THE ROLE OF AXIOMS AND MODELS IN THE THEORY OF PHYSICAL KNOWLEDGE I.

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Introduction

For the recent development of exact sciences and particularly for that of physics the following are characteristic:

1. By experimentalist working with developed technics, a high number of properties of matter and physical phenomena differing to a considerable extent from that of the hitherto known properties, moreover contradicting them, and often quite striking characteristics are recognized within a relatively short time.

2. The conceptions and theorems of individual branches of sciences were becoming quite abstract and individual concepts and laws were also used in other branches of sciences. Thus, the content of concepts, and laws, respectively their extension, during a short period undergo such considerable changes which might be justified, sometimes considered with good reason as being revolutionary ones.

3. The increasingly thorough revealing of the manifold properties of nature, in organic connection with each other leads, however, to the differentiation of the individual branches of sciences.

The properties enumerated in the above three points, characteristic for exact sciences are consequences of the development of human knowledge. Human beings are penetrating ever more profoundly into the knowledge of objective reality, which requires the supervision of old theories, a new interpretation of traditional concepts which the abundance of material calls for specialization.

The above-mentioned three factors which are closely related to each other, are characteristic for all natural sciences, but most plastically they appear in physics. Thus, contradictions prove to be the most exponent here and, therefore, can. be solved within the shortest time. In our paper problems exclusively arising in physics are dealt with, though most of them can be — mutatis mutandis — refer to problems of other natural sciences too.

Difficulties encountered owing to the above mentioned reasons are experienced in scientific research work as well as in teaching. The main difficulty consists of the fact, that researches and also the high level teaching staff can keep step only with the development of a single branch or only of a few branches of physics, whereas they are out-of-date in some other branches at least at a level corresponding to modern results. The backwardness is mainly due to the fact, that the enumerated factors are also acting within a short space of time in a vast number of branches.

The backwardness in details is of course natural and is not detrimental in itself. It becomes detrimental only then when it manifests itself in the interpretation of fundamental concepts and laws, respectively, when it appears to be rigidly insisting on the old content of concepts and laws. The occurrence of both factors may result in serious mistakes in regard to research, teaching, and hinder the correct formulation of ideology of an individual person, respectively, hinder the elasticity of the already developed ideology of dialectical materialism.

It is known that in the process of recognition we are going over from observation, from the experiment to theoretical considerations and from that again to experiment, i.e. to practice. Though the relations contained between this tripartition have already been thoroughly examined in several excellent works by the classics of Marxism and the problems which arose have completely been solved within the frame of dialectical materialism. The interaction between theory and practice is, however, so manifold that its discussion from a new aspect is always up-to-date and stimulating to further researchs.

In science and particularly in physics it seems to be appropriate to develop every branch of physics, starting out from possibly small numbers and simple starting conditions, concisely without internal contradictions and in an elegant manner. It is also required that our knowledge concerning reality be easy to survey and the degree of abstraction be measurable. I.e. we have to know the measure of abstraction of the used concepts and laws, as well as their validity limits. Whereas, from the point of view of research it is particularly stimulating to examine whether all the possibilities have been exploited, i.e. whether some further plausible alternatives of the theory have not been omitted.

It is evident that the solution of the raised problems ought to be seen in the increased axiomatization of the branches of physics, and at the same time, in the purposeful development according to the points of view of knowledge and logics of the general models of theory.

The importance of the model formation is therefore evident, and so often emphasized that it is indeed superfluous to go into details even if we are now considering the regular building out of general discipline models.[1]

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[1] Under a discipline model such a general theoretical model of a branch of science is to be understood, which is developed for the simplification of the complicated dynamical and structural conditions of the real world in order to give unambiguously and quantitatively

The importance of axiomatization in physics is, however, less accepted or at least rarely pointed out, though its useful effect has been felt in the case of mechanics and particularly in that of thermodynamics. Considering the importance of the application of the axiomatic method and furthermore, that some people are of the opinion that the axiomatization is an action for an end in itself we deem it as necessary to demonstrate already here the lack which occurs when in a branch of science no axiomatic method at all is used.

The axiomatic method means, that by recognizing the impossibility of determining every concept and to prove every theorem used in a branch of science, the concepts and theorems are retraced to basic concepts and basic theorems, which are to a certain extent, an abstraction of objective reality. Therefore, the scientific discipline in which the relation of the derived concepts and theorems, on the basic concepts and theorems as well as their validity limits are not clarified (at least in an implicite form), then serious difficulties are encountered in formulating a uniform theory for scientific requirements.[2]

In this paper — even if schematically — we should like to show the advantages of the conscious application of axiomatic methods, as well as to make an explicite attempt to connect axiomatism with model formulation at a gnosiological level. More exactly we should like to show, that physical theories whether they are concise or not, are axiomatic model-theories anyway. This means, that at an adequately developed degree of abstraction the properties of individual discipline models can always be characterized by the system of axioms. Finally we hope to succeed in enlightening, to a certain extent, the relation between sensorial and intellectual recognition, so that it may correspond to materialistic ephistemology, but in a way that was hitherto scarcely examined.

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the laws of a class of phenomena and their validity limits. Such a discipline model is for instance the theoretical model of classical mechanics by which the description of state variations related to the pure change of place of bodies with high rest masses and low velocities is given. Similarly the discipline model of classical thermodynamics signifies the totality of quantitative relations and laws valid under the simplified conditions which is determined by the paradox concept of "equilibrium process". The manner and circumstances of the determination of discipline models is dealt with in detail further on. Care should be taken not to confound the discipline model interpreted as the theoretical model of a branch of science with the ordinary concrete concept of a model, of which there will be question also later on.

[2] As it becames evident from the followings, there is no branch of science which were missing the use at least the hidden use of the elements of the axiomatic method. Moreover this method cannot be missed in scientifical views such as the diverse variations of religions in which the statement of the existence of God, Buddha is a basic theorem, an "axiom" according to formal logics. It is quite a different problem that no reality is in a religious ideology based upon the existence of empirically not confirmable concepts as basic theorems. This means, that its axioms are empty from the point of view of the real world and the theory derived from them is false, though not necessarily in contradiction with the theorems of formal logics. We dont want to mention that in the different religious ideologies also from the points of view of formal logics several contradictions are contained. It is however, evident that even not scientifical mental constructions are necessarily built upon basic theorems and basic concepts and this is particularly the situation for theories of scientific requirements.

First of all, we shall show how much theories are in need of axioms. Then philosophical problems related to the concept of the axiom will be outlined.

1. The role of axioms in theory[3]

From a formal logical point of view every science is a certain system of concepts referring to decrees and conclusions which by determined methods may be drawn from them. The concepts, decrees and conclusions are fundamental forms of thinking. Whereas the scientific method is such a general action which establishes connections between fundamental forms of thinking and mobilizes concepts according to the purposes of science. The movement of concepts is the motion of a determined course of thinking, by which to a certain extent the motion of reality is reflected this corresponding to the existing content and volume of concepts.

Every science — thus natural sciences too, — is on the one hand a method and on the other hand a theory. Both are a unity but not of the same identity. The method is the regularized course and relation of basic fundamental forms of thinking as a motion.

Whereas, the theory of a science dealing with a determined domain of reality is a relation of concepts, decrees and conclusions reflecting the objective conditions of the respective topics.

The basic problem of each science is, to what degree and to what extent the concepts and theorems building up its theory are true, i.e. to what extent they might be considered as a good approximation of objective reality. In a more developed branch of science, by which analytical and perhaps also synthetical decrees might be made, the concepts are interpreted by formal definitions, wehreas the formal confirmation of theorems and laws are performed in a deductive manner. The formal definition of a concept is equivalent to giving its exact contents — hence its important characteristics — and extension, i.e. its relation to other concepts. By the definition of a concept, therefore, the knowledge of other concepts, the confirmation of a theorem and that of other theorems is required. Thus, if we want to define in a deductive manner each concept and to confirm each theorem, then either an infinite series of concepts and theorems is achieved or we return to an already previously encountered basic element, thus commit the error of a circulus vitiosus.[4]

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[3] The role of the axiomatic method in mathematics is analysed in detail by A. N. KOLMOGOROV, Great Sovietic Encyclopedy vol. I. page 613 (Russian).

[4] Three main forms of the determination of a concept is known by formal logics, the genetic, the nominal and the real or objective definition.

Though in exact natural sciences all the three methods of determination are used the first two methods are in general not satisfactory and also the objective determination is in general used with the aid of quantities representing concepts in the form of rigorous quantitative relations. In these sciences beside of quantitative definitions in general only the "primary terminuses" as for instance "every", "all", "exists", "no", "and", "than if", "only

In order to eliminate the difficulty encountered in all branches of science, one has to choose individual concepts and theorems, which are considered as being correct without any definitions and deduction. These concepts will be the basic concepts and theorems of the respective discipline. Basic theorems referring to the basic concepts are axioms, whereas the system of axioms of the discipline in question is formed by the system of basic theorems.

Aristoteles already knew that "all sciences should be based on proof, but the knowledge of direct basic theorems cannot be proved."[5] However, a problem arises whether the correctness of basic theorems and axioms within the frame of a given branch of science cannot be confirmed, then according to what criteria are they to be considered as true?

According to the idealists, basic theorems and axioms are a priori ones, and the criterion of their correctness is direct evidence. It was tried to solve this problem by formal logics with the aid of mathematics, so that for all systems of axioms of all disciplines a satisfaction of certain requirements is needed. By these requirements which are known from mathematical logics in the purest form as regards the system of axioms, the existence of completeness; the counterdiction of a free being and that of independence are required. We do not deal here with this problem, as to how this satisfaction of these requirements for a system of axioms could either be or could at all be established. It should be, however, mentioned that even in such an apparently dominantly deductive branch of science as mathematics, we cannot give a positive answer concerning completeness, whereas, concerning the further requirements in some simpler cases only.[6] Thus, it is justified to raise the question whether in general positive replies might at all be obtained.

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then", "then and only then" are playing an important role. Therefore in exact sciences in the majority of cases the way which leads to the definition of a new concept can be followed and the foregoings can be relatively rapidly confirmed.

[5] Analytica posteriora, Vol. 1 Chapter 3.

[6] The description of the examinations of mathematical logical character referring to the independence and completeness as well as contradiction freeliness of a system of axioms cannot be dealt with. Their detailed analysis is not justified, because the real criteria of the correctness of a system of axioms are not these requirements.

Their significance moves only within the frame of formal logics. It should be however, noted that particularly the examination referring to the completeness of the system of axioms is very complicated, because the concept of completeness might have many formulations not equivalent with one another. (Monomorphism, izomorphism, categoricity). On the other hand the three requirements are evidently not to be considered with an identical importance neither for the judgment of the formal logical correctness of a system of axioms. The value of the content of the system of axioms is not influenced by the dependence or indepence of the system of axioms. It makes no trouble if the individual axioms of a system of axioms are superfluous, hence if they are too determined from the formal logical point of view. The problem of independence is thus even as regards formal logics, only an aesthetical problem, the realization of which is endeavoured, but if such cosmetics of a system of axioms requires too much effort — at least at the beginning — so we are rather disregarding neglecting it. This is the situation in the system of axioms of some discipline of physics developed up to now for instance in classicial mechanics, and thermodynamics. There is hence, no reason for having an aversion against the axiomatic method only because at the beginning in a discipline no system consisting of independent axioms can be formulated. For instance Newton's second and third axioms are evidently not independ-

On the basis of the history of development of mathematics, dialectic materialism gives the following answer to the emerging problems.

The fact that in the course of our thoughts certain starting point theorems which are considered as axioms are correct, and also that there is a characterizing property for sciences in which, to the deductive method of developing theorems, a considerable role is given. This has already been the situation since a long time in mathematics, and this tendency can also be observed in theoretical physics which is, to a great extent, differentiated and became very abstract. Therefore, the application of the axiomatic method is also required in physics.

Concepts and theorems of mathematics and even more directly of physics refer to the materially objectively existing world. Thus, for the satisfaction of the above mentioned formal logical requirements — as a possible control — which might be, however, necessary from the gnosiological aspect — concepts and theorems of science can be correct only if they refer to the real world i.e. if details and conditions of objective reality are reflected to a certain approximation by them. The consideration of basic concepts and axioms as the reflections of objective reality, however, means, that axioms are the general results arrived at from the examination of the world, hence they are not starting points but are results. According to dialectic materialism, axioms are not of an a priori origin, neither are statements expressing predestinated harmony in nature, but such products of the examination of an objectively existing reality which have been produced in the course of logical inductions by the continuous control of practice. Therefore, axioms have been created by the historical and logical generalization of empirical results.[7] Thus, they are starting points only for logical thinkers working with deductive methods, and to prove them means to demonstrate their origin. By a concise application of the dialectic materialistic method the roots of the origin of axioms are to be shown in their contents, volume, as well as in their validity limits, whereas, from the changes taking place in the course of time it can be stated, that the basic theorems of a branch of science are formed and developed during the continuous interaction of induction and deduction by the constant control of practice.

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ent axioms, their value is however not affected by this font. Whereas the quick and exact development of the theorems of the theory is enabled. The most important formal logical requirement which should be sustained within a model theory concerning a system of axioms is the requirement of being counterdiction free, (see later on). Further on we will see that the single objective criterion of the validity of axioms is, that they shall be in accordance with our knowledges referring to a determined domain of reality, with experimental experience and with practice.

[7] The following remark is made by Lenin concerning the origin of axioms: "Human mind was completed by the practical activity of man, to repeat the different logical forms in billion and billion of cases in order that they have significance of an axiom". LENIN: Filozófiai füzetek, p. 166 Szikra 1954.

The axioms of no scientific disciplines and those of any branch of physics are to be considered as dogmas, neither are they to be recognized as a result of intuition or as a subjective discovery. Thus, the basic validity of an axiom is not direct subjective evidence, due to their simplicity — the more so because among theorems which can be proved by their aid — there are often those to be found which are more evident as axioms themselves — but their accordance with our further knowledge referring to reality with practice.

2. Experiment and theory[8]

To the fundamental elements of a group of laws, the system of axioms of a discipline prevailing in the real world can be conjugated. The relation between these laws and axioms can only be understood if one knows the scientific historical instances connected to experiment and theory. Further it can be enlightened through the relation of inductive and deductive conclusion methods by experience, theory, practice and social necessity. Our task is, on the basis of historical facts and materialistical ideology, to examine the role of the methodical process of induction and deduction in the formulation and development of physical theories, keeping the constant relation and interaction of experience, abstraction and practice in mind.

In the course of history it has often occurred, that some researchers believed in the omnipotence of the inductive method, whereas others in that of the deductive method, thus emphasizing the primary role of empirism, respectively that of theory. It is doubtless when reviewing the history of physics experimentation is dominant in certain periods, whereas in other epochs the theoretical development prevails. Development of theories takes the direction towards construction of a discipline ever more by using the more general and more abstract method namely the deductive one. This fact is clearly shown also by the history of geometry, astronomy, physics, chemistry, moreover by that of biology. On the other hand, the idea of the possibility of an a priori knowledge is to be found in the longwearing invariancy of Euclidean geometry in those circumstances that the inductive way which leads to it, could scarcely have been followed before Euclides. On the other hand Bacon, Galilei, Newton and Faraday, founders of modern natural sciences. believed rather in regular experimenting. It is, however, doubtless that before the establishment of the Euclidian system of axioms certain observations were also needed, because the first apostles and their followers concerned with regular experimenting were not completely saved from the idea of endeavouring to achieve generalities. Thus one can calmly state that in a given era the proportion of experimental, resp. of theoretical investigations

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[8] The examination of the relation of experiment and physics is dealt with in detail by Max BORN: in his book entitled Experiment and Theory in Physics (Cambridge University Press.)

might increase or decrease, and thus, the relative quantitative relation of applied inductive resp. deductive research methods could change to a considerable extent; but essentially both exist in every epoch. Historically it is evident, that empirism and induction are the primaries, and only if sufficient empirical data are available do the theories of different degrees of development appear. The primary task is to arrange and interprete on the basis of logical and uniform principles the large quantity of empirical material. It is also evident and necessary that at an adequate degree of accuracy the application of a deductive respectively axiomatic method be made possible, by which the development of a branch of science is rendered possible in an exact, concise and elegant manner, and also gives the possibility of arriving to analytical decrees indicating the direction of further development, and perhaps also that of synthetical ones is ensured.

The foregoing have already been several times examined concerning the development of a system of axioms of individual chapters of mathematics (particularly of geometry), and is also confirmed concerning the details. In physics a classical and successful example for axiomatical development is thermodynamics, the axiomatical building up of which took place right before our own eyes, thus these circumstances could easily be followed.[9]

At the end of the last century, classical thermodynamics similarly to classical mechanics and electrodynamics was thought by the majority of physicists essentially to be finished. There was, however, in the assumption of being finished a relevant difference between heat theory, and for instance, theory of electricity. Electromagnetic phenomena known until the turn of the century were correctly described, almost without exception, by Maxwellian electrodynamics, at the same time by classical heat theory only the equilibrium, the so-called quasi-static and, therefore, reversible processes could be described and an account could be given only of the course of non-statical processes varying in time, and, therefore, irreversible. On the other hand it is a well known fact, that macroscopical processes effectively taking place in nature are always irreversible, thus it is comprehensible that a theory giving the description of these processes is very important, as from the scientifical point of view, as well as from that of application.

It is true that since the middle of the last century several attempts were made in order to develop a heat theory of effective dynamic character, in which also an account is given of the course of thermical processes and can therefore be called thermodynamics. However, such a theory could not be

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[9] Of course attempts have been made for and this building up axiomatically every branch of physics, should not be underestimated. Such examinations have, however been made up to now to the highest extent in thermodynamics in which the method applied contributed not only to the pure and exact ordering and development of the theory but also significant new results have been achieved by it. SOMMERFELD in the preface of his work »Vorlesungen über Thermodynamik und Statistik« Wiesbaden 1952 calles thermodynamics the prototype of axiomatically constructed sciences.

founded until the year of 1930. (Since no variations in time occur in classical thermodynamics, and so this discipline is now called thermostatics.) Considering that this problem was already up-to-date at the end of the nineteenth century, some physicists committed everything in order to be successful, thus it is quite clear that owing to this great endeavour many incorrect concepts and theories were born.

We should like to state that some researches spoke of entropy flow divergencies, vortexes without any foundation, as if the only question would be the description of an ordinary hydrodynamic problem as in the case of thermal phenomena. These desperate investigations at the turn of the century warned the careful researchers to partake in an increased vigilance and they had been hereby compelled to repeatedly examine the basic concepts and theorems of thermodynamics (thermostatics) and to rigorously outline the validity limits of the theory built up on the model of reversible processes. The examination and estabilishing of the validity limits of basic concepts and theorems of heat theory was realized by infinitely many repeated processes and these finally led to building up of axiomatic thermostatics.[10]

3. Experiment — model — theory

A system of axioms of a discipline to be axiomaticized those being at an adequate stage of development should simultaneously satisfy the requirements of reality as those of theory in such a way that in theory only concepts abstracted from reality should be used.

Our previous problem again occurs in a more explicit form as follows: what is the degree of abstraction, how generally and how profoundly do the abstracted concepts reflect the properties of the objects of the real world. To what extent are the axioms of the system and the theorems derived from those accurate copies of laws of the real world. Hence, what degree of abstraction is required by the first step of knowledge from experiences to that of abstract thinking, further in which way can the degree of abstraction be controlled during its application in effective practice of results obtained from theory?

Hence, the formulation of the individual concepts and theorems means that in every branch of science an abstraction depending on its stage of development should be carried out. As regards the whole discipline in question, it can be stated that in place of the real world, respectively, of its parts, structure and dynamism more or less idealized pictures of more simple structures ought to be put. Namely, simpler structures and mechanisms are more accessible for scientific analysis than the real ones, further, at a given stage

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[10] See in detail I. GYARMATI: The "crisis of thermodynamics" and a new theory. Fizikai Szemle VI. nr. 6. Budapest 1956.

of development — which at a given epoch are determined by the accuracy of concepts and theorems to be formulated — just these are the ones to be constructed.

For producing new concepts and theorems just as for filling in the already known ones by new contents, the starting point of its foundation is always the experiment. This also refers to the cases when this is not directly visible, because the priority of experiment is screened by some hypothesis. The experimentalist either proves or denies the practical activity of research i.e. primarily during scientific experimentation, the already earlier established theoretical theorems, on the other hand its experimental results might become sources of new concepts and theorems i.e. of new theories. Thus, the experimentalist essentially carries out the same process with his instruments, his organs of sense and his intellect in the founding of a new theory as does his theoretical colleague who works in the abstraction of new concepts and confirmation of the new theorems with mathematical and logical tools. If the experimentalist endeavours to establish in his experiments the objective laws, practically in objective forms with the aid of instruments and organs of senses under the purest conditions and in their most characteristic form, then he is actually carrying out the same work as the theoretical researcher does in thinking. Thus, it is also indispensable for experimentalists to observe one or the other aspect of experimental subjects in their purest form, i.e. free of disturbing moments, further to consider the whole subject to be examined and the related processes in as near approximation as possible to a unity. The experiment prepared with the most unambiguous choice of the required conditions and circumstances, and by examinations free of disturbing effects of one or more essential characters of the phenomena examined, thus, in a practical way the soil for forming the concepts and decrees referring to the phenomenon, hence for the logical abstraction.

Empirical data, however, collected during the practical activity of research, hence data obtained by pure induction, only very incompletely and roughly reflect the manifold and complicated structure of the real world. On the other hand, a collection of data even if listed in a tabellary order cannot be regarded uniformly. Therefore, already the experimentalist needs a picture which provides a connection between the real world and experimental data, tables, as functions of relations obtained by him. This connection between the real world and empirical data is idealized material, body, space; process from the point of view of scientific analysis obtained by abstraction which contain only essential properties, containing them uniformly, however, hence the physical model.

Well developed physical models which are widespreadly used are to a great number well known from the disciplines of classical physics as well. Neither the descriptions of these nor their enumeration is our task, however, we shall remember the models of classical mechanics, the material point, the rigid body, the deformable body, respectively, within the latter the friction free and frictioning, viscous, incompressible and compressible fluids etc.

The point charge of electrodynamics, the dipoles and multipoles of the charge system, further in other respects the process models of static, stationary, quasi-stationary etc., fields, display a similar model-likeness and this is the type of the optical model which has considerable practical significance: the particular model of geometric optics. Finally some models of modern branches of science should be mentioned, for instance, the atomic shell model, the shell and liquid-drop model of atomic nuclei, Landau and Gorter's two fluid-models of liquid Helium without which there cannot be question of any theory in the above mentioned branches.[11]

The importance of the correct choice of model theory is confirmed by those scientific historical data, which show that from among the branches of physics and as regards their concepts exact, first of all those were developed which had models that could be determined by uniform, clear and often unambiguous conditions, and the description of which could also be carried out quantitatively. The successive and approximative knowledge of the complicated and manifold world consists in the formulation of simpler and more idealized models than in models compatible with empirism, moreover in models reflecting more exactly the conditions of the real world and relying upon recently obtained empirical facts as basic sources.

In the above-mentioned examples abstraction and simplification, indispensable in the choice of models (with the exception of static, stationary and quasi-stationary electric fields) was mentioned, mainly in connection with the structural conditions of nature. However, by the exceptions it is shown that abstraction and simplification are very important factors from the point of view of the complicated course of phenomena in regard the manner of description, too, also the clarification of individual processes. On the basis of what has already been mentioned above, considering a whole discipline model, structural and dynamic models or (process models) are to be distinguished. Since the properties of the structural models can easily be visualized and are well known, only some interesting aspects of dynamic models are dealt with in detail here.

From among dynamic models it is doubtless that the abstract model of equilibrium is the simplest one. The model of quasi-static processes is a little more complicated, this being based on virtual processes between systems in the equilibrium state or virtual processes taking place between systems in reversible processes, and alternatively on the possibility of reversible processes as a limiting case. The dynamical model of stationary processes is even more

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[11] Models enumerated here are evidently discipline models, because the total of a branch of science or at least some organically related part of it is built upon it.

complicated. This model, though similarly based on the equilibrium state of stationarity in time, on the state of steady systems, however, in a stationary state the constancy in time can only be attained with the aid of the surroundings of the system by taking them into account and by keeping the corresponding parameters satisfactory for the requirements of prescribed values. The theoretical models of quasi-stationary processes and turbulent phenomena are even more complicated, and in certain cases these process-models cannot be unambiguously defined.

Reviewing the different branches of physics, it can be seen that the rapid development and the widespread applicability of classical mechanics and electrodynamics is primarily due to the correct choice of models in reference to the structural built up of matter. It is just by the properties of models that the application of theories beyond the frames of the models is limited to larger circles. Contrary to mechanics and electrodynamics, first of all classical thermodynamics is to be considered as a theory having no structural character but a dynamic one. A considerable simplification of the dynamism of processes is used by this theory when it is based on the equilibrium model of quasi-static (reversible) processes. Since this is question of phenomenological theories, it is clearly shown by their formation, that rough structural models are applied when the dynamic conditions can be inspected relatively easily, moreover when they can eventually be also observed. This is the situation in the case of simpler forms of motion, for instance, in mechanics. The reason for this is that in such cases the rigorous internal structure (molecular structure) can be completely left out of consideration, and thus the adequate approximation of a phenomenological description requires only the building out of a rough macro-structural model.

The situation is quite different in thermodynamics having a more complicated form of motion. In this theory the internal fine structure cannot be completely left out of consideration. It has indeed to be taken into account even for the simplest phenomena (for instance evaporation) at least from its existential point of view in order to physically interprete this phenomena. In these cases microstructure can already not be left out of consideration i.e. it can not be replaced any longer by a rough structured macromodel. The reason for it is that the macroscopic dynamism of thermodynamic processes, though in general and so also computed in this manner, depend to a decisive extent on the internal molecular structures and on the variation in time of the microstructures. Thus it is comprehensible why in theories of phenomenological thermodynamics, first of all the dynamic condition should be simplified, i.e. what is the reason that at the beginning of the development of theory one could base theory on the simplest dynamic model; on the model of equilibrium. On the basis of the foregoings, an answer can be given also to the problem.

As a summary the followings can be stated concerning the relation of experiment, model and theory. From the structural and dynamical points of view the evaluation arrangement of the empirical material and its relation to reality require the building out of such models on which these conditions could be expressed qualitatively as well as quantitatively. In the individual physical disciplines depending on their particular problems, structural and dynamical models are utilized. Such models had already been needed by experimentalists for exact and well defined but possibly simple forms. But, in the majority of cases experimentalists could not considerably advance in abstraction except for the exact model, and the description of the fundamental properties describing the same. The detailed building out of the theory on the basis of a determined model is awaiting its theoretical colleague, the experimental knowledge of which, however, in general, does not exceed the knowledge of data and relations referring to the characteristical properties of the model in question and the existential conditions of these properties.

It is advisable to differentiate between experimental and theoretical physicists, and on the other hand, on the basis of experience of the last decades this has also proved to be fructiferous.

The endeavour of physical idealists is to confront theoretical examinations with experimental facts by making use of this division of labour (let us remember the adherents of this view believing in the omnipotence of experimental research, which became widespread in Germany under the leadership of Stark and Lénárd, by whom theory was rejected as a "Jewish" invention, whereas experiment was referred to as the only true and high style "Arian" method). Whereas on the other hand the complete inproductiveness of experiments was emphasized by Eddington and Milne, because according to their opinion, for researchers at home in mathematics and philosophy (idealistic philosophy) the laws of nature are evident without any experiments.

Indeed the situation is that the theoretical physicist relies on the observations of the experimentalist, as if the experiment had been carried out by himself. Reversely the experimentalist relies in exactly the same way on the results of his theoretical colleague, as if those had been attained by him. The base upon which the knowledges of both rely is the exact physical model.

From the point of view of the ideology of dialectic materialism the foregoings result is that that, in relationship between experiment and theory — an important role is due to the physical model, in which experimental results are summarized, placed into order giving a uniform picture which can also be quantitatively described.

This uniform picture, the physical model, is the scheme which is commonly produced by the experimentalist and theoretical researcher, in order to build upon it the theory corresponding to the doctrine, by the concepts and theorems of the model.

In the first stage of recognition which leads from experience to abstract thinking, from the essential to the deepest essence, thus a middle degree — as first a uniform essence, the physical model — should be inserted, keeping in mind, that the model itself was produced from abstraction.

4. Model theory and axiomatics

In the preceding it could be seen that with a physical model the dynamic and structural conditions of the real world and, in general, only one of them is decidedly reflected. Briefly: a complete physical model is a rougher representation than the original one of the structural and dynamical conditions of the real world.

It has already been dealt with under points 1 and 2 that all the concepts and theorems of a theory, corresponding to fundamental concepts and theorems of a system of axioms can only then to a certain approximation be correct if they are abstracted from reality, and thus reflect reality. The correct formulation of the model of a theory at a given stage of development is thus, corresponding to the problem, when fundamental concepts and theorems abstracted from objective reality can be unified to a complex unity of a branch of science for the model of a theory. Expressed in other words: In which way can, by a system of axioms referring to the fundamental concepts an empirically controllable model theory, be defined and limited at an attained degree of abstraction and accuracy? Reversely, by what system of axioms could the basic properties of a physical model be satisfied?[12]

The representation of a physical model by a system of axioms i.e. the synthesis of clarity and accuracy leads to the building out of an axiomatic model theory. In this synthesis the properties of the requirements of the fundamental concepts and theorems of a theory, aligned to these properties should simultaneously be satisfied. The requirements of objective reality and a theory can only then simultaneously and correctly be satisfied if in theory only such concepts abstracted from the empirical knowledge of reality are used of which the contents and extent exactly corresponds to a model serving as a description scheme of the model. In this conception it might also be stated that a model theory can just be defined as exact if a system of axioms express and determine the essential properties of the model.[13] Such a definition should be considered as a recursive one, in the sense, that the fundamental concepts and theorems

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[12] Further on the discipline model defined by the system of axioms will be called: the model theory. Of course there might be question of a model theory also if the model of the branch of science which is the basis of the theory is not fixed. This is the case for instance in biology the less exact branches of science, though it is doubtless that also this science has a determined and even more determined theoretical models. Theoretical models of biology are, however, to defined only qualitatively. Thus though there might be question of biological models, those are not quantitative ones, and therefore they are unfortunately in general not unambiguous. Therefore they essentially differ from model theories of quantitavely axiomaticizable sciences.

[13] It is worthwhile to note.that in some mathematical branches of science, — owing to the exceedingly high degree of abstraction — the role of the model loses its importance or apparently

of the system of axioms expressing the basic properties of the model are simultaneously also defined with the aid of the axioms.The discipline in question can, of course, not be extracted from the development process, owing to which it was produced in a form corresponding to the given epoch. Doing so we would arrive to a tautology. Hence, to the axiomatic model theory there is a long route of development, whereas the method used in development is successive approximation. This method in its pure and quantitative form is known from mathematics, and one of its applications serves, for instance, the approximative determination of arbitrary accuracy of the unknown of a higher order of algebraic equations. Its role in the process of recognition gives enlightenment as follows.

When a new branch of science is born neither the experimentalist nor any reasoning human being can at the beginning recognize without any preceding facts, and in possession of only a few experimental data, all the facts and relations of a certain realm of problems. Thus, primarily he starts out from a primitive model of a simple theory, in which there can still be found many subjective features and hypothetical elements. If perceptions are interpreted on the basis of such model pictures, then contradictions may arise. Contradictions can only be resolved by modifying the starting basis of the original model as well as the fundamental concepts and theorems determining its properties i.e. the system of axioms of the discipline.

Thus, owing to this constant comparison of the model and its system of axioms with experience, it constantly improves and develops.

On the basis of an axiomatic model theory it can clearly be seen that the formalization of a system of axioms does by no means signify the end of scientific research. Namely, however correct a system of axioms may be and how impeccable it is logically, strictly taken it never refers to the real world, but to a more or less approximative reflected image; namely that of the model. Hence, a system of axioms cannot be gnosiologically faultless, not only because it cannot be faultless from the gnosiological point of view, but first of all because the laws of a model theory determined by a system of axioms obtained as the convergency limit of an approximation series, are only more or less truely reflected pictures of the objective laws of the real world. Thus, also the relative character of the axioms is evident, because at each stage of historical development, the limit of which has been expressed by them was attained by model theories representing our knowledges uniformly and generally during the description of objective reality.

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disappears. This is the case for instance if the theory might be considered as the direct definition of the system of real numbers. Similarly, the system of axioms of the group theory is the direct definition of the concepts of the group without a median model. This exceptional situation of the mathematical disciplines is due to the particular character of mathematics and the circumstance that the relation of mathematics to the real world is much more indirect as that one of physics.

5. Theory — model — practice

Under point 3 we arrived to the fact that recognition, leading from experience to abstract thinking, between experience and theory as a median degree, — as a primary and uniformly descriptive essence, — the model should be placed. In abstraction the model constitutes such a connection which is commonly produced by the experimentalist and theoretical researcher with the aid of experience, and to the basis of which after having established the system of fundamental theorems of the latter, the whole theory is built up. Descriptively it can be stated that the theoretical researcher relies on the basis of the model and directs his attention upwards to the details of the ever more abstract theoretical construction, and is eventually concerned with the improvement of the model self. Whereas, from the point of view of the experimentalist, in the majority of cases the knowledge of the welldefined scheme of a theoretical model is already sufficient and satisfactory enough to interprete and systematize the experimental data, and on the other hand, it allows to exactly follow the development of the theory without dealing with its details.[14]

When on the basis of the concepts and theorems of an abstract branch of science a process should be intentionally produced by adequate devices, then theory is applied in practice.

The practical application of concepts and theorems of the system is not carried out in one single step, but in many stages, similarly to the abstraction process. From among these stages the model is again the one and the most essential one.

A technical application of the model theory corresponding to practical requirements is again preceded by a great many control experiments.

The purpose of these experiments is to confirm from as many points of view as possible the correctness of the conclusions drawn from the system of axioms of one of the model theories by mathematical deduction. Since abstract concepts of the theory refer to the discipline model containing the conditions, those simplifying and ensuring the validity of the system of axioms. Therefore, the conditions of experimental control have always to be in agree-

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[14] On the basis of the foregoings very important conclusions can be drawn concerning the teaching of physics as well. Lower level teaching shall always arrive inductively to the development of uniform theoretical models of the corresponding disciplines and to the purest description of their essential features and of their relations. Thus the advanced studies can rely upon a solid basis and might start by an eventual further extension of it — at the beginning of course only in an inductive way — with the total development of the theory built upon the model. In practice it unfortunately often happens, that students making their studies of experimental physics dont arrive to the clear understanding of the theoretical model of a branch of science. Thus for instance who cant make difference between the theoretical model of geometric optics and wave optics wont understand it neither by the solutions of wave equations in the course of his theoretical studies. Such and similar examples are unfortunately often encountered, therefore it is worthwhile for teachers to supervise the material of their lectures and their methods of teaching with the aim whether they succeeded in injecting into the students the uniform sketch of the theoretical model of the branch of science, in the course of teaching the experimental material and the fundamental laws of the corresponding discipline.

ment with the conditions ensuring the validity of the discipline model of the applied theory.

Expressed in other words: the general model of the theory correctly gives account of the objective reality to a certain approximation, only in the case of well defined experimental conditions on the basis of conclusions and legacies reflecting its laws. Owing to this fact the experiments ought to be realized under conditions satisfying the discipline model. On the application of the general model theory of rigid bodies it is, for instance, not possible to draw even approximative conclusions and to establish artificial devices from the theory on that basis when the applied material, at least to the required approximation, does not fulfill the conditions which are required by the validity domain of the general laws of classical mechanics and by the well defined conditions of the model of a rigid body. Somewhat more difficult conditions are encountered when the concepts and theorems of classical heat theory are to be used for the description of thermodynamic properties of relatively small sized systems.

In such cases fluctuations of considerable intensity occur in the system. The situation is also a similar one if the theory is to be used for the description of such systems, respectively, for the execution of such constructions in which irreversible transport processes take place. The enumeration of examples — particularly in microphysical respect — could without end be continued. From our point of view it only is important as regards the application of laws and theorems of the model theory, equally during the control experiments, as in realized, and operating technical constructions already in the course of planning construction and exacution — the conditions determining the discipline model. The laws characterizing it as well as the conclusions derived from it ought to be, so to say, "preformed" into the device. Perhaps it might also be stated that during the processes of planning construction and execution, the discipline model is "objectivized". The discipline model between the frames of laws and theorems and the condition giving the validity limits of same, the experiment gives the expected result, respectively, technical device operates.[15] If in a device the theory of the abstract model of theories, necessary for the operation of the device, is not realized then the device does not operate. Hence, the general theoretical model of a branch of science is again to be found between theory and practice. It is in the process of planning construction

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[15] Of course a technical device operates usually according to the laws of model theories of different branches of science.

For the planning and execution of a steam engine first of all the model theory of classical mechanics referring to rigid bodies as well that one of classical heat theory valid for reversible processes should be taken into consideration. At the same time for the operation of a cosmic rocket the knowledge of quite a series of scientifical branches is needed. A cosmic "experiment" gives simultaneously account of the correctness of many branches of sciences more over of the simultaneous validity being so to say in interaction with one another of their corresponding discipline models.

and execution, and is finally realized in the operating device in the particular synthesis of structure and operation.

Speaking of practice in such a sense that under given circumstances it realizes the concepts and laws of a theory, then we are producing such a construction by which the generalization is realized in the singular. Its consequence is, of course, that by the structure and operation of the device only a special part or parts of the theoretical model, in the majority of cases (of many) is realized, hence not the whole discipline model (or the totality of these complete models). In other words it could be stated that an abstract discipline model forming the complete theoretical scheme of a branch of science is concretized i.e. in practice, only specific part models[16].

In the reverse process this — in the course during abstraction from experience versus theory — to synthetical process, when in the course of abstraction experimental facts arising from different — mostly neighbouring — domains of reality are logically connected, generalized, and by connecting in many steps, resulting of several such generalizations in which a particular synthesis characterizing a certain branch of science, the theoretical model is developed.[17]

As a summary with the development of recognition, by the improvement of theories, the continuous interaction of experience, experiment and abstract thinking is assumed. We endeavoured to demonstrate that experiment and every days practice is nothing but a particular connection of the abstraction activity of the intellect and of the sensual activity, which is realized either in the abstract theoretical or in the concretized practical model, or in the already built up device. The theoretical model is concretized in all instruments or devices used during experimentation and application, so that during this time the system of axioms of the theory, the system of knowledge of its laws and theorems, thus the whole theory is realized.

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[16] The "objectivization" the general model in the course of applications and its splitting into smaller part models is particularly evident in such cases when before the final execution of a device the designing engineer is performing concrete part model maquettes etc. In this respect for instance the median role from theory versus practice of the model is proved and illustrated concretely by the existence of the well-known similarity theories of hydro- and aerodynamics. The maquette however, can be always only a part model and can never incarnate the whole discipline model.

[17] There are of course also diversities as regards the role of the model on the way leading from experience towards theory, respectively on the way into the reverse direction. These are however, not general ones and are requiring detailed analyses from case to case, whereas this problem will not be dealt with here.