A CONTRIBUTION TO THE INTERNATIONAL SEMINAR ON

"EDUCATION OF PHYSICISTS FOR WORK IN INDUSTRY"

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1. Education and training

The title for this seminar seems to have been very carefully chosen, so the concepts appearing in it should be taken seriously. They appear in the order of increasing specification. The raison d'être of this seminar certainly lies in the adjunction "Work in Industry" to "Education of Physicists". It is however, not quite trivial to insist on the first two nouns.

Education, in my opinion, implies the harmonic development of a large number of interwoven aptitudes and attitudes, whereas training usually applies to a narrow range of skills. My intention here, of course, is not to start a discussion of vocabulary. I insist on these aspects, because I want to take a stand right away in favour of the general versus special in the Education of Physicists for Work in Industry. I certainly shall have to amplify and to qualify this statement in the further development of my thoughts. But I think one can take it safely as a starting point, as zeroth approximation, so to speak. I want to say even more. I believe that the demand for the general is the most important single demand that industry can put to the University; it is also an important contribution on the part of industry to the solution of the crisis that the University undergoes. My preference for the general also certainly permeates this exposition of my thoughts about our subject.

2. Physicists

The term physicist, too, needs to be elucidated. On the one hand, the variety of activities that a person with the education or training of a physicist is called upon to perform in industry is astonishingly large. On the other hand, the qualification of physicist may apply to persons with rather different educations. It seems to me useful to back this up with statistical information. So far as I know, such information is very scarce for Europe, and when it is obtainable it applies to single countries rather than to Europe as a whole; besides, the differences are so great as to make comparison hazardous without first studying these differences. We must therefore rely on statistics concerning the U.S.; fortunately, such statistics are available in the report on "Physics Manpower", prepared by Susanne Ellis for the American Institute of Physics. (I think that the drawing up of similar statistics for Europe ought to be one of the tasks of the new European Physical Society.)

The more specific questions that I should like to answer here in the first place are the following : what proportion of physicists goes to industry, what education is theirs, and what, then, is their activity ? Being obliged, as I am, however, to rely on data that were available to me, I have to offer but partial answers to these questions.

Table 1 shows that in 1964 in the U.S. 42 % of all physicists worked in industry and 39 % in educational institutions. By physicist we must understand here physics bachelors, physics masters, and physics doctors. We find that physicists with the lowest degrees tend to go to industry, whereas those with the highest degrees concentrate in educational institutions. From among the physics bachelors, 57 % worked in industry and 15 % in educational institutions, but only 33 % of the physics doctors worked in industry and 53 % of them worked in educational institutions. And this despite a large salary difference (see Figs 1, 2 and 3); the annual median salary for physics doctors is 45 % higher in industry than in educational institutions. Another way to present the same data (Table 2) shows that 65 % of all physicists working in educational institutions have a doctor's degree, whereas this is the case only for 37 % of those physicists who work in industry. For physics bachelors, the corresponding proportions are 10 % and 35 %. Only employment with the government seems to attract fewer physics doctors (29 %).

What may be most significant, however, is that the tendency for physicists with lower qualifications to concentrate in industry seems to grow stronger. In 1964-65 only 17 % from among the new doctor's degree recipients went to industry, and 65 % to educational institutions. For the bachelor's degree, the tendency is the reverse : 50 % went to industry, and 21 % to educational institutions (Table 3). Another presentation of the same data (Table 4) shows that only 10 % of the physicists who joined industry in 1964-65 hold a doctor's degree. The conclusion that one arrives at on examining these, admitedly scanty, data is that in a few years the largest part of physicists in industry will have low or medium qualifications (Table 5). Without making the doctor's degree a fetish, it is to be feared that only a small fraction of physicists will have the "breadth of vision of the man who is capable of looking beyond the actual complex of problems". And I wonder whether the bulk of today's industrial managements would find it desirable for all physicists to have that "breadth of vision" and act accordingly.

The tendency towards a diminuishing breadth of vision is after all not so astonishing. In the development of modern industry, the activity of most men has become more and more a fragment only of a meaningful whole, even though this fragment may require highly developed skills. This was the price for industrial development. But many say, and I with them, that today we may, and must, restore meaningfulness to human work.

These considerations may somewhat mitigate our fears about the situation of the majority of physicists in industry. They may however not dispense us with the necessity of carefully distinguishing between the various activities that a physicist may be called upon to perform in an industrial organisation : from production control to fundamental research, on to technological strategy. The problems that a physicist will have to face in these various activities differ strongly one from the other. But in each activity -- and here I agree with Prof. Ganzhorn -- a physicist should be capable of looking beyond the immediate aspect of the problems he is facing. Whence the need for a predominantly general education.

Unfortunately, I cannot say anything about the actual distribution of work activities of physicists working for the various types of employer that we have considered in the preceding tables. (The material that was available to me in the short time at my disposal does not contain such data.) What I could show are data on the work activity of physicists according to their academic degrees (Tables 6 and 7, and Fig. 4. See also Figs 5 and 6). But I do not see in these tables anything we ought to discuss here and now.

The old distinction between fundamental and applied research is maintained, and it is the usefulness of that which we should discuss.

3. Fundamental or not, is that the question ?

The problem is, as we all know, that the notion of fundamental research is not a very clear one. The meaning of the word fundamental itself is clear enough. We may follow the "Concise Oxford Dictionary" and give the word the closely related meanings "going to the roots" or "serving as foundation".

The trouble is that one man's foundation is another man's superstructure. In my view, it is perfectly possible to perform a fundamental research in mechanical engineering, for instance, insofar as it goes to the roots of a problem of mechanical engineering; contrariwise, many investigations in elementary particle physics (as in any other branch of science) fail to go to the roots; they are then not fundamental. It may perhaps be argued that elementary particle physics, as a whole, is a more fundamental branch of knowledge than is mechanical engineering, but this is not the point. Our purpose here is to evolve criteria on which to judge research. It is not to indulge in the, philosophically untenable, effort of establishing a hierarchy of sciences.

How, then, are we to judge whether a research is fundamental or not. The first question to ask is of course : "fundamental to what (i.e. serving as foundation of what) ?" Hence the necessity to embed the research concerned into a large ensemble, to view it as part of a whole, or in yet other words, to put it into perspective. The choice of the ensemble is generally not unique;

however it has to be made before we can answer the second question, -- that which concerns the place of the research within the chosen ensemble. Together, these two questions enable the motives and the relevance of the research to be assessed. If the purpose of the research is to answer questions of consequence for the chosen large ensemble, it could be called fundamental. It does not matter, though, whether a research is given this name or another so long as it is judged according to the type of criteria discussed above. If this is done, however, one arrives at the conclusion that a large part of the research done in fields purported to be fundamental is not fundamental, whereas industrial research, as performed in the large industrial laboratories, often is. The embedding that is chosen in industrial research or in elementary particle physics is not the same, but the question of relevance within the chosen ensemble should be asked in both cases.

One would thus come to the conclusion that research without an adequate, conscious and extrapersonal motivation can be fundamental only by accident. But we know how much scientific and technical progress owe to such accidents, and how dangerous it would be to eliminate them by overmotivation and overplanning. (The plan must foresee a realm of the unplanned.)

Thus, in spite of fluent border lines two principal types of research may be distinguished. The first one is the outcome of a conscious, predominantly extrapersonal, motivation. It may be called fundamental, but after all it should perhaps better be called "integrated" (to avoid confusion with research in a fundamental domain of sciences). In the second type of research, the prevailing incentive is personal and often difficult to perceive. (Doing things because one knows a lot about them, may be one of these personal incentives.) This type of research I would call "research as hobby". Academic research often comes close to it.

In any outstanding research, however, the personal motives meet an objective purpose.

4. Aptitudes and attitudes

From the preceding considerations it follows that a physicist should be able to do integrated research, that is, to put the research into perspective and actually conduct it. This is true irrespective of the place where the research is performed (and teaching, too, may be viewed as integrated research). In a physicist's work for industry some kinds of perspective simply gain importance that may be secondary in another type of work.

What does the activity of integration consists of in the everyday life of a physicist concerned with industrial problems ? To answer this question, I rely on my own experience and that of my colleagues, which is the experience of physicists working for industry, not within industry. Although, therefore, I do not cover all aspects of a physicist's work for industry, I trust that I shall be able to illustrate some of the central problems.

The first thing to realize is that you are never given problems -- you have to find them yourself. I mean here problems in physics. Some industry may approach the laboratory with the request to solve one of its technical problems; or you may come across such a problem yourself and think that something could and should be done. Almost never will such a problem be one in physics. The first thing to do, then, is to break down the technical problem into smaller ones that are co-extensive with well-formulated, or at least formulable, problems in physics (or more generally in science).

Sometimes the wolf approaches one disguised as a sheep. One is given what seems to be a problem in physics. Very often it is a complex problem, and one wonders what on earth this problem has to do with any problem of the person or industry that brought it along. Then one's duty -- irrespective of the high esteem in which one may hold the originator of the problem -- is to find out the original trouble or the original intent, and to break it down into partial problems of which some may be in physics. (A physician would not proceed otherwise with a patient asking a remedy for a given combination of ailments.) Sometimes one arrives at the problem as it was given to begin with, but often this is not the case.

Thus, paradoxically, the first step towards integration may be analytical.

Similar, sometimes, is the experience of a theoretician or a mathematician who is approached by an experimentalist. There are some very useful descriptions of physical phenomena that culminate in a few empirical parameters and that enable a wealth of phenomena to be described. One would then like the theoretician to produce a theory for these parameters. Very often this is not possible, because these parameters reflect a large number of intricately connected elementary processes. The theoretician is then obliged to get to the root, that is to say, to disentangle these processes, and thereby, perhaps, destroy the parameters. Likewise for the mathematician who is presented with an equation and asked to solve it. That equation is ostensibly the simplified expression of a physical process; in fact, the simplifications frequently appear as such only to a man of good will whose knowledge in mathematics is a few tricks, and old ones at that.

The moral of the story is the following. If you want your research to stand a chance of success, you must remain its master. If you want to remain its master, you must have an understanding, a feeling of familiarity, and a certain comfort with the methods both of the domains where your problem originated and of the fields of science you need for its solution.

Does that mean that you must be not only a universal physicist, but also a talented engineer, gadgeteer, mathematician, and an economist too, while we are about it ? By no means. I have said that you must remain master of your research, not that you should be master over your fellow scientists working on the same problem. They too should remain masters of the common research. This is the principle of relativity that is at the base of team-work or interdisciplinary research. Such an enterprise cannot be run by people who are specialists only. Each participant should have a broad distribution of knowledge. There must be prominent peaks somewhere in that distribution, otherwise it is not worth while to undertake a common effort; the distributions should overlap, otherwise the effort will not be in common.

Thus I come to the conclusion that one of the important abilities of the industrial physicist is to ask pertinent questions. These questions may serve two purposes. Some questions serve to break down a large non-physical problem into a number of smaller ones, some of which are formulated as problems in physics. It is the physicist who should do this breakdown; it is his safeguard against the danger of the problems in physics eclipsing the large original one. Then there is the question why (why do I -- do you -- want to know this ?). This question is the vehicle of integration. Once the physics problem is thus integrated into a larger whole, it emerges that its solution demands the collaboration of several specialists. Very often, already the activity of integration requires collaboration. Thus the industrial physicist should be able to co-operate with other scientists. His education should prepare his intellect and his comportment for this.

Another aptitude that serves an industrial physicist greatly is the ability to do non-experimental, that is, theoretical work. For this he does not need highly developed mathematical or computational skills (all of theoretical physics is not mathematical).

But he should be capable of understanding and comparing theories about the subject of his investigation and confronting them with experimental data. Even the simple comparison of experimental data often is not a simple undertaking.

As to the type of mathematics that is important for a physicist, especially for one who does not specialise in mathematical physics, I would call it qualitative mathematics. Good physicists have always excelled in qualitative argumentation, that is, in a particular brand of thinking which is based on the evaluation of orders of magnitude. They should become aware of the fact that there is another type of qualitative thinking that is based on very precise mathematics. Group theory, and algebra in general, belong to this type of mathematics, and so do also fixed point theorems in topology, stability theory of dynamical systems, various existence theorems, logic and so on. In all these cases the outcome is not a real number, but essentially yes or no. To get the real numbers, which after all one needs too, computers are available, but to understand computers one needs qualitative mathematics.

Now you may say : "So physicists integrate, co-operate, communicate and so on, but who does the work ?" I hope to show that a proper general education in physics will enable an industrial physicist to meet all special requirements in physics that he will have to face, but above all the most important one -- having the courage to sit down and try to figure something out even though that something is not completely familiar.

The image of industrial physics as I see it, is that of an intellectual adventure, like any research. Insofar as industry fulfils its paramount rôle for the welfare of mankind, industrial physics is also a moral challenge. It is in any case an ambitious enterprise.

5. Education of physicists

Here I shall make only a few remarks about what a physicist should be taught so that he be prepared for work in industry. The question how he should be taught may however be even more important, and the various interesting suggestions that can be found in the documents that have served to prepare this seminar should be amply discussed.

What an industrial physicist needs in the first place is a proper general education in physics, and mathematics, and he shares this need with any kind of physicists. Thus a large part of education will be the same for all physicists, and there is so far no need for a separate education programme for physicists aiming at a career in industry.

A proper general education in physics and mathematics is based on a teaching that emphasizes concepts more than facts, general methods more than special tricks. Of course, for anyone but a neoplatonist, concepts grow out of experience summarized in facts; and methods start as tricks. Concepts and methods are understood only when their limitations are known, that is, when they are confronted with new facts, new problems. Thus in teaching concepts and methods, one takes account of the facts in the proper way and to the proper extent.

There is nothing whatsoever new in these views. All good physics courses of the past have embodied them. But to do this today, a physics course may have to differ at places radically from those of the past. The preparation of such a course may constitute a difficult task, an integrated research, as I said before. We have to demand that university professors should have available both the time and the means to prepare such courses.

Specialization, too, plays an important rôle in the general education of a physicist. The rôle is paradigmatic. Every physicist should experience what it means to know a subject deeply, he should learn how one gets to that depth by choosing the appropriate experimental or mathematical techniques, by retrieving and co-ordinating the appropriate information; and working on problems that are not given to him but that he discovers. Furthermore, it is in depth that one finds the roots, the foundation.

The choice of domain of specialization has almost no importance; it does not have to coincide with the choice of the future professional activity. Even if the physicist will not change his specialization every ten years, his specialization will change.

Applied physics should perhaps be replaced by something more general. As we know, the term is very vague. There is no place in physics where a physicicist does not apply something, and almost no part of physics is without applications. But physics may be applied to physics itself in a non-trivial way. (This is forgotten by those fanatics of applied research, who say "no application - no satisfaction".) Obviously this is not what is meant by applied physics; what is meant is physics applied outside of physics. More generally I advocate the introduction of courses where physics, or part of it, is embedded into a (larger) ensemble that is not physics. (We may call that again applied physics or coin a new term for it.)

An excellent example of such a course is the case history of a particular finished typical industrial research (as described on page 9 of Dr Greebe's contribution).

Another example may be thematic courses : A lecture (or seminar) on memories could include very general philosophical, physiological, considerations together with fundamental physics and advanced technology. The preparation of such an undertaking would again be a research. We should give university professors the time and the means to do such things. Courses similar in texture to these two examples could contain the excitement, the spirit of adventure of science and research that have generally disappeared from traditional courses in applied physics.

The outcome of this discussion seems to be that everything is important for a physicist; the study of all of it, however, would exceed the time that society can reasonably allot to university studies. Everything is important indeed, but there are priorities and choices. Everybody need not to do the same things. There is not one curriculum; there are curricula. The university is after all not a school. After having learned in general, in specialized or in applied courses how to choose or to produce the tools that he needs for his thinking and his doing, the student should be able, and should be given the possibility, to choose according to his abilities and inclinations, from among a variety of subjects, either to round of or to sharpen his education.

General subjects such as sociology, philosophy, economics, logic, history of science and of technology should be taught in the institutions where physicists are educated, so that it should not be difficult for students to follow one of these courses. They should however really feel the need to do this; their interest in these subjects should be stimulated by the problems they met while studying physics. The rôle of these general subjects is not that of furnishing matter for discussion after work; they become important if their study leaves traces in the every-day laboratory life of the physicist.

6. Industry, society, university

To conclude, let us ask again which are, in the last analysis, the governing principles of the education that University should give to physicists to prepare them for work in industry.

These are :

The capability to integrate, to put what one is doing, what one is asked to do, into perspective; University should teach this by example. Science should not be a retail business of specialized articles.

The urge to have valid motivations for what one is doing, the urge to ask again and again the question why. This question probes the scientific relevance of a given research as well as the social relevance of science. But it probes the social rôle of industry too. (Although the welfare of mankind is unthinkable without industry, everything that industry strives for does not contribute to that welfare. Furthermore industry does not provide so far for needs that are not solvent.)

The courage to venture outside trodden paths.

I think that the preceding three points could also be the governing principles for a reform of the University. Such a reform, however, should come from the University itself. The University should certainly not ignore industry's expectations; nonetheless it should investigate them critically and come to its own conclusions.

As conclusion to these considerations, nothing can serve better than a fragment from O. Benfey's comments (as reported in A. Nesty's paper) :

"In the eyes of the new college generation, learning and academic training simply for proficiency are not enough : students need to see a significant purpose before they will channel their energies in that direction. With regard to contemplating a career in industry, the ideal of raising our own standard of living is no longer sufficient. That standard is very high already and is taken for granted. Our college students see little idealism in contributing to it. What would probably inspire them would be to learn more of industry's contribution, much of it going on already, to the eradication of poverty at home and the establishing of the industrial base of the developing countries. Industry is the organized technological energy of our country and the college generation wants to know where its enormous power is being directed. Those companies that can convincingly demonstrate their corporate concern to raise standards of living of the less fortunate here and abroad may well find the ablest graduate students joining them."

Acknowledgements

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Table 1

USA 1964. Distribution of Full-time Employed Physicists. I.

	Degree							
Type of employer	Bachelor's		Master's		Doctor's		Physicist's	
	N	%	N	%	N	%	N	%
Educational institutions	756	15	1985	37	5071	53	7812	39
Industry or self-employed	2888	57	2350	44	3106	33	8344	42
Government	1172	23	792	15	796	8	2760	14
Non-profit	176	4	193	4	537	6	906	4
Other	36	1	33	-	47	-	116	1
Total	5028	100	5353	100	9557	100	19938	100

Table 2

USA 1964. Distribution of Full-time Employed Physicists. II.

	Type of Employer											
	Educational institutions		Industry or self-employed		Government		Non-profit		Other		All Employers	
Degree	N	%	N	%	N	%	N	%	N	%	N	%
Bachelor's	756	10	2888	35	1172	42	176	20	36	31	5028	25
Master's	1985	25	2350	28	792	29	193	21	33	28	5353	27
Doctor's	5071	65	3106	37	796	29	537	59	47	41	9557	48
Total	7812	100	8344	100	2760	100	906	100	116	100	19938	100

Table 3

USA 1964-65. Employment of New Recipients of Degrees. I.

Type of employer		Degree			
		Bachelor's	Master's	Doctor's	Physicist's
Educational Institutions	%	21	35	56	35
Industry or self-employment	%	50	42	17	39
Government	%	16	20	11	17
Non-profit	%	-	3	5	3
Other	%	13	-	11	6
Total	%	100	100	100	100
	N	1545	2300	1100	4945

Table 4

USA 1964-65. Employment of New Recipients of Degrees. II.

			Type of Employer				
			Educational institutions	Industry (or self-employment)	Government	Non-profit organizations	Other
Degree	N	%	%	%	%	%	%
Bachelor's	1545	31	19	40	30	--	62
Master's	2300	47	46	50	55	56	--
Doctor's	1100	22	35	10	15	44	38
Total	4945	100	100	100	100	100	100

Table 5

USA 1964. Trend in Employment of Physicists.

		Educational institutions	Industry or self-employment	Government	Non-profit	Other
		%	%	%	%	%
Physicists working for		39	42	14	4	1
of these	bachelors	10	35	42	20	31
	masters	25	28	29	21	28
	doctors	65	37	29	59	41
New Physicists going to		35	39	17	3	6
of these	bachelors	19	40	30	-	62
	masters	46	50	55	56	-
	doctors	35	10	15	44	38

Table 6

USA 1964. Primary Work Activity of Physicists. I.

Work activity	Degree							
	Bachelor's		Master's		Doctor's		Physicist's	
	N	%	N	%	N	%	N	%
R & D	3031	60	2732	51	5412	57	11175	56
Basic R	634	13	826	15	4041	42	5501	28
Applied R	1326	26	1343	25	1178	12	3847	19
D	1071	21	563	11	193	3	1827	9
Management	1069	21	826	15	1564	16	3459	18
of R & D	757	15	672	12	1329	14	2758	14
general	312	6	154	3	235	2	701	4
Teaching	491	10	1450	29	2298	24	4239	21
Other	437	9	255	5	283	3	975	5
Total	5028	100	5353	100	9557	100	19938	100

Table 7

USA 1964. Primary Work Activity of Physicists. II a.

Degree	Research and Development		Basic Research		Applied Research		Development		Teaching	
	N	%	N	%	N	%	N	%	N	%
Bachelor's	3031	27	634	12	1326	34	1071	59	491	12
Master's	2732	25	826	15	1343	35	563	31	1450	34
Doctor's	5412	48	4041	73	1178	31	193	10	2298	54
Total	11175	100	5501	100	3847	100	1827	100	4239	100

Table 7

USA 1964. Primary Work Activity of Physicists. II b.

Degree	Management		Management of R & D		General Management		Other		All Activities	
	N	%	N	%	N	%	N	%	N	%
Bachelor's	1069	31	757	28	312	44	437	45	5028	25
Master's	826	24	672	24	154	22	255	26	5353	27
Doctor's	1564	45	1329	48	235	34	283	29	9557	48
Total	3459	100	2758	100	701	100	975	100	19938	100