THE PAST AND FUTURE OF HIGH-ENERGY PHYSICS*

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Ladies and Gentlemen, I am extremely grateful to the Organizing Committee and to Professor Johnsen who have asked me to speak before such an illustrious crowd to which I do not belong. As you probably know, I am not an accelerator physicist, I am just a theorist. Moreover, I am facing two difficulties. One is that the ladies are present and, in my experience, it is very hard to please both physicist husbands and their ladies -- there is an exclusion principle involved. The second is that I am supposed to talk about the future, and I would like to quote the Danish writer Storm-Petersen who said that prediction is a very difficult art, especially when it is applied to the future. Therefore, I shall begin by applying it to the past.

Particle physics is the science of the basic structure of matter. It is the basis of modern natural science and it is really a child of the 20th century. I believe that the 20th century will be known, in future centuries, for the great intellectual edifice of Science that has been erected during this time -- not the least reason being that there is not much more to brag about in this wonderful century.

Right at the start, in 1900, Planck found the fundamental role of the quantum of action; in 1905, Einstein conceived his relativity theory; and 1911 is the important date when Rutherford discovered the structure and the electric nature of the atom. During the following twenty years (1911 to 1930) this discovery, together with Bohr's first interpretation and the subsequent development of Quantum Mechanics, led to the explanation, at least in principle, of all the properties of the atomic world: its scale, its energies, the molecules, the chemistry, the properties of matter in bulk, solids, liquids, gases, in short, the world which we see around us.

The progress of Science did not stop. In the following twenty years the structure of the nucleus was cleared up, beginning with the discovery of the neutron. This progress was tied to the development of higher and higher artificial sources of energy. Then, again, twenty years later (1950 to 1970) a new development started which penetrated into the structure of the particles that make up the nucleus, namely, the structure of the nucleon.

So we have had a new step in physics every twenty years and a discovery of a new realm of phenomena. This development is summarized in

CONDITIONAL ELEMENTARITY

Elementary particles:

Atoms	(for Chemists)	($\frac{1}{10}$ eV)
Nuclei, Electrons	(for Atomic Physicists)	(1-100 eV)
Nucleons, Electrons, Neutrinos	(for Nuclear Physicists)	(10^5-10^7 eV)
Nucleons in excited states Quarks ? Light and heavy electrons Neutrinos Mesons	(for High-energy Physicists) (10^7 - 10^{10} eV)	

Figure 1

Fig. 1. It indicates in each column a few decisive features of those three steps and leaves room for a subsequent step. The last column contains indications about the kinds of processes which are observed in these different realms of physical phenomena.

The discovery of the nucleus revealed the existence of a new force in nature: the nuclear force. This is a revolutionary development, with new forces, new events and new phenomena being found but, at the same time, it is also a very conservative development because at each step we were able to use, for its description, fundamentally the same simple concepts which were used before. For example, we use the concept of spectra of quantum states in each of the steps as shown in Fig. 2, the quantum states of

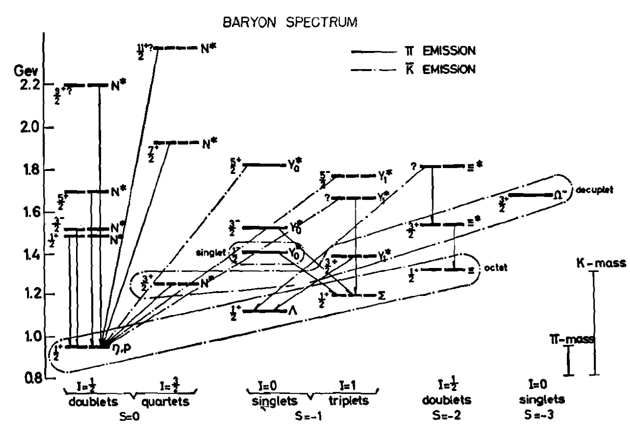


Figure 2

the nucleon, the excited nucleon states. The only difference is that the energies involved become bigger and bigger -- volts, million volts, billion volts. The next three figures show the kinds of instruments one uses to study these things: the

* Evening Lecture delivered on September 22, 1971, after the Conference Buffet Supper. Chairman for this Lecture was K. Johnsen; Scientific Secretaries were: P. Strolin and K. Tittel.

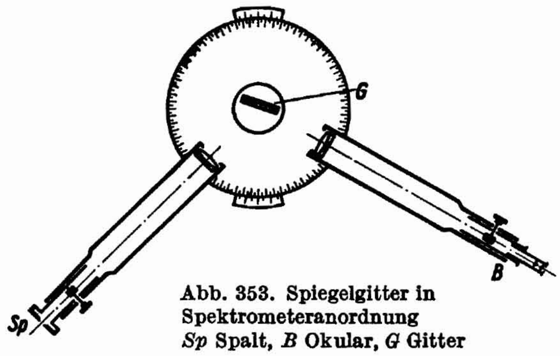


Figure 3

Figure 4

spectroscope in Fig. 3, then the cyclotron in Fig. 4 (this is the cyclotron at Dubna), and finally in Fig. 5 is the spectroscope which all of you may remember. The picture shows the spectroscope that we used here in the old days when things were pleasantly small and when we had cattle grazing up there beyond the French border. Now other creatures are grazing at that place!

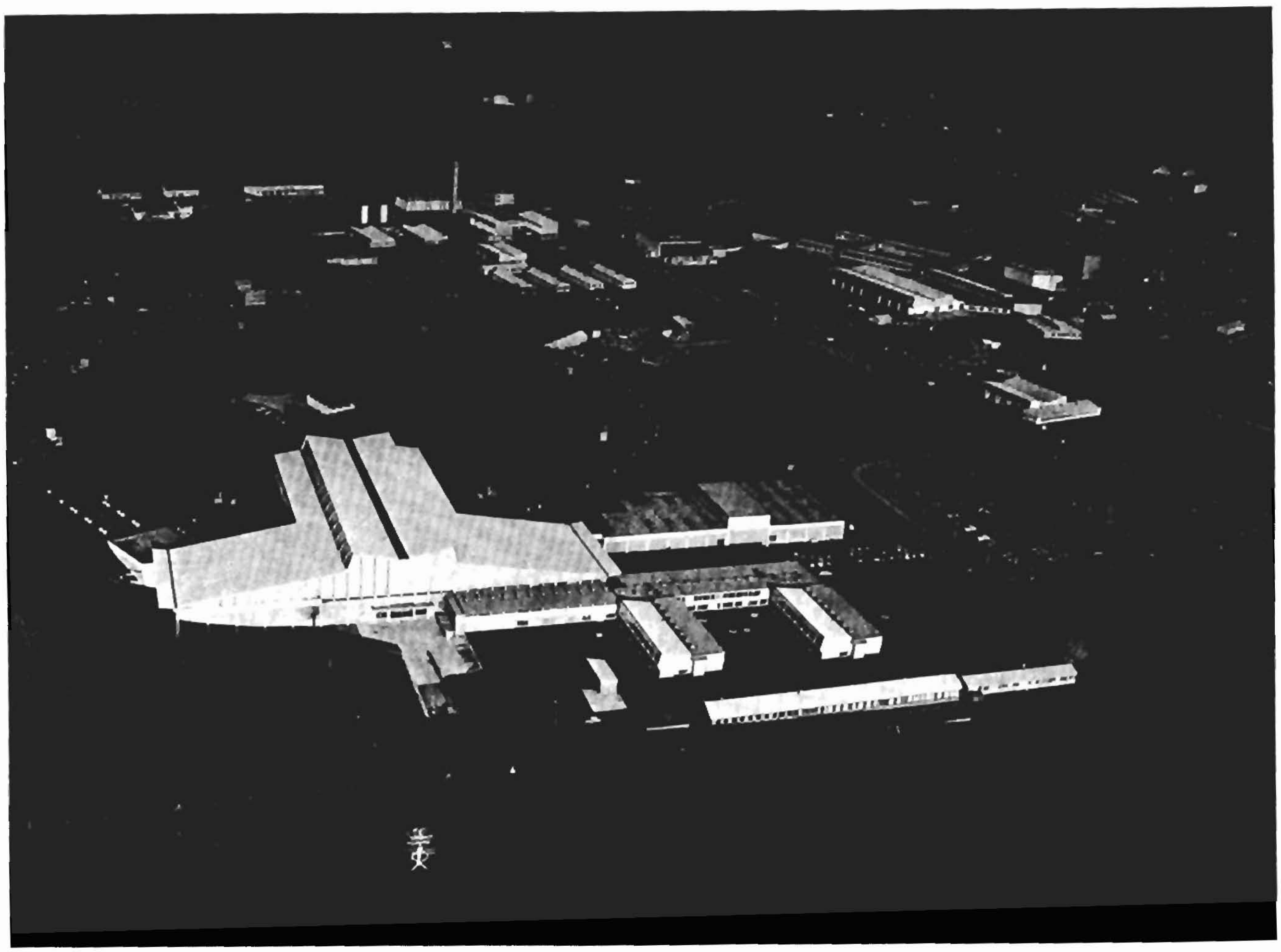


Figure 5

Perhaps I could talk about these steps in a slightly different way (Fig. 6). I begin with the molecule and say that the molecule is made of atoms, and the atom is made of nuclei and electrons; the nuclei are made of nucleons, and the nucleons are made of .... . Here I stop -- we have arrived at the moment which separates the past from the future.

System	Elementary Particles	Interactions	Size (cm)	Relevant Energies (eV)	Ordering Quantum Numbers	Emitted Quanta in Transitions
Atoms Molecules	Nuclei Electrons	Electro-magnetic	10^{-8}	10^{-1} – 10^{3}	J	Photons
Nuclei	Proton Neutron (nucleon)	Nuclear Weak	10^{-12}	10^{5} – 10^{7}	J,I	Photons Lepton Pairs (eV)
Baryon Meson	? (Quarks ?)	Strong Weak	10^{-13}	10^{8} – 10^{9}	J,I,S	Photons Lepton Pairs (eν), (μν) Mesons
Quark ? e, μ ?	?	?	?	?	?	?

STEPS IN THE STRUCTURE OF MATTER

Figure 6

The forces between the atoms in the molecule are the so-called chemical forces shown in Fig. 7. But there are some "printing mistakes", the units for the abscissa are supposed to be Angströms and those for the ordinate are volts. You see a repulsion at distances of a fraction of an Angström and an attraction at somewhat larger distances. Within the atom, the force between electrons and the nucleus is the simple electrostatic force, the familiar Coulomb force, e^2/r. It was one of the great successes of Quantum Mechanics that this simple Coulomb force explains the chemical force in a satisfactory way.

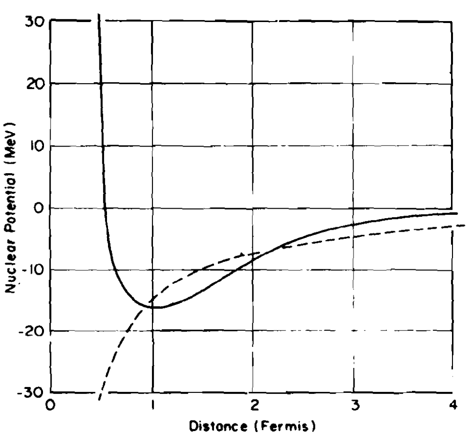


Figure 7

The nucleons are kept together within the nucleus by the nuclear force, shown again in Fig. 7 where now the units are, not volts but million volts, and not Angströms but "fermis". This force seemingly has the same character. Now, the chemical force was understood when we found out about the structure of the atoms. Therefore, we are hopeful that we will be able to explain the nuclear force when we know more about the structure of the nucleons.

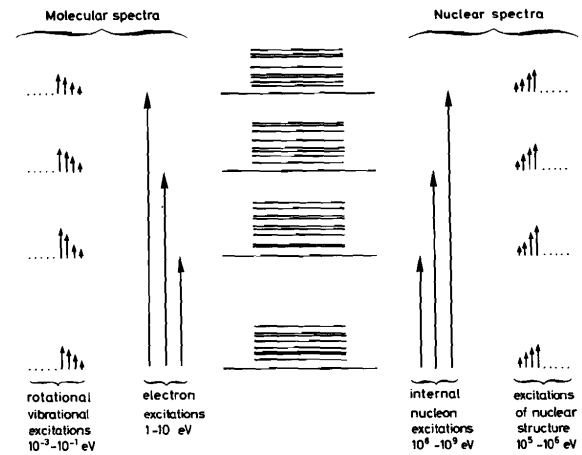


Figure 8

The parallelism between chemical and nuclear forces is further emphasized by what is shown in Fig. 8. Here are the molecular spectra which consist of several steps: rotational, vibrational excitations, and then electron excitations which are larger. We find the same thing in nuclei: the ordinary nuclear-structure excitation, then the excitation of each nucleon to its own hyperon state, to a higher baryon state. We get the hypernuclear spectra added to it. It is interesting that the structure is similar, only the energies are much larger. But even the ratios between the fine structure and the large structure are roughly of the same order of magnitude. I do not want to imply that the theory of the nuclear forces will be similar to the theory of the chemical forces, but there is an interesting parallelism here which is illustrated in Fig. 9. But at present we must leave the question marks at the relevant places.

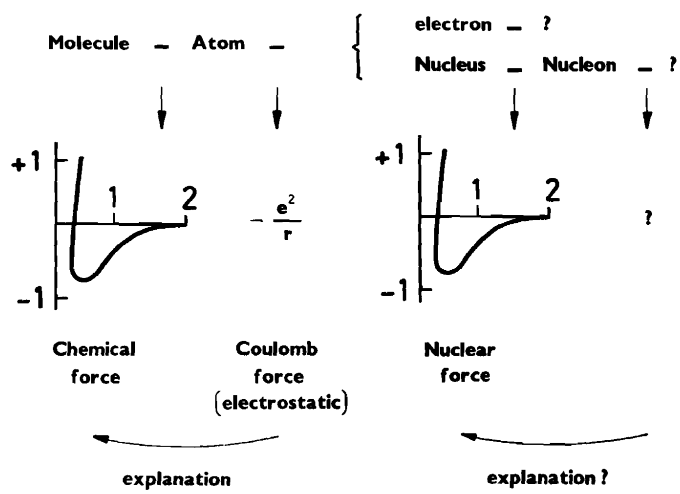


Figure 9

As an illustration of this tremendous development from molecule to nucleon, I would like to show four pictures of different Franck-Hertz experiments. In 1914, Franck and Hertz bombarded atoms with electrons and measured the energies which these electrons lose in this bombardment. They lose a definite amount of energy, corresponding to the excited quantum states of the bombarded system. A Franck-Hertz experiment with a hydrogen molecule, where the energies are fractions of volts, is shown in Fig. 10. A Franck-Hertz experiment with helium atoms is shown in Fig. 11 (unfortunately, I could not get the original Franck-Hertz picture for this) and the excited state of helium lies about 17 V above the ground state. Then, an excitation of the nucleus by electron scattering (done at SLAC by H. Kendall and J. Friedman) is shown in Fig. 12 where we have millions of volts excitation. Finally, the excitation of the quantum states of the proton itself, where we are dealing with fractions of billions of volts, is shown in Fig. 13 (also done at SLAC by the same authors). Between the first and last experiment, we have a difference in energy of a factor of 10^{10} which shows the tremendous progress of instru-

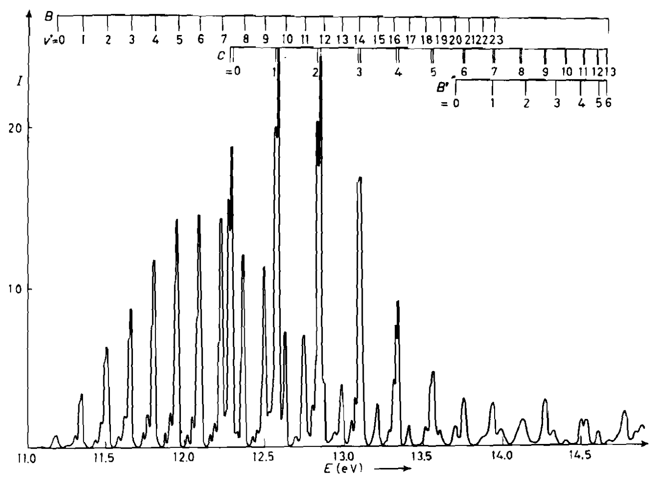


Figure 10

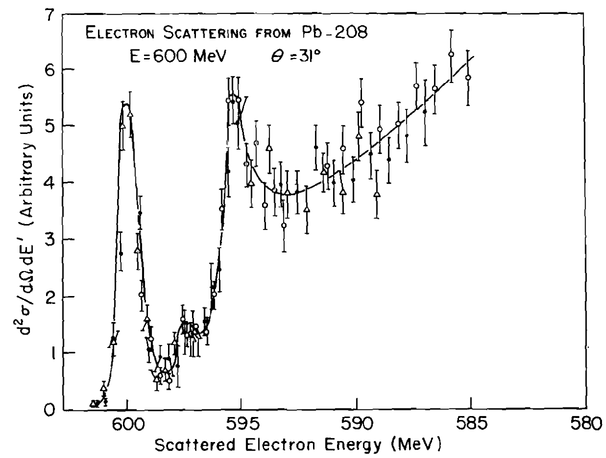


Figure 12

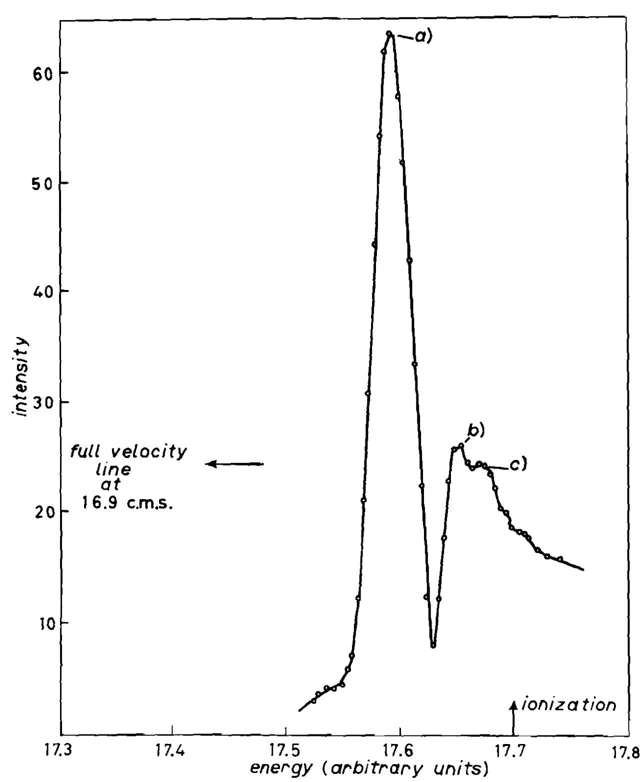


Figure 11

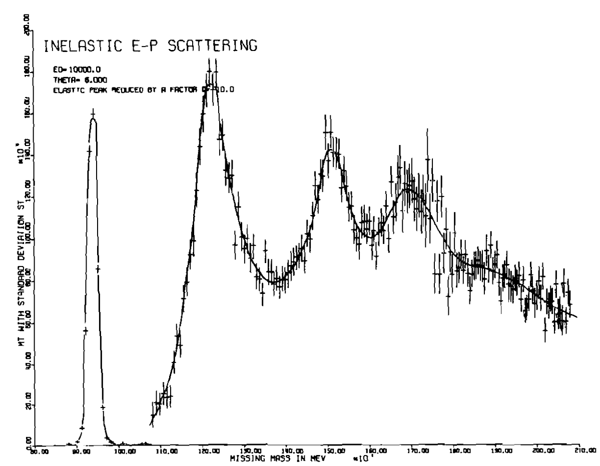


Figure 13

mental capabilities and, at the same time, it shows that we are looking essentially at the same kind of process. This is what I meant by speaking of the revolutionary and the conservative aspects in the development of our science. We have had a tremendous change, mainly in the instrumental apparatus, but we are still building on the same ideas that were here before.

I would now like to spend a little time on a few sociological considerations concerning physics research, in particular high-energy physics research. Physicists are not equal -- some are more, some are less, some are theorists and some are experimental physicists. The division between theory and experiment is a very old one. The two types of work have the same aim but the two aspects have shown themselves very early in the history of science. We find the early pair, Ticho Brahe and Kepler, experimenter and theorist; later Hertz and Maxwell, Rutherford and Bohr. One could perhaps use the words: exploration and explanation. This division was not so marked at the beginning as it became later, due to the mounting complications both in the mathematical and the instrumental approaches to the problems. In the 20th century, particularly in the development of atomic physics, we find experimenters like Röntgen, Rutherford, Franck, Moseley, Mandelstam, Yaffe, Zeeman, and many others; on the theoretical side, Heisenberg, Bohr, Sommerfeld, Born, Schrödinger, Dirac, de Broglie, Einstein, Frenkel, Pauli, and so on. Due to the tremendous success of quantum theory, the theoretical group acquired a certain amount of glory which they deserve but it must be remembered that the work which they have done was based upon vast amounts of experimental discovery. When I mentioned the different names of experimental physicists, I should have added the legion of spectroscopists who studied carefully, and in detail, the spectra of many atoms, the Zeeman effect, Stark effect, anomalous Zeeman effect. All of these results contributed essentially to quantum mechanics which would, in fact, have been impossible without them. Quantum mechanics developed so fast in the nineteen-twenties only because an enormous amount of experimental material was assembled and available.

When we go to the next step, nuclear physics, we find a similar development. We find again great experimenters like Chadwick, Bothe, Stern, Segrè, Rabi; and we find the theorists: Wigner, Landau, Tamm, Bethe, and many others. I should not leave out one name: Enrico Fermi, who achieved the rare feat of belonging to both categories. It would be interesting to make a study of those personalities who were able to do this and to find out how they did it. I am sure that Felix Bloch also belongs in this category. Again, I would like to add to the list of experimental physicists, the legion of spectroscopists who have studied, ordered and measured the numerous nuclear spectra which were the basis of our insight into nuclear structure.

But something new entered the picture -- in this period from the thirties to the fifties, a new type of physicist appeared. No longer do we have only the experimental physicists and the theoretical physicists, but we have a new group which, for lack of a better word, I shall call the machine physicists. Of course we know who is the great, the first one who created that job: it was Ernest Lawrence. And there were many others. I would not like to leave out Stanley Livingston, nor McMillan and Veksler. But from now on, I will refrain from making lists of people because I am coming too close to the present. To "exploration" and to "explanation" I should now add "invention" which previously, when things were not so sophisticated, was done by the experimental physicists and sometimes even by the theorists.

In the third step, in particle physics from 1950 to now, the appearance of this third category of physicists is obviously manifest. We have three large groups: the theorists, the experimenters and the machine physicists and the last group includes also the builders of great instruments, such as the bubble chambers, the many new detecting devices and beam equipments. I should also like to add, again, to the non-named list of experimental physicists, the legion of spectroscopists who, with great care and great ingenuity and insistence, measure the different excited states of baryons and mesons, their quantum numbers, order them, list them, etc.

The theoretical achievements in nuclear-structure physics were still pretty high but did not quite reach the glory of the theory in the 1924-1928 period. But I would remind you of Wigner, Fermi, and Landau, and of all that came from their work. When we come to the third period, to particle physics, I believe that the success of theory has lagged behind, compared with the other categories of physicists. I would not say that it is because of lack of ingenuity, it is just the difficulty of the subject. So far, theory has only succeeded in playing a role in ordering and finding regularities in the experimental results. It has had a number of striking successes, such as the recognition of associated production, the strangeness quantum number, current algebra, Regge poles, the parity violation and, last but not least, the discovery of the SU_3-symmetry which led to the finding of a new particle. These are great achievements of bringing things into the right perspective -- they are not explanations. It is very hard to define what one means by explanation, and I would not like to attempt such a definition. I am just comparing this kind of achievement with the achievement of quantum mechanics in the twenties. However, in this third period, the machine physicists, to my mind, have assumed a specific importance. Not only the theorists but also, I think, the experimenters in some ways are now behind the machine physicists. I feel that the centre of creative innovation has gone to this group of physicists, and I am glad to have this opportunity to say this in public.

Let us look at the facts -- I shall start somewhere in the middle. At the end of World War II, the principle of phase stability produced a new family of accelerators. They made it possible, first with the Cosmotron and then with the Bevatron, to discover the strangeness, associated production, the τ-puzzle, the puzzle which led to the violation of parity. The Bevatron showed the existence of an antiworld, the hadron spectroscopy, and the discovery of the numerous mesons, which I would call a new form of energy currency. The invention of the bubble chamber has revolutionized the field. Another step was the invention of the alternating-gradient principle (strong-focusing) which produced, among other things, the Brookhaven AGS and the CERN PS. These brought into existence neutrino physics -- certainly, a step into a completely new world of phenomena -- the experiments leading to the Regge poles and what one generally calls asymptotia, how cross sections and other phenomena behave at very high energies. Then, the development of electron accelerators brought new ideas into being: the vector dominance in electromagnetic reactions with hadrons, a new way of dealing with meson physics, then lately the graininess of the structure of the nucleon which, in some ways, is a repetition of the old Rutherford experiment. I should also include, among new developments, RF separators, fast ejection and wire chambers. Finally, my list of examples (which is by no means complete) contains the idea of storage rings. Electron-positron storage rings are perhaps the cleanest realization of what one might call pure energy which can be transformed into hadrons and mesons. It has been possible to check quantum electrodynamics, the only field of which today's theorists can be really proud. And finally, there are the proton-proton storage rings at CERN and the proton-antiproton rings to be soon completed at Novosibirsk. They are just about to bring us again a completely new world of phenomena and, concomitantly, of new ideas. So we see how, in these developments, the ingenuity and inventiveness of this third group of physicists has played an essential role. This does not mean that there is no ingenuity and inventiveness among the others but, somehow in the present period of history, the big pushes, the new openings, have been prompted by the achievements of this group.

The impact of this situation may be so strong that experimental physicists need a little encouragement. After all, they have worked very hard and their work is the essence and the backbone of our knowledge. One cannot deny, however, that the experimental physicists are too much under the influence of their theoretical colleagues. There is a little story which illustrates this point. A drunk, at a dark street corner at night, has lost his key and is looking for it under a lamp but cannot find it by the lamp post. Somebody sees him and says, "But you may, perhaps, have lost it somewhere else". The drunk replies, "Yes, but somewhere else there is no light". I do believe that this story has some significance because present-day theory, due to the difficulty of the problems, sheds light upon only a very small part of the street and I am convinced that the key is not going to be there, but somewhere else. Perhaps the "light" should rather come from the experimenter's own ingenious exploitation of instrumental possibilities and, of course, from his innate instinct. We need a little more of Rutherford's spirit who said, on one occasion, "The theoretical physicists have their tails up and it is time we experimentalists pulled them down again!"

The split between experimental physicists and machine physicists is, perhaps, unavoidable but it is not a desirable development. There is no fundamental difference between small or large detection devices on the one hand, and accelerators and beams on the other. The ugly word "user" which is so frequently employed ("user" groups, "user" organizations, "user" protests) symbolizes an unhealthy relation which ought to be counteracted. Fortunately, the work at storage rings forces the two to collaborate intimately, since that kind of machine is an inextricable part of the experiment. Only the cosmic-ray physicists are true "users" of a high-energy beam; if one pursues this picture further one would be forced to put the machine physicists at the same level as the Almighty .... .

Let me, at this point, mention a difficult and awkward problem -- I am coming back to the sociology of high-energy physics. This is the problem of public recognition, the problem of publications, in particular of publications in experimental physics. The title pages contain only the names of the experimentalists and not the names of those whose ingenuity has provided the means for carrying out the work. This is understandable because the list of names of the authors should show who is responsible for the correctness, or incorrectness, of the results that are published. The names of those people who have built the machine are not in the list. Well, in some respects, these people are not responsible for whether the experiment's measurements are right or wrong. But, in other respects, they have contributed essentially to the result. I do not see any immediate solution for repairing this obvious injustice. These people who, as I have tried to describe, have actually carried out the main steps forward, are forgotten -- at least in the physics literature. Their work is published, of course, in the technical journals of applied physics, etc. I am not able to propose a solution for this problem. I am pleasantly surprised that the machine physicists still go on building such wonderful contraptions. Obviously, they are satisfied with the reality of their own achievements, a wonderful thing from the ethical point of view. It reminds me of a famous poem by Goethe: "Ich singe wie der Vogel singt, der in den Zweigen wohnet, der Ton der aus der Kehle dringt ist Lohn der reichlich lohnet." It is a poem about an artist who, before the court of the king, refuses a golden chain for his song and says, "I sing like the birds sing in the trees, and the very sound of my voice is my richest reward." Probably this solution is not entirely satisfactory for the machine physicist, but I cannot produce a better one except seriously to admonish experimenters to be sure that, at the least, the builders of the accelerators and other gadgets used in the different experiments are quoted and mentioned in the papers.

Now I should like to come to the second part of my talk, namely, the future developments. But before I start, I would like to make two remarks. Firstly, if one could predict the future, we shall not need the machines. If there is a theory that has worked so well that it can predict what is going to happen, then physics will be over. I hasten to add that, in my view, this will never happen: Nature will always be much richer than we humans can imagine. Secondly, I would remark that the future of this field is to some extent connected with the financial support. I am not going to say much about the financial support but I would like to say one thing: Science is a very vigorous activity, it is the essential contribution of this century to our culture, it is the basis of the life we live. In addition, high-energy physics is a spear-head, the front line of science in general. So I just cannot imagine, in spite of the crises, and in spite of the doubts which seemingly pervade this world, that this activity will cease. It may become a little more difficult. Perhaps, it is even good that it is a little more difficult to get money (but nobody outside should hear this), it may eliminate accumulated mediocrity. But I do not believe for a moment that, in the future, high-energy physics will stop because of financial troubles. There will be difficulties, but it will go on. If we need any proof of this, we just have to look around and see that, even in these hard times, there is considerable activity for the future: in the Soviet Union, the Serpukhov machine is working full-speed and with great success; in the United States, the machine at NAL (Batavia) was approved, funded, and is almost finished; and in Europe, the 300-GeV machine is being built. It does not appear to me to be a fundamental question; it looks to me like a period of difficulty and of some slow-down which, from the philosophical point of view, we do not need to be too much concerned about. We should be concerned about the widespread doubts with respect to the importance of science. But I do not think that we need to fear that science will not maintain itself.

Now, what about the future? As I said at the beginning, there were three periods of twenty years, starting with the Rutherford atom in 1910, then with the neutron in 1930, then with the discovery of hadron resonances in 1950. Now we are in the 1970's. According to this analysis, we are ready for a new opening-up of the horizon. I believe that we can expect to see it in the next twenty years.

Let me mention a few scattered straws in the wind. There is what I would call the beginning of electron spectroscopy. Have the electrons some kind of internal structure? So far, we have not discovered much of it but, if one examines what we know about leptons, then one sees in Fig. 14 the incipient features of a spectrum. There are two neutrinos, a little above them lies the electron, and then away up there is the muon. Transitions occur only from the muon to the muon-neutrinos; seemingly, there are no cross-transitions, which may or may not be a fundamental law. Well, is this the end of it -- or is that the beginning? It could very well be that the new machines will show that there are more excited electrons, and that the leptons themselves will show us a complicated spectrum. It may not. However, this next decade will give us a lot more neutrino physics, neutrino reac-

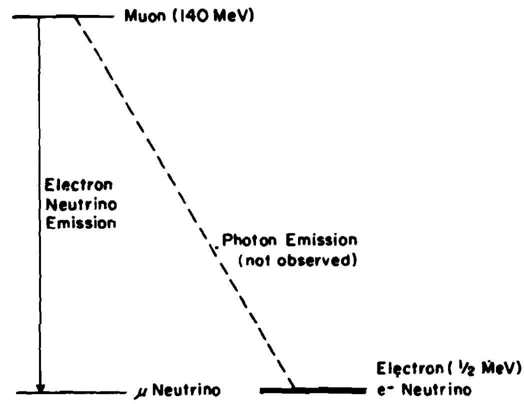
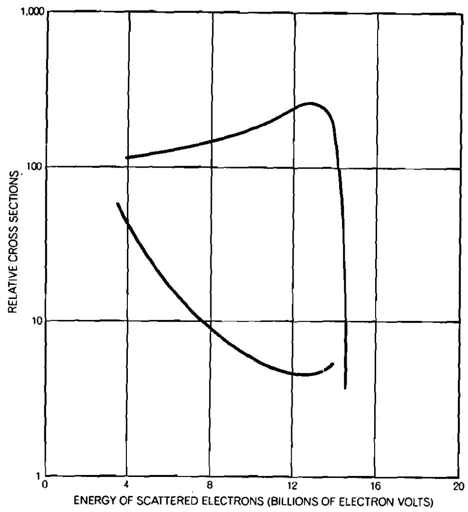


Figure 14

tions and other experiments with muon beams and other beams, in order to investigate this question. So, whatever will come out, this spectrum (which in a very rough way I would call the structure of the electron) is a new field that may be opened up in the next decade.

The next indication is the quark problem. Nobody knows whether or not quarks exist but there is certainly a clear indication that many phenomena look as if quarks did exist. Additional experimental material that will come from the proton and the electron storage rings, and perhaps even more important from electron-proton storage rings (which would expand the energy range of electron experiments that have contributed so much to this), will give us many new phenomena, new food for thought, to obtain better insight about this realm of nature where we now refer to quarks. Quarks may even exist!

The third development, of which we already see the beginning, is that to which I have already referred as the graininess of the proton. Taken from an article in the Scientific American by H. Kendall and W. K. H. Panofsky, Fig. 15 shows very clearly the parallelism of two experiments: the deep inelastic scattering at SLAC and the old Rutherford experiment. Rutherford bombarded atoms with alpha-particles and he found that the alpha-particles were strongly deviated. This means that they received a big momentum transfer, much bigger than one would have thought if the atom had been merely a smeared-out charge (as thought by Thomson, for example). The lower curve shows what one would have expected in a scattering of electrons, with 10^9 times higher energy than in Rutherford's experiment, if the charge would have been smeared out over the well-known size of the proton. Actually, one observed the upper curve which is about forty times larger. A quantitative analysis has shown that, exactly as in Rutherford's experiment, the electron is scattered backwards as if a portion of the charge were concentrated on a very small scale.



EVIDENCE that the internal structures of the proton and the neutron from which inelastic scattering takes place are much smaller than the nucleons either in their ground state or in their excited state is summarized in this graph, which covers a portion of the spectrum recorded by the M.I.T.-SLAC group in which the predicted scattering cross section (*bottom curve*) is lower by a factor of 40 than the observed cross section (*top curve*). The data were obtained at a scattering angle of six degrees; the energy of the incident electrons was 16 GeV.

Figure 15

By the way, it is interesting to contemplate how Rutherford determined the charge of the nucleus and found out that the nuclear charge is proportional to the atomic number. Rutherford made one assumption, namely, that there is only one nucleus per atom. How did he know this? If he had had some other reasons for believing that there are three, four, or five nuclei, then he could never have determined the charge of each of them; it is only the sum of the squares of the charges which he could have found. We are somewhat in this sort of situation in the SLAC experiments with protons because we believe (and I think we are correct) that if there is a charged parton in the proton, it is not the only one, there are several and, therefore, one cannot make such easy conclusions about what the charge is.

Anyway, here is evidence of a substructure of the proton, something of still unknown nature. It would be wonderful if they were quarks. But, at present, we do not have much reason, in fact we have some difficulties in associating them with quarks. Nevertheless, here is a tremendous promise; more experiments are necessary, at higher energy and with greater accuracy. It highlights the importance of electron-proton interactions and points to electron-proton storage rings as a wonderful means to arrive at higher energies in the centre of mass.

The fourth point I would mention is the relation of particle physics with astronomy. As you know, we are now living at a time when astronomy has developed very rapidly, with discoveries of quasars, pulsars, etc. Evidently, tremendous energies are concentrated, particularly in the quasar, energies that are probably comparable to the energies we are dealing with in particle processes. One might expect, in the next decades, a closer relationship between astronomical and particle observations. This will bring us new insights, in particular concerning the fundamental question of a connection between particle interactions and gravity, a force which plays a role in astronomy but, so far, no role whatsoever in particle physics, with the exception of a few theoretical ideas. And this again may be a possibility for an opening-up, of a new way of looking at Nature.

Therefore, I believe that in the next twenty years there will be a lot of exploration and discovery but, at least at the beginning, I believe that it will be mostly exploration and discovery. I feel that the amount of experimental material necessary for "explanations" is not yet large enough. We are apt to underestimate the amount of experimental material that was necessary in the past because, when we learn about things today, we never learn the tedious ways in which we came to the explanations, but only the most logical and direct way.

I would like to touch on another thought about the relation of high-energy physics with astronomy. So far, physics has been the science of the world as it is, but now we are asking about problems of the history of the world -- the world as it was. The historical aspect of the three realms that I have described can be seen in Fig. 16. The atomic realm is what happens at normal temperatures on earth, on the planets, and on the surface of stars. In the history of the matter of which we are composed, this realm refers to the latest period, from today to a few billion years back. The realm of nuclear phenomena refers to an earlier period, to the time when the sun was created and when our matter was located in the interior of some stars and then ejected during some supernova explosion. But if we go to the mesonic world or, for lack of a better word, the world of high-energy physics, this may or may not refer to phenomena such as those observed in quasars, which are very early stages in the Universe, or perhaps to those associated with the "Big Bang" that was supposedly the beginning of our Universe, 10^{10} or 10^{11} years ago.

Let me end my talk on an aesthetic note. There is something I envy the astronomers: the

THE THREE REALMS OF PHENOMENA

	Energy	Location	Role in History
Atomic	$0 - 10^4$ eV	Earth, Planets Star Surfaces	10^9 BC ⟶ Present
Nuclear	$10^5 - 10^7$ eV	Star Interiors	10^{10} BC
Mesonic	$10^8 - 10^{10}$ eV	? (Quasars)	? (Big Bang ?)

Figure 16

phenomena which astronomers observe are beautiful from an aesthetic point of view, which is not always the case in particle physics. Although I must admit that there is a certain pleasure in looking at a bubble-chamber picture, it does not have the attraction and beauty of astronomical phenomena. This is why I should like to show you some pictures of nuclear physics in the sky. For example, two nebulae (one is the famous Orion nebula) are shown in Figs. 17 and 18. It is in such nebulae that stars are formed and where the formation of the elements begins. One of the phenomena where high-energy physics comes in is shown in Fig. 19, an exploding galaxy. We see jets emitted in which possible energies are developed, where mesons and hyperons may play an important role. It is wonderful to contemplate that we have created here at CERN (and at other places in the world) situations and conditions that are similar to the ones observed in such pictures. Another example of such a jet is shown in Fig. 20. Finally, I would like to show you something where Nature competes with you, in my audience. In Fig. 21, we see the construction site of a natural accelerator. The two pictures are of a galaxy, one taken previously and one taken recently. The recent one shows a supernova and this is the site of a new accelerator because, shortly after the supernova calms down, there will be in the centre of it a fast-rotating pulsar with an enormous magnetic field which accelerates particles up to 10^{19} eV. As long as you people have not yet built an accelerator for 10^{19} eV, Nature will still have the upper hand!

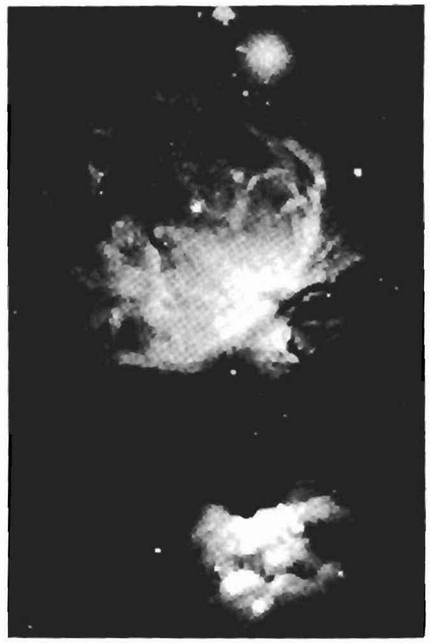


Figure 18

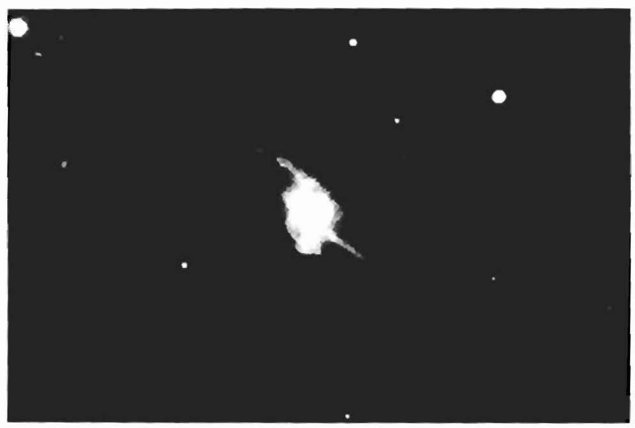


Figure 19

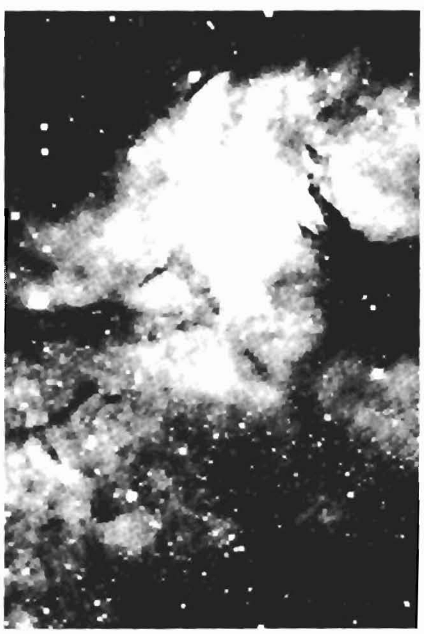


Figure 17

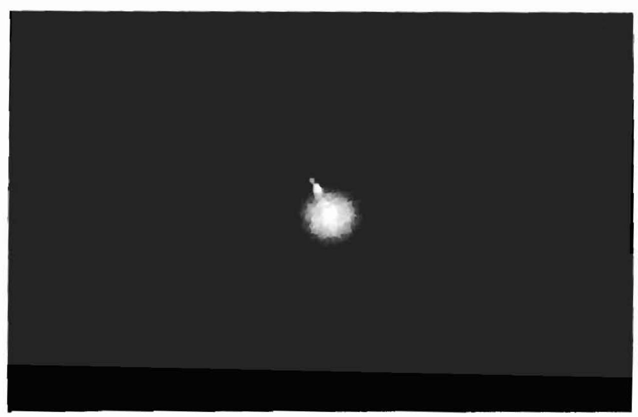


Figure 20

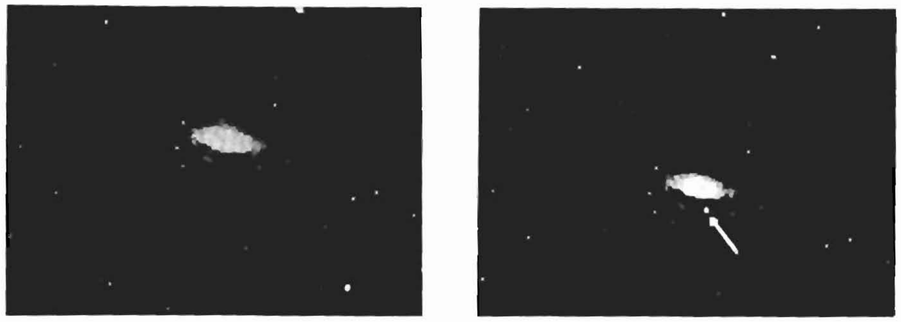


Figure 21

DISCUSSION

MRS. E. McMILLAN: Do you not think there could be medical advances coming from high-energy physics in the next 20 years?

V. F. WEISSKOPF: It is always very difficult, in particular in our field, to talk about applications because we are so far ahead -- I don't mean in the sense of value but in the sense of very basic knowledge. If one starts talking about the applications of this field, I nearly always have the feeling that one is not doing justice to this field. It is quite clear that there will be applications, in particular in medicine. For instance, the π mesons are supposed to be an extremely useful tool, and I am quite sure that there must be others because let me say it this way, the application of this field is bound to come. If one finds so many completely new phenomena such as those that we have brought out of the far darkness of the Universe into the knowledge of our world, then this must have some interactions, some important effects that may sometimes be used. To talk about this is somehow difficult and perhaps not even quite correct, because one can only make so few, and such poor remarks of the possibilities and these are not adequate compared to the greatness of the things which we find.

L. KOWARSKI: I would like to comment on your three kinds of physicists in a perspective somewhat more extended in time. Early experimentalists worked with their hands: Galileo's legendary tossing of stones from the Tower of Pisa, or the alchemists mixing by hand the ingredients in their mixing bowls. In a similar way the theoreticians manipulated their numerical quantities and symbols by their unaided brain-power. Then came the machines to extend the experimenter's manual skill and to open whole new worlds of things to be handled in ways nobody could predict or even imagine before they really got going. Now we are at the beginning of a new kind of extension by machine: the computer comes to supplement the theoretician's brain. We cannot foresee what this fourth kind of creativity in physics will bring, but we may expect that, just as Ernest Lawrence's contribution was decisive to the development of the nuclear machines, the name of John von Neumann will be remembered in connection with the origins of computational physics.