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Construction of Large Accelerators: Scientific and Political Aspects

W. Heisenberg

During the past years, there has been much talk of a large accelerator to be constructed by the combined efforts of the governments, engineers, and physicists of various European countries. The question of the urgency of the project, its financing, and its location have been the subject of public controversy and discussions. Finally, however, an agreement was reached to build the accelerator at the European Center of Nuclear Research (CERN) in Geneva, with a number of European states participating in its financing and completion, such as France, Great Britain, Italy, and the German Federal Republic. All important decisions with respect to this controversial project have thus been taken, and I believe that the majority of the participants—meaning the physicists as well as the representatives of the participating governments, in the Federal Republic as well as in the other European countries—are well satisfied with the result. Just for this reason, it may be of interest to recall the guidelines which have played a role in the decision, since we may expect similar large cooperative projects in the future, and the same questions of the relationship between science and society and of the conditions for international scientific collaboration will then arise again. Therefore, one may learn a good deal from the discussions which led to the decision, and I should like to express some thoughts of a more general nature about the relationship between government and science and their possible collaboration, which were stimulated by these discussions.

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Progress through Large Accelerators

Let me start with a few words about the physical problems to be investigated with the help of the large accelerator. Progress in atomic physics during the last hundred years has been closely connected with the construction of ever larger accelerators—using the word "accelerator" in its very general meaning. In ordinary discharge tubes, such as those used in advertisements, the electrons have to traverse a potential difference of only a few volts to be sufficiently accelerated so that they may modify the atomic shells of gas atoms with which they collide and excite these atoms to radiation. Such electrons with energies of a few electron volts have been used to investigate the atomic shells and to uncover, finally, the regularities of their structure. Atomic shell stands here for the totality of the electrons surrounding the atomic nucleus.

In the atomic nuclei the binding energies are about 1 million times larger than in the electronic shells. In the beginning of the 1930's. Cockroft and Walton in Cambridge built a high-voltage machine with which they were able to accelerate protons up to energies of the order of 1 million electron volts. Very soon thereafter, Lawrence and Livingston in the United States constructed their first cyclotron, which produced particles of about the same energy. With such machines it became possible to affect light atomic nuclei, to knock elementary particles out of them, or to attach other particles to them. In this manner one learned in the course of the 1930's to understand the structure of atomic nuclei, which—as has been well known ever since—consist of two kinds of particles, protons and neutrons.

The next group of such machines, which may already be called large accelerators, was built in the 1950's. In these machines protons were to be accelerated up to the order of several billion electron volts (Gev). With their help it was hoped to modify also the elementary particles known at the time, possibly to break them up into still smaller fragments, to find still smaller elementary building blocks. These large accelerators, too—among them those in Berkeley, Geneva, Hamburg, Brookhaven, Serpuchov—have fully measured up to expectation. It turned out that it is, indeed, possible to modify elementary particles, to raise them to excited states, to split them into many parts. But—and this was definitely new—the fragments are no smaller than the particles which were made to collide. It is no longer properly a question of division, but rather of the generation of matter from energy. In such energetic collisions the resulting elementary particles all belong to the same family. One might say that the elementary particles are simply different forms which energy can assume in order to become matter; but there are no particles which are more elementary than the ones we already know. Such was the state of experimental research some years ago, and on the basis of this knowledge it had to be decided whether or not to build still larger accelerators with energies of the order of several hundred billion electron volts and of correspondingly high costs.

Factors Involved in Building Larger Accelerators

In favor of this step spoke first of all the simple consideration that, as was pointed out above, each transition from smaller to larger accelerators resulted in new discoveries. Why shouldn't it go on this way? Entering a new energy region cannot fail to lead to new information, and nobody can exclude the possibility that part of this information will be highly interesting and quite surprising. But even setting aside such surprises, it may be important to learn how, for example, the interaction responsible for radioactivity behaves at high energies. The experimental evidence now available does not permit us to form a reliable conjecture, and it is quite possible that knowledge of the behavior at yet higher energies will bring about fundamental advances in understanding the spectrum of elementary particles.

I wish to emphasize at this point the central importance of these problems for all of physics. It is likely that, in the last analysis, all laws of physics will be reducible to the laws governing the behavior of the smallest material particles; hence, it is crucial to determine these laws. But apart from the importance of large accelerators for the extension of elementary particle physics, their construction will lead to new technical experiences, which may become valuable in entirely different fields. With such accelerators one will have to go to the extreme limits of what is technically feasible, and what is learned may have practical applications. I may remind you, for example, of the recently developed technique of superconducting magnets, which may well be utilized in the construction of a new large accelerator. Thus, there are many reasons in favor of building large accelerators with energies of the order of 300 Gev or more, and if it were possible to construct such machines for a few million marks, nobody would doubt that it should be done. Unfortunately, however, the costs run into billions. This is why it was necessary, considering the other needs of the state, to ask whether such enormous expenditures could be reduced or, at least, postponed. Are they really absolutely necessary?

To start with, it must be admitted that the reasons for expecting new basic results with higher energies are not entirely conclusive. Nature has given us a new and unexpected answer to our attempts to divide the elementary particles, which is that in these processes we are no longer dealing with division, but with a transformation of energy into matter. Probably, it will be the same with still higher energies, and hence we must take into account the possibility that, however much we increase the energy, nothing essentially new is going to happen. In fact, extremely energetic particles up to about 1 million Gev have been observed in cosmic radiation, and no basically new phenomena have been found. Hence, it is possible that the large body of experimental data on elementary particles accumulated so far suffices to comprehend the laws of nature in this field, and that we do not require a further extension to higher energies. Indeed, it is hard to imagine that a theory, hypothetical at its inception, although able to account correctly for all existing experiments within their limits of accuracy, might yet break down in the unexplored region of still higher energies. But even if one considers experiments in the range of high-energy physics as absolutely necessary, one might entertain the hope that within several years or decades it will be possible to build a large accelerator at much lower cost because by that time technology, for example that of superconducting magnets, will have advanced far enough or new principles of construction will have been found. Applying such reasoning, one could have argued for postponing the construction of a large accelerator, at least for a few years. You will realize that physical and technological arguments could hardly have sufficed to make a clear-cut decision, and hence it is also necessary to weigh the factors relating to broader questions of science and of foreign affairs which affect such a decision.

Let us start with the effects of such a decision on education and research in our own country. The amount to be spent on an accelerator of 300 Gev or more is so large that it cannot be easily raised in addition to the existing research budget, not even for an international cooperative project. Thus, quite embarrassing questions of priority come up for society or the government, for instance in this form: Should we build another university in view of the fact that the number of our institutions of higher education is insufficient or, instead, participate in a large international accelerator project? Or put in another way: Should we spend several millions per annum on the protection of our environment, against the pollution of rivers, lakes, and air, or should we use them on elementary particle physics? Such questions are embarrassing because totally incommensurable goals have to be compared with respect to their priority. On the one hand stands the pursuit of pure research concerning the problems of physics and science, which later on may have, although only indirectly, important economic consequences, and on the other an immediate practical concern of everyday life, such as the possibility for our children to attend college or the provision of a healthy environment for them. How does one decide such questions?

Attitudes and Influence of Scientists

It seems to me, first of all, that those physicists who wish to construct the large accelerator, who want to work with it, ought to realize the great difficulties inherent in these problems. It is not enough to dispose of these questions by shifting the responsibility for them to the government, to say casually that the necessary sum should be taken out of the defense budget. For those responsible for the commonwealth the question of the security of this commonwealth must have higher priority than participating in a large project for the study of elementary particles. In other words, a decision to build a large accelerator involves questions of politics which even physicists cannot simply ignore.

An excellent example of the proper attitude in such a situation was given by the British physicists. If I am correctly informed, the British physicists made the following proposal to their government: that it participate in the European accelerator project, but that it also cut correspondingly the national budget for elementary particle physics in order to balance the costs. It was even considered to shut down a great and distinguished research institute in the same field, the Rutherford Laboratory in Cambridge. Such a proposal is based in part on the conviction that the experiments to be performed with the new European giant accelerator will be more interesting and important than those that can be made with the smaller machines in the Rutherford Laboratory, and in part on the recognition that during the past decades physicists have already put high demands on the economy of their country, and hence ought to be circumspect in making any further requests. The British physicists were paying careful attention to the welfare of their community while putting forward their wishes.

Let me make here a general remark which goes beyond the immediate subject of this article. It seems to me an unfortunate phenomenon of our time—not only in our country and certainly not only among physicists—that many of us are tempted to make demands on the government without reciprocating or sacrificing something of our own. It may be a question of demanding an education, grants, having a voice in difficult questions, or simply of demanding a lot of leisure time, extensive vacation trips, material well-being. I am afraid that again and again the tendency manifests itself to consider it unncessary to justify these demands by one's own sacrifices. The good example of the British physicists points to the more general question of what the relationship of the physicists, and scientists in general, to their government ought to be.

Most people seem to agree that in our time the government needs the advice of scientists. Science and technology play such an important role in modern life, in the economy, in questions of education, and in the preparation of political decisions, that advisory committees of scientists and engineers are indispensable in order to render the work of the government easier. Such advisory committees have, indeed, been established in all modern industrial countries. In the Federal Republic, advisory councils exist on several levels, helping the government in the distribution of public funds for research purposes, in decisions on large research and development projects, in problems of higher education, and so forth. Examples are the Atomic Energy Commission, the Scientific Council of the Ministry of Economic Affairs, and the Advisory Council for Research. Lately, the reorganization of these advisory committees has been much discussed.

Quite apart from all this, the government in Bonn is naturally surrounded by lobbies of certain economic interest groups, in industry or in agriculture, who wish to make themselves heard. This, too, is entirely legitimate in a democracy since it is the task of the government to find as just a balance as possible between the various interests of the citizens of the country. Therefore, it is important for the government to be informed about these interests.

It seems to me extremely important, however, that the distinction between advisory committees and special interest groups remain clearly marked. The moment an advisory committee becomes also an interest group, it ceases to be useful as an advisory committee. The government can only profit from an entirely unbiased council. The government's participation in a large international scientific-technological project such as the large accelerator project leads, therefore, to a difficult dilemma. On the one hand, counseling by specialists in the field of high-energy physics is indispensable because they are the only ones capable of correctly judging the details. On the other hand, these specialists are necessarily also an interested party since they or their students will want to work with the large accelerator. This difficulty cannot be avoided. Clearly it was also felt by the British physicists, and they tried to sacrifice some of their interests so they would be able to play the role of adviser with a clear conscience.

But even if one assumes that all participants fully appreciate these problems, the task of evaluating the priority of such a scientific-technological project over others remains extremely difficult. How important is scientific knowledge? How important is it to obtain it soon, and not in 10 or 20 or 30 years? Those who have spent their lives being active in science will give high priority to scientific knowledge and are in a position to adduce many sound and weighty reasons. But a politician who, before entering politics, was a businessman or a farmer may consider questions of economy or of environmental protection more important, and he, too, will be able to find many convincing arguments for his point of view. Or, on the contrary, he may be in danger of overvaluing scientific knowledge because science appears to him awesome and strange and because, impressed by modern technology, he overrates its potentialities.

In view of this unavoidable uncertainty of the politician, it is the first duty of the adviser to provide the authorities with a completely factual, unvarnished picture of the scientific plans and their expected significance. All arguments in favor, but also all those against the project, must be presented and elucidated as objectively as possible so that the politician will be supplied with the best information obtainable. In expounding the reasons for or against such a project it is important to put the burden of proof where it belongs. If it is a question of a billion-mark project, which will require sacrifices in other areas, the proponent of such a project is the one to bring proof of its urgency, of the results expected from it. It is not up to the opponent to prove that the project is not all that important. It will never be possible to prove that a scientific project breaking new ground will not produce startling and important new discoveries. But this alone can never provide sufficient reason for spending billions. Hence, the burden of proof must definitely lie with those who want to claim such extremely large public funds.

But even if such proof is furnished, it will be difficult enough for the politicians to make up their minds. It facilitates their work that similar decisions must, after all, be made in other countries as well and that they can take their bearings from them. In the case of an international project, such as the European giant accelerator, other countries which may take part in it have to deal with exactly the same problems. In such a situation, the decision will have to be taken more or less jointly.

Cooperation of European States

The international character of such a large project introduces some new aspects which have not yet been dealt with. We all agree, I think, that it is extremely important for the future of our continent to form a true community of all the small European states. A large scientific project whose importance is accepted by everybody, but which because of the high costs involved can no longer be carried by a single European country alone, represents an ideal case of such a cooperative effort. When it is a question of pure science, economic and political competition are no longer significantly involved, results and technical know-how do not have to be kept secret. A common interest in fascinating scientific problems unites young physicists and technicians from different countries in fruitful work; without any further effort, a steady exchange of opinions takes place and an unconscious assimilation of interests results, the importance of which cannot be overemphasized with regard to the future goal, the unity of Europe. Large international projects should, therefore, be supported if only because they are international. In view of this unifying potential one should not be overly critical and skeptical with respect to the scientific possibilities and arguments.

As a matter of fact, during the postwar years several such international projects and installations have come into being in Europe, which have been significant examples of scientific cooperation. The best institution of this kind is the nuclear center, CERN, in Geneva. Since 1959 its proton-synchrotron of 30 Gev has been in use and has made possible a number of highly interesting experiments. Last year, the large intersecting storage rings were put in operation, corresponding—with respect to the collision energy of two protons—to an accelerator of about 1700 Gev. It will be the only machine of its kind in the world. Shortly afterward, it was decided to build a new European giant accelerator of several hundred billion electron volts in Geneva. Europe will thus be in a position to play a leading role in high-energy physics for the next 10 to 20 years, provided as good use will be made of these machines as has been made of the proton-synchrotron. In Trieste, on Italian soil, a very successful international center for theoretical physics has been created; it is supported not only by European countries, but also by non-European ones, and maintains particularly good contacts with Eastern Europe and Asia. In Ispra on Lake Maggiore, also in Italy, developmental and research problems in the field of reactor technology are being carried out on behalf of the European Atomic Energy Community (EURATOM). This, again, is a large international cooperative project supported by several European countries. In Grenoble, France, a reactor with a very high neutron flux has been installed through French and German cooperation, where scientific and technical investigations can be made about the behavior of materials under the influence of strong irradiation. Similar international installations in other fields, for example, for space research, exist in Belgium and Holland.

There is, indeed, great interest in international scientific collaboration, and one may be fully satisfied with the successful results obtained in the various institutions. Nevertheless, when a decision to found another such international scientific installation is taken, difficult new problems arise concerning its site, in particular, but also its financing, the distribution of contracts, and appointments to the leading positions. The question of location is by far the most difficult one because, as a rule, it must be decided from a political rather than a purely objective point of view. It is true that the technical or scientific purpose to be achieved will often impose certain conditions which greatly restrict the choice of location. For a large accelerator, for example, a large level surface must be available which is geologically stable, that is, which does not become deformed by ground motions or distorted by atmospheric conditions, and the amount of earth moving required for the erection of the accelerator must not be too costly. Moreover, the installation must be conveniently located, schools and colleges must be easy to reach, and so on. Thus, there are quite a number of conditions which must be satisfied, but as a rule, it is not too difficult to find sites in different parts of Europe which satisfy all of them.

In the final account, it is necessary to make a political decision, and the question is which factors play the most important role. Since all these international scientific centers are erected through cooperative European efforts, it seems to me that these installations ought to be more or less uniformly distributed over Europe. One may, of course, debate the meaning of this vague concept "more or less uniformly." But glancing at a map of Europe and looking over the spatial distribution of the international scientific installations built until now, it is evident that their distribution is still rather uneven and should in the future become more uniform. This argument is sometimes countered by pointing out that one aim ought to be the United States of Europe, in which case the location within Europe would no longer matter. But the case of the United States of America demonstrates that this is not so, that even in such a large, politically unified country one must pay attention to a uniform distribution of scientific institutions. Thus, the latest American giant accelerator, which is to furnish approximately 400 Gev, was built at Batavia, Illinois, not far from Chicago, whereas the two former centers for high-energy physics were constructed in the West, in California, and in the East, at Brookhaven, New York. In Europe, the question of the site played an important part in the debates about the giant accelerator. But the possibility of making use of the already existing infrastructure at CERN, and thus of considerably reducing the costs of the new installation, finally won out over the other possibility, to create the new European research center in a region far removed from other centers of this kind. Let us hope, however, that future installations will contribute to a more uniform distribution over Europe.

Obsolescence in Physics

There was another reason for locating the new giant accelerator at CERN. Another European center for high-energy physics independent of Geneva would have tied down a staff of thousands to work at the new site. Many young and talented physicists and technicians would have turned to this very specialized field of elementary particle physics and accelerator technology. During the coming years they would probably have been so fascinated by the problems in this field that it would have been difficult for them to change later on to another one. On the other hand, the preoccupation with the special problems of elementary particle physics will sooner or later come to an end, just as it has happened with so many other branches of physics which have been absorbed—together with their applications—by technology. If one projects "the end of elementary particle physics" to a very remote point in time, as some physicists do, one may feel justified in not giving any thought to the future activity of elementary particle physicists. But the United States has already closed down some of its accelerator installations and dismissed physicists and technicians working there. This shows that one does these young people an injustice by not taking an interest in their future after having involved them in this specialized field. For this reason, it was a wise decision to build the new large accelerator in Geneva, where the proton-synchrotron and the large intersecting storage rings were built. Although in Geneva, too, personnel will be considerably increased, this will not happen to the same extent as in a completely new accelerator station. The dangers for the distant future have thus been somewhat reduced by choosing Geneva as the site. Still another argument, rather incidental: the spatial restriction of the site, which the choice of Geneva entails, has technical consequences. It forces the designers to make use of the latest technical developments, for example superconducting magnets, in order to obtain such high energies within so little space. The new project will, therefore, necessarily be much more modern than the one planned earlier.

I think I have presented most of the arguments which played a part in the final decision. Let me repeat them in a few words. First of all, there is the satisfaction of working on a meaningful cooperative project, but also uncertainty with respect to the forthcoming results with the new instrument, the question whether the experience gained with the earlier accelerators may not suffice to comprehend the world of elementary particles. There is the further question of progress in technology; might it not be the case that in a few years accelerators with the required energies can be built much more cheaply than now by using new technical processes? An additional difficulty was the necessity for the participating nations to come to a fair decision with respect to the site, and for each of the individual governments to renounce plans or projects of their own in favor of the international accelerator. It seems to me that in view of all these difficulties the final decision is a very good solution, an appropriate compromise between the various interests, and a valuable contribution to the strengthening of the European community.

Motives behind the Building of Giant Accelerators

In conclusion, however, let me leave this level of practical considerations, scientific reasoning, and political negotiations and, descending to a somewhat deeper level, ask: Why, after all, do we humans make such strenuous efforts to build a large accelerator, why do we spend billions on a scientific instrument which, at least for the moment, does not promise any economic return? When I once put this question to the American ambassador in Bonn, I received the following reply: In ancient Egypt pyramids were built, in the Christian Middle Ages magnificent cathedrals, and in our time we are building giant scientific instruments. In ancient Egypt the royal ancestors represented a bond to the deity, and the trust in help and support deriving from this bond manifested itself in the erection of these giant tombs. In the Christian Middle Ages the believers went into the cathedrals firmly convinced of obtaining deliverance from their suffering. In our time we trust almost blindly in science and rational thought, and we are bringing enormous material sacrifices to further science, to increase our knowledge of the world. The American ambassador's comparison contains without doubt part of the truth, and if we mean by religion in a very general way the center of trust forming the kernel of a society, it must be admitted that religious motives are the driving force behind the building of these giant accelerators. Still, one must ask oneself here whether the power of the goddess "Reason" is, indeed, as large as it was hoped at the time of the French Revolution. The experiences of our century seem to indicate that it is rather limited. However one may judge this power, our minimal demand must be that we do not blindly commit ourselves to it, but that we act sensibly and critically if it is a question of investing enormous funds in large scientific projects. This has certainly been the case with regard to the Geneva giant accelerator, and it must be hoped that in the future, too, similar scrupulous care will be taken in deciding on such large projects.

Note

1. This article was translated by Sonja Bargmann.

Reaction Wood: Its Structure and Function

Lignification may generate the force active in restoring the trunks of leaning trees to the vertical.

G. Scurfield

The Problem Stated

Wherever trees are found, but perhaps most often on exposed seacoasts, high mountains receiving heavy snow, unstable slopes with shifting rocks or scree, and the banks of uncertain rivers, it is not uncommon to find some with main stems which have not grown upright during part or all of their lifetime. The form of the stems of these trees is usually such as to suggest that, after being bent or tilted, they have striven to regain a vertical position. We are to be concerned with the mechanism of this recovery process.

Morphology

There are two morphological consequences of displacing the main stem of a tree from the vertical.

1) If the displacement is severe, as when large trees are partially uprooted without being killed, but especially when stems are caused to overarch (naturally, as under snow load, or artificially, as in trellising, for example), stem growth is continued from a lateral bud so placed that the stem it produces is as nearly vertical as possible. That part of the tilted main stem which lies beyond the sprouting lateral may subsequently die, the lateral taking over the role of main stem. If more than one lateral grows out, a tree may develop a stem similar to that shown in Fig. 1a.

Should the displacement from the

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