CBPF-CS-006/97

Physics Research for Development: Cultural and Teaching Aspects

by

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Abstract

Physics research should go together with university teaching both in the advanced countries and in the developing nations.

In view of the continuous progress in physics, teaching must be frequently modified so as to offer the recent models, ideas and inventions to students,

Second degree teachers should have the opportunity to interact with research laboratories so as to review their scientific culture — they must be adequately financially supported.

Among the cultural aspects of physics research are strong beliefs of creative physicists which may become prejudices against new ideas — this will be discussed in this paper.

Presented to the International Conference on Physics and Physicists for Development, University of Twente, Enschede, The Netherlands, September 10-11, 1990.

Physics teaching at the university level requires physics research. This is true in the industrialized countries but must also be true in the less developed nations. Of course, not all universities in the latter countries have the means for most of the equipment needed in experimental scientific investigation. And this is one of the problems which professors have had to face throughout their careers and the main theme of the fight they have to carry out so that the university authorities, the government and the society understand their aspirations.

Physics students have to learn the basis of classical physics — essentially mechanics, thermodynamics, electromagnetism (and optics) — so as to be able to study quantum physics — atomic and condensed matter physics, nuclear physics and elementes of high energy physics — the only one capable to explain the very existence and stability of matter, the world as it is.

At the same time that theoretical courses are offered on these subjects the students have to learn, on the one hand, the mathematical techniques indispensable to physics, and on the other hand, the laboratory manipulations which allow them to reproduce phenomena, measure parameters and constants of nature, see directly how physical laws are experimentally established.

A teacher who is also an investigator will lead the student to recognize the importance of research work in the build up of the physical picture which he presents.

He will lead the student to recognize that the aim of his university courses is not the encyclopedic accumulation of knowledge, but rather its utilisation in the description and understanding of natural phenomena. He may know who discovered a given law — and this is not so important — but rather he must know which laws he must utilize in an attempt to understand and consistently describe a new situation.

Trivially, a painter is not one who knows the name of who painted a picture hanging in a museum of fine arts; he is the one who knows how to utilize the techniques previously developed to achieve new artistic visions, including inventing new techniques, to develop an art which arises in his interaction with the world and which will finally be the expression of his intuition and imagination, of his feelings and emotions, of his inner world. The knowledge of the names of who made a given artistic or scientific invention, and under historical and sociological conditions, is of course relevant and is the result of the beautiful work of historians. But history will come only after the facts have happened. Physics research finds the facts, discovers the physical laws, weaves the tissue of theories, of the physical "Wealtanschaung".

And this connection of physics teaching and physics research is important even in the undergraduate university courses. It will greatly contribute to prepare the students for the graduate courses where he will start doing research himself. The sooner the student is able to make research work the better.

There is a tendency in some countries to create post-graduate courses in addition to the usual series of graduate courses. It is important that the lectures charge of graduate students be not too heavy so as to allow them time for research. Of course, given the subtleties inherent to investigation, the individual manners of attacking a problem and formulating attempts at finding a solution to it, are connected to the intuition and feelings of the research worker; these are qualities which the student will not learn from books, but that he will develop in his interaction with his teachers, who will know how to transmit them, provided they are professional research workers also. Seminar discussions are relevant in this connection.

The sometimes spread notion that a research worker is not necessarily a good teacher is not totally correct and leads to the erroneous affirmation — not uncommon among education specialists — that university teaching must be separated from research work. It occurs not unfrequently that some research men have no facility of oral presentation of lectures, are not clear and/or eloquent. But the professional investigator has in general the deep overview and the firmness in his presentation of course that only the search for new ideas and new experiments can confer.

And what we require in the university teaching are not fluent speakers — the essential quality of university professor is to communicate more information and insight to the students than what is written in texbooks, and this is almost always contained in comments which are the fruit of reflexions developped along his research work.

Physics teaching at the second degree level is usually deficient in most countries. Teachers are not well paid, texbooks are in general not good, laboratory equipment is lacking in high-school establishments. The improvement of the teaching at this level will contribute to the adequate education of youth. And well educated young people are the basis — *sina qua non* — for the development of nations.

If the fundamental problems of second degree teaching are conveniently solved, the next important question which arises is the permanent renovation of the scientific (and cultural) knowledge of secondary teachers.

I believe it would be important if scholarships were permanently available for second degree science teachers to spend a few months each year at a university where research work is carried out and to attend special lectures and seminars. For the advancement of physics is continuous and well established new results must be communicated to the graduate and undergraduate students, as soon as possible. A continuous renovation of physics teaching is imperative. In particular, the physical world cannot be described without quantum mechanics. This discipline must therefore find a place, in its elementary foundations and principles, even in the last years of secondary level teaching. And the basic description of matter and energy in terms of elementary particles can also be intuitively taught to the latter students.

This brings us to the question of the cultural aspects of physics research.

As his investigation proceeds, the physicist is led to contemplate the evolution of physics, the genesis of ideas and theories in his field, the development which took place in science from its origin to our times.

Paul Adrien Maurice Dirac, the brilliant theorist of quantum physics, expresses his view of the evolution of the physical ideas in the following precise words[1]:

> *"When one looks over the development of physics, one sees that it can be pictured as a rather steady development with many small steps and superposed on that a number of big jumps. Of course, it is these big jumps which are the most interesting features of this development. The background of steady development is largely logical, people are working out the ideas which follow the previous set-up according to standard methods. But then when we have a big jump, it means that something entirely new has to be introduced. These big jumps usually consist in overcoming a prejudice"*

We are thus brought up to the idea that certain beliefs which seem natural during a certain time become prejudices which are obstacles to the further development of the theories. Up to the year 1930, the prejudice that elmentary particles ought to be only the electron, the proton and the photon was in the mind of physicists and it was probably due to this belief that Dirac himself identified the hole formed by an unoccupied state of negative energy, a solution of Dirac's electron relativistic wave equation, with a proton and not with a positron as it must be[2].

It was also perhaps due to this prejudice that Wolfgang Pauli[3] never published the notion of neutrino which he announced in a letter to a meeting of physicists on December 4, 1930 as a solution to the problem of electrons emitted by radio-active nuclei having a continuous energy spectrum.

Probably, still the same prejudice was responsible for the fact that Hideki Yukawa's 1935 paper[4], in which he proposed a new field to describe inter-nucleonic interactions and a corresponding new particle with mass intermediate between those of the electron and of the proton, remained practically unnoticied. *"When Niels Bohr visited Japan just before the discovery of the "mesotron" by C.D. Anderson and S.H. Neddermeyer, Yukawa tried to explain his meson theory to him. But Bohr's reaction was not positive, << why do you want to introduce hypothetical particles (to account for nuclear forces)? >>"*[5].

The prejudice against new particles fell only in 1947 when the discovery of pions and of the $\pi - \mu$ decay[6] marked the beginning of elementary particle physics as a discipline independent from nuclear physics. Since then, through the discovery of a large number of hadronic particles we have been led to the unification models of forces in the Universe based on families of quarks and leptons as the ultimate elements of matter, and of gauge-bosons as the carriers of interactions.

And present-day physicists are not shy to propose new particles and to search for them in high-energy accelerators.

Again Dirac, in a beautiful paper in 1931, proposed the existence of magnetic monopoles, which, by the way, are not yet found experimentally, in a formalism where the fundamental concept of a non-integrable phase factor is introduced. Here is what Dirac says in the introduction of this paper[7]:

> *"The steady progress of physics requires for its theoretical formalism a mathematics that gets continually more advanced. This is only natural and to be expected. What, however, was not expected by the scientific workers of the last century was the particular form that the line of advancement of the mathematics would take, namely, it was expected that the mathematics would get more and more complicated, but would rest on a permanent basis of axioms and definitions, while actually the modern physical developments have required a mathematics that continually shifts its foundations and gets more abstract. Non-euclidean geometry and non commutative algebra, which were at one time considered to be purely fictions of the mind and pastimes for logical thinkers, have now been found to be very necessary for the description of general facts of the physical world".*

In this paper, he proposes a theory which gives a connection between the smallest electric charge and the smallest magnetic pole and which exhibits a symmetry between electricity and magnetism *"quite foreign to current views"*. He proposed, therefore, to overcome the prejudice that monopoles do not exist — and we still do not know whether this is valid or not.

Another prejudice which physicists — and the most brillliant ones among them — strongly assume was that all geometrical symmetries were exact for all types of interactions. In view of a certain puzzle concerning strange particles, T.D. Lee and C.N. Yang were led to raise the question of parity conservation in weak interactions — that is to say, the exact symmetry of these interactions with respect to left-right reflection. Lee and Yang wrote in their paper[8]: *"It will become clear that existing experiments do indicate parity conservation in strong and electromagnetic interactions to a high degree of accuracy, but for the weak interactions (i.e. decay interactions for the mesons and hyperons, and various Fermi interactions) parity conservation is so far only an extrapolated hypothesis unsupported by experimental evidence".*

As experiment[9] confirmed that parity was not actually conserved in weak interactions, several physicists were shocked in their beliefs. Here is what has said Eugene P.

Wigner, the great theoretical physicist, responsible for many group theoretical discoveries in physics, in a Colloquium on the History of Particle Physics[10]:

> *"Frankly, I was fully convinced that both time reversal invariance and reflecion symmetry are valid. It was a great shock to me when the lack of validity of these was proved [· · ·]. It is possible to think that the whole existence of the weak interaction is due to some initial condition of the world, but I can't believe it and therefore I am as puzzled as before by the lack of validity of these invariances. If we believe in the simplicity and beauty of all laws of nature, these invariances should be valid. Would you contradict me?".*

Pauli[3] also describes his reaction to this discovery in a letter to Victor Weisskopf in the following words:

> *"Now the-first shock is over and I begin to collect myself again (as one says in Munich). Yes, it was very dramatic. On Monday 21st a 8:15 p.m. I was supposed to give a talk about past and recent history of the neutrino. At 5 p.m. the mail brought me three experimental papers: C.S. Wu, Lederman and Telegdi: the latter was so kind as to send them to me. The same morning, I received two theoretical papers, one by Yang, Lee and Oehme, the second by Yang and Lee about the two-component spinor theory".*

And after a few lines:

> *"Now, where shall I start? It is good that I did not make a bet. It would have resulted in a heavy loss of money (which I cannot afford); I did make a fool of myself, however (which I think I can afford to do) — incidentally only in letters or orally and not in anything that was printed. But the others now have the right to laugh at me. What shocks me is not the fact that "God is just left handed" but that in spite of this He exhibits Himself as left/right symmetric when the expresses Himself strongly. In short, the real problem now is why the strong interactions are left/right symmetric. How can the strength of an interaction produce or create symmetry groups, invariance or conservation laws".*

Students, therefore, receive scientific information from their teachers but also at the same time their beliefs and prejudices as participants in the research work they carry out — and it could not be otherwise. This was, for instance, the case of Max Planck who attended the lectures, when he was student, of the chemist Hermann Kolbe who refused the atomic theory on the grounds that this theory gave a false interpretation of the laws of chemistry. Planck was thus convinced since 1881 that atomism could possibly not lead to the development of science. In 1883, Planck wrote, in support of the law of increase of entropy as an absolute law and against Boltzmann's affirmation that the entropy increases almost always instead of always[11]: *"The consistent implementation of the second law is incompatible with the assumption of finite atoms. One may anticipate that in the course of the further development of the theory a battle between these two hypothesis will develop which will cost one of them its life".*

Equally against the atomic theory were the physical-chemist Wilhelm Ostwald, the physicists Ernst Mach and Georg Helm; whereas, independently from them and against them, attempts were made at evaluating the molecular and atomic dimensions by several physicists, notably Thomas Young as early as 1816, J. Loschmidt, W. Thomson (Lord Kelvin), James Clerk Maxwell and Johannes Diderik van der Waals. The controversy continued and in his Doctoral thesis, Albert Einstein described a new theoretical determination of molecular radii and Avogadro's number. It was up to Jean Perrin, who worked experimentlly for the determination of the molecular parameters, to announce the ultimate result of the battle announced by Planck:

> *"The atomic theory has triumphed. Until recently still numerous, its adversaries, at last vanquished, renounced one after another their challenges which were, for so long, legitimate and undoubtedly usefull* [12]*".*

The victory of atomism, the work which led the discovery of the electron and to the nuclear model of the atom, led to the formation of a belief, among the founders of quantum mechanics, that matter was constituted of a small number of fundamental particles and from this belief resulted the prejudice against the conception of new elementary particles.

On the other hand, as is well known, the quantum foundation needed for the derivation of the Planck's radiation law — so well verified by experimental measurements — received from Planck himself a stubborn resistance. He did not like the replacement of the notion of the continuous change of energy by that of the discrete change by quanta. The opposition was stronger to Einstein's idea of photon. If physicists had to admit the results of quantum theory they tried to localize the quantum paradoxes in the obscure domain of the interaction between matter and radiation. For, according to Planck, *" what happens in the vacuum is rigorously described by Maxwell's equations*[13]. We know that only after the discovery of the Compton effect in 1923 did the resistance to Einstein's light quantum structure of radiation propagation in vacuum started to fade away.

The reaction of most great physicists, like Pauli and Wigner, against the lack of validity of time reversal invariance and reflexion symmetry by weak interactions, illustrates a cultural aspect of physics research namely that of a strong belief in a simple, elegant description of nature, which takes for granted that its laws and their equations should show more geometrical symmetries rather than less, although the initial conditions, which are separated from these equations, do not show any symmetry. Wigner's question is whether the absence of some symmetry is not the indication of an interaction of the initial conditions with the physical laws.

In their research work to discover models and theories, physicists are guided by some inner feelings, by some mysterious intuitions which spark the mental process of creation.

According to Dirac[1], *is more important to have beauty in one's equation than to have them fit experiment"*. Essentially the same philosophy is adopted by Einstein when he says: *I am convinced that we can discover by means of purely mathematical constructions the concepts and the laws connecting them with each other, which furnish the key to the understanding of natural phenomena. Experience may suggest the appropriate mathematical concepts but they most certainly cannot be deduced from it. Experience remains, of course, the sole criterion of the physical utility of mathematical constructions. But the creative principle resides in mathematics. In a certain sense, therefore, I hold it true that pure thought can grasp reality, as the ancients dreamed* [14]*"*.

The problem is that not all possible mathematical beautiful constructions are physically valid. And about the notion that physical laws would begin and end with experience, Einstein writes: *A clear recognition of the erroneousness of this notion really only came with the general theory of relativity.* A philosophy which, through Isaac Newton and Galilei, goes back to Pythagoras and his disciples according to whom the principles of the numbers are the elements of all beings and the whole Heaven is harmony and number[15].

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International cooperation is an important point to be brought up in the University and secondary science teaching. In the particular case of physics, one has the well-known examples of international laboratories in the field of high-energy physics such as the European Organization of Nuclear Research (CERN), in Geneva, maintained by European nations, the national labotatories in the United States such as the Fermi National Laboratory, the future Superconducting Supercollider Laboratory, and so many others in the U.S. and other countries which open their doors to physicists of developing nations for research with high-energy accelerators.

And now allow me to come to a point which is relevant in any meeting on science and development. This is a theme which has been the subject of an enormous number of international conferences, projects and programmes. But the great problems of the underdeveloped nations remain without solution and become more dramatic, in spite of the tons of articles, and books and (weightless?) speeches. Throughout these 50 years, many events happended in the world, wars of liberation from subjugation and oppression, the replacement of democratic governments by military dictatorships as in Latin America, and more recently the replacement of the revolutionaty winners by democratically elected governments. Science and technology arose as strategic means of promoting progress in the industrialized nations.

There is at present, in the year 1990, a definite tendency throughout the world, for the adoption of democracy as the political system and of the corresponding economy as defined by the lines of force of the market. Those countries which have a political system capable of offering education and health care for their populations are the ones most likely to achieve further development.

Those coutries, as found in Africa, in Asia, in the Americas, which were unable to give generalized education to their peoples — and the colonial empires did not do much to promote education in their colonies (they were not there to build up nations) — are the ones who face the most serious difficulties to overcome the underdevelopment barriers.

We, in the developing nations, carry a historical weight on our shoulders. Nothing that happens in history can be erased. The historical event propagates itself as waves throughout the life of human communities. That is why the efforts to be made by those peoples who were under domination must be greater in order to achieve their social and cultural aspirations.

Scientific research, scientific education appear as fundamental options for all men who desire to know where they came from, where and who they are and where they will go. The great question is this: which new measures in the economic and political domains must be taken by the developing nations to ensure well-being for their populations, the elimination of poverty and misery?

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