# PEACEFUL USES OF ATOMIC ENERGY

# Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy

Held in Geneva
1 September - 13 September 1958

## Volume 30
## Fundamental Physics

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## PREFACE

More than 2,100 papers were submitted by the nations, the specialized agencies, and the International Atomic Energy Agency, which participated in the Second United Nations International Conference on the Peaceful Uses of Atomic Energy. The number of papers was thus about twice that involved in the First Conference. Provision was therefore made to hold five concurrent technical sessions in comparison with the three that were held in 1955. Even so, the percentage of orally presented papers was less in 1958 than in 1955.

In arranging the programme, the Conference Secretariat aimed at achieving a balance, allowing adequate time for presentation of as many papers as possible and, nevertheless, leaving time for discussion of the data presented. Three afternoons were left free of programme activities so that informal meetings and discussions among smaller groups could be arranged. No records of these informal meetings were made.

A scientific editorial team assembled by the United Nations checked and edited all of the material included in these volumes. This team consisted of: Mr. John H. Martens, Miss L. Ourom, Dr. Walter M. Barss, Dr. Lewis G. Bassett, Mr. K. R. E. Smith, Martha Gerrard, Mr. F. Hudswell, Betty Guttman, Dr. John H. Pomeroy, Mr. W. B. Woollen, Dr. K. S. Singwi, Mr. T. E. F. Carr, Dr. A. C. Kolb, Dr. A. H. S. Matterson, Mr. S. Peter Welgos, Dr. I. D. Rojanski and Dr. David Finkelstein.

The speedy publication of such a vast bulk of literature obviously presents considerable problems. The efforts of the editors have therefore been primarily directed towards scientific accuracy. Editing for style has of necessity been kept to a minimum, and this should be noted particularly in connection with the English translations of certain papers from French, Russian and Spanish.

The Governments of the Union of Soviet Socialist Republics and of Czechoslovakia provided English translations of the papers submitted by them. Similarly, the Government of Canada provided French-language versions of the Canadian papers selected for the French edition. Such assistance from Governments has helped greatly to speed publication.

The task of printing this very large collection of scientific information has been shared by printers in Canada, France, Switzerland, the United Kingdom and the United States of America.

The complete Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy are published in a 33-volume English-language edition as follows:

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| 3 | Processing of Raw Materials | E-10, E-6 and E-7a |
| 4 | Production of Nuclear Materials and Isotopes | E-11, E-12, C-14, C-15 |
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# Session 15

## RECENT DEVELOPMENTS IN FUNDAMENTAL PHYSICS

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# Startup of a 10-Bev Synchrophasotron and First Results of Physical Research

By V. I. Veksler*

In February 1957, after the adjustments had been made, the powerful accelerator of the Joint Institute for Nuclear Research was first put into operation. In May 1957 the protons moving in the vacuum chamber of the accelerator were accelerated to an energy of 10 Bev. This is the largest energy ever attained artificially by physicists in their laboratories; particles of such high energies were only available in cosmic rays.

## CONSTRUCTION

The accelerator is a giant atomic machine. It consists of a big ring-shaped electromagnet, between the poles of which the accelerated protons revolve inside the high-vacuum chamber. The electromagnet consists of 192 ш-shaped blocks; each of them is composed of sheets of special steel 10 mm thick, and they are isolated from one another by insulating gaskets. The total weight of the electromagnet is about 36,000 tons.

A concrete support about 15,000 tons in weight serves as foundation for the electromagnet. Construction of the foundation was completed long before the assembling of the electromagnet, and about a year and a half was allowed before the adjustment and operation of the accelerator so as to eliminate settling irregularities. Geodesic investigations had shown that the deformation of the foundation was practically complete a year after the electromagnet had been mounted.

Figure 1 presents a general view of the synchrophasotron electromagnet. As is seen from this figure, the electromagnet of the accelerator consists of four quadrants separated by rectilinear sections. In two of these sections the accelerating electrodes are placed. The third section is used for the ejection of particle beams of various kinds, and the fourth houses the apparatus for the injection of particles into the synchrophasotron.

Figure 2 shows the injection arrangement. It consists of a 600-kv impulse transformer, accelerating tube, linear accelerator (which accelerates protons up to 9 Mev) as well as a magnetic-optical system.

The vacuum chamber, inside which the accelerated protons move, is evacuated in two stages. Its volume is about 200 m$^3$. It is pumped out by 56 vapour pumps on the high-vacuum side and by 16 for the fore-vacuum. In order to prevent the loss of particles during acceleration, as follows from experiments and calculations, it is necessary to provide for a sufficiently high vacuum in the chamber. At present a vacuum of $5\times10^{-6}$ mm Hg is maintained.

The particles acquire an energy of 10 Bev in about 3 sec. In order to provide for stability of motion and to prevent the loss of particles during such a long period of time, the magnetic field must satisfy the necessary conditions. In other words the magnetic forces must return the particles to their equilibrium position if any accidental deviation from the horizontal plane occurs. This holds also for the deviation of particles with respect to the position of their equilibrium orbit in the radial direction.

Specialists working in the field of accelerating machines know very well that the difficulties in construction and especially those concerning the startup of an accelerator become greater as the ratio of the radius of the particle orbit to the aperture of the gap in which the accelerated protons are moving is increased. The radius of the particle orbit in the Joint Institute synchrophasotron is so great (it equals 28 m and is almost two times more than that of the Bevatron) that at our aperture it is necessary to have exact tolerances for all the accelerator elements, and for the magnetic field first of all.

In order to secure azimuthal homogeneity with the necessary precision of some hundredths of a percent, special compensating winding is placed on each of the 192 poles of the synchrophasotron electromagnet.

Still more critical is the requirement of homogeneity of the position of the median magnetic surface. As follows from the calculations and experiments, a change of the first harmonic of the median magnetic surface by only 1 cm leads to a distortion of 5–6 cm in the orbit plane around which accelerated particles oscillate vertically.

The total aperture of the electromagnet gap in which the accelerated particles move equals approximately 32 cm, of which only 24 cm is working aperture because of magnetic properties. To correct the median surface, to increase the radial magnitude of the working space, and to choose the optimal conditions of particle motion inside the vacuum chamber about 30 pairs of conductors were laid to regulate the magnetic characteristics of the synchrophasotron.

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* Academy of Sciences of the USSR.

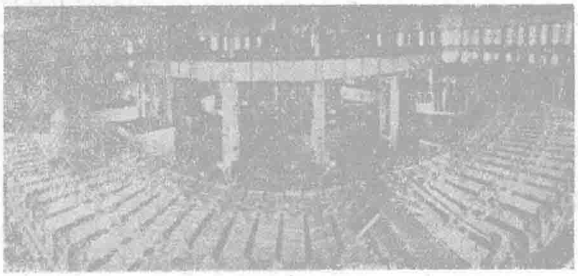

Figure 1

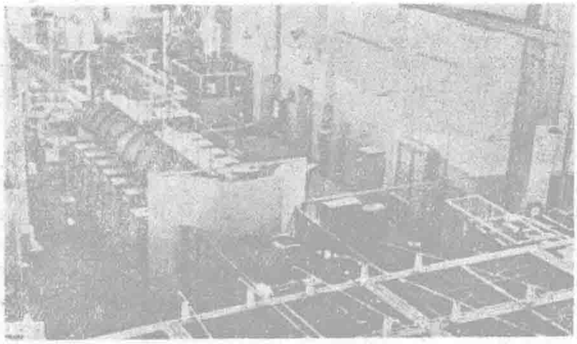

Figure 2

The electromagnet is supplied by a powerful substation consisting of four parallel working units each of 37,000 kva. Thus, the total peak capacity of these four units is over 140,000 kva. But because of the inductance of the system the average capacity used by the electromagnet from the network is much lower and does not exceed 10,000 kw under normal working conditions. A general view of the hall where these machines are placed is shown in Fig. 3.

Alternating current supplied by the generators is rectified by 96 powerful mercury ignitrons comprising four groups according to the number of generators. The peak capacity of each mercury rectifier is almost 9000 kw. One of these devices is shown in Fig. 4.

In the pause between the working cycles the demagnetization system is switched on, giving a series of current impulses of opposite polarity, with an amplitude decreasing in time.

The feeding system of the electromagnet worked out by the Soviet engineers appeared to be highly effective and reliable at work.

Particle acceleration with the synchrophasotron of the Joint Institute, as well as with well-known American accelerators (the Cosmotron and the Bevatron), is based upon the principle of phase self-stability, which makes it possible to overcome a principal difficulty which at one time hampered the development of cyclotrons. This difficulty was as follows: with the increase of energy of the particles their mass also increases and therefore the usual mechanism of resonance acceleration does not work any more. In our synchrophasotron during the time of acceleration the total mass of the protons rises approximately 10 times. To provide a continuous increase of the accelerated particle energy under such conditions, the frequency of the alternating electric field affecting the particles during their passage through the accelerating tubes must change in accordance with the magnetic field determining the period of proton revolution in the accelerator. In this case the protons are accelerated by the electric field synchronously with their motion and continuously increase their energy. Such synchronism is guaranteed in our accelerator with a precision up to 0.1%.

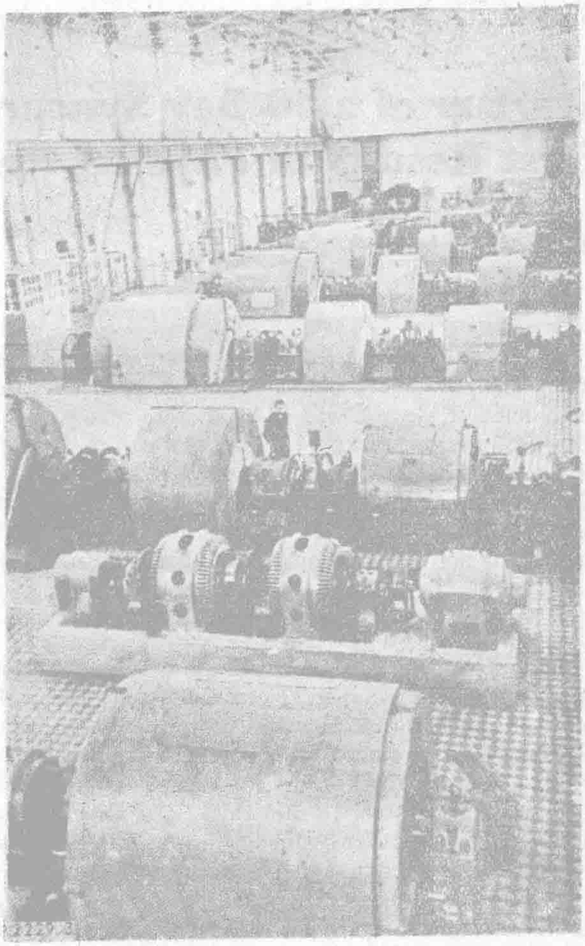

Figure 3

The electronics system which controls all the processes related to the acceleration of particles is situated in separate screened rooms, and is shown in Fig. 5. The synchrophasotron is remotely-controlled from a separate building at a distance of approximately 300 m. One can see the central control panel in Fig. 6.

After the accelerator was started up and the protons had been accelerated up to the calculated energy of 10 Bev, it took much time to choose optimal working conditions for the most important units of the synchrophasotron. This work is still being carried out and we are gradually increasing the intensity of the accelerated particle beam. At present, the ion source, which injects protons into the linear accelerator, gives

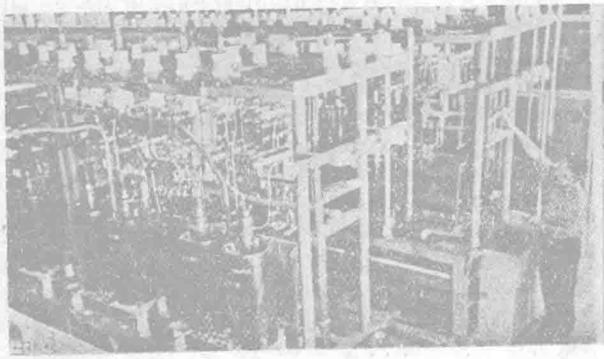

Figure 4

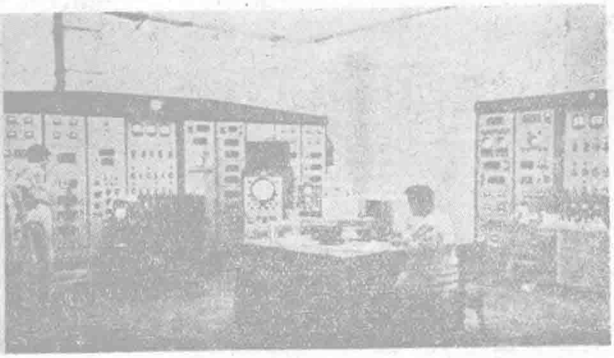

Figure 5

approximately 20–30 ma proton current in a well-focused proton beam. The linear accelerator yields up to 250 microamperes. Injection is realized for 300 microseconds and in the course of this time approximately $1 \times 10^{11}$ particles are injected into the vacuum chamber.

The accelerated beam is being observed at various stages by means of different targets, as well as by pick-up electrodes of vertical and horizontal types, placed in the ejecting rectilinear section. In Fig. 7 a typical oscillogram of the beam obtained with the help of pick-up electrodes is represented.

When increasing the intensity of the beam some phenomena perturbing the motion of particles, including various resonances of fine character, were observed and removed. Thus, for instance, it was found that the resonance between the harmonics of the magnetic field of 1200 and 600 hertz frequencies and the phase oscillations of particles leads to a considerable loss of particles. Although, for instance, a 600 hertz harmonic of magnetic field is only $8 \times 10^{-2}$ oersted in amplitude, i.e., less than one-thousandth of a per cent, such a resonance led to an 80% loss of accelerated particles. Resonance losses were eliminated by a corresponding variation of the high-frequency electrical field amplitude.

Time does not permit my speaking in detail about the vast number of investigations which were carried out in order to increase the intensity of the accelerated proton beam. But, as a result of this work, the beam intensity was increased about $10^3$–$10^4$ times and at present it is approximately $10^9$ particles per pulse.

## NUCLEAR EMULSION EXPERIMENTS

In addition to the work aimed at increasing the beam intensity and the preparation of different apparatus for scientific research, nuclear emulsion experiments were started. An interesting direction which already made it possible to obtain some preliminary results is the study of elastic and inelastic scattering of high-energy protons by nuclei and nucleons.

For 10-Bev protons the de Broglie wavelength is $2 \times 10^{-15}$ cm, i.e., 100 times less than the size of a nucleus. Therefore, elastic proton scattering with such a short wavelength may yield rather interesting new data on nucleon structure. However, at such high energies elastic scattering is of a diffractional nature and concentrated in the region of very small angles almost in the direction of the beam. For instance, the angles of 10-Bev proton diffractional scattering by light nuclei (C, N, O) do not exceed 1 degree. This is the reason why insufficient data on elastic proton scattering by nuclei and nucleons are available even in the energy region of a few Bev.

Making use of a characteristic feature of the Joint Institute synchrophasotron a group of physicists of

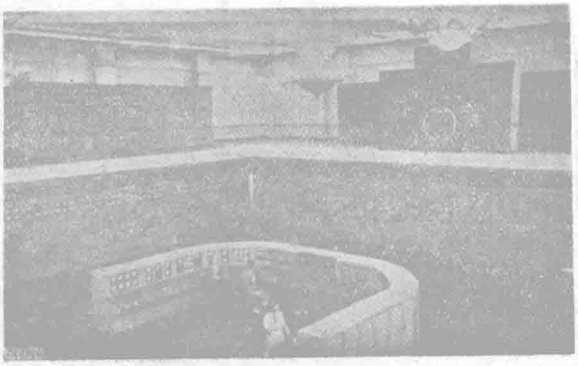

Figure 6

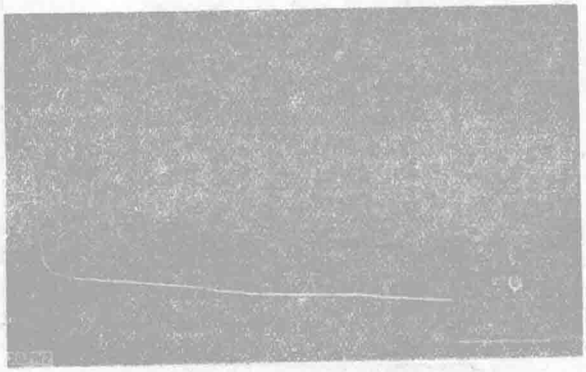

Figure 7. A typical oscillogram of the beam obtained with the help of pick-up electrodes; duration of acceleration cycle, 2.72 seconds

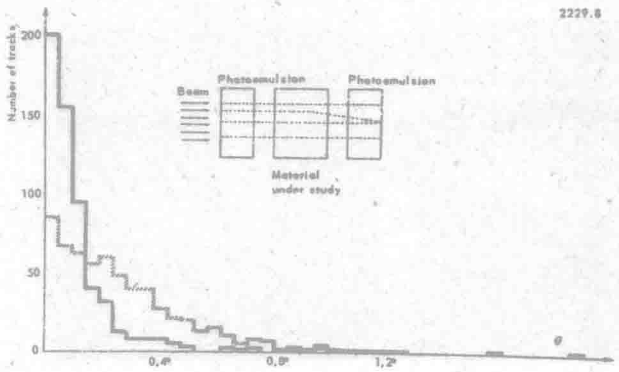


Figure 8

the High Energy Laboratory (M. J. Danysz, V. B. Lubimov, M. I. Podgoretsky, *et al.*) suggested a very ingenious method for studying the elastic scattering of high-energy protons.

The vertical and radial extent of the proton beam accelerated up to 10 Bev is very small, only 3–6 cm. Therefore the angular spread of the particles is less than 6 minutes. This is determined by the ratio of the free oscillation amplitude to the radius of the orbit, which is negligible. Thus we have something of a parallel proton beam inside the vacuum chamber of the accelerator and this makes it possible to investigate effectively the elastic scattering of high-energy protons by placing the material we intend to investigate inside the vacuum chamber and by determining the angular spread of the particles passing through such a target.

Figure 8 is given as an illustration of the possibilities of this method. This figure represents the angular distribution of protons accelerated up to 9 Bev, before and after passing through stripped emulsions (the stack is 36 g/cm² thick). In this way the diffractional proton scattering by emulsion nuclei was investigated. One can see a sharp difference between the angular distributions. A model of a nucleus in the form of a "black ball" agrees very well with these experiments. The number of particle traces was more than 2000, i.e., the statistics were quite satisfactory.

Another method of studying diffractional scattering has been developed by K. D. Tolstoy and E. I. Tsyganov. This method, too, is based on the above-mentioned advantage of the synchrophasotron, which is particularly effective in the study of the diffractional scattering of protons by protons. This second method differs from that usually used in that the beam of high-energy protons is perpendicular to that of the photosensitive layers of the emulsion stack. In this way, traces of elastically scattered protons can be easily distinguished by their coplanarity and by the sharp difference in the ionizing power of the primary and slow secondary protons. With this method approximately 10 times as many particle traces can be registered as with the usual method. The experiments on the diffractional scattering of protons by protons now in progress may obviously yield some data about the effective dimensions and transparency of the "nucleon".

I now come to the first experimental results, relating to inelastic collisions of protons and nucleons.

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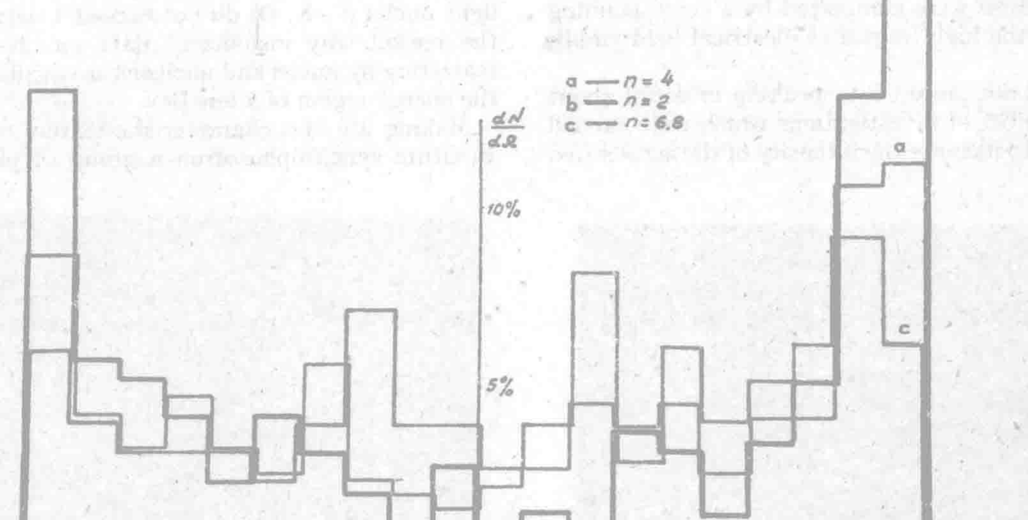


Figure 9

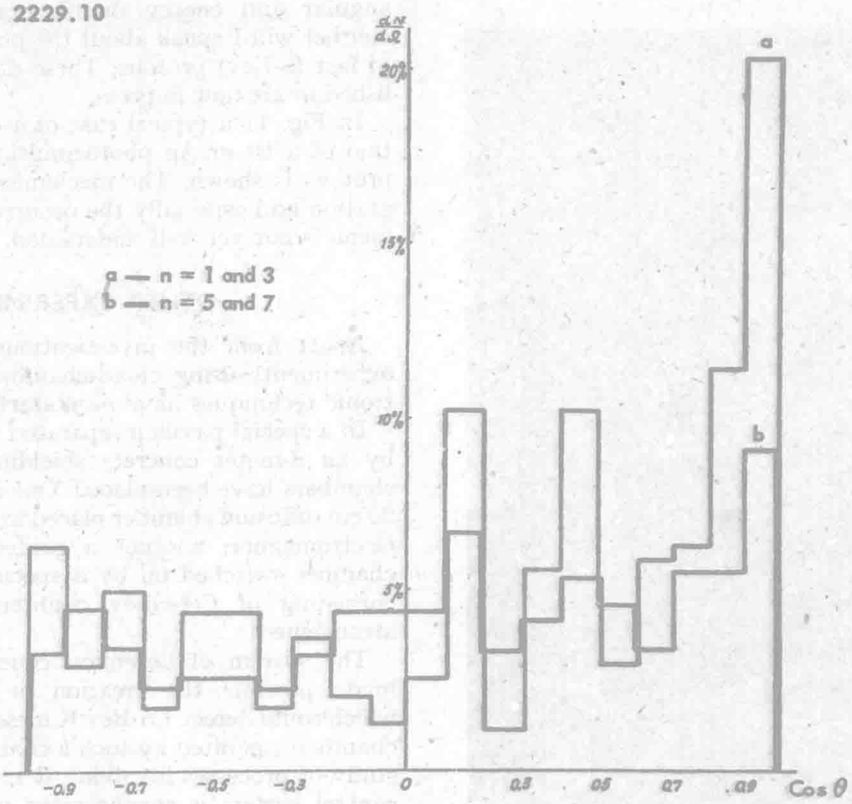

Figure 10

Using stripped emulsions we have studied processes in which the collision of high-energy (9 Bev) protons and free protons or quasi-free protons or neutrons in the nucleus leads to the appearance of different numbers of high-speed relativistic particles.

Figure 9 shows the angular distribution of charged particles accompanying inelastic proton-proton collisions. The angular distributions relating to processes in which different numbers of secondary mesons take part are shown by the different graphs. Graph (*b*) indicates the results relating to two high-speed particles resulting from a collision, and (*c*) indicates the angular distribution in cases where 6–8 particles are generated. It can be clearly seen that when the number of particles generated is low, the angular distribution, although symmetrical about the 90° axis, is distinctly anisotropic in the centre of gravity system. On the other hand, for collisions in which a number of secondary mesons are generated, the angular distribution is practically isotropic.

Figure 10 shows similar distributions for inelastic collisions of a proton and a quasi-free neutron of the nucleus. As in the case of proton-proton collisions, a sharp difference is apparent in the angular distribution according to whether a small or a large number of secondary particles are generated. However, in the case of proton-neutron collisions, by contrast to proton-proton collisions, distinct asymmetry of the angular distribution of the particles emitted is observed when a small number of particles are generated. When the number of particles generated during the collision is large, then, just as in the case of proton-proton collisions, the angular distribution of the particles is isotropic.

These results are preliminary, but without any doubt they indicate the existence of two quite different types of collisions, peripheral and central. We may say roughly that the nucleon has two regions: the peripheral region or shell and the kernel.

When the peripheral collision takes place, a relatively small number of secondary mesons are generated and the nucleons keep their character, i.e., proton remains proton and neutron remains neutron. When the kernels collide, a large number of mesons are generated and then the proton may become a neutron and

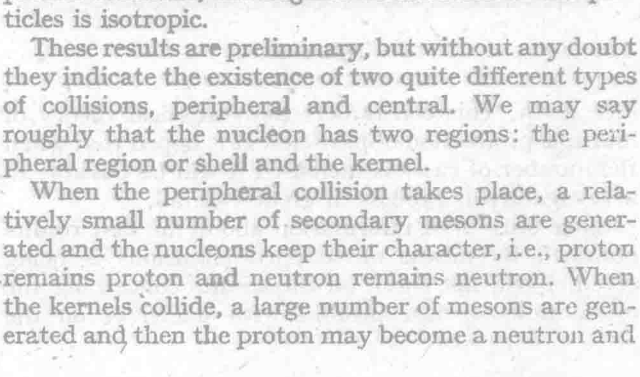

Figure 11

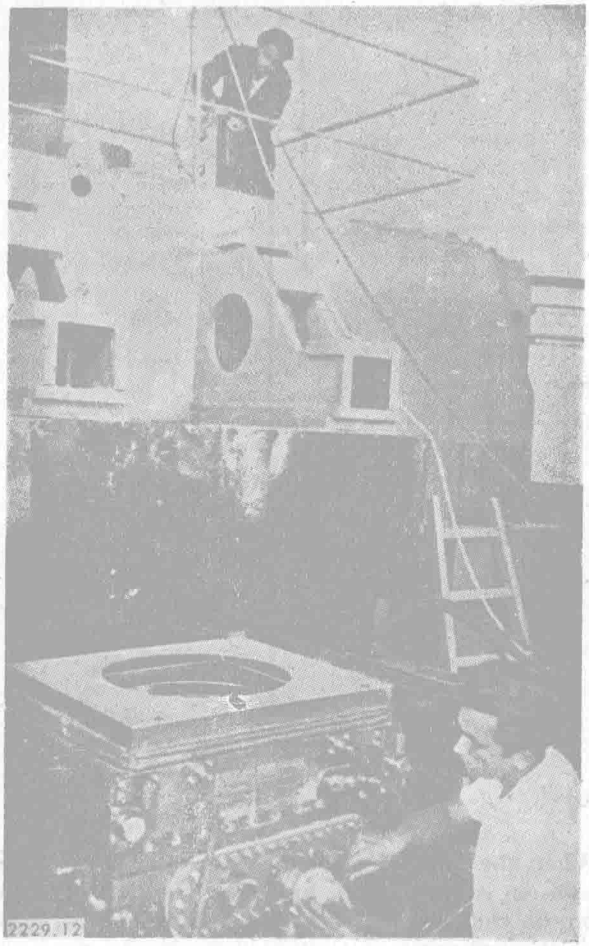


Figure 12

vice versa. This contradicts the statistical theory of multiple production of particles. It is hoped that when the number of cases is increased it will be possible to investigate this process in greater detail.

Since only brief information about the first results obtained by means of stripped emulsions is being given, I will not dwell on the results concerning the interactions of fast protons with nuclei or on the

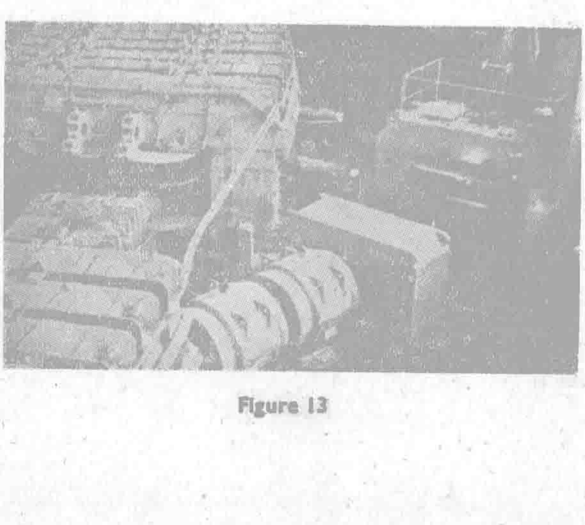

Figure 13

angular and energy distribution of star particles. Neither will I speak about the problem of energy loss of fast (9-Bev) protons. These data are already published or are now in press.

In Fig. 11 a typical case of a complete disintegration of a Br or Ag photoemulsion nucleus by 9-Bev protons is shown. The mechanism of such a disintegration and especially the occurrence of these phenomena is not yet well understood.

## OTHER EXPERIMENTS

Apart from the investigations mentioned above, experiments using cloud-chamber and various electronic techniques have been started.

In a special pavilion separated from the accelerator by an 8-meter concrete shielding wall some cloud chambers have been placed. One is a large $200\times150\times30$ cm diffusion chamber placed in the gap of a 500-ton electromagnet, another a guided $50\times50$ cm cloud chamber switched on by a special electronic system consisting of Cerenkov counters and some other arrangements.

The system of Cerenkov counters we have used made possible the creation of K-meson channels which could detect 1.5-Bev K mesons. One of the cloud chambers operated by such a channel is meant for the study of processes involving K mesons (Fig. 12). The control system is synchronized with the accelerator and makes it possible to increase the efficiency of the cloud chamber by increasing the number of high-velocity particles inside the chamber.

Figure 13 shows a pion channel including some quadruple lenses and a propane bubble chamber placed at the end of the channel. This chamber was designed by a group of Chinese and Soviet physicists and engineers under the guidance of Professor Wang Kuan-Chang and M. I. Soloviev, and has the dimensions $50\times35\times35$ cm. The $50\times15$ cm liquid hydrogen bubble chambers hown in Fig. 14 is being constructed now on the K-meson beam.

In conclusion I would like to say a few words about a new idea that is to be incorporated in experiments with our synchrophasotron.

As is known, the study of the properties of antiprotons, discovered by a group of American physicists in 1955, is rather difficult because antiproton generation is a very rare phenomenon compared with pion production (one antiproton per about $10^4$–$10^5$ pions). But antiproton experiments would be considerably easier if the antiprotons were separated from the accompanying pion background.

The high-energy protons accelerated by our synchrophasotron make it possible to get the high intensity of the antiproton beam, whereas the use of the features of the accelerator itself provides a sufficiently purified high-energy antiproton beam.

V. A. Petukhov and the author of this report proposed in 1956 a method of spatial separation of antiprotons and $\pi$ mesons. At present, a number of elements of such an antiproton device have already been built. The principle of this device may be easily understood from the scheme shown in Fig. 15. A beam of protons accelerated to the maximum energy is divided into 70 separate small bundles by using a special resonator working on the 70th harmonic with respect to the main frequency, and periodically, during a short interval of time, hits a target placed inside the vacuum chamber of the synchrophasotron. The generated antiprotons, together with the negatively charged $\pi$ mesons, are deflected by the main magnetic field of the accelerator and led outside. Further, the magnetic-optical system, consisting of an analysing magnet and of quadruple lenses, releases a narrow region of momenta in the outcoming beam. At the given momentum the antiproton velocity differs from that of $\pi$ mesons, moving practically at the velocity of light. Therefore, by choosing a sufficiently long flight path one can separate, at a certain distance from the accelerator, the antiproton beam from that of the $\pi$ mesons completely. The system of resonators placed there, in which the transverse high-frequency electric field is excited, deviates the particles in one direction or the other in accordance with the phase. If the distance from the target to the centre of the deviating system is chosen so that the difference between the time of flight of the $\pi$ mesons and that of the antiprotons is equal to a half-period of the electric field change, then the $\pi$ mesons and the antiprotons would be deviated in opposite directions and, at a certain distance beyond the deviating system, would be separated in space.

The particles of momentum approximately 3 Bev/$c$ would be separated in our case.

The calculation of the antiproton track shows that using this method one can obtain slightly spread (because of the scattering of the particles along the walls of the collimators) antiproton and $\pi$-meson beams which are separated in the horizontal plane. At the distance of 50 meters from the target the beams are 10 cm across, and the interval between them 50 cm. In this way, the ratio of the number of pions and antiprotons would be changed some hundred times.

## CONCLUSION

In conclusion, let me express the hope that the startup of our big 10-Bev synchrophasotron together with the American accelerators (Cosmotron and Bevatron) now in operation will give still more possibilities for progress in the study of fundamental problems of nucleon structure and the nature of elementary particles.

A large group of physicists, engineers and technicians of the following research organizations took part in the work on the startup of the synchrophasotron: the High Energy Laboratory of the Joint Institute for Nuclear Research, the Lebedev Physical Institute of the USSR Academy of Sciences, Radiotechnical Institute of the USSR Academy of Sciences, Physical-Technical Institute of the Ukrainian Academy of

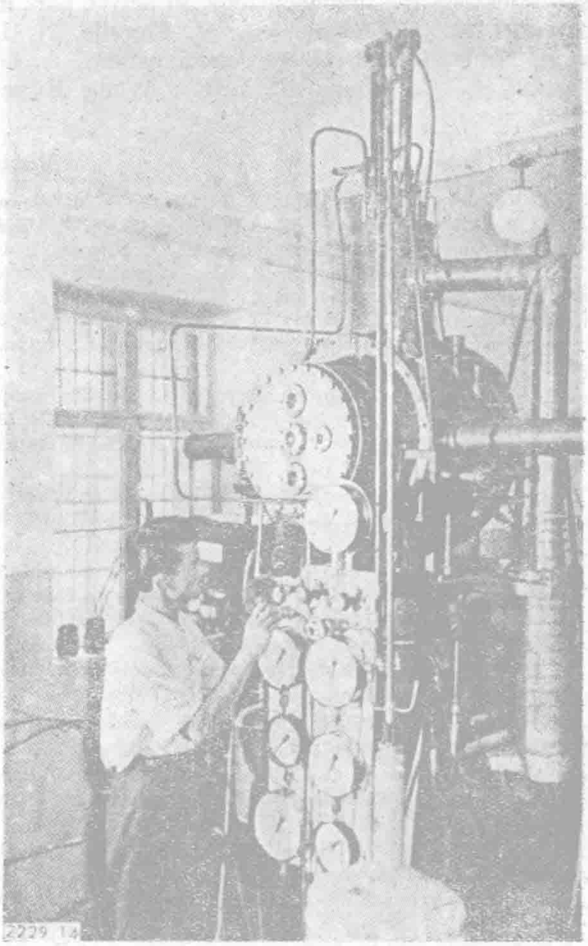


Figure 14

Sciences, Institute of Electrophysical Apparatus and some other organizations.

A detailed description of theoretical investigations and experiments concerning the adjustment and starting of the synchrophasotron is given in different papers published in Soviet and foreign journals.

The construction of physical apparatus and scientific research on the synchrophasotron is being performed by the physicists and engineers of the High

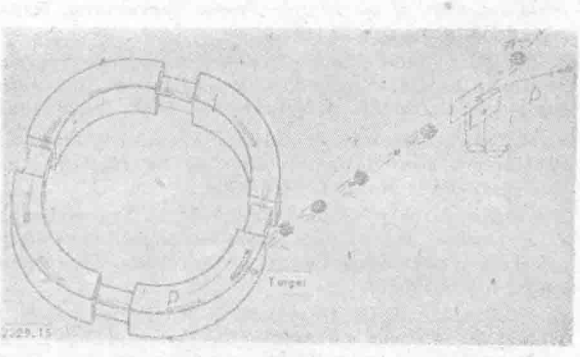


Figure 15. Scheme of the antiproton channel

Energy Laboratory. In addition to the above-mentioned scientists the following took an active part in this work: K. V. Chekhlov, L. V. Chuvilo, N. I. Pavlov, N. B. Rubin, I. N. Semenyushkin, A. G. Zeldovich, L. P. Zinoviev (USSR); Wang Kuan-Chang, Wang Shu-Fen (The Chinese People's Republic); M. J. Danysz (Poland); E. Katz (Romania); P. K. Markov (Bulgaria); Wi Chun-Wop (The Korean People's Democratic Republic); F. Bradna (Czechoslovakia) and others.

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