ON METHODOLOGICAL PROBLEMS OF TECHNOLOGY*

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1. Introduction

It is a sign of the times to find in the last number of the "Endeavour" this title to a leading article : "Towards a unity of knowledge" [1]. Prior to the statement : " . . . the once important distinction between pure and applied science is increasingly being seen to be an artificial one," the author asks : " . . how can science be infused into the humanities, and the humane studies into science, without so diluting either that their savour is lost?" The previous remark : " . . . what seem to be moral problems often have material roots, without which they would not arise," is obviously a preparatory notice for introducing the analysis of unification in humanistic problems, based on moral motives, and of scientific problems correlated to materialistic topics.

In our days, the unity of science and humanism is already in full discussion everywhere ; therefore, I think, it is important to emphasize this unity, at the beginning of the present lecture. But when discussing any branch of science — in our case technology — another motive, and a deeper one, may be found in the necessity of laying stress upon this unity, just because we have to reveal the contrast between our topic and other branches, too. Only, in this way will our reflections be dialectical *i. e.* scientific. We can imagine and also understand, that well-informed marxists are hardly pleased at hearing on every occasion this term. One is well aware of the idle employ made by some garrulous disciples of the delicate mental instrument called dialectic, and it is difficult to say which is better : to fight against the rather insufficient application of dialectics in science, or to struggle against the widespread shallowness of its use. Both are probably necessary.

Dialectics have somehow really turned into a commonplace, and I am not very fond of commonplaces. Yet, the question is, how to gain some profit of the so-called commonplaces for our scientific work. Let us quote Engels [2] : "Probably, the same gentlemen, who up to now have decried the transformation of quantity . . . into quality as myticism and incomprehensible transcendentalism, will now declare that it is indeed something quite selfevident,

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trivial and commonplace . . ." "But to have formulated for the first time in its universally valid form a general law of development of nature, society and thought, will always remain an act of historical importance."

Now, I hardly believe that my present discourse on methodology would represent a feat of historical importance ; on the contrary, I feel anxious of the impression of truism, that could be evoked in my auditors. But in this case may I recur to a passage in a novel by Freeman, in which a lady asks :

— "And, in general, is this Dr. Thorndyke human?"

— "Quite so — was the answer — because, in my opinion, the generally adopted criteria, of being human, are walking upright and the relative position of the big toe . . ."

— "I did not think of this" — the lady replied. — "By the word human I alluded to something of importance."

— "I think, what I said is really important. Kindly imagine, what could happen if my learned colleague would be observed, in periwig and robe, going on all fours to the Court. This would cause a public scandal" [3].

Walking upright and the position of the big toe . . . both are commonplaces. But I am not more ambitious than Freeman's hero. Exposing some of the principles of methodology which in my opinion are fundamental, I should be very glad if I could convince my auditors that these, even if seemingly or really banal, are very important for every technologist, and as significant for humanity as walking upright and the position of the big toe.

2. About technology and methodology

In 1947, when contributing critical remarks to the discussion on the book by Alexandroff, Zhdanoff noticed that the book did not give an exact definition "on the subject of the philosophical history as a science" [4]. According to the opinion of Bernal, on science no definition can be made : "Science is so old, it has undergone so many changes in its history, it is so linked at every point with other social activities that any attemptive definition . . . can only express more or less inadequately one of the aspects, often a minor one that it has had at some period of its growth" [5]. Some other thinkers go further and consider the definition of commonly intelligible things as a humbug [6]. As for me, I am ready to join in the point of view of Bernal according to whom : "To a human activity which is itself only an inseparable aspect of the unic and unrepeatable process of social evolution, the idea of definition does not strictly apply" [7]. Technology is the science of technics, technics began with social development, and both have become interwoven by mutual interdependence. Therefore I will not try to give a definition of technics, and I will only make some preliminary remarks on the variety of meanings about this word.

Technology is — according to some thinkers — the science of practice; but it is not always declared that the notion of practice is tacitly confined to that of engineering practice, *viz.* to that of technique in a more restricted sense, and sometimes it is assumed, that another kind of practice, *e. g.* that of the natural science, is in itself a part of this science. In the field of engineering, science proper is often opposed to technique, whereas in the field of natural sciences both are considered as belonging together, although theoretic problems (λογία) and practice or experiment (τεχνή) can be dealt with in these sciences quite independently in the same way.

This opposition of "science" to "technique" is the source of continous disputes, often towering like a stormy cloud. I have quoted from "Endeavour" a passage in which this opposition has been denounced as an artificial one. But it is possible to quote a long series of opinions, pro and contra. In 1949 forty-two contributors of the "Rencontres Internationales", in Geneva, touched on this problem during the dispute on "Technical progress and moral progress". Both aspects: the contrast between "science" and "technique", and the interrelation or even identity of these two, had their sponsors. In his letter addressed to the "Rencontres", the world-famous idealistic philosopher, Benedetto Croce, writes as follows: "Technique is not different from the much worshipped science, that now, disguised in its synonym, is exposed to calumniation and blame" [8]. Haldane, the materialist, is essentially of the same opinion; talking of cerebral centers of speach and of movement, and especially of their proximity, he adds: "Yet it could be said that we started to think with our hands earlier than to think with symbols called words" [9]. We can also find the opposite view of this by some idealistic thinkers [10] as well as by some materialistic ones [11].

In my opinion such an everlasting, centuries, or even milleniums old opposition should undoubtedly have deeper motives. Take for instance a script originating from the period of the New Kingdom of Egypt (1750—110 b. C.), in which a father, in an admonition to his son, describes the cruelties of manual labour and advises him to prefer the calling of a scripturist [12]; or consider the passage of Plutarchos on Archimedes, stating: "he looked upon the work of an engineer and everything that ministers to the needs of life as ignoble and vulgar" [13], and let us observe that this point of view haunts us through all the Middle Ages up to our days. Historical marxism will consider all this as evidence for the role of social factors. I had myself the opportunity to call the attention to sudden changes in the history of science mostly coinciding with the separation of theory from practice, or inversely, with the unification of both and with their repeated segregation, connected with the stagnancy, respectively with the revolutionary changes in production [14]. In my opinion, to overlook the unity of technology and proper science is an exaggeration, as well as to deny their differences. Perhaps this lecture will reveal the really dialectic unity and opposition also in the methodology of the sciences, and in our case, in the methodology of technology.

But there is another confusion. It is not a rare idea that "technology" only applies to the techniques used in *factories*, *i. e.* it refers not to the whole, but only to a part of the technical sciences. Thus the word is used not in two, but in three meanings, in a more and more restricted sense. It is firstly understood as the science of practice in general, secondly as the science of technical practice, and thirdly as the science of practice in factories [15].

As already exposed, distinction can be made between theory and practice, as well in proper science as in the technical sciences. Therefore, we can distinguish the *methodology of theory* in natural sciences from the methodology of theory in technical sciences, and likewise we can distinguish *the methodology of* the technical *practice* from that of practice in pure science. In other words, one may relize *four kinds* of methodology : the one in theory, and the other in practice of natural sciences, and further, the one in theory and the other in practice of technical sciences. In this paper, I intend mainly to deal with *methodology of plants and factories* without making any differences between theory and practice of technology. Anyway, I shall make some hints on methodology of technical sciences and beyond that on methodology of science in general, in order to analyse, not only the discrepancies, but also their correlations. We are namely obliged to do that when starting from the unity of theory and practice, in other words, when both may be "scientific" or "unscientific" according to the methodic or unmethodic way we may approach them[16]. Pearson says : "Everything can form a subject for science ; only the method itself is decisive" [17].

Problems of methodology can only be dealt with by employing all weapons of science : observation, experiment and thought. I am convinced that the confusion in the theory of knowledge, affecting epistemology of technical sciences, is cheafly due to the empirical rather than theoretical approach of many technologists to such problems, according to their predisposition to simple practicism. In Shaw's novel "Cashel Byron's profession" we read :

— "Does Mr. Byron ever think?"

— "Think" — said Mrs. Skene emphatically. — "Never! There is'nt a more cheerful lad in existence, miss."

Well, among our technologists, here and there, we can often meet such cheerful lads.

3. Development of the technological methodology

Heiberg's discovery of the short treatise entitled "*On method*" by Archimedes [19] caused a great sensation among scientists. About nineteen centuries before Descartes this study reveals that Archimedes actually used mechanical models to arrive at mathematical results, though afterwards he discarded them in the proof [20]. *The art of model testing, this most important chapter of technological methodology, already appears in ancient times.*

Now, it is striking to see that, close after World War I, Le Chatelier in his well-known book intitled "Science Industrielle" did not mention at all the problem of modelling, and neither did he do so in the revised edition of 1936, published under the title "La Méthode dans les Sciences Expérimentales" [21], although at the time the work of Reynolds [22] had already been long known, and so had the works of Kirpitcheff and of Federman, as well as the achievements in the field of model tests reached by the Russians, respectively by the Soviet school [23].

This art of model testing — one may say : the procedure of experimentation carried out on a small scale replica — is, among others, a most characteristic feature to differentiate technological methods from those of theoretic sciences and, in opposition to Le Chatelier [24] and to Planck [25], I am disposed to see a qualitative difference between these two methods. In the above-quoted work Le Chatelier says : "Il n'y a qu'une seule Science" ; and he sees the unique difference between "industrial science" and "pure science" in "a different grouping" [26]. Therefore he begins by establishing general principles of scientific methodology, and he goes hardly any further than that. The intensive progress of industry, and especially the methods in Soviet Russia's planned economy brought about since then a sudden development of technologic methodology. It is sufficient to compare the contents of the above-quoted book by Le Chatelier with those of the book by Killeffer, published in 1948 [27], in order to see the change in conception during the last 12 years. In the work of Le Chatelier [28] the fundamental principles of Descartes, i. e. *the principle of tabula rasa* and *the principle of division* (the separation of parameters) are on the first place ; in Killeffer's book these two principles are not mentioned at all. Le Chatelier then deals with the *principle* of Taylor, referring to *scientific organization* treated in detail by Killeffer [29], in connexion with the problem of pilot plant experimentation ; follows the importance of hypotheses, compared by the other to the method of Edison, known as "try-it-and-see" [30]. Although, among the fundamental principles, Le Chatelier does not mention the role played by *observation*, nevertheless he later on devotes 5 chapters to this problem ; on the other hand with the development of hypotheses *by meditation* Le Chatelier deals, and so does Killeffer [31], in one chapter only. As one can see, the American author treats some topics that are hardly dealt with, or not at all, in the work of Le Chatelier ; on the other side, he does not even touch upon the main themes of the French author. Separate chapters are devoted by Killeffer to *documentation* (chapter 3), *process research* (ch. 6), *product research* (ch. 7), *equipment research* (ch. 8), *progressive development in research* (ch. 9), *pilot plants* (ch. 11), *evaluation* (ch. 12—13). Deviating from the views of Le Chatelier, in the American expert's writings the methodology of technological research is already distinguished in *three fundamental types*, and the *documentation* is treated, as well as the methodology of *stepwise experimentation* (absolutely neglected by the French author) up to the level of pilot and full size plants : he had already divided into smaller units some topics undivided for Le Chatelier. One may state that for Killeffer the objects on investigation are rather the *differences* between the technological and the scientific methodology.

Killeffer only touches superficially on a characteristic difference, although not an essential one, between the two methods, viz. the teamwork. To this problem a special study is devoted by D. V. Hill [32].

From the point of view of methodology, the significance of teamwork increases, the more we recede from the field of laboratories and the nearer we approach *the life of full size plants*, going through the intermediate gradation of pilot plants. Beyond a certain limit, the increase of the number of persons working in a technological community, leads to a sudden qualitative change. Within the scope of technological activities, difference is to be made therefore between the methodology of *experimentation* and that of *productive processes*, as well as we are bound to investigate both in their relations to each other. In the activity of the experimentalist the stress lies on *change*, on ever new try-outs ; in factory production the stress lies on *repetition*, i. e. routine work, although there is no experiment without repetition, and no production without changes. Within the scope of natural sciences, the boundaries between these two categories are not so clearly defined, although there are some scientific branches in which routine work is important : e. g. in astronomy or in meteorology.

The two methods, the one of preparing, and the other of verifying the production, are both in rapid development, beside and interwoven into each other. But I would not like to give the impression as if we should already have reached more than the outlinings. Up till now, in the literature of methodology, the differentiations and connections mentioned are presented only in an embryonic stage. Therefore we have to face the problem, whether we are already in the position to expose the laws of this methodology ; in other words, whether we are able to establish a well-defined system of methods, ruled by exact correlations, a system that could be valid in every well-conducted technological process.

Now, from my own experience as well as from the literature, may I draw a decidedly positive answer? In technology a *fixed system, clearly characterized has developed, being observed, in full conscience or instinctively, by all technologists.*

We have seen how this system has become more and more conscious in technological research, how the single phases necessarily developed as follows : *choice of theme, documentation, establishing of hypotheses* [33], *experimentation*, and finally *evaluation of results*. Besides, in the sequence of these operations (which in itself is a characteristical invariant, although, excepted the purpose, it does not much differ from the method of research practised in natural sciences) a system can already be defined : the consequent employ of the principle of *tabula rasa*, i. e. of the absence of prejudice, and of the *principle of separation of variables* claimed by Descartes ; in close relation to this, the work must be organized scientifically ; afterwards — and this is the first deviation from the methods of natural sciences — we must make the experiments by means of *a series of devices built up in an ever increasing scale ;* and finally — as another deviation from the natural scientist's methods — in making the *evaluation* we have to include, as a decisive factor, *the parameter of costs*, and in close connection to this, *the parameter of waste* [34]. Of course, any technologic experiment, should it be successful in every other respect, has to be discarded from the practice, whenever the costs surpass those of a similar product of the same quality, manufactured by other technological processes.

"The technology of producing any industrial product" — I quote from "Research" — "begins with some principle, perhaps not recognized as such because frequently the most tidy process scientifically is not commercially the most profitable. The profit may be in the waste products." [35].

4. Opposition and connection between technological and scientific methods

In our days the elaboration of a processing plan for a new technology, and the erection of a new factory without having reached an adequately successful production by continuous pilot plant experiments, only may happen in industrially undeveloped countries. On the other hand, as with the growth of experimental apparatus, the costs become higher and higher, it is not advisable to build a pilot plant without an intermediate step inserted between it and the laboratory. Therefore the scientific methodology of technical innovations is, first of all, *the methodology of a stepwise development of manufacturing, beginning from theoretical and laboratory stage up to the normal factory level.*

Factory experience proves that between the theoretical beginnings and the final factory level, at least three steps are needed : the laboratory level, the modelling level and the pilot plant. In the case of large-scale or revolutionary innovations, a fourth step may be necessary : the building of an experimental factory, which will then serve as a prototype or model-plant, in order to facilitate the elaboration of final factory plans. All this shows the above-mentioned systematism of technological development.

The same high level of systematization can be observed in the second chapter of technological methodology : that of *manufacturing*. The development of this system is rapidly progressing, both in capitalistic and in planned economies, although in the first ones its development is somewhat hampered by the economical market conditions and by the law of profiting [36]. Thus, the technology of manufacturing can be considered as a really scientific one only in a planned economy [37]. But in both economical systems, the development is the outcome of innovations and inventions, introduced into the very process of manufacturing. No technical science could be imagined without technical development ; this single fact is enough to prove that the technological methodology has problems of its own, problems which do not appear, or have a decisive role, in nonpractical sciences. In pure science the insertion of something new into the established old is never connected with such large-scale investitions as in technology, and therefore the road to new things can never involve such decisive economical consequences as in factory life. Technological research cannot be detached from factory activities : this sort of research has always a *final target.*

The actual tasks, to be solved by a correct methodology, are not less important within factory technology *i. e.* in *routine work.* There are certain laws of right organization and control of the works, that have to be meticulously observed, when troubles or deficiencies in the running of the whole apparatus should be avoided, when the percentage of waste should be kept at the least possible level, and when the whole production should be at the most favourable costs.

This chapter on methodology of factory production gives rules for a continuous verification of the whole. Therefore, the *factory laboratories* must be differentiated, in their site, equipment and methods, from those *devoted to experimental work.* The principles of these verifying laboratories are restricted to those of *tabula rasa* and of *separation of parameters*, to *scientific organization and control*, and finally to the *evaluation* with the parameters of cost and waste. The essential deviation of this program from the other one is that a stepwise development of experiments is never needed ; the important need is to organize a *continuous series of measurements.* Therefore, the main character of the work and of the equipment of experimental laboratories is *change*, that of the veryfying laboratories a *steady flow* of typical measurements. All this proves the existence of well-developed methodology in the field of continuous production.

Finally, it was mentioned that experiment as well as control are characterized by *one common feature :* the *team-work.* As already exposed by Le Chatelier [38], pure science takes generally into account only a few — 2 or 3 — parameters. By means of adequate methods — chemically pure materials, regulators of deviation, small size equipment. etc. — the number of the decisive variables is restricted to the minimum ; and therefore each theme needs the cooperation of but few collaborators. In technological research and control the large number of variables, the great series even of the same parameters claim a great number of team-workers ; and this involves a lot of psychological problems. Thus, psychotechnic — not only in the technical, but also in the humanistic sense — is important in technological methodology as well [39].

In order to show how the large number of variables leads to a real *qualitative* difference between the methods practised in pure science on one side and in technology on the other, the following quotation from Le Chatelier's work will suffice :

"If scientists would have finished their studies... and the elaboration of all fundamental laws of nature, manufacturers would only have to group these partial laws in order to have at their disposal some complex rules needed for their special tasks. But the study of nature has hardly begun, and the end of the world is to be expected earlier than the finish of these studies. Contrary to theoretic experts, the practical man is bound to make special studies concerning some complex relations indispensable for his purposes, and, to this end, he must recur to speedy methods, which are often discarded by scientists. Take for instance a function with ten variables, a frequent case in the industrial field ; if the law should be established with the exactitude of pure science, measurements would be needed, say, for ten values of each of the ten variables. The number of experiments would be in this case 10^{10} *i. e.* ten milliards. Supposing only one minute as necessary for a single experiment (and it is quite insufficient), the whole research would need 20 000 years.

Therefore, the technologist, at the start, discards the variables that he considers as affecting negligibly the final results ; suppose, he leaves out 5 of these. He can further simplify by the considering that out of the endless number of the possible values of a variable, he is only interested in those within a small interval ; that between close limits, the arc of a curve may well be supplanted by the tangent ; finally, that a straight line is defined by two points. Thus the research will go on by measuring 2 values of each of the five retained variables ; that makes 2^5 *i. e.* 32 experiments, a task easy to achieve. For this reason, the methods of pure science are never able to substitute industrial research : both of them have to go on parallelly" [40].

The differences between technological methods and those of pure science, are obviously of qualitative nature, simply because the first ones are complex and bound to a large number of variables. The technologist is not in the position to reduce at his pleasure this number — *e. g.* by refining raw materials to the utmost or by an intricate equipment — because, beyond certain limits, he would reach the "plafond", *i. e.* the utmost level of prime costs. And this reveals the importance of the costparameter.

But the nature of technology involves some other methodological consequences : first, there is the *empiric method of "try-and-see"* ; and there is the *rule of large numbers*, *i. e.* the application of statistical mathematics indispensable in this field. Now, from this point of view, the qualitative difference between pure science and technics is not an absolute one ; in the course of development these methods always come nearer to, and become interwoven with each other. Empiricism becomes more and more systematic and scientific : in technics (*e. g.* in the ceramic of oxides) the application of chemically pure materials becomes more and more general, and by automatic control the deviation of parameters becomes more restricted ; the notion of models, respectively the theory of dimensions becomes more and more familiar. On the other hand, it is now evident that empiricism can be only restricted, but not fully eliminated from the practice of pure science, as, in this, opposition and connection between accidental and regular, *i. e.* the life itself, becomes manifest ; and science, even the purest one, is fortunately a living part of life [41].

In some industrial branches this intermingling of science and production is to-day so far reaching that we are compelled to differentiate the so-called scientific plants from the traditional workshops. In these plants — *e. g.* in Hungary, at the United Incandescent Bulbs Ltd. and at the Phylaxia Works, or abroad at the works of Norton and Phillips — the large-scale production is also considered as serial experiment, and all data thus obtained form the raw-material for new research and development in the respective Research Institute. The new and more perfect product enters in a new large-scale production and so on in a spiral circulation through production and research. In such plants there is no more contrast or difference between research-methods or production-methods, and therefore it is a practical *and* theoretical mistake, to separate the research organization from that of production, as it happened in both of our above-mentioned plants. Quite a similar correlation can be observed in the methodology of medical science : it is known that extensive statistical data for pathology can only be gained in big hospitals, and therefore healing practice cannot be separated from medical research. The law of *large* numbers is fundamental for statistics ; its very name indicates that it cannot be valid for *small* ones.

5. Choice of subject and documentation

We have seen that Killeffer divides technological research into three parts : *research of product, research of equipment and research of process* [42]. Somewhat different is the division established by Finkelburg [43] ; in his opinion the most important fields of present technological research comprise *constructing materials, measurement* and *manufacture.*

Each of these special fields calls for a specialized analysis of method in just as many books. Within this scope industrial revolution progresses with incredible speed towards the age of atomic energy and of automatization. In the present period of transition towards full automatization, an important phase is the "Data-Reduction Equipment", composed of an automatic logging (a periodic measurement of a number of quantities), of an off-normal indication (usually by comparing field-quantities with potentials from pre-set potentiometers), and of a dynamic error information by mechanical, pneumatic or electronic devices [44]. But the trend of our times is to supplant the cooperation between machines and men by automatics, and therefore methodology will undergo a far-reaching change : manual labour will be eliminated, with a lot of social and psychological consequences. In 1956, in the German Democratic Republic, I had the opportunity to visit an Institute in which a staff of 300 persons, under the leadership of Dr. Costa, elaborates the complete automatics for all branches of the silicate industry [45]. An adage of the Eskimoes says : "nobody can hunt seals while singing and whistling on the hill." But automatics perhaps, some day, will realise such a hunting by singing and whistling ; and in this respect a quotation by Aristoteles may be interesting : "The existence of a slavery will end when weaving shuttles will automatically move". Therefore I consider automatics (and kybernetics) as the most important, the most rapidly evolving chapter in technological methodology.

In China people say that "the kitchen begins at the market : with what the cook choses for dinner". The sound development of industry begins in the same way, with the right idea, with the right choice of theme. Most of the failures in innovations are predetermined by the first action : by sowing dragon's teeth. Many inventors *e. g.* are occupied in rediscovering the gunpowder, and what is worse, a *moist* one. All depends upon *documentation ;* and it may be sufficient to consider how often the perpetuum mobile is still an object for the zealous activity of some so-called inventors. Therefore I consider documentation as equally decisive in technological methodology [46].

Unfortunately, good documentation is a problem anywhere in the world. Although as is known, the Soviet Academy of Sciences has an Information Service for Science and Technology which publishes "express" journals to provide information 2—3 weeks after the foreign publication has been received [47], this very exception proves the rule.

In Great Britain, the really alarming problem of documentation was the subject of a wide-spread discussion, Parliament included [48]. All over the world, there is a swift spreading of civilization, the result of which, in formerly backward countries, is manifested by amazing abundance of scientific literature. The documentating apparatus established before World War II proved therefore to be ridiculously insufficient. There is a trend to organize translations by means of kybernetics, but the outcome of this is rather poor. To cite Dr. Albert Fonó, kybernetics are mainly founded on the logical system of Aristoteles, on the principle of "tertium non datur". But the human language is by no means logical, neither is man himself. Even when making use of all the technical facilities, *e. g.* by beginning with a standardized classificator and ending with cards automatically grouped, in my opinion technological methodology has still to go the whole hog. A revolutionary change, perhaps in the form of an artificial language with a logical construction, would help to establish a new order out of this chaotic state ; and the second industrial revolution would as badly need such an aid, as the first one was compelled to establish the unified meter system.

And yet, by methodically applied documentation, a lot of superfluous and costly work can be avoided, and new ideas can raise through association. On the other hand, too much documentation risk to baffle the free mental activity, especially as to-day much publication is so full of stuff, as to be often indigestible. Besides, repetition may lead to pertinaceous prejudices, as well as it happens with advertising. During a walk you see on the wall a gigantic figure, signing a check with a Parker pen. A witty line on the placard says :

"Will you all be happy men,
go and buy a Parker pen."

Annoyed, you say to yourself : "I do not want to be happy, and I don't buy a Parker." The next day, seeing the advertisement, you may think that perhaps there *is* something about this Parker. And on the fifth or sixth day you decide that the Parker should be tried out, and you go and buy the pen. After some weeks you cannot even think without the Parker.

It is far easier to proclaim the principle of "tabula rasa" than to keep to it.

6. The art of model testing as a method of technology

We have emphasized how "*stepwise modelling*" plays a central role in technological methodology. A great activity can be observed today about dimensional analysis (called also principle of similitude) and about the connexed theory of modelling ; so it is possible to make only a rather short review of the extensive literature on the subject [49].

The source of a technological innovation is often founded on a single observation, followed by a reflection, *i. e.* by a mental experiment. Looked at in this way, any idea has a theoretic character, and therefore a methodical procedure claims a preceding theoretical analysis. If it should prove that the idea is unfeasible, no experiment should follow. But when in doubt, or if the analysis proves the soundness of the idea, verification by laboratory tests is necessary.

The methods used in laboratories are known, more than those of mental analysis. Nevertheless the results of laboratory tests are often overestimated especially by non technologists, as a wide-spread conviction exists that any operation successful in a laboratory is granted on a large scale, too. The error can be exemplified by a world wide known happening. The Observatory of Mount Palomar was furnished with a glass disk of 5 m in diameter, on which the mirror for the telescope had to be polished. The greatest difficulties arose out of the large dimensions of the disk. To cool off a disk of only somewhat smaller dimensions, without the risk of stresses and of cracking, is much easier. The cooling of bodies with a bad heat-conductivity is in fact not characterized by parameters simply proportional to the dimensions. Therefore one cannot say that a disk five times as large as another, could cause difficulties, let us say, 5-times as hard as with the first one in cooling. On the contrary, difficulties increase much faster than dimensions, and above a certain size the difficulties are simply insuperable. This is the reason why, after the first disk had failed, a second one had to be cast with immense costs [50].

Therefore, it is not advisable to build a pilot plant as soon as laboratory work has been successful, but modelling must be inserted. The main task of modelling is to draw the experimenter's attention to those parameters that with increasing size exert an increasing influence on the procedure. Besides, every technological apparatus is characterized by an optimum size as to efficiency and cost. *Determination of this optimal size is perhaps the most important task of technological methodology.*

Pilot plant experiments, when they were preceded by modelling, can be carried out with a much greater security, than without them. But such experiments are often made also in order to find the solution for problems that are already in the near proximity of continuous large-scale production. An outstanding role of pilot plant experiments is to verify quality fluctuation of raw materials which might influence the whole process, to investigate possible troubles of working, and first of all, to determine the percentual waste to be expected in the large-scale production. *Should the result prove that this waste cannot be restricted below a tolerable limit, the process is unacceptable.* It is an inherent feature of technology that the risk to have built a pilot plant, which may afterwards prove superfluous, cannot be avoided. With careful model experiments such a risk can be reduced to a minimum, but with regard to the scale effect of increasing dimensions it cannot be reduced to nil.

Experimental plants differ from the pilot plant inasmuch, as the production there is run at full scale, and the limits of the adjustability of equipment are narrower than in pilot plants. There are also special plants, in which the task is not the elaboration of a new technology, but the experimental production of new articles by the same procedure.

In practice, according to the chemical or physical feature of the process, we discern chemical, mechanical, thermal or electrical technologies, and it is known that, *e. g.*, the methodology of mechanical technologies is quite different from that of the chemical ones. But in every case *no method can be adapted on a larger scale without previous trial*, and in this respect model-testing is fundamental. As early as 70 years ago, Reynolds ventured to state : ,,Experimenting with models seems to afford a ready means of investigating and determining beforehand the effect of any purposed estuary or harbor works ; a means, after what I have seen, I should feel it madness to neglect before entering upon any costly undertaking" [51].

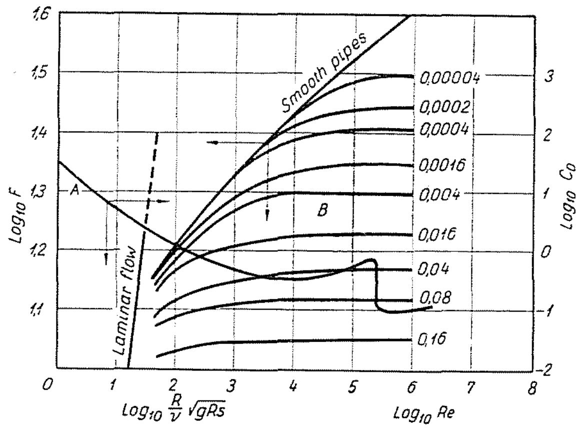

Fig. 1. Drag coefficient for smooth spheres in function of the Reynolds number (Curve "A"). — The abscissa bears the logarithm of the Reynolds number *Re* ; the ordinate — on the right — represents the drag coefficient. With the ordinate on the left, which represents the logarithm of *F* (Curves "B"), an inverse Stanton diagram is shown, the abscissa values for which are the logarithms of the ratio $\frac{R}{4F}$

Model test has become the main instrument in technological methodology, because in the times of the first industrial revolution full scale experiments proved uncontrollable and too costly, and also because, in several branches of technology — such as in thermal processes or in hydraulics — no reliable method of calculation, based on reliable physical laws, was at our disposal. The method of modelling developed as an intermediate type between strictly scientific and half-ways empirical procedures.

But correct modelling is bound to some preliminary conditions, and one of these, in my opinion, can be considered as the fundamental law of technological model testing. This law is a direct consequence of the general law of quantity changing into quality, and a lot of unsuccessful technological experiments are due to the neglect of this law, which can be expressed as follows :

condition of a correct model test is to find the threshold value, above which a sudden change of quality occurs in the behaviour of the model. And I call "threshold value" of the scale the number separating the two groupes of scales, each of which incorporates models of a different quality character.

Every experimenter of model testing is familiar with diagrams similar to the following (Fig. 1), which demonstrates such a sudden change or deviation of quality.

With the curve "*A*", the abscissa bears the logarithm of the Reynolds number *Re*, and the ordinate (on the right) represents the drag coefficient. At the value 5,5 of *Re*, the drag coefficient shows a sudden sinking [52]. The curves "*B*", (a modification of the well-known Stanton diagram) where the abscissa represents the logarithm of the ratio $\frac{Re}{4F} = \frac{R}{\nu}\sqrt{gRs}$ and the ordinate (on the left) represents the logarithm of F (where $F = \sqrt{8/f}$ and f is the friction factor) a similar change can be observed, between the laminar and turbulant flow, at the point where the abscissa value is $\sim 1{,}75$.

We may ask what can be the significance of these phenomena in model testing. Let us see an example. Two tunnel kilns are tested, and for the first one $\log_{10} Re = 3$, for the other one it is $= 7$. If we determine the drag coefficient of the passing of gas in both furnaces, and according to the ideas of Le Chatelier, we trace a straight line between the two points as determined by the two log values and the two values of the drag coefficient, this straight line will seem as an acceptable approximation for all the kiln sizes between the first two put to test. Evidently, for a kiln with a Reynolds number having the logarithm equalling 5,5, *i. e.* in the vicinity of the above-mentioned sudden change, the consequences drawn from the route of our straight line would be entirely false. The same source of error would arise when operating with the two other variables in Figure 1, if we did not consider the change from turbulent to laminar flow.

As for hydraulic problems, this kind of inattentiveness is not likely to happen anymore, as since after Reynolds in model testing this transition point is always subject to special care. But there are a number of parameters, the scale effect of which is unknown. In similar cases, *there is a probable danger that the threshold quantity, i. e. the critical scale, could be overleapt.*

But there are other pitfalls in modelling. The use of the principle of similarity, a chief aspect of methodology in model-experiments, will quickly make us perceive that geometrical similarity does not necessarily involve a physical one; on the contrary, this never occurs: a complete similarity does not exist [53]. In other words the scale effect is *always* working (wherefrom the "approximative model testing"), with a gradational change below and above the critical scale, and with a sudden change in the vicinity of the threshold value. Moreover we must ever be aware that threshold values of different parameters are never in coincidence with each other. As Langhaar states: "An important part of the work of the model engineer — indeed the most important part — is to justify his departures from complete similarity or to apply theoretical corrections to compensate them" [54]. There are, anyhow, parameters without scale effect [55] but only experiments could disclose such exceptional singularities. There are some other difficulties, too. The dimensional analysis is far from revealing the role played by all variables. But analysis can only be successful, if we can find the decisive variables [56] and this condition sometimes cannot be fulfilled. And if it is fulfilled, in first approximation we are bound to form a hypothesis on the mechanism of the process, which may permit to determine the main factors, but this, as in all kinds of hypotheses, can only be proved by experiment, and this prove is not always successful. Therefore some people call the dimensional analysis the theory of experiment. It is not the less necessary to make sure that our equations are homogene in respect to dimensions; this test is only feasible when the equation comprises all the variables that are at hand in the analytical deduction. Finally, another source of uncertainty may arise when the fundamental principles of the method are not clearly defined [57].

From what has been related, one may easily infer that modelling is not the way to find the philosopher's stone. The last decisive answer in most cases can be found by experimental production on a large scale, and the main decisive factor is the *percentage of waste.*

These weak points of dimensional analysis may be ascribed to its excessive generality. But this feature is at the same time the source of advantages. Let us glance at Figure 1. In this, there are 4 variables, the effect of which is illustrated in correlations: the speed V, the diameter D, the density ϱ, and the dynamic viscosity μ. In order to illustrate the single effect of each variable, perhaps about 25 figures would be necessary. A practicable way of concentrated illustration can be revealed only by some model experiments, as these lead to the certainty that decisive are not the single variables, but the dimensionless quantities expressed by the functions in the form of Re and C_D. When *e. g.* one has to determine the braking effect of a sphere of 3 m dia, falling through the air with a velocity of abt. 30 m/s — that would surely cause immense costs — it is quite enough to take a small sphere of the same Reynolds number and of 30 cm dia., falling through water with a velocity of abt. 4 m/s; this latter is surely an experiment easily carried out. Now, geometric similarity is not the only case in which dimensional analysis can be useful for technological experiments. By Drobot dimensional analysis is shown as helpful for the verification of samples [58]. This case proves a wide interpretability of model testing, and reveals the large applicability in production of the mutual representation of grouped parameters; but all these topics transgress the limits of the present lecture [59].

7. Mathematical evaluation

When speaking about evaluation of experimental and routine work in technology, and touching on the role of costs and waste parameters, respectively, of the measurements in series, the importance of statistical mathematics inevitably appears [60].

But in this field one must take care not to stir up a hive of bees. May I quote, as an example, the remark of Jeffreys — who professes to be a realist— about the specialists of probability?

"I disagree utterly with many arguments produced by the chief current schools of statistics, but I rarely differ seriously from the conclusions ; their practice is far better than their recept" [61]. I think, nobody could more be competent than Jeffreys (with the exception of Einstein, who shares this opinion as far as theoretical physicists are concerned [62]) to state that a large group of statisticians "do not practise what they preach". When I see that according to Le Chatelier the approximative calculus is but a deception [63] ; when according to Lippmann "everybody believes in the law of errors, the experimenters because they think it is a mathematical theorem, and the mathematicians, because they think it an experimental fact" [64] ; when Stebbing declares, "There can be no doubt at all that precise predictions concerning the behaviour of macroscopic bodies are made and are exactly verified within the limit of experimental error" (*i. e.* the experimental control of exact pre-indications is inexactly exact) ; when again, we find the ironical reply of Jeffreys : "without the saving phrase at the end the statement is intelligible and false. With it, it is meaningless" [65] ; when Rényi, as a rigorous censurer, makes use of the whole arsenal of Marxistic epistemology against the sceptics of probability calculus as well as against the idealists of exact mathematics [66] — I myself, am rather inclined to leave this dispute to the mathematicians, as from the point of view of technological methodology, the approximation calculus has been justified by practice itself. As for me, this is quite sufficient, just as it was sufficient for Maxwell, who dared to say : „ . . . the true logic for this world is the calculus of Probabilities . . ." [67].

As far as methodology is concerned, may I refer to one of my papers [68], in which I explained the preconditions of the applicability of mathematics in technology. There are some technical devices of applied mathematics well contrived to help us in evaluating parameters of experiments and of production ; all these already belong to a new discipline. Nomograms, mechanical and electronical devices have revolutionized the whole evaluation process, and in the present state of things calculation, through kybernetics, is closely attached to control [69]. When speaking of team-work, calculating groups in industry will be considered separately.

8. Scientific organization of labour. Team-work

Let us overlook a detailed review of the rapid development of team-work, and forbear from estimating its increasing importance in the Soviet economy in comparison to the capitalistic one. It is enough to refer to the literature [70] and to state that the complexity of technology, the ever accelerating development of methods involves a steady increase in systematic division of labour, in technological research as well as in plants. Typical systems have been developed for research institutes, dividing methodically each theme of research. The themes are attacked by teams of physicists, chemists and calculators, and continued by *developing engineers*, who elaborate the research,

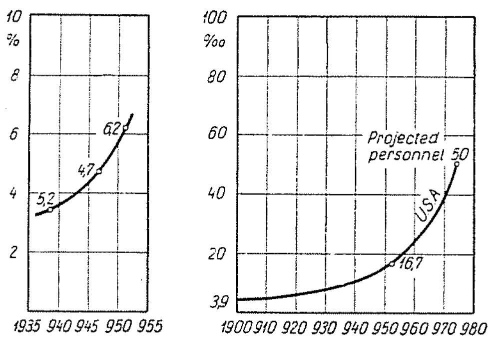

Fig. 2. University education in the Soviet Union in percents of age classes (Left) — The number of engineers per one thousand of workers in the USA (Right)

matured to technological stage, until that of industrial application. It is superfluous to point out the much greater importance of team-work in factory production. This labour division has produced many types of specialists. But also it has been revealed that team-work cannot be organized without „generalists", *i. e.*, paradoxically expressed, without specialists of general surveying [71].

By this increasing development of technological and industrial team-work, during the last century, the *problem of scientific organization of labour* has been raised, by which the name of Taylor became world-known. This chapter of technological methodology is to-day a wide-spread branch of science, and within the scope of the present lecture it is impossible to go into details. Therefore, I will only draw the attention to the differing features of the scientific organization of labour in the capitalism on one hand, in socialism on the other, and to the connexed problems of a psychological nature [72].

Scientific organization of labour, seen as a part of technological methodology, has brought about the discipline of psychotechnics, now grown to the general psychology of labour. And the field of studies is growing yet larger in social and political respect to the education, but such an inquiry would lead too far afield. Therefore, let us only emphasize that a methodic, scientific technology cannot be realized without a scientific, methodic psychology of labour. In my opinion even our planned economy suffers from lack of psychological methods, of an expert treatment of the teams of work, these living organized groups. In order to illustrate the importance of such problems, the curves in Figure 2 may come to witness the fact that the new methodology calls for an increasing relative number of technicians [72].

Really, the exposed development of technological methodology imposes such an increase in proportion to the technical progress and neglection of this principle makes such progress thoroughly hopeless [74]. To quote a remark by P. M. S. Blackett : "... mistakes in education policy may take decades to rectify" [75].

9. Efficiency of methodical research in technology

In our country there is no much confidence in the efficiency of a methodic research in technology, just because this system is not well-known. An anecdote should be cited. Faraday, who showed one of his instruments to a Member of the Government, was asked by the latter for what purpose such a thing could be used? "Sir, sometimes you will be able to tax it."

In his paper already referred to, George Adam writes [76] : "Science had a most important influence in calling forth the second industrial revolution; this further evoked heavy consequences ; the position of science in society and production changed ; science gained a new significance ; all this developed a new social process : *the scientific achievements took place among the productive forces on a new, qualitatively higher degree of efficiency*." The same author quotes further a statement by Walter Reuther, President of the AFL-CIO : „The great spreading of industrial research and the connected current of innovations, were sufficient in themselves to increase unmeasurably the natural growth of productivity, to such a degree that *all the ideas we had formed of the normal development became antiquated*" [77].

I shall not cite the ciphers by which Adam proved this general thesis [78], so much the more that I have published similar data myself [79]. Only one of these may be quoted. Based on ciphers published by "The Economist", the average cost of production per man in the USA and the UK is *five times* as much as in our country, and the average personal cost per one scientist or engineer, including overhead costs for auxiliary personal and services in the USA, amounts to abt. 1 300 000 Forint per annum [80]. The reasons for this are quite evident. According to the documentation published by the National Service Foundation, a proportion of the income arising from research to the expenses is 25 : 1, notwithstanding that, after the statistics of the Du Pont Concern, 33% of the primary ideas are discarded in the laboratories, a further 50% reveals inefficient on production level, and 10% reach the department for development ; only a fraction of this percentage comes in production [81].

The so-called Redman curve serves to show [82] the great differences in lucrativeness between capitals invested in a conservative, competitive, or not competitive (*i. e.* producing brand new types of products) industries. Figure 3, in the first case, shows that at the beginning the cash in hand is nil, in the second one, after two years it sinks to zero but then a gradual increase follows, and in the third case the sinking of cash ends within 5 years, and the

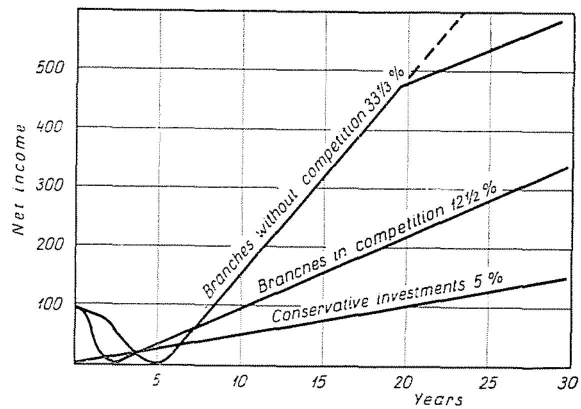

Fig. 3. Income of industrial investments. — The curves illustrate the cash in hand as a function of time in years

following increase is characterized by the steepest line among all three. The ciphers of course give average data ; nevertheless, it is evident that the first period of stagnancy becomes longer if the first investments are more hazardous, but the incomes increase the more. In view of the enormous costs required by modern research, it is evident that the third type of investment is only possible for firms possessing a great reserve of funds, but this is a new argument to throw light on the gigantic possibilities of a planned socialist economy.

In our country, for the moment things are quite different. Because of its *indirect character*, the efficiency of technological research has not yet been appreciated and some people quickly assume a plaintive attitude when a research fails at the first tests. The data referred to and my own experience bear witness that in research, as in every kind of human enterprise, "not every cracknel becomes crisp enough". But in our country research is sometimes looked at as a selling-automaton for chocolates : the penny goes in, the chocolate comes out.

Introduction to technological methodology of research should begin with the adage of the cracknel.

10. Technology and natural science

This lecture would be incomplete, if I did not touch on the delicate question raised in the dispute between technologists and scientists about the "rank" of technology and science, although I think that through our re lections this contest has lost much of its sharpness. I shall not spend many words for this problem which seems rather one of vanity. Anyhow it is necessary to touch upon the question from the humanistic point of view mentioned at beginning.

Some thinkers extolled technics up to the skies ; others trampled it down to earth. According to Francis Bacon : "Nowe among all the benefits that could be conferred upon mankind, I found none so great as the discovery of new arts, endowments and commodities for the bettering of man's life. For I saw that among rude people in the primitive times the authors of inventions and discoveries were consecrated and numbered among the gods" [83]. Aristoteles says that the right name for technical skill is σοφια, *i. e.* science, wisdom [84]. Campagnolo said : "Technics are the concrete manifestation of morals" [85]. According to Wendt : "Technics steadily trend to transform human labour from a manual into an intellectual, *i. e.* from a physical into a spiritual one. Spirit, grown once mighty, will fight until entire personal and political freedom will be attained. Man, liberated, will enrich intellectual life and upraise our civilization" [86]. The same statement is to be found by Haldane [87] : "Would a deity descend to earth and ask humanity, which one, the craftsman or the scientist is the more dispensable, a loud and uniform verdict would expel scientists from the State's temple"[88]. In a book of Zschimmer, "Philosophy of technics", we can read in Hegel's style : "Technics have a purpose of their own, never aimed at by art or by any other social activity : the purpose to realize a divine state of man in the conscious freedom of creative thought, as the final aim of organic development towards the majestic idea of infinite perfectness" [89]. Whenever hearing a like exaggeration, a friend of mine used to exclaim : "Bounce!"

But let us see the other versions. "The glorious palace of the modern and liberal technical civilization is really a gigantic jail, in which everyone is condemned to a forced labour for lifetime" — are the words of von Mayer [90]. "The spirit of technique probably prepares its own destruction, and surely prepares that of human life" [91]. "Anything expressed by the word technic, leaves a bad taste of superficial tendencies : the bad taste of a trivial encyclopedia, which never reach the depth of things. The false mask of science has finally to be torn off the face of technology . . . True academic knowledge can never turn into a vulgar economy of herds" [92]. "The final meaning of technics, is the destruction of personality" — says Auburtin [93]. "The human race will change into a race of ants . . . Like in those, our organs of eating and grasping will develop at the price of a degenerated brain." And speaking of a cottage in England, he continues : "On the plains and on the hills, everywhere a lot of cells each of the same type, and in every cell an Englishman is sitting, dressed with the same clothes. All are surrounded by the same type of furniture, and all are reading the same sportspaper. Each and everyone have the same thoughts . . . *A frightening outlook into the future. . .*" Contrarywise, they quote with predilection the majesty of "pure", selfcontained science. According to Aristoteles : "God's activity, surpassing all imagination of happiness . . . is the act of pure contemplation, and the human activity which approaches this happiness is the most related to contemplation" [94].

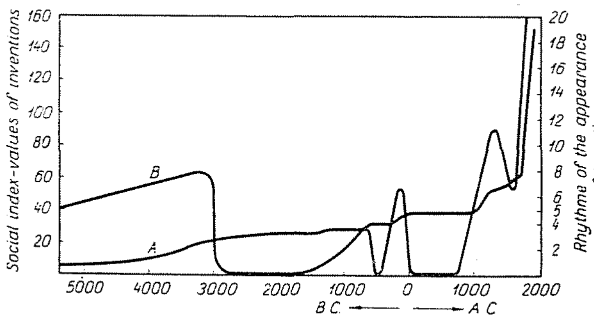

Fig. 4. Technical implements used during history. The abscissa bears the years. — For curve "A", the ordinates (scale on the left) represent the social value of inventions in a conventional unit. The curve "B" is the differential of the first. For this, the ordinates (scale on the right) express the average increase of the technical implements. — The values of the ordinates of "A" represent the quantity of fundamental machines and tools by use in a system of average evaluation. The values of the ordinates of the curve "B" are percents of the implements estimated for the preceding period

"How do you imagine the Paradise?" — an old sailor was asked. — "To be always tipsy and to have one's pipe" — was the answer.

But the dispute goes on, *pro and contra*, which originates from the other, which has gained more from the other : technics or science? The partisans of technics cite with pleasure the famous saying of Engels from a letter addressed to Starkenburg : "If, as you say, technic largely depends upon the state of science, science depends still far more on the *state* and on the *requirements* of technique. If society has a technical need, it helps science forward far more than ten universities" [95]. And in another place : "Up to now, they used to boast of what production owes to science ; but science owes much more to production" [96]. Both of these cases are illustrated by many examples [97].

One can also find authors who blame both science and technics. In Ovidius' Songs, in Platon's meditation on the Golden Age, in Horatius' laments on ships and fire, in Rousseau's "Émile", in the irrationalistic scriptures by Klages, in the "technical metaphysics" by Hansjacob and Stur [98], an ever louder lamentation of "*laudatores temporis acti*" is heard, which decries the progress of science and technics, beginning with the Holy Bible, which sees the Devil's own hand in the eating from the fruits of the tree of knowledge. All the technical or scientific achievements, from the wheel up to the present day steam engine and to the atomic pile, were condemned [99], sometimes with apocalyptic expressions. As Bernanos writes [100] : "Science dissembles as a messenger of life and pleasure, whereas it is only the carrier of death and

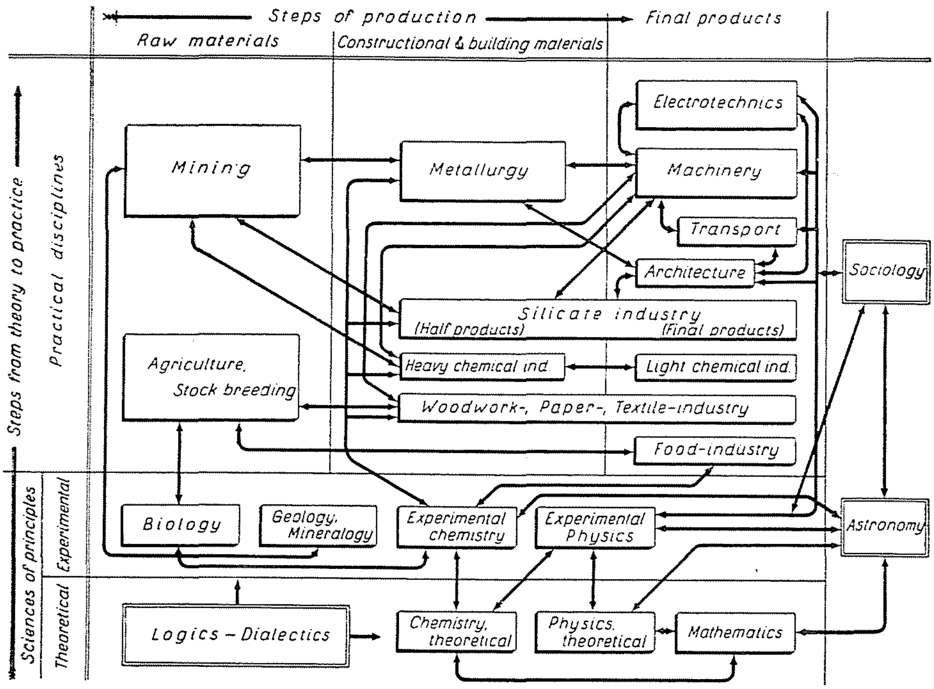

Fig. 5. Correlation between theoretical and practical sciences. The figure shows, as basis, the sciences of principles as fundamentals. Practical disciplines are grouped according to the steps of production enumerated on the top line. Arrows showing in both directions illustrate the correlation between the single branches or disciplines. This diagram only comprises technical and related sciences ; medical and historical or jurisprudential topics are not included

desperation." "I declare that the lack of balance between our own life-conditions on one side and science or technics on the other, shall continually increase" . . . "Perhaps, only a few hours are at our disposal to condemn the world", were the exclamations uttered by René Sudre during the "Rencontres" in Geneva [101]. "Touch wood", remarked Benedetto Croce laughingly on hearing of similar visions.

It is time to get out of this mess ; we should find a reasonable (and again a dialectic) compromise between the two extremes, in the common origin and the mutual influence of science and technics during social development, in which practice becomes more and more scientific and science more and more practical. We may agree that science is destined, in the first place, to study the phenomena of nature, *i. e.* that in science the stress lies on *discovery*, whereas, in technology, the main line is *invention* of new toles and methods of production ; therefore, technics are firmly bound to aims, whereas in science this is rather an exception. Perhaps the quarrel could be settled in this way.

But let us look at these two diagrams (Fig. 4 and 5), which eloquently show — the first one — the parallel development of inventions and scientific results, [102], and — the second — the interwoving of science and practice. As a modest technologist may I express the hope that sciences are not called "pure" because of the surmise that technology is something "impure"? Whether the *homo faber* looks with contempt at the *homo sapiens* or vice versa, it is always man who is subject to contempt ; and one might bear in mind that all philosophy of death begins with the contempt of man.

Summary

The technological methodology differs in many respects from the methodology of the so-called pure sciences. The present survey chiefly concerns these differences. Today there is a marked tendency to consider technology as "application" of pure science. In the author's opinion pure science can be considered as "application" of technology as well as the contrary is true. Reciprocity between the two types of sciences is emphasized.

The chief difference is seen in the number of variables, which in pure sciences is very small in comparison to those to be considered in technology, on one side ; in the very different scale of apparatus, with the fundamental consequences of the scale effect, on the other side. Among the variables to be considered in technology there is one which is fundamental, but does not play any part in pure science : the cost. Another variable, which has a special importance in technology, is the psychology of technicians. Team-work becomes particularly necessary in modern technological research. The role of mathematics, in technology, differs fundamentally, in many respects, from the role played in pure science.

At the end a synopsis is given of the connections between pure sciences and technologies.

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