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SOME REGULARITIES OF THE DEVELOPMENT OF SCIENCE IN THE TWENTIETH CENTURY

Scientific research as a whole is an immensely complicated process which may be considered from the most different points of view: gnosiological, sociological, economical, juridical, and so forth. In that process, however, there seem to be distinguishable some general regularities, certain developmental trends that determine the main directions of changes taking place within the themes and methods of scientific research.

The present paper is an attempt to show just those developmental trends of contemporary science. Taking their rise from the past (and thus being the object of a historical analysis), these trends will probably last for the next decennia. They will characterize the qualitative and quantitative development of twentieth century research, and the revolution within science, which is taking place under our very eyes. To the trends in question belong, first of all, the tendencies to integration.

"VERTICAL" INTEGRATION OF SCIENCE

The term: "vertical" integration of science can be used for defining the rapprochement of scientific research to socio-economic practice, and the ensuing rapprochement — within science itself — between the basic research, the applied research and the developmental research.

As a result of such an integration, the importance of science in the economic, social and cultural development of the whole world and, first of all, of the highly-developed countries has greatly increased during the last decennia. This has found a reiterated expression in the declarations and programmes of parties and governments. As an example, two definitions of the role of science, dating almost from the same period, can be cited here: "the direct productive force" whose application "becomes a decisive factor of a powerful growth of the productive forces of society" (*The Programme of the Communist Party of the Soviet Union*, 1961 [1]); the factor which "revolutionizes methods of production, changes social relationships" (*The Programme of the Republican Party of the United States*, 1959 [2]).

Such statements form a clear contrast with the attitude taken by politicians some scores of years ago and — in some cases — even ten years ago. Such a change of the attitude towards science was not brought about, of course, by a sudden transformation of politicians. True enough, there could be observed, in this sphere, even violent changes of opinions, for instance those making their appearance in the United States after the first artificial satellite has been launched by the Soviet Union. In general, the feedback between scientific research and practice was gradually getting closer and closer.

Several factors determining that process can be distinguished.

1) The close connection of scientific research — as a cause and as a consequence at the same time — with the rapidity of technological progress enabling an increased production and consumption of consumer goods; motor-car production can be an example of this. Characteristic, as well, are the great changes within the apparently very conservative food industry. This technological progress is also being dictated by the competition in the world market, which can be exemplified by the constant advance in the construction of machines, motor-cars, ships, and so forth.

2) The rise in the living standards and, consequently, the increased requirements concerning health protection as well as the growing cultural needs and services. Examples may be offered, on the one hand, by the struggle against epidemic diseases; on the other, by the development of television.

3) The transition from machines and technologies based upon comparatively simple laws of physics where every success was determined by practical knowledge and by the designer's intuition — to machines and technologies based upon the utilization of complex physico-chemical effects, the mastery of which calls for thorough scientific studies; this may be exemplified by the nuclear technology or semiconductor electronics exploiting atomic processes.

4) The practical possibilities already obtained and anticipated in the domain of technology, agriculture and medicine which have been opened

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[1] Cp.: *XXII Zjazd Komunistycznej Partii Związku Radzieckiego* (*The XXII Congress of the Communist Party of the Soviet Union*). Warszawa 1961, pp. 573 and 630.

[2] Quotation from the paper of S. Dedijer, *International Comparisons of Science*. "New Scientist", 1964, N. 379.

owing to a number of factors, such as: nuclear investigations, chemistry of polymers, discovery of antibiotics, isolation of nuclein acids, and so forth.

5) The tragic but indisputable fact of the immense influence exerted by armaments upon the direction and extent of scientific research in some countries.

The general laws of economic behaviour, and more particularly the pursuit of the most effective solutions apply fully to the appreciation of the effects of applied research. The comparative calculation is usually favorable to solutions based on new scientific results. Sometimes, however, this proves to be the case only after a certain critical point has been passed, the product obtained with the new method being initially

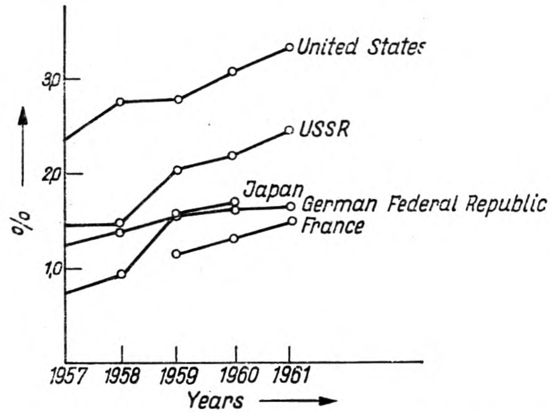

Fig. 1. Research expenditure in percentage of the gross national product in some countries in 1957—1961. Based on: *Étude bibliographique comparative sur les dépenses à la recherche scientifique et technique (de 1957 à 1963). Document de travail du secrétariat Unesco.* Paris 1963

more expensive (at times even much more expensive) than that obtained with the traditional method. Such was the case formerly with the production of plastics, so is the case now with the energy obtained in nuclear reactors. In cases like these, the economic calculation continues to be a factor hampering any bold investment, and simultaneously forcing further research with a view to perfecting the production process.

The variety of tasks posed before science by the national economy has given rise to an enormous extension of research centres. There has been a considerable increase in the number of scientific workers, and a still more considerable one in the costs of research work, reckoned both with respect to one working post and, the more so, in absolute figures.

One of the most conclusive indices for the general appreciation of the development of science and — at the same time — of its increasing social significance is the share of the gross national product devoted to research expenditure. There could be raised, indeed, some substantial objections about how the above index is being computed in particular countries; none the less the level of expenditures on science and their changes can be described thus with an adequate precision (Figure 1).

In general, the development of scientific research is more rapid than that of the production itself, and this tendency is showing no signs of slackening. It may be anticipated, therefore, that the percentage of gross national product, destined for research, will continue to grow. One should not believe, of course, that the said increase will be of linear character. It will certainly proceed along a logistic curve showing a point of inflection, and afterwards tending towards a certain horizontal asymptote [3]. When taking into account the perspectives of a further development of biochemistry, of utilizing nuclear energy, of applying plastics, of exploring outer space, and so forth, it may be anticipated that the inflection of the curve will not take place until a lapse of several or even of more than ten years, the national product share destined for research will probably be stabilized at the level of at least 4—5 per cent.

The concentration of research, to be observed nowadays in the great centres of technologically leading countries, is bound up with the increasing stratification of the world level of science to the detriment of less--developed countries.

There exist, at present, immense disproportions in the domain of expenditures on science: in the leading countries *per capita* research expenditure is more than ten dollars or, in certain cases, more than twenty dollars, whereas in the less-developed countries the corresponding figure is only dollars 0.1—0.3. Those disproportions, moreover, are not being obliterated with the passage of time but become more and more marked.

The above phenomenon is unfavourable not only from the human point of view, but also because it hampers the feedback between research and the economic and cultural requirements of the less-developed countries. It is only to an insignificant degree that the international organizations, such as Unesco, succeed in solving this problem. One factor attenuating the consequences of the stratification is the fact that the geography of the utilization of research need not necessarily correspond to the geographical distribution of research centres. In particular, the international institutes may radiate influence far beyond the frontiers of the country in which they are situated. It may be said, therefore,

[3] Cp. e.g.: D. J. de Solla Price, *Little Science, Big Science*. New York — London 1963, pp. 20—21.

that the proper popularization of the results of research work is, at least for the present, the main way towards surmounting the disproportions in the development of science between nations, and towards completing the circuit of feedback between theory and practice in the countries now on the way of development.

The above-mentioned feedback brings about not only a quantitative growth of research work, but also certain changes in its scope. The most characteristic phenomenon is, at present, the increasing significance of basic research, more particularly the rapid development of directed basic investigations, which was not very widespread in the past. On the whole, about 7—15 per cent of general expenditures on science are now being assigned for basic research in certain countries, whereas that index, twenty years ago, was fluctuating between 3 and 8 per cent.

The reasons for the increased importance of basic investigations reside in the very essence of the trend towards the "vertical" integration of science. For the experience of the last years has shown that the creation of a theoretical reserve, that is, the prosecution of research not connected with the direct and present-day requirements of practice, is exceedingly worth while, since it offers potential possibilities for a rapid leap towards quite new constructions and technologies. A classical example may be the works on theoretical physics in the United States on the eve of taking up the decision about starting the atom bomb production; it is, moreover, owing to the high level of theoretical mechanics that the hard problems of rocket and supersonic aircraft flight have been quickly mastered in the course of the last 25 years.

The further increase of links existing between the basic and applied research has become, at present, a very difficult matter and, at the same time, a very pressing one.

The deep-going specialization, stimulating the formation of a hermetic language within the particular sciences, as it is the case e.g. of mathematics, gives rise to increasing difficulties. On the other hand, however, the development of collective research, exemplified by the participation of physicists and biologists in the activities of factory laboratories, paves the way for such an integration. It appears, then, that there will emerge in the future a tendency towards combining both basic and applied research within a single scientific institution, with the simultaneous deepening of the division existing in that field between the research teams.

A considerable integrating influence is being exerted by the growing pace of scientific research, especially of the applied and developmental ones, owing to which the tune-lag between the establishment of physical foundations of an invention and its being put into practice is steadily decreasing. So, for instance, photography once waited more than a century for the practical realization of the already known principle, and the telephone more than fifty years. In this century, the above distance has still been of 15 years for the radar, but already no more than 6 years for the atom bomb and merely 2 years for the maser. In certain cases we have even to do with a "negative" time when the physical principle is being discovered empirically in a production plant and only later on supported theoretically; an example may be the discovery of the influence exerted by the changes of the dislocation structure of material on its own mechanical properties.

Once a new phenomenon has been discovered, the research work begins, at present, to develop in parallel in many laboratories, resulting in a veritable avalanche of publications (this phenomenon is illustrated by Figure 2). Such a parallel prosecution of basic investigations results

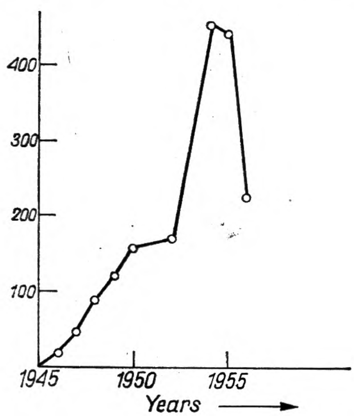

Fig. 2. Numbers of articles and *communiqués* on the scope of Quantum Radiophysics (Microwave Spectroscopy and Radio Spectroscopy of solids and gases, radiation quantum boosters = masers), published in the American monthly "Physical Review" in 1945 to 1956; the maximum occurring in the period of building the first gas masers. Based on an elaboration by Mrs. A. Jankowska, M. Sc.

in their subsequent acceleration and their turning almost to the style of sporting competitions; for there achieves recognition only he who is first to publish certain results. This rapid pace of basic research, moreover, is bound up with a rapid obsolescence of its results, which is illustrated by Figure 3.

"HORIZONTAL" INTEGRATION OF SCIENCE

The tendency to a "vertical" integration interlaces indissolubly with the tendencies to a "horizontal" integration consisting in the mutual penetration and overlapping of traditional disciplines, as well as in the concentration of various kinds of research around the complex problems.

One often opposes the specialization to the "horizontal" integration. These trends, however, are not altogether contradictory, but they supplement each other to a great extent, for the development of teamwork methods enables a co-operation of various branches of knowledge.

The "horizontal" integration of science proceeds along different, and frequently quite dissimilar paths. One may distinguish, however, two basic kinds of integration: integration around a problem and interscience integration, there existing also some transitional forms.

The integration around a problem is closely connected with the "vertical" one. It was and is appearing at quite a number of practical applications of science, and with a particular clearness at the big engineering works and the preparatives for military actions. It is, however, not until the last quarter of a century that both the frequency and the range of this kind of integration have become so considerable as to condition in great measure the development of research as it does at present.

An already now classical example of such a "horizontal" integration are the investigations dating from the period of the Second World War, in the matter of radar and guided missiles (on the basis of the latter

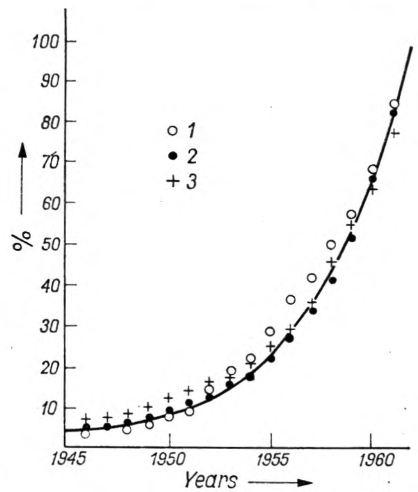

Fig. 3. Percentages of citations in physics journals (April to May, 1963), originating before a given year. The diagram comes from the article by S. Dedijer, as cited in footnote 2

1 — "Nuclear Physics" (Great Britain);
2 — "Physical Review" (United States);
3 — "JETP" (U.S.S.R.)

research arose — as is generally known — cybernetics). In the post-war period, a considerable part of expenditure on research in scientifically and technologically leading countries is destined for the two complex and integrating problems: utilization of nuclear energy and cosmic research. In the United States, for instance, more than 8.5 per cent of the general research expenditure are being allocated for each of those problems.

Two kinds of integrating problems may be distinguished. For the "centripetal" problems, the integrating factor is the object of research, for the "centrifugal" ones — the common method or instrument of research (for instance, the source of isotope radiation).

A "centripetal" problem is for the most part a clearly set task, for instance, the fight against cancer diseases, the construction of nuclear-power plants, and so forth. A task like that is usually of a practical character, that is to say, both kinds of integration, the "horizontal" and the "vertical" one, are interconnected here. At times, however, the "vertical" integration does not clearly occur in such investigations. Let us mention here, for example, cosmic research which is at present of a mostly cognitive character, though being linked with a far-reaching hope of practical advantages in the future. Science itself is becoming, too, one of the "centripetal" problems, since the various aspects of its development are dealt with by a group of selected departments of many disciplines, bearing a common denomination: science of science (or: science of scientific activity).

In the case of a "centrifugal" problem, the common method or instrument may be applied in various domains of science and practice which are sometimes linked with one another in that manner only. So, for instance, the investigations concerning the influence exerted by the radiation upon plants have little reference to the radiological detection of faults, they are, however, interconnected due to the radioactive isotopes being applied in both cases. Consequently, both the agriculturist and the technologist, while using isotopes, are using the same language: the denotations of irradiation units, the classification of isotopes, and so on. A closer direct connection, bearing the character of a "vertical" integration, occurs in this case between the agriculturist and technologist on the one hand, and the specialist in isotope physics and isotope technics — on the other. The agriculturist, for instance, must be able to estimate what type of isotope source would be suitable for him and to know how to use it; the designer of isotope equipment, on the other hand, ought to be aware of what purposes the apparatus designed by him should serve and in what conditions it would work.

The integration around a problem consists rather in a joint command and strategy of research than in its substantial connection, though, in fact, it presupposes a substantial link between the particular sections of research work. The complex investigations of that kind are being carried on, as a rule, in a collective way, each of the collaborators performing some determined tasks within his own speciality while acting as a committed and committing party in relation to other research workers.

In the case of such tasks, there must however act, in addition to specialistic panels, a co-ordinating team whose members, or particular individuals acting its part, have to show an extensive knowledge or at least orient themselves in all the questions comprised with the integrating problem.

On account of the extent of expenditure which is mostly necessary for conducting the complex research work, the initiative of taking it up most frequently rests not with the scientists, but with the state or with the business organizations. It is more and more often, besides, that the initiative and general co-ordination of such research, simultaneously conducted in various countries, passes to international bodies, this being already to-day the foundation of the importance and authority of such organizations, as World Health Organization, Food and Agriculture Organization, World Meteorological Organization and others.

A specific kind of the integration around a problem are the investigations concerning the effects of scientific and technological activities. Technology connected with science has become not only a considerable economic force, but also a force conducive to determined social changes, and a natural force as well, introducing important changes into animate and inanimate nature. In those spheres, the effects of technological activity may be not only positive, but also negative. It can, for instance, entail an intensification of social conflicts as it happens, for example, in the cases when the automation insufficiently prepared from the viewpoint of employment problems leads to unemployment. It also can negatively affect man's natural environment. So there arises a need for all-round inquiries into the effects of technological activities, both natural, dealt with by man's ecology among others, and social, investigated by sociologists and economists. An example of a far-flung social research of that kind are in Poland the investigations concerning the socio-economic processes taking place around the arising new big industrial centres (Płock, Puławy).

Of a different character are the interscience integration processes. The integration takes here place within the very process of scientific cognition when it is necessary to reach for methods and stocks of information, originating in various disciplines, in order to get a full description and comprehension of certain phenomena. The mechanism of the integration may here act in different ways.

1) At the contact point of two sciences, there arises an interscience drawing to an equal extent from the methods and information of both the disciplines; as typical examples may here serve: biochemistry and history of science.

2) One of the disciplines is dominating in this "border strip" while the second constitutes but a certain additional substratum or supplement; so, for instance, the designer of machines must be familiar with problems of electronics, the phonetician — with those of acoustics, etc.

3) One of the disciplines utilizes the other one as a research method; a typical example thereof may be here mathematics made use of in the activities of natural sciences, and in the recent years to an ever-increasing extent of the social ones, too. Out of this combination, there may arise a new discipline, as for instance biometry, econometry, etc. During the recent ten years or so, a role analogous to that of mathematics has begun to be played by the cybernetics.

4) The combinations may comprise the fundamental assumptions of

certain sciences and some divisions of philosophy, in particular the theory of knowledge. Those combinations recently became intensified as a result of the progress in the cognition of the micro- and macro-structure of the universe as well as of new discoveries in the field of biochemistry and genetics. In connection with this, there has been an increase of scientists' interest in philosophic problems and there has also become stronger, in the consciousness of philosophers, the awareness of the necessity to draw consequences from the achievements of contemporary knowledge. A characteristic example of these trends is the broad discussion on this topic, being recently conducted in the scientific institutes of the Soviet Academy of Sciences.

With interscience integration the interpenetration of sciences reaches far deeper than with the integration around problems. It is not enough here to issue orders to the neighbouring field of science, here one has to know how to use its methods by oneself. Thus, it does not suffice to have, for instance, a team of biologists and of chemists — necessary are here genuine biochemists, well versed in operating with methods specific for both of these sciences.

The immediate causes of interscience integration are thus the actual needs of science. In this case the problems of organization and of co-ordination arise as secondary effects. Thus development of biochemical institutions (for example) was a result, and not the cause of integration processes occurring within science itself, due to the initiative of the scientists themselves.

Seeing the "horizontal" integration processes occurring more and more frequently in the recent times, one may formulate the following conclusions.

I. The importance of complex problems for the general development of science keeps increasing constantly, as collective efforts lead more and more often to the solution of great scientific problems. The more important and more responsible task is thus becoming the choice of such problems and of the proper research strategy. The development of research of this type leads to the rise of scientific problem institutes, sometimes replacing the discipline-bound centres, and this tendency is likely to deepen in the future.

II. It is the collective teamwork that is decisive for the success of complex research. The studying and perfecting of collective research forms is therefore one of the main problems of the contemporary organization of science. It seems that the international scientific organizations ought to undertake more extensive studies on this problem from the viewpoint of psychology, sociology, and organization of the fields of scientific activity.

III. In view of the huge means needed for complex research the international co-operation in this field is now becoming particularly important. Special protection and care is to be devoted to such international scientific contacts as tend toward a common, or at least co-ordinated, solving of the great research problems, as it is already happening to some extent in the sphere of nuclear and cosmic research. Another positive example are here the big Unesco and ICSU research programs, as — for instance — the Years of the Quiet Sun, or the biological program. A valuable element in the scientific-organizational activities of this type may be the research work conducted by Unesco on the present--day developmental trends of science.

IV. The interscience integration overthrows traditional divisions of science, and creates new branches of scientific activity. This entails consequences for the organization of academic training, with the view of deepening the theoretical teaching basis and extending the specialization frames.

V. As it appears, the integration by problems is likely to show the following trends in the near future:

1) further stress on problems of basic knowledge concerning the "cultivation" of our planet; examples of such integrated "centripetal" research already planned might be: the hydrologic decade, investigations into Earth's mantle, oceanographic research;
2) there will continue the development of research work concerning basic problems bent on extending the field of our science; it is here that belong, among others, the activities in cosmic, genetic, and nuclear research;
3) of an increasing importance will be problems, the solution of which aims at improving mankind's living conditions; it is here that the problems of fighting epidemic diseases, search of new food bases (photosynthesis, synthesis of albumens), research work on man's ecology in contemporary conditions, come in;
4) it is probable that for some time there still will be conducted research work with the view of improving military equipment.

VI. In the sphere of interscience integration there seem to take shape the following tendencies:

1) the rise of various border disciplines between the exact and the biological sciences (as, for instance, biochemistry, bionics, etc.);
2) the creation of new disciplines, based upon a wide utilization of mathematical and cybernetical methods (as, for instance, econometry, sociometry, mathematical linguistics, etc.);
3) the penetration of physics into applied disciplines, this provoking a regrouping within the range of classical applied sciences;
4) an ever tighter linking of social sciences with natural and applied sciences.

THE STRUCTURE OF THE DEVELOPMENT OF SCIENCE AND THE PACE OF ITS DEVELOPMENT

The pace of scientific development increases so vehemently that it becomes necessary to analyze the results of this pace for the structure of the development of science.

It is possible to distinguish, in the development of many scientific disciplines during the recent centuries, cycles composed of periods of slow gathering of information, and of periods of determined qualitative changes that may be termed scientific revolutions [4].

Such a revolution introduces new bases into a certain scientific discipline, comprising: the general scientific law, or a collection of such laws, the way of approaching a determined group of phenomena, the range of detailed problems possible to be solved on this basis, the model ways of solutions, the general features of the relevant scientific equipment, etc.[5]. Tracks are being thus created on which science proceeds step by step, solving ever more complicated problems of determined types by ever more improving methods. Thus, for instance, the eighteenth and nineteenth century mechanics of the Heavens was solving — on the foundation of Newton's laws and by means of methods indicated by him — the successive problems connected with the movements of planets, their satellites, and comets, applying ever more exact and subtle methods of mathematical analysis, at that.

The foundations of a given discipline, introduced by the scientific revolution, get codified in manuals, and are being taught in schools and in institutions of higher learning as indisputable scientific achievements, and scientific workers specialized in the relevant topics tacitly regard them as the only possible research bases. Conviction of this kind is strongest in narrow specialities, sharply separated from the remaining fields [6].

Sooner or later, however, the constant refining of research methods

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[4] The analysis of those cycles for the exact sciences, and in particular for various branches of physics and chemistry, has been made by Thomas S. Kuhn in his book *The Structure of Scientific Revolutions*. Chicago—London 1962.

[5] Kuhn calls such bases "paradigms", determining them as "universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners" (*op. cit.*, p. X).

[6] The situation in such fields is very aptly characterized by Mr. Alvin M. Weinberg, Manager of Oak Ridge National Laboratory in his article: *Criteria for Scientific Choice*, published in N. 2/1963 of the British "Minerva" periodical: "The scientific literature in a given field tends to form a closed universe; workers in a field, when they criticize each other, tend to adopt the same unstated assumptions. A referee of a scientific paper asks whether the paper conforms to the rules of the scientific community, to which both referee and author belong, not whether the rules themselves are valid" (p. 162).

and the utilization of same towards ever different phenomena lead to the discovery of some anomalies, i.e. of phenomena or problems, the clarification or solution of which is not to be achieved on the foundations being in force. Such an anomaly in relation to classical physics were the results of Michelson's experiments, and in relation to Newton's mechanics of the Heavens the deviations of the perihelium of Mercury. The assertion of anomalies is — as a rule — possible only on the ground of a highly developed research at a given stage of science, as it is only then that, against the background of the perfectly arranged material, become clearly distinct the anomalies infringing upon the order prevailing in the given field.

The revealing of the anomalies, as well as the discovery of essential contradictions in the foundations of the given discipline as a result of those anomalies getting multiplied, may lead to the attempts at clarifying them through a subsequent subtilization and articulation of the methods already known, through a partial change of the foundations then accepted. Or it may give rise to the search of new bases for the given discipline, that is, to the preparation of a new scientific revolution. Thus, for instance, the experiments of Michelson initially induced Fitzgerald and Lorentz to articulate the ether conception then valid, whereas Einstein accomplished a scientific revolution, by giving completely new bases to physics.

The change of the foundations of science alters as well the picture of the world seen by it, with which some of the problems fade away from the field of vision, while others are denied their scientific features. Such a splendid scientific achievement, as e.g. Newton's gravitation theory evaded the question concerning the essence of gravitational forces[7], introducing without any explanation some remote action, while previously Descartes, on reducing the whole of physics to the study of contact interactions between elementary material particles, tried to give a physical interpretation of the essence of gravitational phenomena in his vortex theory. It is not until two centuries after Newton that the theory of relativity in some measure reverted to the Cartesian problems, giving a new explanation of the essence of gravitation. Thus, science does not proceed through successive relative truths to the absolute truth in a monotonic way; it shows hesitations, the axis of which only asymptotically draws nearer and nearer to the absolute truth.

The constant acceleration of the pace of science development results in a shortening of the duration of the cycles of that development, concisely described above. Aristotle's theory of gravitation lasted for two

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[7] Newton himself was inclined to look for the answer to this question in supernatural activities.

thousand years, that of Newton — only two hundred, indeed; the atomistic-corpuscular theory of Dalton-Avogadro, based on the assumption of the indivisibility of atom, underlay the views on the structure of matter for one hundred years, Rutherford's and Bohr's theory of atom structure — just no more than ten years or so.

The acceleration of development cycles, however, does not mean their fading away. There seem to be no marks indicating that science might start developing in an evolutionary and cumulative way without passing — in accordance with the general laws of dialectics — through the qualitative changes, that is to say, through scientific revolutions. Figure 3 is evidence, too, of the profundity of changes occurring in physics. The shorter become, however, the cycles and more frequent the scientific revolutions, the more important is it to facilitate, with the appropriate means of scientific policy, the course of the cycles by levelling or eliminating the factors that impede that course, i.e. handicap the progress of science.

Under the factors that stabilize the foundations of the scientific discipline, being valid in a given period, undoubtedly belongs the teaching of those foundations in schools and institutions of higher learning in a way suggesting their indisputability and integrity. Another factor acting in the course of years of research work is the tendency towards confining oneself to a certain narrow group of themes [8]. The consequence of the above two factors was and is the fact that the scientists abandon the foundations, upon which they were reared, only with reluctance, so to say under compulsion, and that they offer resistance to the ideas and conceptions diverging from the above foundations.

It is then no accident that the new foundations of science were being created, more often than not, either by young scientists (Einstein, Bohr, L. de Broglie) or by those having freshly engaged in a given discipline (Newton, Dalton, Pasteur), that is to say, those having not had the time to acquire a routine handicapping the progress. Such a situation remarkably contributes to slow down the pace of scientific development.

A handicapping influence may be exerted, besides, by extra-scientific factors, first of all by those ideological and social, opposing such

[8] The eminent Soviet physicist, L. A. Arcimovitch, described this phenomenon in his paper *Some Regularities in the Development of Physics* published in the collection *Диалектический материализм и современное естествознание*. Москва 1964 (*Dialectic Materialism and Contemporary Science*), as follows: "A calm and quiet life in the conditions of an extremely narrow specialization with a complete lack of interest in what is going on at the neighbour's, unfortunately happens frequently enough in some scientific institutes. Achieving a great discovery is, under these circumstances, as difficult as the purchase, so to speak, of Aladin's lamp in a department store" (p. 36).

new scientific theories as could endanger their development or undermine their existence; it is enough to remember the opposition of religious institutions against Copernicus's system or against the theory of evolution; still more examples, and of a more present interest, at that, are offered by social sciences.

Various manifestations of conservatism in science are linked with greater or smaller retardations in its development and provoke — with the scientific workers — a considerable waste of time and energy, used up both for surmounting the resistances and for rather unproductive research conducted on the base of already outdated assumptions.

Under the means of overcoming that conservatism, which are at the disposal of the scientific policy [9], belongs, firstly, the breaking of the isolation of specialized scientific groups that are able, indeed, to achieve favourable detailed results based upon valid mental foundations and schemes of action, but easily become bearers of an opposition against scientific revolutions.

The tendencies towards the integration, both "vertical" and "horizontal", as discussed above, are then of importance not only on account of the ever closer connections of science with the requirements of national life, but also on account of the needs of the internal development of science.

The second group of means intended for fighting conservatism includes the reforms within the system of training the scientific workers, so that they might not only get prepared for work on the basis of an up-to-date theory, but also become able, if not to provoke, then at least to recognize and conform themselves to the scientific revolution. The system of education is so far characterized by the tendency to present to students, and even to young scientific workers the given discipline as a collection of logically connected propositions representing with the greatest possible faithfulness a determined section of reality, it being understood that the gaps still existing in that representation may be sooner or later filled on the basis of the known laws and tested methods. Such a direction is frequently given not only by the lecturers of an average calibre, but also by outstanding professors. That situation is characterized as follows by the creator and governor of the National Institute of Optics at Arcetri near Florence (Italy), Professor Vasco Ronchi:

"Chaque chercheur veut se donner l'illusion d'avoir découvert la «Vérité», même s'il doit pour cela détruire quelques «vérités» pressenties par ses prédécesseurs. Pour convaincre élèves et collègues que celle qui vient d'être découverte est une «Vérité vraie», il faut oublier que toutes

[9] It is not a question here of administrative measures, which are not relevant to the general problem of scientific policy.

les vérités scientifiques sont provisoires même les plus durables. Il existe toujours une tendance inconsciente à transformer la vérité en dogme" [10].

The tendencies towards dogmatizing the higher studies have recently undergone a subsequent intensification in connection with a considerable increment of the number of students, which must have led to a certain disindividualization of studies, in a sense, to their mechanization. In the post-graduate preparation of the scientific personnel, those tendencies do not manifest themselves so sharply. The ever wider introduction, however, of an exact division of labour in the scientific institutions, based on a far-flung specialization of workers, leads, as well, to a disindividualization of scientific workers [11].

Higher teaching, and the more so training of scientific workers, can not be then reduced to mastering assumptions just at the moment valid in the given discipline, and its laws and research methods. It ought to consist, to a large extent, in working out an ability to accept a critical attitude towards those assumptions and methods, with simultaneously preventing a narrow specialization. This requires, however, one's getting rid of the ballast of knowledge mastered purely or to an overwhelming degree by heart, thus of all the information easily available from a handbook, manual, or dictionary. This concerns as well the rules of a determined proceeding in determined research work conditions — which does not deny the necessity of getting acquainted on well selected examples with the research techniques characteristic for the given discipline.

The history of science can be of considerable importance to the antidogmatic training of scientists, for as professor Ronchi words it: "... *l'Histoire de la Science est précisément là pour démontrer que toutes les vérités scientifiques sont provisoires*" [12]. This, of course, does not mean that university or a doctor's graduate training of physics, for instance, may be replaced by teaching the history of physics, nor does it mean that introducing the history of physics as a new vast matter would be suitable and appropriate. Lecturing on physics ought, on the contrary, be conducted to a great extent in a way both historical and philosophical, with discussions on fundamental assumptions, both matter-of-fact and methodological changing with successive periods of the development of science.

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[10] V. Ronchi, *Considérations et expériences concernant l'enseignement de l'histoire de la science.* "Organon", 1964, N. 1, p. 281.

[11] In his already quoted paper, L. A. Arcimovitch writes about it as follows: "We should... inculcate in our young scientific workers the disgust for a narrow specialization devaluating the whole preparation obtained by the scientific worker during his studies in a higher school, contracting the range of his interests and eventually transforming him into a skilled preparator only" (p. 37).

[12] Cited paper, p. 281.

INFLUENCE OF NEW SCIENTIFIC EQUIPMENT

The contemporary development of new equipment serving for scientific work is characterized by two trends, first of all: the introduction of ever more complex and ever more expensive devices, as well as the increasing application of cybernetic equipment.

Investigation into intricate physical and chemical phenomena, getting acquainted with the structure of microcosmos on the one hand, and with the general structure of the Cosmos on the other, the development of molecular biology approaching the discovery of the profound mechanism of the phenomena of life, reconnaissance aiming at extending man's expansion beyond Earth — all this requires new, ever more sophisticated equipment. Its high costs, besides, making scientific research work more and more dependent on the aid of the state or on the assistance of powerful financial groups constitute one of the elements of the "vertical" integration, i.e. of the feedback between scientific research and practice. This expenditure, often exceeding the actual possibilities of middle and smaller countries, stimulates international scientific co-operation, an example of which may be the international nuclear research institutes (Centre Européen des Recherches Nucléaires in Geneva, the United Nuclear Research Institute in Dubna).

The development of the research equipment induces some changes in the character and in the system of scientific work as well. It aggravates the specialization of scientific workers, bringing it sometimes to an intensive division of labour. The costliness of the equipment also sometimes leads to the reversal of previously existing principles of the planning of scientific research: it is no more the scientific worker who selects and matches the equipment to the programme of the research conducted, but the scientific workers are chosen for working out information that may be furnished by the equipment established.

Science is getting transformed at present into one of the production forces. With it is connected among others a certain assimilating of the character of scientific work to that one in a big mechanized industry, since operating some intricate equipment shows some features analogous to the operating of machinery. Of course the division of labour does not extend to the point of the scientific worker becoming "a mere addition" [13] to the equipment, in particular in view of his being able to have at his disposal technical workers for assistance. Nevertheless the development of the equipment evokes certain trends towards

[13] The *Communist Manifesto* thus determined the position to which the machine was reducing the worker in a mechanized industry.

a narrowing of the scientific worker's qualifications, thus toward their degradation at that [14].

Another factor stimulating the specialization is the constant and swift increase of the stocks of scientific material, which — first of all — finds its expression in the growing avalanche of publications. Estimates show that the scientific books published every year may be counted in tens of thousands, and in the about thirty thousand scientific periodicals appearing at present there make their appearance at least half a million of papers [15]. In the result, there immensely grows the part of the scientific worker's time devoted to his getting acquainted with the scientific publications i.e. to not creative but receptive work.

A considerable portion of a scientific worker's time is being used up, too, for activities connected with the preparation of material, that is later — together with the material drawn from reading — to be the foundation for creative research. The preparing of material requires creative work as well, though: the choice of testing devices and of their utilization, the planning of the mathematical method for processing the data obtained from the experiments or observations, the setting of a key for archivistic investigations or statistical elaborations; a considerable part of time in this stage of research work, however, is devoted to work deprived of creative character: the performing of observations or experiments according to some method once established, of standard calculations, the looking through of records material, the elaboration of statistical data, etc. It may be generally stated that a scientific worker uses up the major part of his time for non-creative, unproductive activities [16].

Out of this results the great importance that the reduction of the non-creative part in the work of scientific workers has both for the intensification of scientific research work and for the overcoming of narrow specialization and for the realization of integrating trends.

The measures aiming at releasing scientific workers from non--creative work, that were being introduced until recently, were of strongly limited character and range. They lay in the division of work on the one hand, i.e. in transferring a part of the preparatory work onto the attendants and the laboratory hands, and in the rationalization

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[14] L. A. Arcimovitch writes about the transformation of the scientific worker into a "skilled preparator". Compare footnote 11.

[15] Compare e.g. the cited book by D. J. de Solla Price, p. 8.

[16] For the historical science it has been estimated that the time of creative work barely amounts to ten per cent of a scientific worker's time destined for research work. Compare the article of G. M. Dobrov, *Badania historyczno-techniczne a cybernetyka* (*Research in the History of Technology and Cybernetics*) in "Kwartalnik Historii Nauki i Techniki" ("Quarterly Journal of the History of Science and Technology"), N. 1/1965.

of library and bibliographical information, in the publishing of abstracts, in the acceleration of calculations by the introduction of logarithms, of the slide rule, and of the arithmometer, in the application of standard measuring devices, etc., on the other.

There is progressing, however, to an ever greater extent in the recent years the realization of new revolutionary technical devices that may, and indubitably will, introduce essential and qualitative changes into the work of scientific workers. Those cybernetic devices are already to-day able to take over and to multiply the functions of human memory by gathering and storing huge amounts of information in a way that makes possible a swift and convenient obtaining of data looked for; they also can transform that information by applying mathematical and logical operations. Already widely known are the applications of modern cybernetic equipment for immensely accelerating calculations of various kinds, for translating scientific texts from one language into another, for the seeking of optimal solutions, for medical diagnostics, etc. There are being conducted attempts, as well, aiming at utilizing that equipment for historical research [17].

There are becoming ever more widespread, too, automatic measuring devices that are able to directly convey measurements to cybernetic units in order to store them in the latters' memory, or for transforming. In a similar way — without man's participation — there can be made visual observations (as, for instance, by the equipment of artificial satellites) and their results recorded on films first, and then — in a suitably transformed shape — preserved in the memory of cybernetic equipment. Of particular importance is in this instance the automation of the big and expensive equipment, that is releasing the scientific workers from tediously operating it and thus making possible the obtaining of data from areas unaccessible — at least for the time being — for man, as for instance, from the surface of Moon.

Such a development of cybernetic devices leads to the transferring to them, to an ever increasing extent, of the non-creative elements in the scientific work, and — taking it more generally — in intellectual work, thus leaving to the human mind the creative work, first of all. And since the memory of cybernetic equipment can be more voluminous and more efficient than the human one, there will be diminishing the need of charging man's mind with the ballast of information, that is going to be better conserved and elementarily transformed by cybernetic devices.

The range of operation of cybernetic equipment is at present still far from its theoretical possibilities, of course, and many a real technical solution far away from economical workability. Such devices are already

[17] Compare, for instance, the cited article by G. M. Dobrov.

setting, however, the direction of development for the oncoming decades, by leading towards a reduction of the percentage of time devoted by scientific workers, and by intellectual workers in general, to non-creative work, in a similar way as the manual worker is being released by the development of automation from his role of being a "mere addition" to machinery.

Prospects of this kind ought to have already now their effects onto the methods of higher training, and in particular upon the methods of training scientific workers. Once, when asked about the speed of sound, Einstein replied that he was not used to charging his memory with information that can be easily found in encyclopaedias. The modern cybernetic equipment and its anticipated development make it the more possible to eliminate the ballast of rules and symbols from training programs and examination requirements, and to devote the talents and time thus released to developing creative mental factors, that certainly to a very limited extent only can be replaced by cybernetic devices [18]. At the same time this will make possible to overcome the trends towards a narrow specialization, and gradually to extend the scientific horizons of the young research workers.

Thus is science, inseparably linked with technology in our era, supplying by itself the means and measures for overcoming the trends toward an exaggerated specialization that threaten its development, by creating conditions that favour integration, and by the same token the fight against dogmatism as well. It is the task of science policy, and to a particularly great extent the policy of training scientific personnel [19], to see to a swift taking advantage of those possibilities. In this problem among others, we recognize the importance of the new scientific discipline — the science of scientific activity.

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[18] A separate discussion will be required by the question to what extent the stock of information recorded in human memory is indispensable to the creative work of mind, since it is obvious that the shifting of the whole stock of information to the cybernetic memory will never be possible. The question of the mind's adaptability to the new working conditions will require, however, suitable thorough investigations.

[19] Some problems connected with this are being dealt with in a more extensive way in the paper by E. Olszewski, *Struktura rozwoju nauki a istniejący system kształcenia pracowników nauki* (*The Structure of the Development of Science and the Existing System of Training Scientific Workers*). "Życie Szkoły Wyższej" ("The Life of Higher Schools"), N. 12/1964.