In defence of high-energy physics

by **Victor F. WEISSKOPF,** Director General of CERN

Early this year, a book with the title Nature of matter – purposes of high-energy physics **(BNL 888 (T-360), edited by L. C. L. Yuan, $1.75) was published by the Brookhaven National Laboratory, U.S.A. In it, thirty of the leading theoretical physicists in America and Europe give their views on the subject and discuss some of the problems and implications involved. Its aim is to provide a degree of communication between high-energy physicists, the scientific community as a whole, and the general public, by presenting a comprehensive basis for a better understanding of the fundamental importance and great depth of high-energy physics.**

One of the contributors to the book is Prof. V. F. Weisskopf, Professor at Massachusetts Institute of Technology and currently Director General of CERN, and what he writes is reproduced here by kind permission of the editor. Distinguishing two trends in the development of science in this century, the 'intensive' and the 'extensive', Prof. Weisskopf shows how these are nevertheless closely interconnected and argues strongly against neglecting 'intensive' research such as sub-nuclear physics just because it has little 'extensive' content. He then explains that recent work in sub-nuclear physics points the way to an understanding of questions such as: why are there only a few stable particles making up matter?, why do there appear to be four different kinds of interaction in the universe?, and how did the universe get into its present state? If the tempo of sub-nuclear research slowed down, these questions would remain unanswered, he says; any subsequent 'extensive' research depending on the answers for its exploitation would then be precluded.

Today the development of science has arrived at a critical stage. The cost of science in terms of money and manpower has reached a point where society is beginning to question its further uninhibited growth.

So far the cost of science has been negligibly small. All basic scientific activity ever undertaken from the times of Archimedes until today amounts, in terms of money expenditure, to less than ten days' output of the industrial world, an amount which is below the yearly increase of world production. This represents an impressive rate of return on a capital investment if one considers that almost all industrial production today is a consequence of basic scientific research. Still, it is true that the requirements of modern basic research are beginning to be substantial and a discussion becomes unavoidable of the importance of basic science and of the relative importance of its different branches.

Clearly, the main targets of attack are the most expensive branches which, in addition, have a certain flavour of 'uselessness', that is, high-energy physics and astronomy. Modern astronomy, however, has the advantage of being connected with 'space'; it therefore profits from the present emphasis on everything that is related to space science. Clearly, this emphasis is not exclusively based on arguments of scientific merit. High-energy physics or — as it should better be named — sub-nuclear physics no longer enjoys such extraneous support, after having ridden on the coat-tails of nuclear energy for a number of years.

Intensive and extensive

Looking at the development of science in the twentieth century one can distinguish two trends, which I will call 'intensive' and 'extensive' research, lacking a better terminology. In short: intensive research goes for the fundamental laws, extensive research goes for the explanation of phenomena in terms of known fundamental laws. As always, distinctions of this kind are not unambiguous, but they are clear in most cases. Solid-state physics, plasma physics, and perhaps also biology, are extensive. High-energy physics and a good part of nuclear physics are intensive.

There is always much less intensive research going on than extensive. Once new fundamental laws are discovered, a large and ever-increasing activity begins in order to apply the discoveries to hitherto unexplained phenomena.

Thus, there are two dimensions to basic research. The frontier of science extends all along a long line from the newest and most modern intensive research, over the extensive research which was recently spawned by the intensive research of yesterday, to the broad and well developed web of extensive research activites based on intensive research of past decades.

One can easily distinguish four important steps of intensive research during this century: electrodynamics and relativity, quantum theory of the atom, nuclear physics and recently sub-nuclear physics. The extensive dimensions of electrodynamics, relativity and quantum theory reach very far today and are constantly expanding. Nuclear physics has already a large extensive part in the detailed studies of nuclear structure and in its astrophysical applications. Sub-nuclear physics is still mostly intensive in its character.

Sub-nuclear research at the frontier

Each part of this scientific frontier is of importance. It would be most dangerous to neglect some parts relative to others. It is often argued that sub-nuclear physics should be given less support because this field leads to very little extensive research, because it attracts too large a proportion of clever scientists, and because the cost per scientist is much higher than in many other parts of the scientific frontier. These reasons, however, are inherent in the fact that sub-nuclear research is at the frontier of intensive research.

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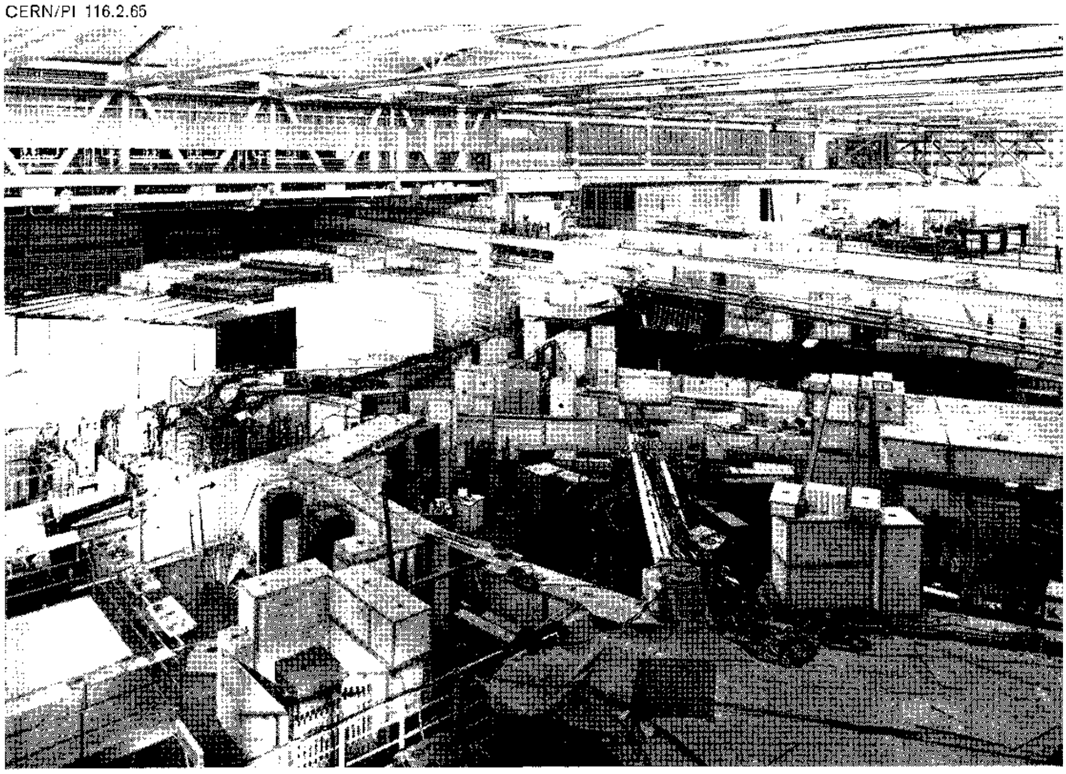

Today's nuclear physics laboratory is very different from that of a generation ago, and this view of part of the South experimental hall of the CERN proton synchrotron is typical. In a certain sense, the plasticine, string and sealing wax of Rutherford and his students can still be found, but to them has been added, as the physicists' basic equipment, such things as concrete shielding blocks, electronic boxes, and cloth, cardboard and wood to keep the light out of spark-chamber viewing systems. In the nearest enclosure, under the cable bridge, is the equipment for the 'Paplep' experiment; further back and to the left is the 'missing-mass spectrometer', with its counting and control systems in another enclosure on the extreme left; behind this is the shielding complex for the neutrino experiment, including the bubble-chamber and spark-chamber block-houses; to the right again, under the black curtains, is the apparatus for the experiment on the K-nought-two decay. In the background on the right is the bridge over the accelerator, connecting with the North experimental hall.

Obviously, the most advanced part of intensive research has yet very little bearing upon the understanding of other phenomena, and therefore its extensive component is small. After all, one is at the very beginning of understanding what is going on at the sub-nuclear frontier itself. Clearly, the same situation existed at earlier periods when other fundamental discoveries were at the frontier of science. Faraday did not know that electricity is the basis of the structure of matter; when the first steps were made towards an understanding of atomic spectra, nobody knew that this would lead to a complete understanding of chemical reactions. Thus the extensive effect of sub-nuclear physics is not yet visible, but even today it seems already probable that sub-nuclear phenomena are important for the understanding of the recently discovered galactic explosions.

The frontier of intensive research has always attracted a certain group of very clever scientists. To work in an uncharted field, to discover new laws of nature and completely new types of phenomena, is a great lure for a scientist. One is placed at the spearhead of a great and successful tradition ranging from Galileo, Newton, Maxwell to Einstein, Bohr, Dirac and Heisenberg. It is improbable, however, that this field should in fact ever deprive other fields of science of skilled manpower. It is by its very nature a limited field. Competition is heavy, success is rare and depends more often than not on luck and opportunity. Many of the best scientific brains avoid this field because of the narrow choice of activities.

The high cost of sub-nuclear physics comes from the fact that it deals with new phenomena which were not previously observed. Sub-nuclear physics requires the study of matter under new conditions. As science progresses, these conditions become increasingly different from normal conditions on earth. Nuclear physics deals with intrastellar conditions and sub-nuclear physics submits matter to even more abnormal conditions. Obviously, it becomes increasingly expensive to create increasingly abnormal environments in a laboratory.

A new world of phenomena

There is today a clear danger that the alleged narrowness and the high cost of sub-nuclear physics will, in fact, retard its development compared to other fields at the scientific frontier. Already the *Physical Review* shows a stronger increase in the number of solid-state-physics papers compared to nuclear-physics papers. This occurs just at a time when sub-nuclear physics begins to reveal the existence of a new world of phenomena within the nucleons. We see today the birth of a third spectroscopy compiling the excited quantum states not of atomic systems or of atomic nuclei, but of the nucleon itself. We find today the first indications of regularities in these level schemes, which will soon lead to an insight into the structure within the nucleon. This insight is bound to bring us nearer to the understanding of some of the most fundamental unsolved questions. Let us list three groups of such questions:

Today we understand the behaviour of matter on the basis of the interaction of atomic nuclei and electrons. But the basic question remains: why is it that the proton, the neutron and the electron are the elementary particles that make up matter under terrestrial conditions? Why are these particles, together with the light quantum and the neutrino, the most stable forms in a long series of particles including the hyperons, the numerous bosons and the heavy electrons? These questions concern the basis of everything scientific. As long as they are not answered, the structure of any form of matter remains essentially not understood. The great triumph of quantum theory was the explanation of the characteristic properties of the elements on the basis of the recognition that the field of a given electric charge admits only certain well-defined quantum states of the electron. This idea is fundamental to all atomic physics, chemistry and molecular biology. However, it is valid only because of the existence of identical electrons and protons with fixed and well defined charges and masses. In fact, quantum theory does not really explain the existence of characteristic intrinsic properties of each element; it deduces it from another unexplained set of facts: the existence of a small number of elementary particles with their own characteristic intrinsic properties. Hence, the basic problem which underlies all physical sciences, that of the structure of matter, is still unsolved. It is precisely that problem which is attacked by sub-nuclear physics.

Another fundamental set of questions is connected with the problem of the different types of interaction between material particles. Physics has solved the problem of unifying a large number of interactions, such as electric and magnetic forces, chemical forces, cohesional forces, capillary forces, etc., all of which are reducible to the quantum effects of electric attraction between nuclei and electrons. But there is still no connexion seen between nuclear, electromagnetic, gravitational and weak interactions. Hence, the task of a consistent understanding of nature has only begun and is in need of further development. It is again mainly sub-nuclear physics which attacks these problems; theoretical research in relativity theory and astronomical research into the structure of the universe will contribute to the solution.

Finally, the same three fields of research are about to tackle the problems of the history of the universe. The question of the origin of matter can already be discussed on scientific grounds. So far, rational ideas are developed only concerning the element formation from a gas of protons and electrons. But the problem of the origin of this gas begins to acquire some scientific aspects with the discovery of matter under extreme conditions of high energy at the centres of galaxies. These phenomena are obviously connected with the interactions of particles at very high energy, as studied in sub-nuclear physics.

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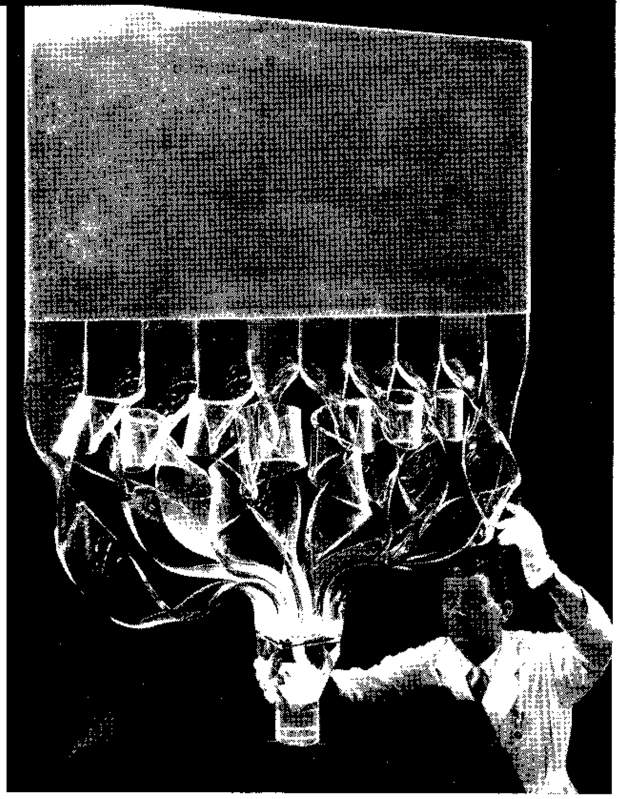

This construction in transparent plastic, displayed by Leslie Thornhill, could well form part of an exhibition of modern sculpture, but it is in reality part of a new scintillation detector for the 'missing-mass spectrometer'. The rectangular part at the top is a sheet of plastic scintillator and the remainder is a complex system of light pipes to transmit light from the scintillator, where it occurs as a flash produced by an incident nuclear particle, to the photomultiplier that detects and records it. Each of the ten plastic strips is 1.2 m long, so that the time taken for light to travel along any one of them is the same. The curves were designed so that the light remains trapped inside each strip, and in use a layer of black tape also prevents external light from entering. The manufacture of this device, in the West workshop at CERN, was a complex operation of bending and glueing, after initial polishing of all the surfaces to a very high degree of perfection, the slightest scratch on the surface of the plastic contributing to a decrease in accuracy of the finished detector.

One broad front

We are facing today a situation where it is threatened that all this promising research will be slowed down by constrained financial support of high-energy physics. And this constraint is based, partially at least, on a claim that the aim of this field is narrow and restricted. The three above-mentioned groups of unsolved questions should be sufficient to invalidate this claim. It is granted that further progress, say, in biology or in solid-state physics is possible without any further research into the sub-nuclear field. But let there be no doubt that the style of the scientific community would change its character if the frontier of intensive research were hampered. It would subtly change towards over-emphasis on extensive research, and this would harm all fields of science. A spirit would be fostered, different from the one which created modern science, if basic questions that can be

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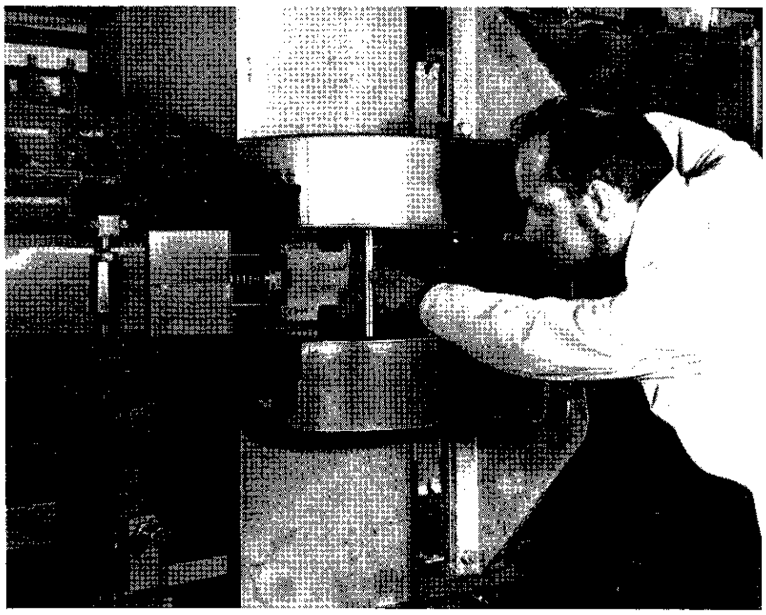

Since its completion at the end of 1959 the CERN PS has been the object of numerous improvements to increase its efficiency, flexibility of use and ease of operation. One of the latest of these is a new quadrupole focusing magnet, shown here being adjusted by Joseph Guillet between the coils of one of the ring magnets of the accelerator. Designed and constructed in the PS Division, this lens is one of 50 which control the spread of the beam immediately after its injection into the synchrotron. At this energy, they replace the 20 much larger quadrupoles of more conventional design, one of which is seen on the left of the photograph.

News from abroad

U. S. A.

Policy for high-energy physics approved by the President

A booklet published in February for the U.S. Joint Committee on Atomic Energy* included the text of the Atomic Energy Commission's proposals for the development of high-energy physics in America, covering the period 1965-1981, which have been submitted to Congress by President Johnson.

Among the specific plans presented are those for the construction of a 200-GeV proton synchrotron, to be completed before 1974, conversion of the Brookhaven AGS to a high-intensity machine, improvements at the Argonne ZGS, the construction of a high-energy electron-positron storage ring at the 20-GeV Stanford linear accelerator, the early construction of two or three large hydrogen bubble chambers, increased support for university high-energy physics groups, and intensive design studies for a proton accelerator of 600 to 1000 GeV energy to come into operation in 1980, with provision for the possible future addition of storage rings.

It is hoped to give further details of this report in the next issue of *CERN COURIER.*

World's first experiment with colliding beams

Spectacular news came from Stanford University (U.S.A.) in March, when it was announced that on 1 February 1965 two electron beams travelling in opposite directions in a pair of intersecting storage rings had at last been made to collide.

The electrons in each beam had an energy of 300 MeV, so that when two of them met head-on their colliding energy was 600 MeV, equivalent to that of a 360 GeV electron hitting a stationary target.

This success, by a team of physicists from Stanford and Princeton Universities, marks the climax of six years of intensive work, the last three of which were years of frustrating problems that sometimes threatened to defeat the whole programme. During the last year in particular, after beams had been successfully stored in the rings, attempts to make them collide resulted in failure, except with relatively weak beams. Repercussions of this frustration were felt at CERN, where doubts were thrown on the feasibility of operating the proton storage rings proposed for the PS, in spite of the confident assurance by the designers that the unexplained electron effects were unlikely to occur to the same extent with the more energetic and less dense proton beams. The new results reflect an improvement of colliding beam operation to an extent that the collection of experimental data on the collision interactions could be started.

The Stanford storage rings are fed from the 'Mark III' linear accelerator, and electrons have been stored in the rings for periods as long as 35 hours. The beam current in each ring is about 0.03 ampères. One of the main experiments now proposed is a new, more severe test of the theory of quantum electrodynamics, made possible by the higher available energy which enables one to investigate 'objects' of smaller size.

* 'High-energy physics programm: report on national policy and background information', Washington, U.S. Government Printing Office, 55 cents.

F. R. of GERMANY - DESY

Accelerator running regularly

News from the 'Deutsches Elektronen-Synchrotron' (DESY) at Hamburg (Federal Republic of Germany) in March was that the accelerator was running on a regular weekly schedule of 96 hours, from 11 p.m. each Monday to 11 p.m. Friday. About 50% of the time was being used for experimental physics (with counters and a bubble chamber) and about 30% for experiments and development work with the accelerator itself, some 20% still being lost because of technical difficulties.

This machine, as well as the similar one (Cambridge Electron Accelerator) in the U.S.A., produces the world's

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answered are left unanswered or are neglected by lack of attention. The questions remain, they cannot be overlooked.

This different spirit will do most harm in the education of young scientists. The study of science is based upon a burning interest in fundamental problems. The attitude of students would be perverted if they were not constantly aware of a lively quest for the solution of the basic problems of science. Even the scientist who will devote his life to purely extensive research must be aware of the existence and the spirit of intensive research. The reason is that, even in the most extensive research, at every step there is always an intensive component: at each unsolved problem one must go back to some fundamental idea, one must try to see more of the essence of the problem. This is an attitude which can be fostered and maintained only if intensive and extensive research have an equal standing in the scientific community. There is one broad front in science and each part of it must be pushed forward with full vigour.

We find strong support today for space technology, which may allow us to explore the unknown parts of the solar system. Exploration of the unknown was always a strong component of human endeavour in our modern civilization. But it must go together, as it always did, with another equally strong component: the explanation of the unknown in whatever form it faces us.

In the beginning of the 16th century, when the scientific era began, Magellan performed the first trip around the earth. But also in the same period Copernicus published his work on the motion of the planets ●