The Role of Pure Science in
EUROPEAN CIVILISATION

By C. F. Powell

1. *The rapid advance of science and its consequences: international collaboration in science*

The subject on which I am to address you raises novel problems of great public interest and importance. We are surely all very conscious of the fact that the headlong advance of science, and the technological developments which it has called into being, have profoundly modified our whole civilization and the process is manifestly continuing. Science is an indispensable and rapidly growing element in our culture.

In a sense this development has crept upon us unawares, for science has not, at least until recently, been advanced on the basis of any well-considered principles of public policy, but rather as a result of the particular interests and abilities of gifted men with very limited technical resources. Indeed, until quite recently, the requirements for the advancement of science, both of men and treasure, were entirely negligible in comparison with the profound changes to which they led. In the circular diagrams which show how the national cake is divided up, there was never any indication of the amount spent on fundamental science because it corresponded to less than the thickness of the lines defining the different sectors. And this is still true today.

But after the last war, the technical needs of science grew rapidly, and in one or two particular sciences they reached the point where the most significant investigations required resources beyond the individual means of any except the economically most powerful states. This first appeared in high-energy nuclear physics, particle physics, and this organisation of CERN, in which many European states pooled their resources and shared the cost, is the result.

The importance of CERN, however, does not depend only on its brilliant success in ensuring that we have an excellent centre for particle physics in Europe, in the first rank on a world scale. Developments in other sciences are forcing them also into forms of international cooperation for which the history of CERN serves as a model and an inspiration.

But we are now looking forward to the needs of the 1980's and you are to hear proposals for a new generation of accelerators which, in the next decade, will eventually involve an annual expenditure several times greater than that of CERN. Although a similar relative increase in pure science as a whole would certainly not make grave inroads into our economies, the amounts involved are no longer insignificant and governments must ask such questions as: Should we in Europe continue to support pure science in general, and particle physics in particular, at the levels of expenditure with which we are now faced? What can we expect to gain from it? What shall we lose if we withdraw? In approaching these problems I shall be particularly concerned with particle physics, but many of the considerations will, I believe, be relevant to other fields of science in the next twenty years; in some of them much earlier.

2. *The progress of high-energy physics*

Let me begin by emphasising the immense promise and vitality of the subject of particle physics as an essential condition for its continued support. High-energy particle physics is the present form of the age-old enquiry into the nature of the fundamental constituents of the material universe. Thirty years ago, as a result of a series of great European discoveries which included the picture

Professor Powell presented the address on which this article is based at a meeting of the Council of the European Organization for Nuclear Research with ministers and representatives of CERN's contributory states at Geneva on October 10, 1964. The author, a member and former chairman of CERN's Scientific Policy Committee, is Melville Wills professor of physics at the University of Bristol. The occasion of his talk was a ceremony commemorating the tenth anniversary of the founding of CERN.

of the neutron and the proton as the constituents of the atomic nucleus, we were tempted to think we were reaching the end of the possibility of penetrating much more deeply into nature; it seemed that, in the final analysis, we could reduce the world to nucleons, electrons, and the quanta of radiation and their interactions. But this view proved to be quite illusory. Especially after the last war, in experiments with cosmic radiation, a whole new world of particles, the mesons and hyperons, which had escaped discovery because they are so extremely short lived, began to be found.

Later, especially in the past ten years, as the great new accelerators came into operation, the study of the detailed properties of these particles was rapidly advanced. The resources for experiment were also increased by powerful new methods of observation, such as the bubble-chambers and the spark-chambers, together with sophisticated computing methods for analysing the significant events which they record in large numbers.

As a result of these innovations, a new world of phenomena has again been revealed. The number of known particles, most of them exceedingly ephemeral, now exceeds one hundred, and they have consequences of fundamental importance for our philosophy. In the first place we begin to believe that the old basic idea of the world as built up of elementary particles in the Greek sense of "atom", "that which cannot be cut", is illusory. All particles including the proton have a structure which we are elucidating. Particles of all types can be created in sufficiently energetic collisions between other particles; and they can be annihilated into other forms of matter and energy when they encounter their own antiparticles. Any particle is not to be conceived as a permanent structure, as was the Greek atom, but as continually transforming, for brief instants, into other forms; and then rapidly resuming its identity. Most of our familiar world is made up of nucleons, electrons, and the quanta of radiation; but only because they are the most stable of the great family of particles, not because they are the more fundamental, so that at our familiar temperatures it is exceedingly improbable that others will secure even the temporary independent existence which their very short lifetimes impose. The very notion of "elementary particle" in the sense in which it has been employed since the time of classical antiquity has been undermined.

Secondly, the behaviour of particles, in their interactions with one another, has forced us to extend widely the conservation laws familiar in classical physics. In describing the complexities of their behaviour we have to acknowledge that they have attributes for which there are no parallels in classical physics or in the world of everyday experience.

Particle physics is thus pursuing its familiar role of penetrating ever more deeply into the material universe so that we are forced to introduce basically new concepts for the description of a radically new experience. "Experimental science," said Clerk Maxwell a hundred years ago, "is continually revealing to us new features of natural processes, and we are thus compelled to search for new forms of thought appropriate for their description."

Bacon also remarked, "the Universe is not to be narrowed down to the limits of the understanding, as has been man's practice up till now; but rather the understanding must be stretched and enlarged to take in the image of the Universe as it is discovered". At the present time, particle physics is exceedingly active in this stretching and enlarging process, and the resources of the human mind are thus being rapidly extended. For us who are well past our first youth, it is a process which, whilst immensely stimulating, is sometimes a little uncomfortable.

Thirdly, in the past year, a very important step has been taken, in the recognition of a remarkable degree of order among the particles. Until quite recently their precise masses, spins, lifetimes, and other parameters appeared as a body of empirical fact, and very few significant regularities had been distinguished. Now, however, it has been shown that the particles can be arranged in well-defined groups, and the validity of the new groupings has been demonstrated by the fact that the existence of missing members and their properties have been predicted and subsequently confirmed.

3. *The significance of recent advances*

The analogy of these advances to the recognition of the Mendeleef periodic table of the chemical elements seems very close. It is a recognition of regularities which guarantee the existence of an underlying order, the fundamental basis of which we may hope to discover. It is not yet the equivalent of the discovery of a new quantum mechanics or of a Pauli exclusion principle, which gave the key to an understanding of the relations between the chemical atoms as a single, ordered family, but it gives the assurance that we may, perhaps quite soon, make fundamental discoveries of not less significance.

The solution of these problems, and there are others of equal significance in the subject, are of profound importance for our deeper understanding of the material universe. All our experience of the development of science suggests that there is indeed an order in nature which we can discover, and that we may hope to resolve our present problems. Such an attitude is very deep in our traditions. A confidence of order in nature, of the existence of laws of nature which men can aspire to elucidate, was an essential condition for the emergence of modern science in Western Europe, rather than in another civilisation, such as the Chinese, of which the thought was in some ways more sophisticated, but in which nature tended to be regarded as inscrutable.

Thus, when the Jesuit missionaries first visited China and explained to the Chinese the Western view that the behaviour of things is ordered by the laws of nature, they were received with a polite scepticism. "We understand," said the Chinese, "that a human law-giver can make laws, and establish sanctions to secure their observance. But surely that presupposes understanding on the part of those governed. Are you suggesting to us that air and water, sticks and stones, have understanding?"

Particle physics is, then, full of life and vitality and will continue to attract a large fraction of the most gifted of the youth of the world in the economically developed countries who devote themselves to science. It seems certain, however, that the solution of present problems will again require a considerable increase in our technical resources, such as the 300 GeV proton accelerator. Can we afford it?

4. *Needs of pure science and the material benefits flowing from it*

In approaching this question we must acknowledge that the share of our resources asked for by science, including fundamental science, is rapidly increasing and that it is a process which cannot continue indefinitely. But it could go on for some time at its present rate without making any very great inroads into the economy. Thus, in economically advanced countries, between two and three percent of the gross national product now goes into all forms of research and development, and between two and three parts in 1000 on fundamental science, as compared with seven percent on armaments. Such a proportion should not, I suppose, be regarded as unduly favourable to fundamental research in a period of human history in which the development of science is the dominant feature of the times, so that a country cannot be strong in any sense without excellent science and scientists.

Although pure nuclear science only gets about one-sixth part of the amount allocated to pure science as a whole, even one part in 2000 of our resources is a substantial sum, and other demands on the public purse are pressing. Why should we allocate a considerable proportion of our scientific resources and manpower to particle physics? Although the subject is so promising, we cannot assert precisely how useful it will be in its influence on other sciences and on practice. In the same speech from which I have already quoted, Clerk Maxwell remarked: "For us who breathe only the spirit of our own age, and who know only the characteristics of contemporary thought, it is as impossible to anticipate the general tone of the science of the future as to predict the particular discoveries it will make." All that we can say is that always in the past great advances in natural philosophy have in the long term led to radical changes in all our thinking, and eventually, through their influence on the resources and morale of science, on all our practice.

If, then, we speak of *pure* science, it is in the sense that it is not directed to the solution of immediate concrete practical problems; but that does not mean that it is not immensely profitable in the long term. The overall longterm return from investments in the fundamental science of the past is very difficult to estimate, but all writers on the subject agree that it is very high. Thus it has recently been remarked that, whereas our present civilisation is essentially based on the consequences of the pure science of the past, everything that has ever been spent on pure science, up

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till now, is equivalent to only two weeks industrial production at present levels. Or, to put it another way, everything that has ever been spent on fundamental science in the past is equivalent to the amount by which this year's production is expected to exceed last year's.

But in different sectors of science the period from discovery to fruition differs widely. The lady of the old story of Benjamin Franklin was right to ask about the use of his new discovery and he was right to emphasise the time-scale to maturity. You will remember that the lady on being shown the demonstration of a new effect in pure science asked, "But Professor Franklin, what's the use of it?", and Franklin replied, "Madam, what is the use of a new-born baby?"

The eventual profitability of particularly penetrating and significant branches of science, such as particle physics or the elucidation of the genetic code in biophysics, is bound to be of a different order of magnitude from that given by less widely ranging investigations, and it will take longer to mature.

5. *The importance of balanced development of science and technology*

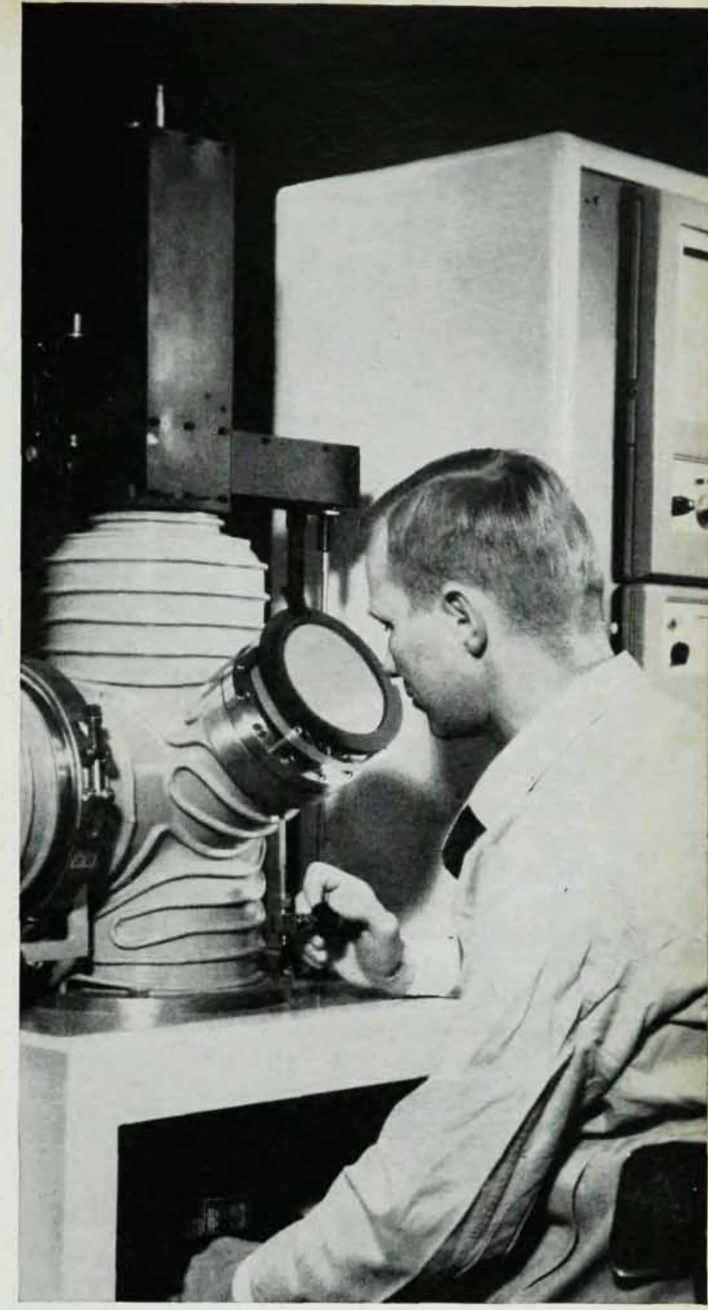
It is also important to remark that the eventual benefits derived from pure research are not only those to which it leads directly. Fundamental research in nuclear physics, in pure science, was undoubtedly an essential element in making nuclear power stations a possibility; but it was only one element in addition to many others involving advances in chemistry, engineering, and solid-state physics, to name only a few. The scientific age is the product of a complex interplay of all science and technology. The problem is to ensure their balanced development, for a deficiency in one branch weakens the whole front of advance.

It is very important not to see the problem too narrowly or to make a judgement on the value of a branch of science solely on the basis of immediate material benefits. The discovery of the universal law of gravitation, or of the origin of species, had little direct influence on economic affairs, but their impact on the standing of science and its development was immense. Or again, the development of quantum mechanics appeared as a remote and abstract advance when it first appeared, but in addition to its great importance for physics, it laid the foundations for theoretical chemistry. It was, therefore, an indispensable element in the chain of developments which contributed to the advances in molecular biology, and the great and significant recent advances in our understanding of living processes. Its ramifications are manifold and priceless.

It is a reasonable speculation that the new advances in particle physics which now seem to be coming within our grasp will not be less significant and productive in the long term than were those in this field in the past. They may not contribute to the advancement of chemistry, for example, because the methods and theory created by past physics may provide all that is there needed. But they may instead be an essential element in bringing into being whole new fields of human practice, of which at the moment we have no inkling. Nobody in the eighteenth century had any intimation of an electrical industry; or in the nineteenth, of the atomic energy industry; and certainly there will be fields of practice in the twenty-first century of which we in the twentieth will know and anticipate nothing, but the foundations for which will be laid by the science of our own times.

We have indeed, in the past year, had a clear indication that particle physics, in addition to its intrinsic interest, will also be of great importance for another vital branch of science, cosmology. Among some of the radio sources, there are recently discovered visible objects, called quasi-stellars, with a brightness about 10^{12} times that of the sun, and in which the energy source is approximately equivalent to the rest-mass of a million suns. Among them are the most remote objects in the universe hitherto identified. Their rate of energy generation is so prodigious that it cannot be due to the kind of nuclear processes which provide the energy liberation in ordinary stellar evolution. For an understanding of these objects, it seems probable that we shall need all the resources of general relativity and of the processes we encounter in particle physics at the highest energy; that for an understanding of the greatest energy-sources known to us in the universe, two branches of natural philosophy which are commonly regarded as among those most remote from practical affairs are indispensable.

In the development of science, similar situations have occurred again and again; yet there is an innate intellectual conservatism in us which makes us slow to see that the explosive developments in science through which we have lived are likely to continue, so that, in the absence of a great human catastrophe, the advance of science, the progress of discovery and of technical innovation, knows no limits; and we fail to draw the appropriate conclusions on major problems of policy.



6. *Pure science an indispensable element in our culture*

But why should *we in Europe* continue to support elementary-particle physics here and now when the expenses are becoming so heavy and other demands on the public purse are so pressing? Why should we not leave this field to other countries and hope to share the fruits of their researches when they mature? It is a question which must be faced; and it should be convincingly answered if we are to proceed.

The tone, the morale, of a laboratory, of a nation, even of a civilisation, is a very delicate and impalpable quality, yet of immense importance for the whole organism. The transition from high achievement to decadence has often in the past seemed to rest upon a razor's edge. There is a sudden loss of confidence; it is as if the well-springs of human creative power have suddenly been dammed-up, frustrated; and this is followed by a rapid decline.

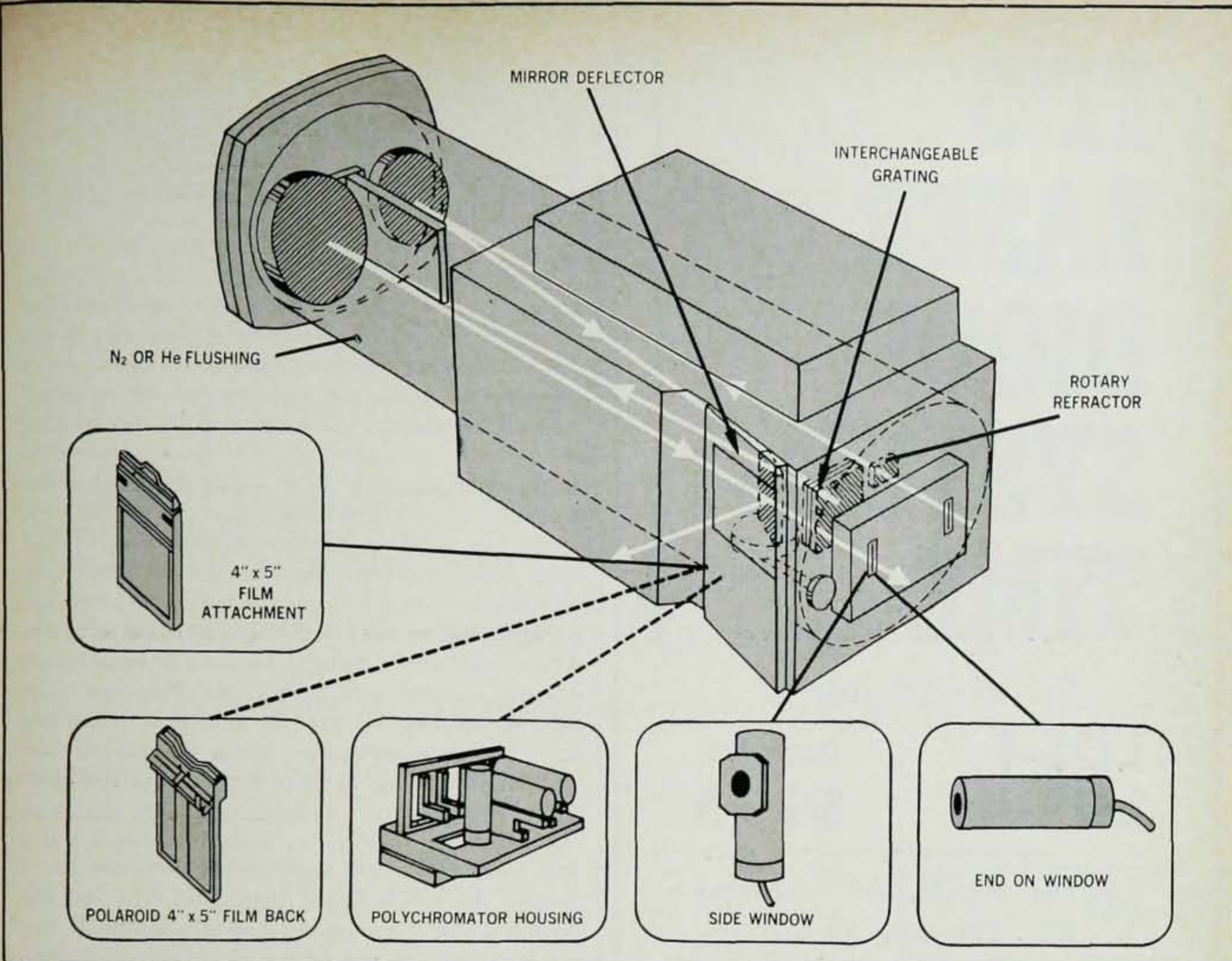
Ours is an advancing scientific culture, and if in Europe we are to make an important contribution to it, we must continue to engage in the most advanced science and technique, both nationally and in collaboration. Man does not live by bread alone, and the benefits derived from science are not to be measured only in terms of its technological consequences. Our forefathers made great decisive contributions to all the arts; to music and drama; to sculpture and architecture; to painting and literature; they built the Parthenon and the Cathedrals of Chartres and Bourges, Durham and Salisbury, Toledo and Burgos, Pisa and Lucca, Freiburg and Ulm. All these things gave little economic return but who would regret the effort. In our time, it is in the sciences that the human creative spirit finds one of its chief means of expression. We must therefore encourage the most gifted of our youth to apply themselves to the most difficult, significant, and demanding of the sciences, and at the present time that must include the physics of "elementary" particles.

In the long run, it is most painful, and very expensive, to have only a derivative culture and not one's own, with all that that implies in independence in thought, self-confidence, and technical mastery. If we left the development of science in the world to the free play of economic factors alone, there would inevitably result a most undesirable concentration of science and scientists in too few centres, those rich in science becoming even richer, and those poor, relatively poorer.

It is not easy to distinguish all the factors which contribute to morale, but I suppose that it is important for the whole of our educational systems that the tradition of penetrating independent enquiry should be kept vigorously alive among us. This is surely especially so in our times when science is beginning to infuse every aspect of education, and the characteristic feature of science is change and development. The continuing theme in human history is the great battle to comprehend better the world around us, and to improve practice in the interests of every aspect of human advancement. People, including children, respect those who are successfully exerting themselves, at all kinds of levels, in this struggle. Immediately we cease to participate, our teaching tends to become stereotyped and pedantic; and in our universities that means that we must continually be involved in significant and essential researches.

So it is most important that we should continue to promote science in Europe effectively, and, elementary-particle physics as an important part of it. The programme you are to hear about is an important element in providing the necessary support. We all understand that it must be considered, taking into account the legitimate claims of other sciences and other public demands upon manpower and treasure. We should all be deeply concerned to see a balanced development. Gifted people are always in demand and they are needed in many fields of technology as well as in fundamental science. But it may be remarked that the great attraction which elementary-particle physics and other growing points in pure science has for many of the most able young minds is not due to an arbitrary fashion. They are drawn to the frontiers of knowledge where the intellectual challenge is greatest. On such minds the subject exerts such a fascination that they will not easily be deflected but will go where it is actively pursued, wherever that may be. But if the subject loses its significance they will quickly drift away to other fields.

Particle physics at the present time is a large-scale operation involving thousands of people in the great national and international laboratories, but the number of key people is rather few and they do not seem to emerge in direct proportion to the increasing number of students we educate. It has been remarked that if, in particle physics, we lost a dozen of our best young physicists from Europe, our future contribution to the subject would be gravely prejudiced. A large number of competent scientists would be left with an indifferent leadership, and good generals make a great difference to the fate of armies. We are producing an encouraging number of gifted young physicists in Europe because we have a great



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tradition in the subject and have given it adequate support since the war, and we must not lose the position we have built up.

7. *Conclusions*

In the future, science may perhaps be organized not on a regional or continental, but on a world scale. It may become the principal creative activity of mankind employing a major part of our growing total resources. We may then be able to plan the general advance of the whole world scientific and technical front in a balanced way on the basis of the internal scientific needs of the different disciplines, with a rational distribution of the total effort between countries or continents, and without first considering their economic costs and returns. But we are clearly far from that situation today; and we in Europe must look to our own culture and our own future. Mr. President, it is said in my country, and no doubt in yours too, that to the shoe-maker there is nothing like leather; but out of a deep respect both for those I am privileged to address, and their grave responsibilities, I have felt bound to express myself with a studied moderation. Nevertheless, I believe the conclusion is inescapable that for the future strength and vitality of this continent and for the maintenance of its great scientific traditions, it is essential to ensure a balanced and effective development of all science and technology. For this purpose we need to establish a well-informed and imaginative attitude to the role of fundamental science, its profound significance for our whole future, and the principles which should govern its proper support; and at the present time the balanced support of science must include adequate provision for one of its most vital and promising branches, high-energy particle physics. For several decades the needs of science have been rapidly increasing, but they still make a relatively very small demand on our resources and this is not the time to stop. If we do, we shall slowly decline, like a limb to which the supply of the life blood is restricted. This continent will then become a sad memorial to its past glories and achievements; and to the inadequacy of the effort with which we met the challenge of our own times.

But if we go on boldly, we shall surely be able to take our full part in the brilliant world of the future which is coming within our grasp as the scientific epoch of mankind, which we are only just entering, comes to maturity.