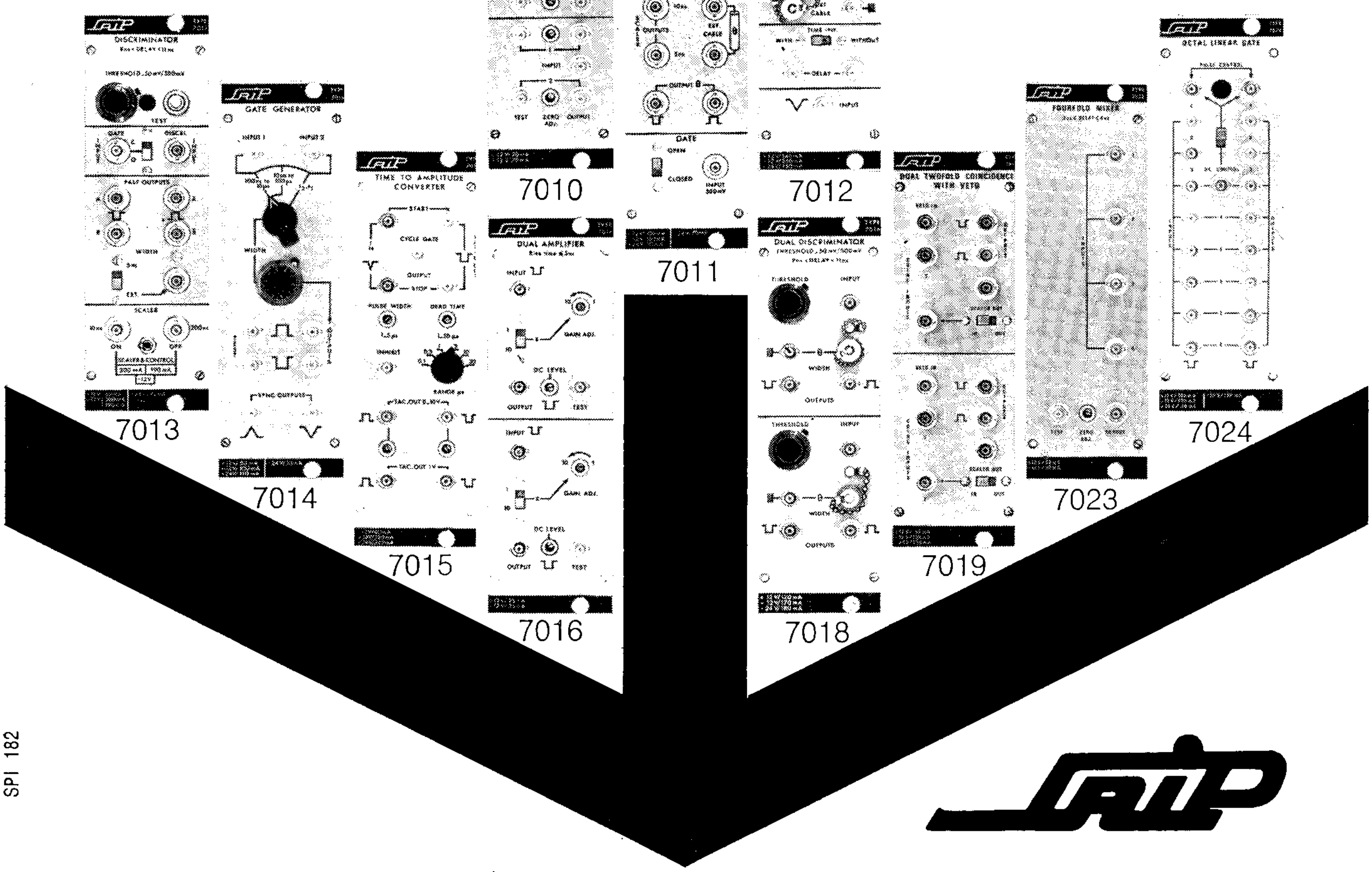
Analogue to digital





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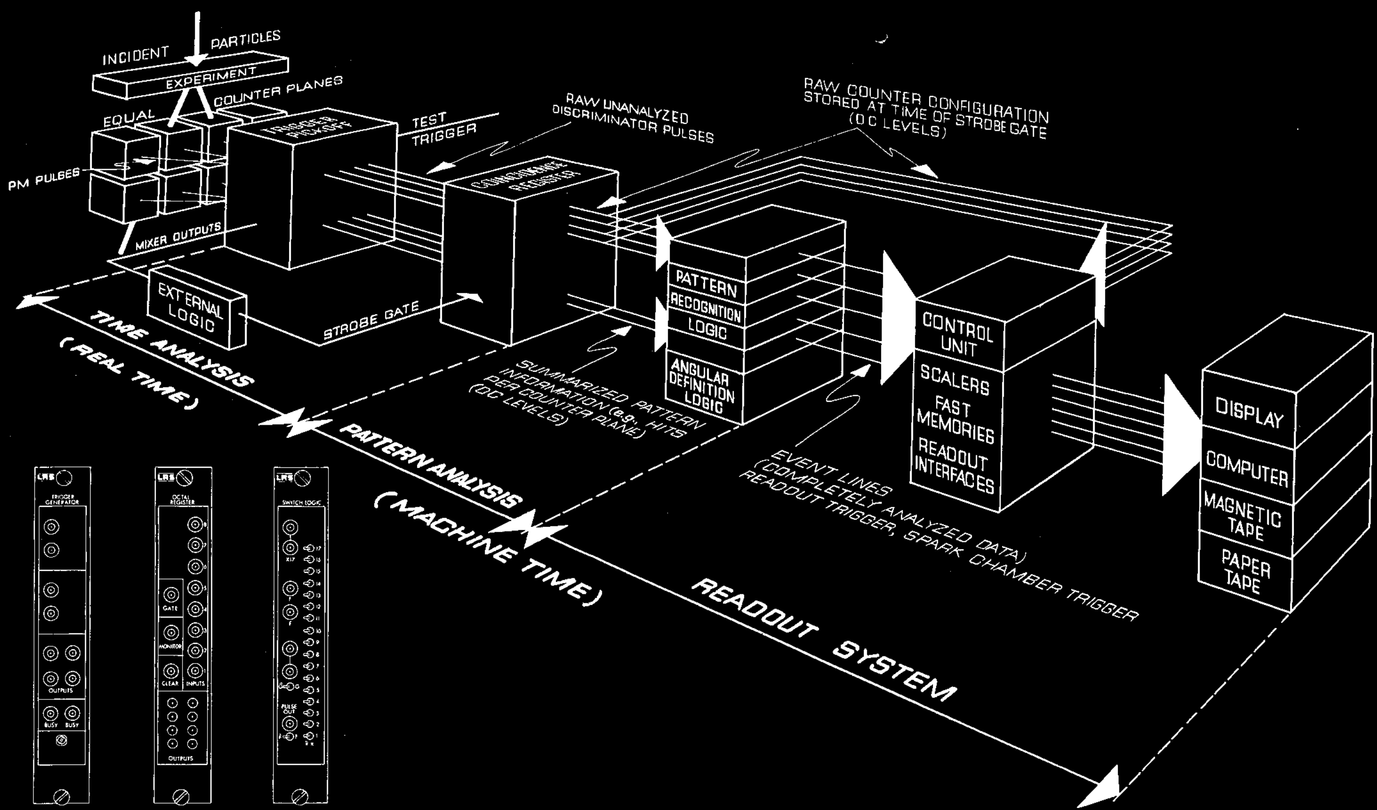

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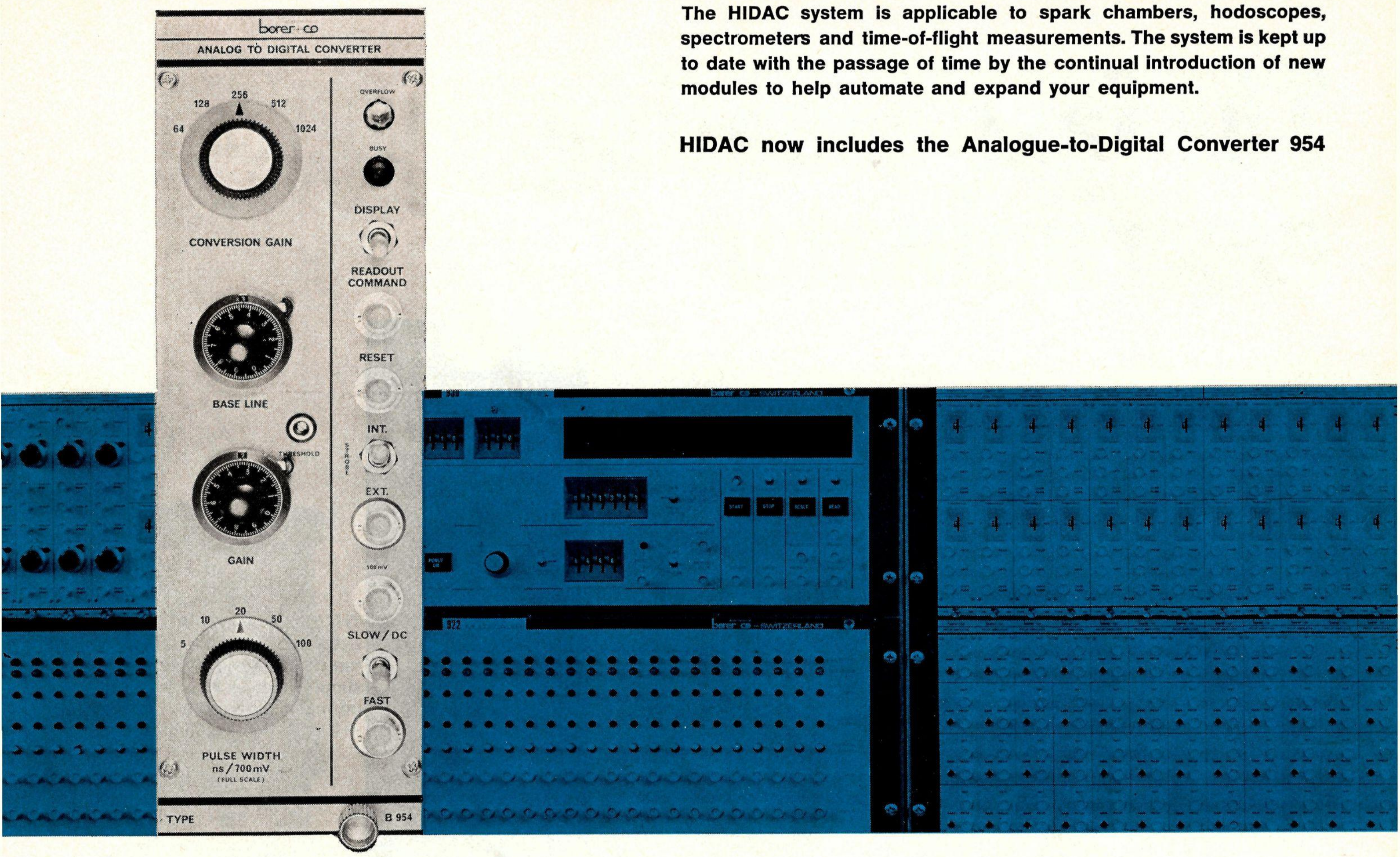

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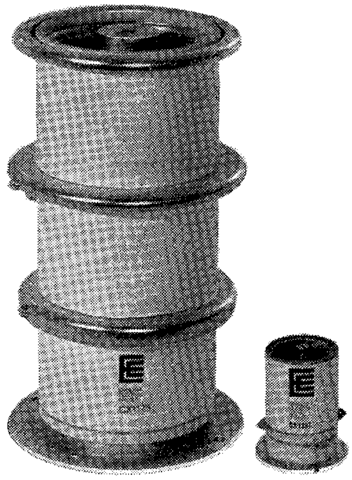
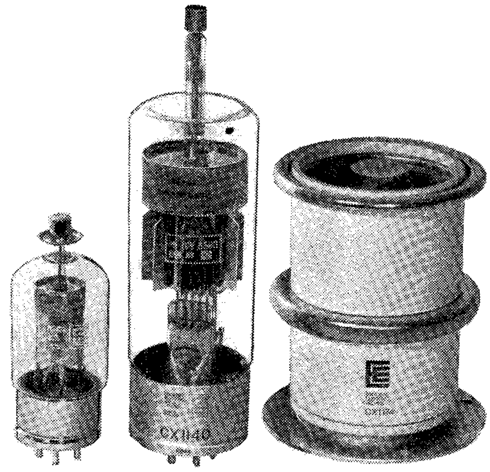
Spark chambers
For pulsing light shutters such as Kerr or Pockel cells.
Electronic crowbars and energy diverters





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CX1168	100.0	70×10^9	80	2500	2.5
CX1171	150	70×10^9	120	2500	2.5
CX1174	120	60×10^9	40	6000	6.0
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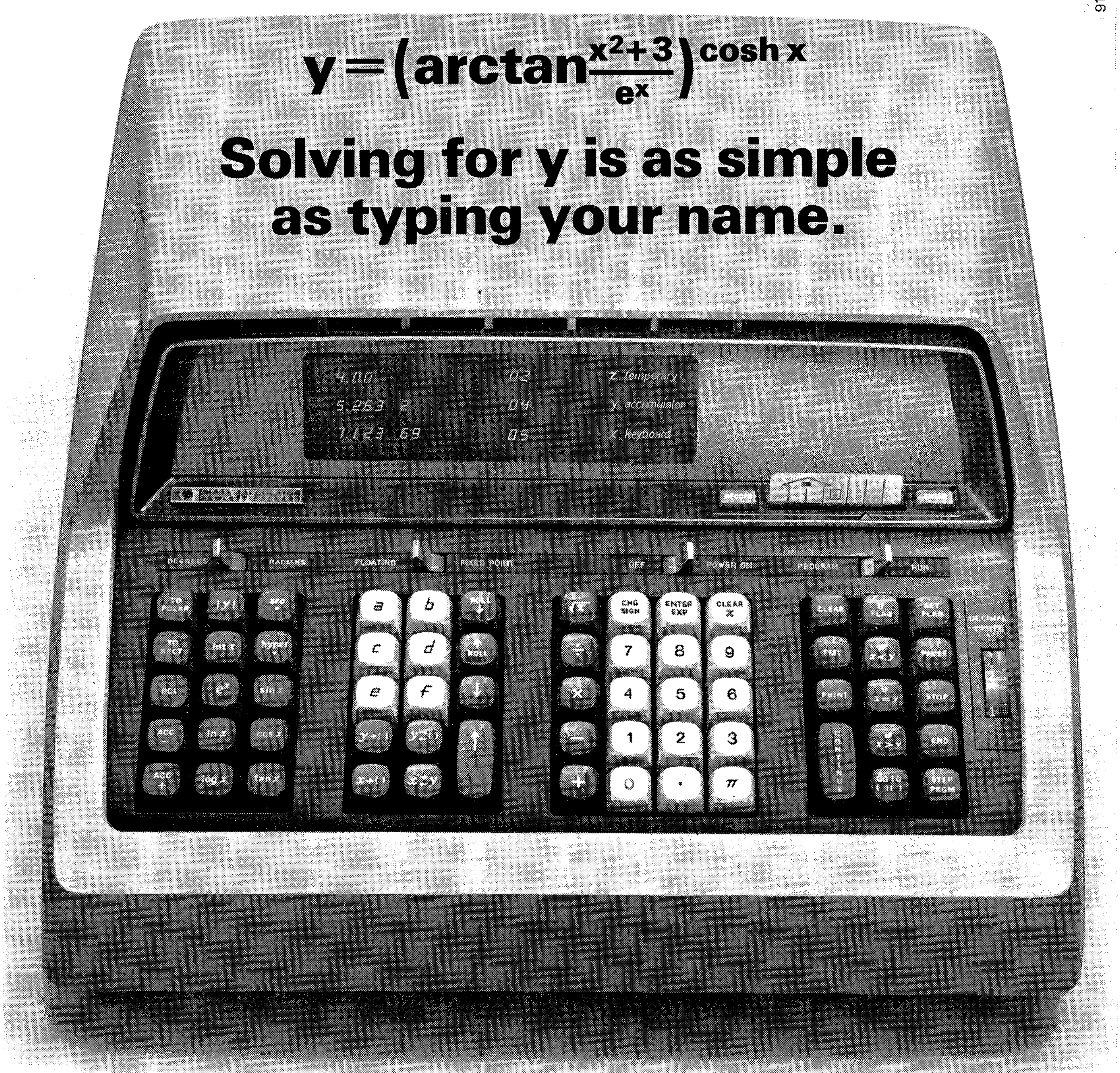

Merely touch the keys. That's all there's to it. Everything is right there. Even the log and trig functions. Plus hyperbolic and exponential functions. The 63 keys tell the story.
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Just a few examples from the repertoire of the 9100A

- Fourier analysis
- elliptic integrals
- real and complex polynomial evaluation
- regression analysis
- analysis of variance
- coordinate geometry
- numerical integration
- transcendental equations
- 2nd-order differential equations
- roots of 5th-order polynomials

All of these are written up for you in the extensive programme library you receive with the instrument.

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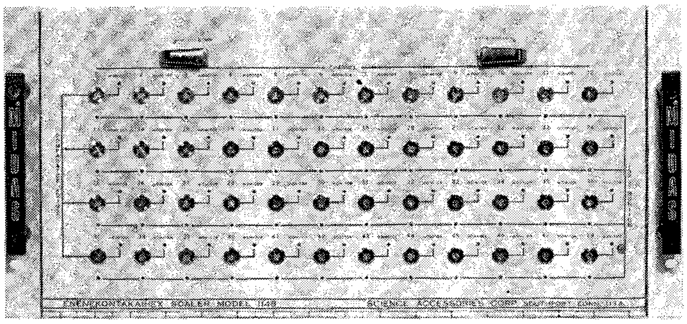
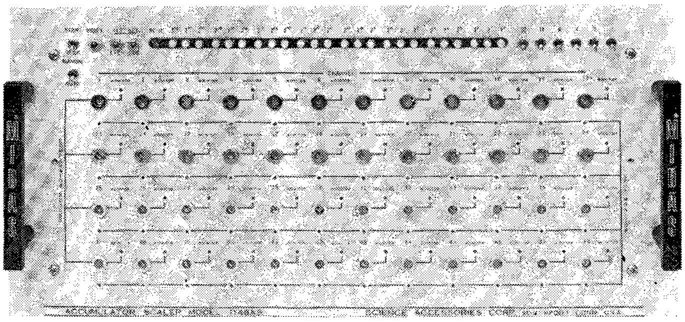
DATA ACQUISITION SYSTEMS FOR HIGH ENERGY PHYSICS



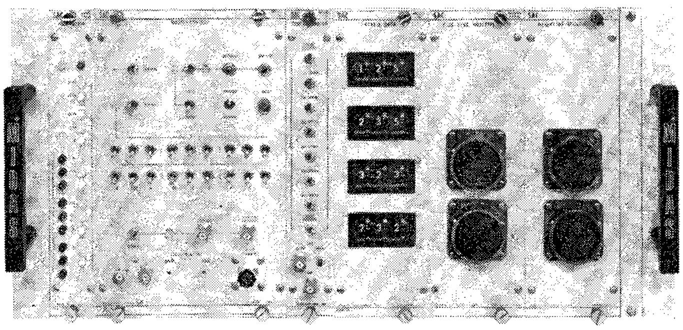
1148 DIGITAL SPARK CHAMBER SCALER UNIT

- Switch select any combination of scalers per unit—2/48, 4/24, 6/16, 8/12
- High adjacent pulse resolution with digital pulse center finder



1148 AS ACCUMULATION SCALER UNIT

- 48, 24 binary bit, 40 MHz scalers-positive and negative input
- Fully computer controllable-random access or sequential readout, individual group start and stop



1100/1200/1300 SERIES DATA ACQUISITION, CONTROL AND READOUT INTERFACE UNITS

- Digital multiplexing, scanning and output device interfaces ranging from typewriters to computers

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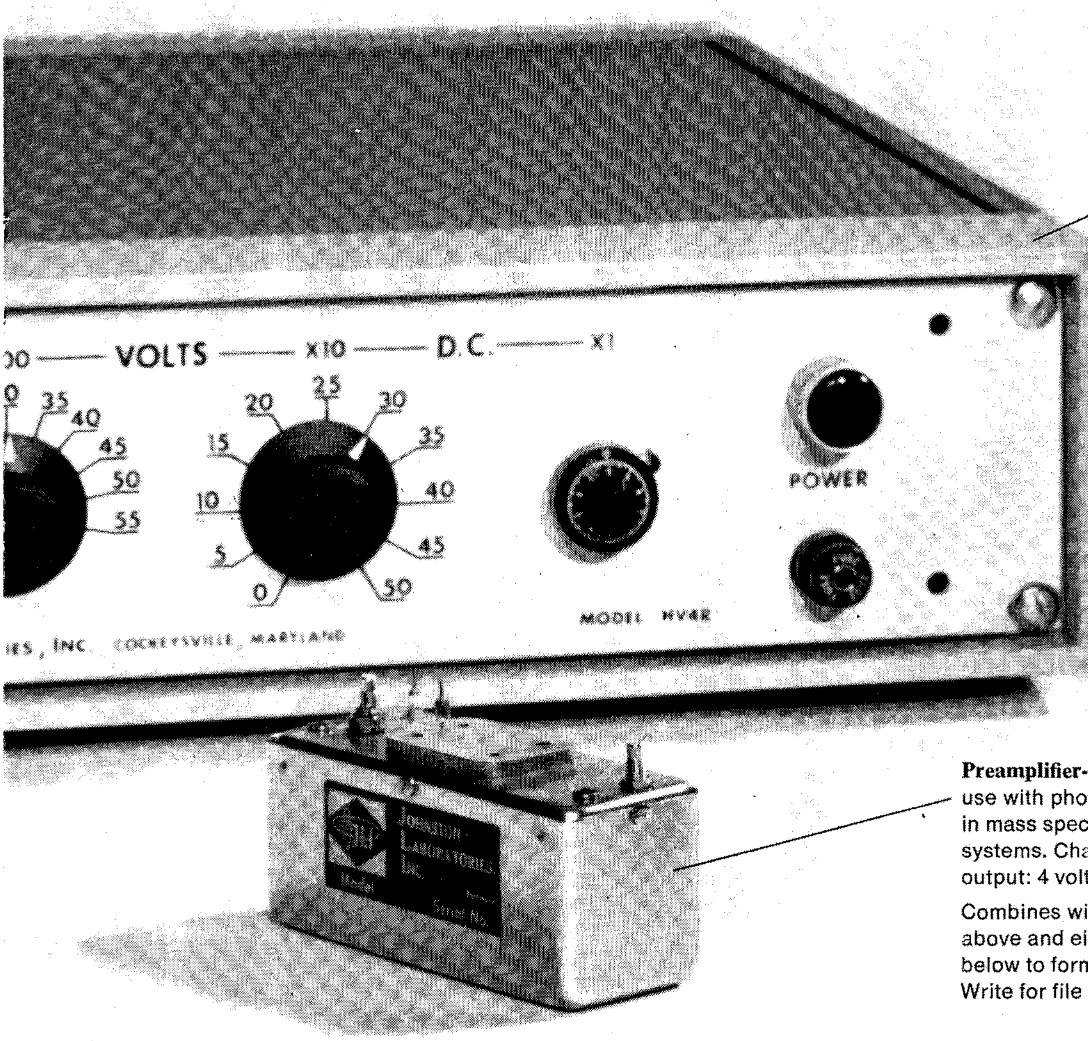
(Four components. Or two systems. You choose.)

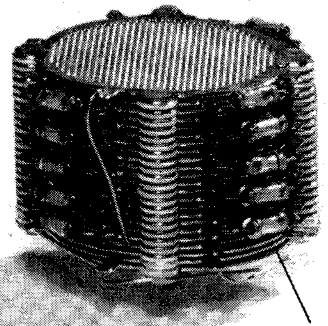


All solid-state high voltage power supply (HV-4R)—ultra low noise for operating photomultipliers, electron multipliers, proportional counters, and ionization chambers. Small, light, 500 to 6,100 volts DC range, reversible polarity, highly filtered, noise: less than 300 μv RMS.

Forms a complete matched system with the preamplifier-amplifier-discriminator and either of the particle multipliers shown below. Write for file HV.

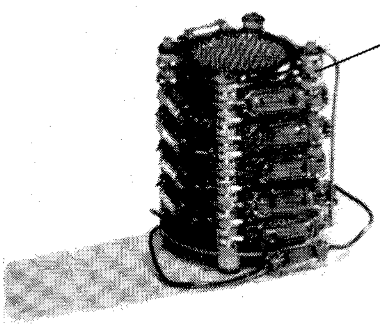
Preamplifier-amplifier-discriminator (PAD-1)—for use with photomultipliers and electron multipliers in mass spectrometers and fast counting systems. Charge sensitive; rise-time: 3 nsec, output: 4 volts into 50Ω, miniaturized, rugged.

Combines with the high voltage power supply above and either of the particle multipliers below to form a complete matched system. Write for file PAD.



Particle multiplier (MM-2), patented—has the same general characteristics as the particle multiplier shown above, but is only half the diameter (1″).

Forms a complete matched system when combined with the high voltage power supply and preamplifier-amplifier-discriminator above. Write for file MM.



Particle multiplier (MM-1), patented—for pulse counting or current measurement of electrons, ions, UV or x-ray photons, and energetic neutral atoms or molecules. Adjustable high gain (up to 10^{10}), stable, guaranteed reactivateable, non-magnetic, no ion feedback or instability, integral resistor chain, small, light, rugged, bakeable, repairable.

Other options available (e.g., interchangeable cathodes.)

Complete matched system when combined with the high voltage power supply and preamplifier-amplifier-discriminator above. Write for file PM.

Johnston Laboratories, Inc.
3 Industry Lane, Cockeysville, Md. 21030.

A LITHIUM DRIFTED GERMANIUM NON-DISPERSIVE X-RAY SPECTROMETER

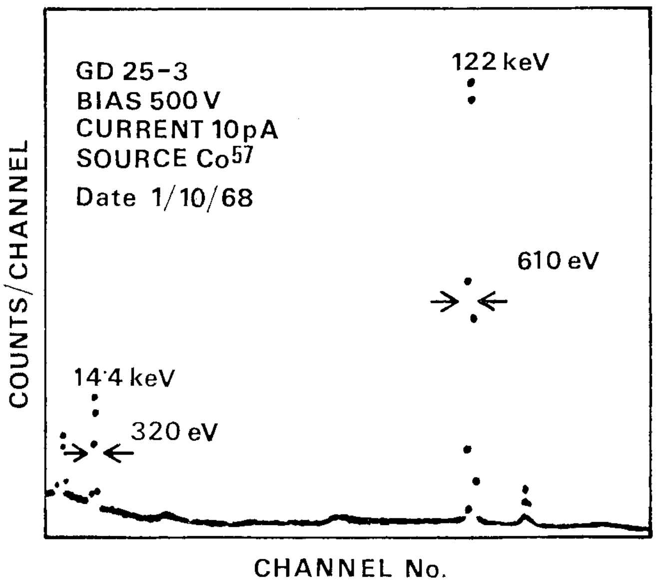
SEMICONDUCTOR RESEARCH GROUP*
NUCLEAR ENTERPRISES LTD., SIGHTHILL, EDINBURGH 11, SCOTLAND

December 12, 1968

Recent advances in the development of germanium X-ray spectrometers are summarised and technical data listed. The use of these devices in the field of research, medicine, industry and non-destructive analysis is discussed, and the higher efficiency relative to silicon is emphasised.

The applications of semiconductor detectors in the energy spectrum above 100keV have been known for several years. Because of their low ionisation energy they now dominate experimental and analytical work in those fields of nuclear spectrometry where energy resolution is of prime importance. However their use has not been so general in the X-ray and gamma-ray region below 100keV. In order to supersede scintillation and proportional counters at these energies a semiconductor detector system must have the following properties. It must be linear, exhibit very good energy resolution (certainly less than 1keV) efficient and also have a very thin window.

At its Edinburgh laboratories Nuclear Enterprises has been developing germanium detectors for the energy identification of X-rays and gamma-rays between 2keV and 100keV. This work has involved stringent control of detector production, cryostat fabrication and the complete redesign of the coupling between the detector and preamplifier first stage. Although this development work is continuing, the results achieved so far have been so good as to justify the marketing of the first range of germanium X-ray spectrometer systems capable of an energy resolution of less than 325eV. Such a system comprises a germanium detector mounted in a cryostat and dc coupled to a low noise sensitive preamplifier with a cooled first stage.



Four basic cryostat designs are available in drip feed and dipstick configurations, with either a horizontal or vertical housing. Full technical specifications of these systems are given below.

There are many interesting applications for these new systems, in basic research, medical work, fluorescence analysis and many other fields. The person doing Mossbauer experiments will be particularly interested to learn of the availability of a detector system which combines the high resolution, only previously obtained from silicon detectors, with the high efficiency of germanium (97% at 60keV for a 5mm detector). One interesting application in the medical field is the *in vivo* imaging of the thyroid gland through use of the Iodine K shell fluorescence X-ray at 28.5keV. A dysprosium source is used to excite Kα X-rays and the detector is scanned across the thyroid to map out iodine distribution. Industrial samples of powders, slurries or liquids may be analysed non-destructively by using the X-ray spectrometer to identify elements from their characteristic X-ray emissions. The source used to excite the X-rays can be an X-ray generator or a radioisotope source mounted on the cryostat to give optimum detector-source-sample presentation. Minimum detectable concentrations can be as low as a few p.p.m.

Technical Specifications

1. DETECTORS

Type No.	Area mm^2	Thickness mm	Window Micron of Ge	Resolution at 14.4keV (Co^{57}) eV FWHM
GDX25-3A	25	3	< 1·0	< 325
GDX25-3	25	3	< 1·0	< 400
GDX50-3	50	3	< 1·0	< 450
GDX100-3	100	3	< 1·0	< 600
GDX200-5	200	5	< 1·0	< 750
GDX300-5	300	5	< 1·0	< 900

2. CRYOSTATS

Type No.	Configuration	Reservoir Capacity
NE 5602	Drip Feed Horizontal	10 or 25
NE 5603	Drip Feed Vertical	10 or 25
NE 5604	Dipstick Horizontal	25 or 31
NE 5605	Dipstick Vertical	25 or 31

All systems are shipped as an integral detector, cryostats with ion pump and power supply, and preamplifier assembly.

*Full details of systems are available from Nuclear Enterprises Ltd., at Sighthill, Edinburgh 11. Tel: 031-443 4060. Telex: 72333

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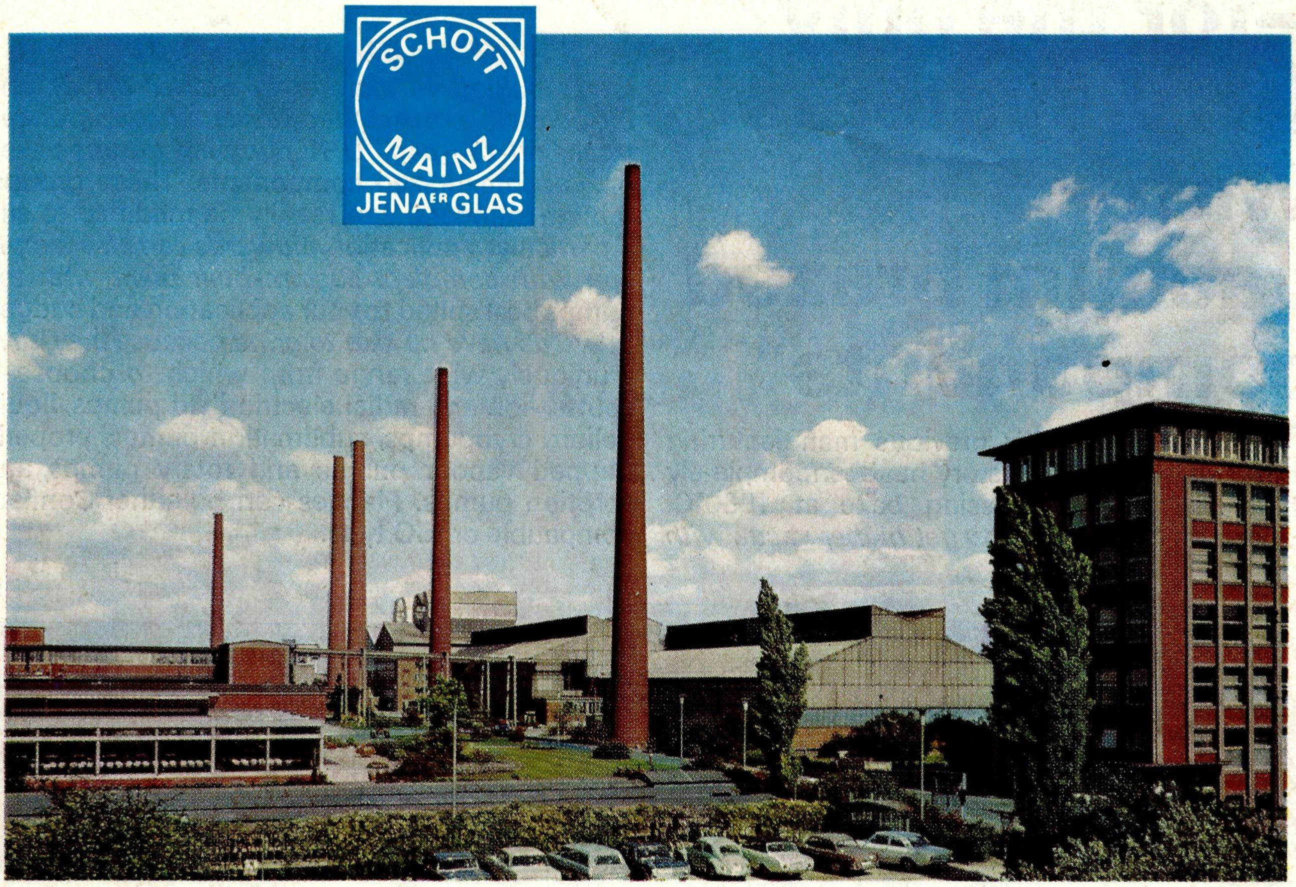

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Shielding windows against gamma radiation. Special observation windows for nuclear installations.

Information and technical data on request.

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