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ELEMENTARY PARTICLE PHYSICS IS EXPENSIVE! IS IT NECESSARY?

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THE collection of articles on the "Nature of Matter" appearing in translation in this issue of "Uspekhi" is certainly of great interest. There is, of course, much repetition in the different articles. My article also partially repeats what has already been discussed there, and not only as a result of the fact that I did read some of the articles very carefully.

Some time ago I was asked to give a lecture on the possible practical applications of high-energy physics. Of course, I had no specific ideas on this subject and I did not give the lecture. Here, however, we are not concerned with specific ideas regarding, let us say, the practical use of hyperons in the national economy etc.

My first comment is that it is unlikely that the path leading to the practical application of particle physics and of high-energy physics (and I think that such applications will come) can be predicted on the basis of our present-day knowledge. The main thing about particle physics is its fundamental nature, so that unexpected discoveries are inevitable. Therefore to ask about the practical application to the national economy of the results obtained through investigations using any given high-energy accelerator would be almost an illegitimate question. One might say that if we knew anything definite regarding this, we would know the solutions of some of our scientific problems and then it would be unnecessary to do research, build accelerators etc.

Moreover, the advanced nature of elementary particle physics is shown not only by the fact that we do not know the answers to certain questions, such as the spin of the Ω particle etc., but also and especially by the fact that we often ask nonbasic questions. The most basic questions are seldom asked in fundamental physics. Advances in high-energy physics depend on the frequency with which decisive basic questions are asked. For example, Lee and Yang asked, Is parity conserved in weak interactions? This question could arise only after persistent tedious experimental work on the properties of K mesons had been done in many laboratories. This work was done without any knowledge that it would lead to far-reaching results.

The physics of elementary particles and of high energies is therefore needed, firstly (as almost everyone understands), because it is really fundamental, and it is the duty of science, especially of materialistic science, to investigate and learn to understand the most unfamiliar and at the same time the "simplest" realms of nature. This is so not only because we are concerned with extremely interesting problems. This is so not only because the human desire for knowledge has no limit, and the spin of the Ω particle is no less legitimate a problem than the deciphering of the Mayan language, or the question whether Napoleon was actually poisoned, or the nature of "quasars." (To answer this last question huge facilities will be required.)

Particle physics is of very special interest. It is concerned with the structure of matter, and in this sense it continues the tradition of the most advanced physics in the past. Particle physics therefore seeks knowledge without which we cannot contemplate any furthering of the interaction between man and nature. Here not only the structure of matter is studied, but also the structure of space and time. Nevertheless, what can we say about the possibility of making practical application of particle physics? I shall attempt to answer this question, but not immediately.

Secondly, particle physics is necessary because it is not remote from other branches of physics and other sciences, such as biology, medicine, geology, astronomy, astrophysics, solid state physics, and chemistry. Despite some skeptical statements that have been made, discoveries in particle physics must influence other sciences. We already see this, especially in connection with space physics, including cosmic ray physics. In this branch of science many publications have already emphasized the importance not only of protons, neutrons, and electrons (the "old" elementary particles), but also of neutrinos, mesons, and hyperons. And this is only the beginning.

I would say that the progress of science at the present time is most strongly characterized by the following. In addition to the increased specialization of scientists which is necessitated by the exponential growth of scientific information, we observe an unprecedented broadening of the whole front of investigations and, if you will, an increase in the number of "hybrid sciences" (biophysics, biochemistry, nuclear astrophysics, radiochemistry, space medicine, muon chemistry, nuclear archeology etc.). The complete disappearance of the Renaissance type of universal scholar has been inevitable. However, the narrowing of interests on the part of most scientists, including the most distinguished men in any given branch of science, is a rule that has its exceptions. In order that science may progress swiftly and that the creation of "hybrid sciences" shall continue at a rapid pace, it is necessary that at least a small number of scientists should expand their interests, even at the expense of profundity, and be able to find relationships between different sciences. From this point of view an important role belongs to unspecialized scientific journals such as the "Scientific American" and "Priroda" (Nature).

A few years ago at a meeting of the Academy of Sciences L. A Artsimovich divided physical investigations into two aspects or classes. Weisskopf recently did the same and gave such exotic names to the two classes that I cannot translate them into Russian. I shall simply refer to them as Class A and class B investigations. Class A science describes nature in terms of new laws, which it endeavors to discover. Class B science explains different facts and processes and searches for new ones in terms of already known laws.

This is not the widely accepted division of science into "pure" and "applied" sciences. Any branch of science may at a given time have both A and B aspects. In particle physics, for example, aspect A is now dominant, while in solid state physics and in plasma physics aspect B is now dominant. The rule is that at any given time class B investigations are based on class A investigations of the preceding period. It would therefore be unreasonable to expect aspect B to be very important in particle physics at the present time. Elements of aspect B are already seen in particle physics, (for example, in its influence on astrophysics etc.), and this means that we have a right to expect the broadening of this aspect.

The history of physics shows that every important, fundamental discovery is followed by an intensification of class B investigations and by the influencing of other branches of science. Whenever one branch of physics influences other branches, practical applications are inevitable. The number of examples is very large.

We now come to still another important reason for needing particle physics. It is needed, thirdly, because it will very probably bring practical benefits. I repeat: we already see the relationship between particle physics and other sciences, and this foreshadows practical applications. Remember the influences on practical chemistry that followed from the relationship between nuclear physics and theoretical chemistry that was discovered by Rutherford. As Wick has remarked, chemistry is a low-energy science; but when Rutherford discovered the atomic nucleus by investigating alpha-particle scattering at energies of a few MeV he was, of course, working in what was then "high-energy" physics. I wish to remind you of one of the very first practical applications of neutron physics (which was once a part of particle physics!) before the era of atomic reactors and modern atomic technology. At the beginning of this century certain relations were determined between geology and nuclear physics, consisting in the fact that the distributions of uranium and thorium in different rocks was of interest to both theoretical geology and geophysics. Out of this arose the extremely practical method of gamma-ray logging in the petroleum industry. Also, nine years after the discovery of the neutron the method of neutron logging was devised, which is widely used in oil fields all over the world and is of great economic importance.

It is certainly true that fifteen years have passed since the first high-energy accelerators were built, and no large-scale practical applications have yet been found. We must not forget that very long periods sometimes elapse between the formulation of physical laws and their practical application [for example, between the Einstein coefficients (1917) and masers (1954)]. We must therefore not demand a practical benefit from particle physics immediately.

What practical applications of contemporary particle physics and high-energy physics are possible in addition to those in chemistry (where we know that investigations employing muons lead to information regarding chemical reaction rates), in medicine (irradiation with pions) etc.? In the spirit of the present article it is, of course, impossible to give a specific answer. But I can mention examples of what might happen. The examples are taken from the actual recent development of particle physics. To be sure, they can remind us somewhat of the Italian proverb, "If grandma had wheels, she would be a coach."

Let us consider the catalysis of nuclear reactions by muons. At the present time this does not, and cannot, lead to practical applications. However, if nature were only a little different, a practical application would be possible. As another example let us consider the nonradiative fission of heavy nuclei by muons, when the 2p − 1s transition of a mesonic atom occurs not through photon emission, but through the excitation of a heavy nucleus and the fission of the latter. In this process the muon remains "alive" (but no practical application is found for this). Here also, if nature were a little different, an application would be possible.

May I recall that at the beginning of the development of particle physics, the discovery, which could be considered secondary from a theoretical point of view, that more than two neutrons are emitted by fissioning uranium, created modern nuclear energy?

At the present time the question of quarks and the associated possible existence of matter having extremely unusual properties is alluring, and not only from a theoretical point of view.

The principal thing to remember is that practical technology arises in an entirely unexpected manner out of the knowledge of new physical laws.

Translated by I. Emin