FROM SCIENTIFIC RESEARCH TO SOCIAL UTILIZATION: SOME REMARKS ON THE TIME-FACTOR

A NEW LOGICAL MODEL OF SCIENTIFIC RESEARCH

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An account is given here of a particular experiment carried out to analyze, on a concrete basis, the period of scientific-technical creation by following the genesis of one modern industrial product and, at the same time, by examining some of the common features of creative processes from scientific research up to technology. [1]

From the discovery to the technical invention

How does the reduction of the period of creative processes manifest itself? This question can be solved the more easily as it is treated even in scientific literature, e.g. by N. M. NIKOLSKY, who says: "One of the most important features of our time . . . is the rapid reduction of the period from scientific discoveries up to the technical inventions achieved on the basis of these discoveries."

"*The periods of time necessary to get from the dicoveries up to the technical inventions*

102 years		for photography
56 years	(1820—1876)	for the telephone
35 years	(1867—1902)	for the wireless
14 years	(1922—1936)	for the television
6 years	(1939—1945)	for the uranium (atomic) bomb
5 years	(1948—1953)	for the transistor
5 years	(1956—1961)	for the laser" [2]

The above data — which can be found in other scientific publications, too — show a considerable reduction of the processes *from science to technical invention.*

In the following chapters we try to verify the exactness of these data in relation to one example, having no possibility to examine more case-studies in this paper. At the same time we use the results of our researches for the genesis of seven modern technical achievements [3].

The historical approach

Where to start the processes *from?* To say: "from the antecedents" is inexact, as their number may be one, or they may be innumerable. However, if the problem is treated with the method of combining the historical element *with* the logical one, the history of sciences *with* the history of technology, it is possible to separate the concrete scientific fundaments of a given technical achievement from the theoretically infinite number of antecedents.

We are aware of the fact that our approach is a particular one, its object being *the interaction of science and technology* in relation to the genesis of one given achievement. This method of approach involves a particular way of using data: they are used *only* to reveal in details certain stages of the genesis of the given product, *stages resulting inevitably from one another.*

The essential meaning of terminology

Though we speak about terminology, as a matter of fact this question is closely connected with the essential contents, the "*abstractly* concrete" character of our research. This means that it is merely accidental what the revealed new result will be: wireless, transistor, laser or anything else, since hidden in EACH OF THEM we find *the regular progress of cognition.* The result of the scientific research, which may be the wireless, the transistor or, for that matter, the laser, is only a specificity of fundamental research, but it is easy to recognize the *GENERAL NATURE* or more exactly, to follow the *regular progress* of the new scientific cognition evolving and realizing its purpose in the course of research activities based on one another. That is the reason why the past and finished processes, if truly reconstructed from type to type of activity will be *in accordance* with this objective progress, which requires, therefore, a suitable terminology. However, the present voluntaristic practice does not help, but rather encumbers the realization of this aim. The scientific terminology used today is an entirely formal one, detached from its original contents.

In the following chapters we shall apply a new system of concepts formulated exclusively by analyzing the processes of scientific-technical creative work. The *specific features of the new system* are the following.

1. *EXPLORATORY RESEARCH (ER)* deals with the intensive examination and perception of the phenomena of nature, their characteristics and laws. The *specific* of this research is the fact that it does *not yet* examine the possibility of the social utilization of its object.

2. *RESEARCH LEADING TO SOCIAL UTILIZATION (RSU)* deals with the social utilization of the recognized new phenomena. This kind

of research examines those characteristics and conditions of the relevant new discoveries that can further their social exploitation. This research usually reveals such aspects of the newly recognized phenomena that may lead to new technical achievements, by laying the theoretical fundaments of the new solutions. The *specific* of this research — as opposed to exploratory research — is that it aims *already* at achieving social utilization and, on the other hand, — as opposed to technological research — that the research object is *not yet* influenced by the practical purposes of mass production.

3. *TECHNOLOGICAL RESEARCH (TR)* deals with the systematical development of the results of research leading to social utilization for mass production. The *specific* of this research is that the practical, economic parameters of the (new) mass production play an important part in determining the object and the contents of the research [4].

The model

In this case study we shall indicate the respective types of research activity for classification purposes. The aim of this model of history of science is to represent in their essentials the sequence, the structural relationships of different types of cognitive activities.

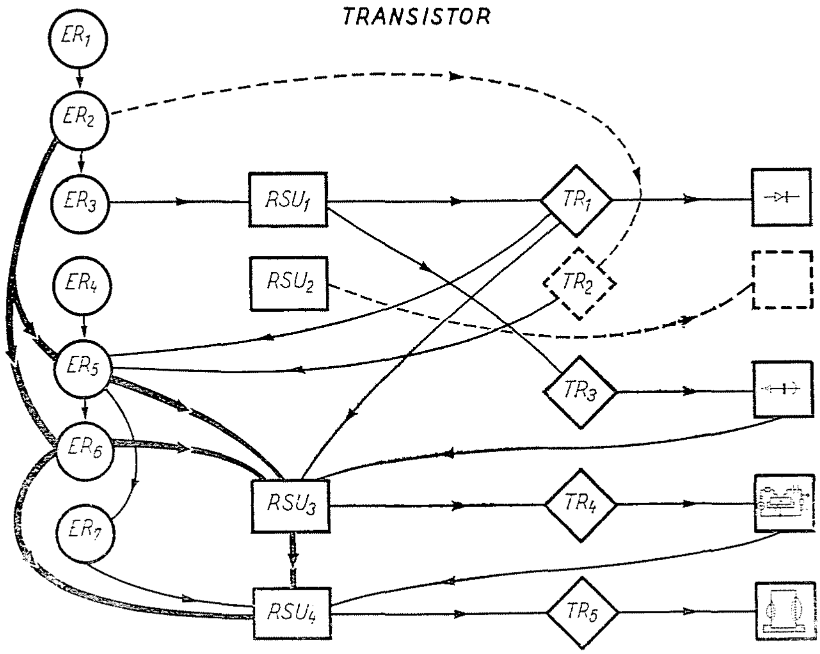
THE TRANSISTOR [5]

In the case of the transistor the transit period *from* the scientific discovery up to the technical invention was only five years — says the above table [6].

First of all the question arises HOW the transistor could have been discovered without getting nearer step by step to the discovery of the *semiconductor as such?* The answer is short and simple: NOHOW!

The first empirical perception of the semiconductor phenomenon is to due to M. Faraday (ER_1 — 1839). The basic principles of methodical semiconductor research are due to the activity of F. Braun. Up to that time the semiconductor effect had been considered rather as an anomaly, a mysterious phenomenon, or it had been explained by the help of *inaccurately developed theories*. Braun stated, on the basis of research work of one decade, that the explanation of non-linear conduction departing from Ohm's rule is NOT to be found in defective or badly functioning laboratory equipment, but it is a case of ANOMALY. Following this lead he got to his most important conclusion: "this proves that the whole anomalous phenomenon MUST HAVE ITS ORIGIN IN THE THIN FILM OF THE SURFACE": (ER_2 — 1877) [7].

According to usual research practice these results made no impression for a long time. It was a matter of course in those years to give preference to the *specific* contents of Braun's experiments as a basis. (*What materials, what voltage, what kinds of instruments* etc. etc.) As semiconductor materials he used, among others, galenite, selenium, metal sulfides. This is the starting



ER = Exploratory Research
RSU = Research leading to Social Utilization
TR = Technological Research
– – – = Failure of Direct Way
——— = Success of Indirect Way

ER_1 = Faraday, perception of semiconductor effect, 1839
ER_2 = Braun, cause of rectification to be found in surface layer, 1877
ER_3 = Braun, perception of contact rectification, 1874—1877
ER_4 = quantum mechanics
ER_5 = Wilson, semiconduction theory, 1931—1932
ER_6 = Tamm, Shockley, existence of surface states, 1932, 1939
ER_7 = Schottky, Davydov, Mott, diffusion theory of rectification, 1938, 1939
RSU_1 = contact detector
RSU_2 = electron tube
RSU_3 = Bardeen, Brattain, point-contact transistor, 1948
RSU_4 = Shockley, junction transistor, 1949
TR_1 = development of contact detector
TR_2 = development of selenium and cuprox rectifier
TR_3 = development of germanium and silicon detector during and after the war
TR_4 = development of point-contact transistor
TR_5 = development of junction transistor

point of the *direct way*. On the basis of Braun's point-contact experiments (ER_3) [8] several scientists discovered, *simultaneously and independently of each other*, the crystal diode (RSU_1) (1904—1907) [9] which served, beside the vacuum-diode, as a new means of rectifying radio waves. Soon, the crystal diode found wide application (TR_1).

On the other hand, the specificity of Braun's basic theory — i.e. *the nature of materials* etc. — was well integrated with previous experiments of similar character and helped their further development (TR_2) [10].

The success of the direct way was increased by the function of the triode (RSU_2) helping to produce a particular amplifier at a relatively early period [11]. These instruments did not work, of course, since the effects of surface states were still unknown.

The failure was due to the fact that the different theories of the 'tens and 'twenties about the mechanism of rectification (e.g. the change of thermionic voltage, and ionization potential, structural transformation, the change of potential barrier etc.) could not offer any solution as to the basic question, the explanation of *non-linear voltage characteristics.*

One can imagine the urging demand of technology to solve these problems. Thus it was not incidental, but a *step towards satisfying a real social demand,* that the rectifying effect of semiconductors was basically explained by the help of quantum mechanics (ER_4).

It is justified to raise the question: *why was* A. H. Wilson *able* to discover the conducting mechanism of semiconductors (ER_5)? [12] The experience of the previous twenty years had proved that *it was not possible* to explain it solely with the motion of electrons. Wilson proved at this point that, in the case of anomalies, a better hypothesis can be propounded through a conception OPPOSED to the accepted one. That is why he assumed not only the motion of negative electrons for anomalous conduction, but, at the same time, that of positively charged holes. *The simultaneous existence of electrons and holes* offered a satisfactory explanation for non-linear conduction, this supposition being in accordance with experience.

But the question of the turning-point indicated by Wilsons's discoveries is not yet exhausted. He recognized the existence of potential barrier at the surface of semiconductors. He used Braun's recognition as a basis (see footnote 7) and concentrated his research on this brilliant anticipation with a great success. *That is why he succeeded, as a first step, to recognize, within the collective term of surface layer, the existence of a potential barrier.*

By introducing the new terms *free hole — free electron, energy band structure and potential barrier* (ER_5), Wilson's activity brought about a change in the long research work carried on for a better understanding of semiconduction. Once more we can witness *simultaneous discoveries independent of one another.* W. Schottky in Germany (1938, 1939), B. Davydov in the USSR (1938, 1939) and N. F. Mott in Great-Britain (1939) established the diffusion theory of rectification (ER_7), stating that the modification of potential barrier height derives from the difference of the thermionic work functions of metal and semiconductor. The trouble was that this assumption was rarely justified by measurements.

To find the cause of this failure, we shall *go back to the fundament* of the previously outlined work of W. Schottky, Davydov and Mott, i.e. essentially to Wilson. In this way the ambiguity of their results will be more understandable. They deduced any further explanation of the semiconductor anomaly *directly* from Wilson's results, though these results did not go beyond the *general* directives of quantum-mechanical methods related to semiconductors (e.g. energy band structure), thus producing a *rough approach* of surface layer. We must understand, however, that Braun's anticipation had not been controlled by scientific methods up to that time ! Thus it happened — and *not before* — that attention was drawn again to the *further* examination of surface layers.

Here we meet again the well-known example taken from the history of science, showing that an answer to one of the puzzles of the social practice as well as to the potential demands of society has been already given within the field of abstract cognition (*ER*), and in spite of this fact *the concrete (professional) demand of society is not yet aware of the possibilities offered by the new theory*. That is the reason why these results are left out of consideration. As a proof of this we refer to the fact that the *existence of surface states* was pointed out by I. E. TAMM in the USSR already in 1932 on the basis of the discoveries of F. BLOCH, A. SOMMERFELD and H. WILSON [13], as well as by W. SHOCKLEY in the USA in 1939, in both cases with quantum mechanical methods, though Shockley, who followed another track, proved also theoretically the existence of surface states (ER_6) [14]. The further elaboration development of this discovery followed by its practical utilization was launched only in 1947.

This can be explained partly by the fact that it was necessary, during World War II, to develop reliable and efficient germanium and silicon rectifiers for radar equipment (TR_3). Experiences collected in the course of development furthered the study of the surface space-charge layer and surface state density ($TR_3 \rightarrow RSU_3$).

J. BARDEEN's far-reaching hypotheses, claiming that potential barriers at semiconductor surface are due much more to surface states than to contact potential differences, *opened the way to the transistor*. In order to prove that W. BRATTAIN produced in the American Bell Laboratory an experimental system for the examination of the surface potential barrier of germanium contact rectifiers (crystal detectors), where he put a new point contact next to the other one. In the case of properly biased point-contacts Bardeen and Brattain experienced *current amplification higher than unity*. Thus they discovered the point-contact transistor (1948) (RSU_3) [15].

The solid-state amplifying device produced like this had a drawback: the uncertain functioning of the point-contact and, as a result, the disturbing effect of surface states. To eliminate these difficulties Shockley produced in 1949 the p-n junction diode and the p-n *junction transistor* [16], where surface states did not influence the functioning of the p-n juctions and the uncertainty of the contacts was eliminated, too (RSU_4).

We can see how *the double process of the direct and the indirect way* repeats itself. What was, after all, the origin of the transistor? The crystal detector. Thus they held, at first, by the obvious, the given solution — in this case:

by the point-contact (TR_4). We know that the contact transistor was produced temporarily even for commerce. Only *after realizing* that this was not quite suitable, did scientific research follow the indirect way, which led, on the high level of modern science and technology, to the *final* development of the idea immanently contained in Braun's anticipation and, rejecting the direct way (the point-contact), produced in the *surface layer* the junction transistor ($RSU_4 \rightarrow TR_5$).

Getting to the end of our case-study the given period of time: 1948—1953 is seen to disregard the *ER* and *RSU* results which served as *a basis* for the discovery of the transistor.

Further on, by reconstructing the logical process it has been demonstrated that *science is also a direct productive force.* We could see that Braun's fundamental principle from 1877 was no mere abstraction, but the contents immanently existing in it was, through a long intermediary chain, the *effective potential basis* for the transistor.

However, we can say even more. This result, this organic interconnection with previous research is not an incidental one. On the contrary! It can be demonstrated in each examined case. The *simultaneous discoveries* are of common occurrence [17] in all disciplines, which proves that science generally develops in this way. To recognize it, however, *IT IS NECESSARY TO RECONSTRUCT THE WAY OF ONE FINAL PRODUCT.*

The model — as it was mentioned before — does not represent the processes in their relative totality. This is the reason why *the regular way of cognition in the scientific-technical processes could be illustrated in its essentials.*

Having no possibility here for other case-studies similar to that of the transistor, let us compare the following data.

Time relations	Assumed time period (18) years	Presumable time period roughly years
Telephone	56	56
Wireless	35	50
Television	14	93
Radar	14	65
Uranium(atomic)bomb	6	46
Transistor	5	115
Laser	5	103
	135	528

Taking the average of the above seven examples as to their presumable time period [19], the result is about 70 years. This is the average time period necessary to get from the scientific discovery up to its economic utilization, i.e. over three times more than the assumed time.

This experiment has revealed that *the assumed time periods are unfounded.* In general it can be said that this is a special kind of "reduction", as *the scientific fundamental is missing* — though to different degrees — *in each example.* The missing fundaments are by no means "general physical antecedents" but results of the *ER* + *RSU* related TO THE OBJECT OF EXAMINATION and serving as fundaments for the respective technical achievements. Still, the diagram of scientific-technical creation is not linear: in each case there is a shorter, seemingly direct way to be recognized at the start.

Technological research is to be found everywhere [20], and this is right, as its function is indispensable. It is wrong, however, if this research is expected — torn away from the interconnection of the whole process — to renew the technical development. Technological research *in itself* leads to temporary results, while the *lasting renewal of technical development can only be based on new scientific results through the medium of TR.*

A good example for this truth is *the so-called "direct way"*. It is called failure, as one has to return after a certain time and start on another — sometimes opposite — way in order to reach one's aim. Thus we find the spark transmitter and the machine transmitter on the way to the *radio*; the more developed varieties of the Nipkow disc on the way to *TV*; the telemobiloscope on the way to the *radar*; the early accelerators on the way to *fission energy*; the development by electron tubes on the way to *transistor*; micro-wave electron tubes (Klystron, HH-tube) on the way to *laser*. Only the limitations, the *impracticability* of this — seemingly direct — way after a certain time compel the scientists to search for new ways of utilization on entirely new theoretical bases. *The double system of the direct and the indirect way* is recognizable in each case. As a matter of fact, human thought growing out of the soil of a new ER will usually try to utilize the new discovery under the old conditions. Only the limitations of this way will make the scientist realize the fact that *a fundamentally new basis has been laid* in the sphere of ER in the given case and the traditional methods are no more sufficient for its utilization, but it is necessary *TO OPEN UP NEW PATHS TO ACHIEVE NEW SOCIAL UTILIZATION. The former method is called the failure of the direct way, the latter — the success of the indirect way.*

Let us remark that the direct way is not an absolute "failure". It is a failure only as a supposition that it must be considered as the main path of scientific-technical evolution, as its "only possible" way. *It is not a* failure, *however, if we recognize its proper place in the evolution of thought*, and realize the fact that it develops on the track of *existing* knowledge, while *new and lasting results can be achieved only by thought advancing by leaps, embodied in contradiction, i.e. on the indirect way*. The direct way proves not to be absolute failure, all the more as it offers a lot of experiences efficient in positive as well as in negative relations. The dominant factor is negative, as it reveals the impracticability of this way *as a whole.* It is positive, however, because many details are found, facilitating the realization of a new technology.

The functional importance of the past

The research of the past is no purpose in itself, or a kind of embellishment to illustrate certain theories [21]. *The past of sciences is a pledge of their future.* More exactly: *the true reconstruction of scientific-technical creative processes is a necessary condition of raising the level of our planning capacity and thus present a BASIS for future generations of scientists to answer the question of HOW TO CARRY ON.*

Summary

On the assumption that the history of science is not so much the history of single discoveries, but rather that of the *method* furthering them a study is made here of this method putting it in the centre of a particular series of experiments and approaching it from a new angle. One outstanding modern technical achievement: the transistor is analyzed by means of reconstructing its history from the beginning up to the threshold of technological realization. Thus a link of real connections is created between the two interdependent sides: theory *and* practice, science *and* technology. Following this lead we realized that the assumption of a reduction of transit period in the creative processes of science and technology is entirely unfounded. It separates the final product from its scientific fundaments without whose existence it *could not have been produced at all*, thus misleading present day scientists working at the new programs of scientific research. The results of this paper offer a proper basis of *understanding the logical processes of scientific discoveries in order to achieve a more efficient system of planning and organizing scientific research.*

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