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ON THE ROLES OF EXPERIMENT AND THEORY IN COGNITION

(Comment on the article by Max Born)*

S. SUVOROV

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I

IN this issue of this journal there is published a translation of an article by Max Born on "Experiment and Theory in Physics." The author is well known as an outstanding theoretical physicist who participated directly in the development of present-day physics and has lived for over a half century in the creative atmosphere of the science, an atmosphere of great and abrupt changes in physical and philosophical ideas. For this reason in itself the present article, in which decisive events in the history of physics are explained by one who witnessed them and took part in them, is of decided interest. This interest is increased by the fact that the article is written not only on the historical but also on the epistemological level, as a discussion of the roles of experiment and theory in the development of contemporary physics.

As is well known, the part played by theory in modern physics has increased immensely. Complicated processes, not directly accessible to observation, are represented in the theory by highly abstract concepts and relations; but is is precisely these abstract representations that enable science to progress. Furthermore, theories that have taken on the greatest importance in physics are characterized by vast powers of generalization, as for example in thermodynamics and the theory of relativity. All this has engendered in some scientists the view that theoretical reasoning may by itself be able, without relying on experiment, to develop knowledge of natural processes. In the West, and in particular in England, where Born worked for many years, Eddington's number mysticism was widely accepted, and Jeans based on speculative arguments a calculation of the time since the "creation of the world."

The sharp edge of Born's article is directed against just such speculations, which have no genuine scientific significance.

We cannot fail to rejoice that such an important scientist as Max Born comes forward against mysticism in science.

Being himself a theorist, Born tries to find the proper role to be assigned to theory, and to emphasize its basic connections with experiment. He shows that every principle that has been confirmed and has achieved great generality, such a principle as that of least action, the laws of thermodynamics, or Pauli's exclusion principle, even though it may seem at first glance to be of an a priori nature, is in actual fact a generalization from experimental results, from "the results of long experience." The general theory of relativity, though in virtue of its mathematical perfection it has an a priori appearance, is also "a gigantic synthesis of a long series of empirical results, and not a spontaneous brain wave."

Born takes a somewhat skeptical attitude toward the later attempts of Einstein, and also of Weyl and of Eddington, to develop the general theory of relativity in the direction of including all the physical features of the world in the differential equations of a single geometrized field; since they have ignored the experimental material of nuclear and quantum physics, these efforts have not given definite results, and the general theory of relativity "did not help in understanding the nature of matter, the existence of different ultimate particles and fields," as Einstein had hoped.

In this "Princeton period" of his life Einstein looked for the further development of science only

*Cambridge University Press, 1944.

from the creative power of thought, and consequently took a course entirely different from that which Born defends in his article. In the report "Physics and Relativity" (1955) dedicated to the fiftieth anniversary of the theory of relativity, Born tells of the reaction this article of his received from Einstein, who perceived in it a reproach to himself: "I sent a copy to Einstein and received a very interesting reply which unfortunately has been lost; but I remember a phrase like this: 'Your thundering against the Hegelism is quite amusing, but I shall continue with my endeavors to guess God's ways.' A man of Einstein's greatness who has achieved so much by thinking has the right to go to the limit of the a priori method. Current physics has not followed him; it has continued to accumulate experimental facts, ... "*

Born regards experiment as the driving force of theory. Experiment constantly discovers in nature things not yet included in existing theory. The development of theories occurs in relation to this. This compulsion to the development of theory is repeatedly emphasized by Born in this article. All the major innovations in physics — whether we think of the relativization of time, or the transition to quantum concepts, or the statistical interpretation of the wave function — appear with a natural necessity, despite the psychological resistance to them of individual scientists. Born testifies that Planck's introduction of the idea of quanta of energy was an act of downright desperation, but that it had to be done because of "the failure of the classical laws to account for the properties of radiant heat."†

Born states correctly that concepts and theories are not free creations of the intelligence. Even the speculations of Eddington on the so-called E-numbers could occur only after the dimensionless numbers had been established experimentally.

Born's criticism of the idea of free creation is also directed against the views of Einstein, who all his life defended his view of theory as a free creation of the intelligence, and also against the conventionalism of H. Poincare. Somewhat later, in an article "Physics and Metaphysics," Born stated even more clearly: "Here is another point where I disagree with Einstein's philosophy. He accepts the doctrine of conventionalism which in my youth was powerfully advocated by the great French mathematician Henri Poincare. According to this view all human concepts are free inventions of the mind and conventions between different minds, justifiable only by their usefulness in ordinary experience. This may be right in a restricted sense, namely for the abstract parts of theories, but not for the connection of the theories with observations, with real things. It neglects the psychological fact that the building of language is not a conscious process. And even in the abstract part of science the use of concepts is often decided by facts, not by conventions."

We are pleased to note the agreement between our previously expressed criticism of the elements of conventionalism in Einstein's ideas* and these remarks of his very close friend Max Born.

The recognition that our concepts and theories are not free inventions of the mind, that they have a content independent of us, is a great step of the natural scientist on the path of progressive thought; this step is all the more valuable because it flows from the immediate professional experience of the scientist, and because it inescapably leads farther, to the question as to what is the source of the objective content of the theories. Consistent reasoning cannot fail to lead to the conclusion that the element of necessity in the development of physical theories is a consequence of the fact that they are the reflection, the image, of the objective world in consciousness. Precisely this path has been followed by many outstanding physical scientists. In particular this path was also travelled by Max Planck, who went from the Machism, to which he inclined in his youth, to materialism, "to the recognition of a self-existent world, independent of the experimenter and standing over against him, which imposes its laws on him whether he will or not."†

It is important that Born also comes to the question of this image, indeed not in connection with the establishment of the independent content of the theories, but in connection with the analysis of the basis of theoretical predictions. This analy-

*Max Born, Physics in My Generation, Pergamon Press, London 1956, page 205.

†It is interesting to note that Planck himself also concluded that a change in our ideas about the world was inevitable, being "a consequence of an irresistible compulsion." "This sort of change," wrote Planck, "becomes a bitter necessity each time experiment encounters a new fact in nature which the existing picture of the world cannot explain."

Cf. "Sinn und Grenzen der exakten Wissenschaft," in the collection: Max Planck, Vorträge und Errinnerungen, Stuttgart 1949, page 371.

*See the introductory article by the writer in the Russian translation of The Evolution of Physics by A. Einstein and L. Infeld, Gostekhizdat, Moscow, 1948 and 1956.

†Max Planck, Naturwissenschaft und reale Aussenwelt, 1940. We pay a tribute of high respect to this outstanding scientist and passionate fighter for the scientific materialistic view of the world; the hundredth anniversary of his birth was recently observed by the scientific community of the entire world, among them Max Born, who was at one time his assistant.

sis is also of interest in itself, since here an attempt is made to bring to light the nature of creation in theoretical work.

In accordance with the main purpose of his article, Born examines theoretical predictions in order to show that they are based in the last analysis on experiment, and not on a priori principles. He divides theoretical predictions into analytical and synthetic predictions.

By an analytical prediction Born means the prediction of results that are the consequence of logical development of a theory from its original premises. As examples of such predictions Born discusses the prediction of the planet Neptune by Adams and Leverrier, the prediction of conical refraction by Hamilton, and the explanations of line and band spectra and of the nature of the metallic state and of chemical valence, and the prediction of para- and orthohydrogen, based on quantum mechanics. Since the original premises of the theory are based on experiment, here the position is clear from the beginning: there is nothing of the a priori about these predictions.

Synthetic predictions, according to Born, are of a more complex nature, but also they open up wider prospects. Let us recall some of the examples he gives of synthetic predictions: Maxwell's addition of the term $\frac{1}{c}\frac{\partial E}{\partial t}$ to the field equation curl $H = 0$; Einstein's development of the ideas of the general theory of relativity, from which followed, in particular, the prediction of the deflection of light rays passing near the Sun; the discovery of non-Euclidean geometry by Lobachevskiĭ and by Gauss; the discovery of noncommutative algebra by Hamilton; de Broglie's association of waves with corpuscles; the discovery of the matrix calculus; obviously, here we should also include the addition by the Japanese physicist Yukawa of a term $\frac{\Phi}{a^2}$ to the wave equation $\Delta\Phi - \frac{1}{c^2}\frac{\partial^2\Phi}{\partial t^2} = 0$.

Born declares that the characteristic feature of synthetic predictions is that they are made "without direct experimental basis", and that the intuition of the scientist plays an essential part in them. Also they are not logical consequences of an existing theory, but on the contrary are themselves the foundation for, or an important part of, a new theory. But perhaps they also rest on a priori principles? Born shows that even in the case of synthetic predictions there is nothing of the a priori. Here he has made use of the concept of a "shape."

Born says that he takes the concept of a shape from Gestalt psychology, and emphasizes that it has established the "experimental fact" that simultaneous sense impressions are not independent of each other like the elements of a mosaic but form a "psychic unit." This idea of the unity of a shape plays an important part in his further arguments. Born goes on to transfer the idea of the unity of a shape to the external world, and speaks of the "shape of physical things". Here he mentions his favorite idea, as he calls it, that the shapes of physical things are the invariants of the equations.* We must not worry about the fact that they are described by the formulas of theoretical physics, says Born: "These have the same kind of reality — I mean: objective reality in the external world, as any shape of familiar things, for instance that of the human body."

Just so, at some stage of cognition the shape conceived may be incomplete, "rough." Because of the fact that the elements of the shape form a unit, and not a mosaic, the scientist can intuitively feel this incompleteness of the shape and complete it by synthetic predictions. "Maxwell's addition of the missing term is just such a smoothing out of a roughness of a shape, though this shape is here a mathematical structure of a more refined type than a sphere (in the previous example about the moon — S. S.)." Furthermore the synthetic prediction is a hypothesis, which Born calls a mathematical one. "If confirmed by experiment it produces new knowledge, and although hypothetical it is a legitimate method. But its success depends in a high degree on intuition. . . ." In any case a synthetic prediction is also based not on a priori or innate ideas, but on a partial knowledge of the shape from experiment and a further hypothetical completing of the shape, with subsequent verification by experiment.

Such are Born's ideas about theory and its relation to experiment. We shall now take the liberty of rearranging his statements in a certain logical order.

The external objective world has effects on us (the possibility of this is not doubted, since we are a part of it and a product of its development); in the complex interaction with the world that begins with our contact with it, that is with elementary experience, we form concepts and theories; the content of these concepts and theories is neither an a priori matter, nor a free invention of thought, since, as the whole history of science shows, they are not arbitrary, but form a single and unified physical shape. This is indeed the shape of "objective reality in the external world." The unity of the shape in our thinking finds its explanation in the fact that it is a consequence of the unity of the

*For more detail see: M. Born, (Physical Reality), Uspekhi Fiz. Nauk 46, No. 2 (1957), and also: S. G. Suvorov, The Problem of "Physical Rea'ity" in the Copenhagen School, ibid.

object it reflects. But this shape is not revealed to us all at once, in a sudden single act; analysis of specific relations that have already been discovered enables us to make hypotheses about relations of an entirely new nature between the various categories of the object ("synthetic prediction"). The correctness of these hypotheses is tested by practice (experiment). From the new relations that have been found logical consequences are deduced ("analytical predictions"). It is thus that a theory — a coherent shape of the object — is formed and developed.

In summarizing Born's statements I have tried to explain the process of cognition in complete agreement with Born's ideas of this process. I have allowed myself only certain "liberties," namely: I have interpreted the frequently used concept "experiment" as the result of our direct interaction (encounter) with the external world, doing this on the basis of a number of antipositivistic pronouncements of the author; and further I have combined Born's statements about the compulsory nature of the development of theories and about the "shapes of physical things", which are regarded by him as the "objective reality in the physical world". This combination of the statements, however, has been only an advantage, giving us features of a unified and consistent concept; and this concept is indeed just the materialistic theory of cognition, which many foreign scientists, including Born himself, have not brought themselves to acknowledge openly.

The advantage gained does not lie in the external form of the theoretical structure, but in the fact that the unified concept enables us to look at various problems under discussion from a more general point of view, and owing to this to reach opinions about them that are somewhat different from those of the author.

II

The main subject of the article by Max Born is a criticism of the doctrine of a priori and innate ideas, a struggle against dogmatism and metaphysical speculations, a defense of the experimental origin of knowledge.

It is true that criticism of a priori ideas is an urgent necessity in contemporary natural science. The grandiose system created by Kant dominated natural science for a long time and hindered its development. In fact, if such general categories as space, time, and causality are a priori categories, forms of our understanding, connected with the nature of our intelligence, then consequently they are given once for all, unchangeable, and independent both of the objects toward which cognition is directed and of the depth of our knowledge of them. It is easy to understand how Kant's a priori doctrine put shackles on cognition. Sooner or later it had to fall under the pressure of the actual facts of natural science itself. The discovery of Lobachevskiĭ's non-Euclidean geometry already gave it a crushing blow: the a priori forms exclude any lack of uniqueness. Furthermore the inevitable appearance in physics of the idea of the field, the analysis of the electrodynamics of moving bodies and the development on this basis of the special theory of relativity, the generalization of the concept of the gravitational field in the general theory of relativity — all these theories, developed under the pressure of undeniable facts, lead to changed ideas about space and time and about their genetic connection with matter and the laws of its motion, and left no room for the idea that they are a priori forms. In just the same way physics has been forced to overcome the Kantian ideas about the a priori origin of the category of causality, because under the pressure of experimental facts in the atomic domain ideas about the nature of this category have had to be changed. Not only in the article we are discussing, but in many papers by Born one sees the necessity of breaking free from the confining doctrine of the a priori. "After relativity has changed the ideas of space and time," Born wrote in one of his articles,* "another of Kant's categories, causality, has to be modified. The a priori character of these categories cannot be maintained." Naturally, if the idea of the a priori origin of such general categories as space, time, and causality had been overthrown, the roots of the belief in the a priori nature of any other principles of physics were destroyed. The primary source of knowledge is experience; this is the conclusion, the opposite of the a priori doctrine, to which contemporary natural science leads with compelling force.

A problem of no less importance is the struggle against dogmatism. We do not have in mind those ideas that arise from prejudice, from the dogmas of religion, or are imported into science from other nonscientific fields. On the contrary, we are speaking of ideas that arise in science itself, on the basis of definite experience. They become dogmatic because of poor methodology; it is not hard to expose the key feature of this methodology: having arisen on the basis of limited experience, ideas that are correct in a relative sense are then absolutized and transferred without being tested to a new and

*"Some Philosophical Aspects of Modern Physics," 1936; see the collection: Max Born, Physics in My Generation, Pergamon Press, London, 1956.

wider range of experience. This process of the petrifaction of ideas and their illegitimate transfer from one domain to another is the essence of dogmatization.

The struggle against dogmatization is not less — perhaps in our time it is even more — important than the struggle against the doctrine of a priori ideas. When our knowledge takes in a new domain of nature, when it makes great strides into the depths of things, it is especially important to have the strength of mind not to shrink from the necessity for a critical reexamination of the general concepts that arose in theories that reflect a different domain of nature or a different level of knowledge.

This critical reexamination of general concepts is a legitimate process of the development of science, which occurs continuously in contemporary natural science. It is only a pity that for many active scientists this process of reexamination of general ideas, like the struggle against the doctrine of a priori ideas, has gone on and is going on without awareness of the development of philosophical thought and of the struggle in philosophy. Knowledge of the development of philosophical thought could accelerate and facilitate this entire process, make clear its limits, and give it a direction appropriate for the description of nature. In particular, it would be clear that reexamination of concepts during a time of abrupt changes can proceed, and historically has proceeded, from different positions. In his own time Mach received great recognition from many natural scientists for his declared war against fetishism in science and against the periodic ossification of concepts. This was at the end of the last century and the beginning of the present one, when changes were occurring in ideas about absolute space and time, about the finite structure of the atom, and so on. But Mach made his attack on dogmatism from positivistic positions; he believed that a guarantee against ossification of concepts in science is to be found in the recognition that concepts are only conventional, and just for this reason very changeable, designations for series of sense impressions. This position for criticism of dogmatism is not tenable for natural scientists, and Born also admits the inacceptability of positivism.

The very first attempts to understand the regularities of the atomic domain led to the conclusion that a further break with classical ideas is necessary. This was a deep break and affected such categories as causality, contingency and necessity, possibility and actuality, physical reality, and so on, and this sharpened the conflict against the a priori doctrine and against dogmatism. In this period theorists tried to discard everything that in one way or another hampered their thought. Without much risk of being mistaken we can say that many scientists in the West came out against materialism only because they mistakenly associated with it ossification of concepts and attempts to impose on nature final and unchangeable laws, which were characteristic only of early, predialectic, materialism.

In this period of sharp change of ideas Heisenberg took the so-called "principle of observability" as a guiding principle for avoiding dogmatic transfer of old and spurious concepts into the new domain. The theory of the processes in question must be constructed by the use of only those quantities that are observable in the given domain of phenomena. If the orbits of the electrons in the atom are not observed, then they are spurious concepts that must be excluded, and in the theory of the atom one must rely only on the observed energy levels. At first glance it seems that this is a reasonable idea; at least it is true that quantum theory made progress only by renouncing the direct attack on the atom with the arsenal of classical ideas — orbits, continuity of radiation, and so on.

In principle Born supports this general proposition of Heisenberg's. He writes that with this principle Heisenberg "wished to found the new mechanics as directly as possible on experience. If this is a 'metaphysical' principle, well, I cannot contradict; I only wish to say that it is exactly the fundamental principle of modern science as a whole, that which distinguishes it from scholasticism and dogmatic systems of philosophy. But if it is taken (as many have taken it) to mean the elimination of all non-observables from theory, it leads to nonsense. For instance, Schrödinger's wave function ψ is such a non-observable quantity, but it was of course later accepted by Heisenberg as a useful concept. He stated not a dogmatic, but a heuristic principle."

But the meaning of introducing the principle of observability is not that it is to save physicists from spurious concepts by the simple recipe: avoid non-observables. Born has remarked that in physics one does not succeed in avoiding quantities that are not directly observable. This is undoubtedly true, and it is not unexpected, because theories operate with categories which are by their nature abstractions, and therefore in the general case are not directly observable. But as soon as it is admitted that non-observables can also legitimately appear in the theory, then nothing remains of the principle of observability, because the general idea of the necessity of developing science on the basis of experience only is by no means an exclusive prerogative of this principle, even if we interpret it in the most favorable sense. Moreover, any influence on science is exerted not by the unexpressed intention of the author of a recipe, but by the actual content of the recipe itself, which reduces just to the exclusion of non-observables. Therefore Born's correct statement that the exclusion from the theory of all non-observables leads to nonsense cannot be taken as anything else than an admission of the incompetence of the "principle of observability."

The question just considered is very instructive from the epistemological point of view. In recommending the principle of observability, Heisenberg makes a double mistake: a factual mistake, which Born also notes (non-observables cannot be excluded from the theory), and a methodological mistake. The methodological mistake consists in the unescapable assumption that a purely empirical recipe could be found as a guarantee against spurious concepts.

But recipes are useless weapons in the field of thought. Furthermore, in reasoning a recipe inevitably becomes at once the very thing against which Heisenberg was trying to aim his "principle of observability" — a dogma, divorced from the actual process of cognition. Guarantees against the introduction of spurious concepts are provided not by some recipe or other, but by the unity of the correct doctrine, which examines as a whole the process of the reflection of the object in cognition, and consequently considers the source and the laws of development of concepts and theories, and finds the general conditions under which concepts developed in one domain can be transferred to another domain.

This is indeed the conception that was spoken of above — the theory of cognition that is based on the recognition of an objective world which is approximately reflected in our theories.

Let us examine how this recognition requires scientists to deal with general categories.

The results of the development of science, especially during the last century and a half, show that the objective world is a unit and at the same time manifests specific properties in its parts. The unity of the objective world is the basis of its capacity for being known; it manifests itself, in particular, in the existence of a single logic and of general categories and laws, such as motion (in the broad sense), space-time forms, causal interrelations, and other equally general or less (but still sufficiently) general categories. In our time, when the possibility has been proved of unlimited reciprocal transformations not only of forms of motion, but also of elementary particles and fields, it would be naive to think that the categories and laws that reflect some objects are not connected with the categories and laws of other objects, though perhaps through complicated intermediate steps. And this connection in fact manifests itself at every point. The general categories discovered in one domain are not entirely discarded, but only changed in form within the range of new experience. In contemporary physics this situation finds its reflection in the fact that new experience is expressed with the same mathematical apparatus, except that it contains characteristic parameters that vanish for the old domain and take definite values for the new. Thus the new theories in physics are generalizations of the old ones.*

In seeking out the outlines of the new theory of atomic processes, physicists relied on the Correspondence Principle, which directly expresses the fact that quantum theory is a generalization of classical theory and goes over into it in cases in which one can neglect a characteristic parameter, the so-called Planck constant or "quantum of action" (1.05×10^{-27} erg sec). As has been stated by Niels Bohr, at a certain stage of the development the Correspondence Principle was the "only guiding principle" in the new quantum theory that gave relations between the unexpected experimental results in the microscopic domain and macroscopic processes.† In this article Born also refers repeatedly to the Correspondence Principle, noting the fact that during the period of the development of quantum mechanics this principle guided the process of derivation of quantum formulas from classical formulas.

In just the same way, W. Heisenberg bases his very latest attempts to create a theory of elementary particles on this same principle: he tries to construct a generalized theory in which there is to appear as a characteristic parameter a new constant, the so-called elementary or minimal

*This conclusion applies with compelling force to contemporary physical science. It is not an accident that it is reached independently by specialists in different fields who study the crucial stages of the development of science, for example the outstanding Russian geometer and famous student of the development of non-Euclidean geometries, V. F. Kagan (cf. V. F. Kagan, Lobachevskiĭ, Moscow 1944, page 328) and also the famous German physicist who discovered light quanta—the first window into the microscopic world—Max Planck (cf. Max Planck, Vorträge und Erinnerungen, article "Sinn und Grenzen der exakten Wissenschaft").

†Cf. N. Bohr, "Discussion with Einstein" in the collection: Albert Einstein: Philosopher-Scientist, 1949.

For more detail on the Correspondence Principle cf. I. V. Kuznetsov, Принцип соответствия в современной физике и его философское значение, (The Correspondence Principle in Contemporary Physics and Its Philosophical Significance), Gostekhizdat, Moscow 1948.

length. The idea is very simple, and at the same time interesting: in regions in which the new constant can be neglected processes follow the laws already known, but in regions comparable with this constant ($\sim 10^{-13}$ cm) laws specifically applying to the elementary particles should manifest themselves, and this should do away with the difficulties with infinities that appear in crude attempts to apply the present theory to elementary particles.* Thus, as in the previous revolutionary stage, when quantum theory was being developed, Heisenberg is trying to construct a generalized theory that is to have as a special case, for a certain value of a new characteristic constant, the presently existing quantum theory. The search for such theories is reasonable only in virtue of the existence of general categories in the external world, in virtue of the unity of the world.

The specific character of structures in the objective world, on the other hand, is manifested particularly in the fact that concepts developed within the limits of old experience cannot be applied unchanged in the domain of new experience. On becoming categories of the new, generalized, theory they themselves change their nature to some extent; thus the momenta and coordinates of microscopic objects, though they have something in common with classical momenta and coordinates, are still different in their fundamental nature; they are quasi-momenta and quasi-coordinates, with a different relation of a specific sort between them: for example, unlike the classical quantities, they do not commute.

The above statements about categories are essentially the two sides of the same proposition: the general categories are altered in a specific way in the changed object, just as in the theories that reflect it. I repeat: this proposition is not the demand of any philosophical dogmas, but a conclusion from the development of natural science, and also of the historical sciences and of philosophy. It is actually by this proposition that Max Born was also guided when, for example, he quite correctly expressed the idea that in quantum physics the principle of causality, as properly understood, is not discarded, but only takes a new form as compared with Laplacian determinism.†

This is the correct doctrine, which regards concepts and theories as reflections of the properties of the material world. For the exclusion of dogmatism and doctrines of the a priori it has no need of special recipes, like Heisenberg's "principle of observability," which have been shown to be unacceptable. It is incompatible with dogmatism simply because it admits the development of the forms of categories and laws in accordance with their transfer to new objects. It is clear that these new forms are not given a priori, but are found out by experiment. In this struggle against a priori ideas and dogmatism, and in this acceptance of objective experience as the source of knowledge, the conception we have described has much in common with the views of Max Born.

Its advantages, however, which are due to its completeness, manifest themselves in the fact that, as compared with Born's discussion, it makes a different evaluation of the role of experiment, and also of the significance of epistemological principles.

Born unconditionally sets experiment in opposition to tradition; he writes that "essential distinction between our time and the middle ages consists in the renunciation of tradition and the establishment of experience as the true source of knowledge." He enters on the path of denying philosophy as a science and rejecting its guiding influence, because he asserts that "as soon as they (principles, i.e., discoveries of natural science — S. S.) have become a part of a philosophical system there begins a process of dogmatization and petrification." And this proposition is regarded as an immutable law of knowledge, manifesting itself in any philosophy. In the concluding words of his article Born thus describes the position of the scientist: "But I believe that there is no philosophical highroad in science, with epistemological signposts. No, we are in a jungle and find our way by trial and error, building our road behind us as we proceed."*

But this attitude is contradicted by the actual history of the development of science, and especially by that of quantum physics. Born is of course right when he states that the development of the new quantum physics represents a deep revolution in ideas. Nevertheless the new ideas did not spring up on bare soil. Born himself notes

*Cf.: "Die Plancksche Entdeckung und die philosophischen Grundfragen der Atomlehre," report by Heisenberg on the occasion of the centenary of the birth of Max Planck, April 1958. Russian translation published in Uspekhi Fiz. Nauk 66, No. 2 (1958).

†M. Born, Natural Philosophy of Cause and Chance, Oxford 1949.

*These views are held not only by Max Born, but also by Niels Bohr. Thus Bohr relates that when Einstein expressed to him a feeling of dissatisfaction because of "the apparent lack of firmly laid down principles for the explanation of nature, in which all could agree," Bohr replied, "in dealing with the task of bringing order into an entirely new field of experience we could hardly trust in any accustomed principles, however broad ....." Cf. N. Bohr, "Discussion with Einstein."

in his article that "both aspects of quantum mechanics are in a large degree based on the work of Hamilton," that Hamilton prepared the way for the wave form of the theory by explaining the connection between geometrical optics and the wave theory and demonstrating the close analogy between Fermat's principle in optics and his own formulation of the principle of least action in dynamics. But also the other form of quantum mechanics, which is characterized by the use of matrices and operators, can be traced to fundamental ideas of Hamilton, to his noncommutative algebra. And we know by the admission of Bohr, Born, and other scientists that the Correspondence Principle, of which we spoke earlier, served as a kind of epistemological signpost at this difficult turning-point in the development of physics. The very statement of the new problems was evidence of great progress in science, and the inability to find the solutions at once only says that the results that had led to the statement of the new problems had not yet been subjected to sufficient analysis and generalization. Whatever novelty may characterize the problems confronting a science, the scientist must not believe that he is in a jungle and is feeling his way blindly.

If we had agreed with the statements quoted above, this would mean that in the name of the struggle against dogmatism we were forgetting an important historical fact, namely that our achievements are the result of the fact that we stand on the shoulders of previous generations, and not at all of nihilism regarding previously attained knowledge; philosophically this would mean we were reducing experience to the given single experiment, that is, were taking the position of pure empiricism. But in putting forward experience as the source of knowledge we understand it to mean not isolated experience, but accumulated experience.

We have grounds for concerning ourselves with accumulated experience precisely because it relates to a lawfully developing objective world, and not to a chaos of random flashes, "elements of sensation." Every experience that reflects the world genuinely, even though not completely, is a step toward deeper knowledge of the world.

It is in this that the materialistic interpretation of experience differs from the positivistic interpretation. Just because it has its source in the external world, experience accumulates and, as Born states correctly, has for us a compelling character. The acceptance of just isolated experiences does not distinguish science from mysticism, because every sort of rubbish, such as spirits of the dead, ghosts, and goblins, can exist in the isolated experiences of the superstitious, those led to believe in mysticism, or the mentally unbalanced.

But experience accumulates not in the form of a sum of separate facts, not in the form of a mosaic. It becomes generalized, takes form at first in a theory of the motion of a definite type of objects, and finally in a single image or shape of the external world, composed of many and various mutually related objects, an image which with the advance of knowledge becomes ever more exact and more refined, going from the primitive and concrete to ever more complex and abstract meanings. If this process of generalization occurs in the domain of sense impressions, as Born declares, it is no less true that it also goes on in the domain of cognition, forming what is called a world view.

The scientist is always guided by his world view, weighs new facts in the light of it, and at the same time enriches and develops his world view in the light of new facts. It is precisely experience, accumulated and generalized in a world view, that led to Born's rejection of Einstein's attempts to construct a theory of a geometrized field which has as its singularities particles with finite rest masses; led him to reject the idea with such conviction that, as he admitted himself in his report "Physics and Relativity" (1955), he did not even take the time to study Einstein's last work in detail.*

In this connection we would also like to point out the following. In this article, devoted to the roles of experiment and theory in physics, one thought is emphasized explicitly and with great force: theories are based on experiment. This is of course correct, but this is only one side of the problem. In the process of cognition theories play a no less important epistemological role. Though cognition begins from experience and experiment, and therefore this is a necessary element of cognition, still theory is just as essential an element of cognition, since it generalizes experiment and gives a coherent image of the object studied, which is the final goal of cognition, the giving of a richer idea of the object than that obtained from direct perception. At the same time, as has already been noted, having first appeared as a generalization of previous experiments, a theory that has been confirmed in practice serves as a guiding principle in the domain of subsequent new experiments. Furthermore, the results of contemporary experiments have such an abstract appearance and depend on such a complicated organization of suit-

*In this report Born said: ". . . . right from the beginning I just did not believe in their success and therefore did not study his difficult papers with sufficient care." (Cf. "Physics and Relativity" in the collection: M. Born, Physics in My Generation, 1956.

able conditions that they can be obtained and given meaning only on the basis of a deeply developed theory; but this last role of theory in the treatment of experiments has also been pointed out by Born.

Thus if we are to understand experience as objective, generalized, historical experience, and not as subjective, isolated, empirical experience, we come to the conclusion that the scientist is by no means in a jungle, that he always has epistemological signposts by which he is guided. The struggle against dogmatism by no means requires the exclusion of the experience accumulated and generalized in theories and in our view of the world, it requires only that new experience has to be taken into account and must enter as a component part into the new image of the objects studied; that it must be taken into account in the search for the particular forms of laws and categories that are inherent in a given domain. Contemporary scientific materialism satisfies this requirement.

The dogmatism that has done harm to science arises not because use is made of experience accumulated and generalized in a unified world view, but because use is made of that world view and those traditions in which the categories are regarded as unchangeable and independent of new experience. Of course, many theories are discarded into the trash can of history. It would be incorrect, however, to follow a priori principles and treat as dogmatism those theories and that world view which truly correspond to generalized experience and have been tested and confirmed by practice.

III

It gives the writer especial pleasure to note the arguments of Born against the operational method of introducing concepts into science by identifying them with operations of measurement (P. W. Bridgman).

Born finds that this method is a reasonable one for defining concepts in classical physics, since here one has to do with quantities accessible to direct measurement. In the quantum theory, however, according to Born the operational method is "rather out of place" and "comes to grief," because in this theory an essential part is played by concepts that cannot be associated with any operation of direct measurement. "I cannot see," Born writes, "what experimental 'operation' could be devised in order to define a mathematical operator? Moreover, I have already mentioned that there are concepts used in wave mechanics which are not observable, for instance, Schrödinger's wave function; there are in principle no means to observe it, hence no 'operational' definition."

Born's criticism of operationalism shows that he is a subtle thinker, who reflects on the processes occurring in the theoretical thinking of physicists, and notices the dangers arising from them. It is all the more essential to point out that the operationalists, like Born, start from a high opinion of the importance of experiment; but in identifying concepts with operations of measurement they have arrived at an apologetics of pure empiricism. In coming out against the operational method of introducing concepts into science, Born has gone against a trend which has had a broad appeal for physicists, to whom it has seemed that this method saves science from uncontrolled speculations. But empiricism has never yet saved anyone from speculations, as Engels showed long ago; and indeed Milne's speculations about the date of the creation of the world, which Born criticizes, arise out of Milne's extreme empiricism.

The writer of these lines has had repeated occasion to speak out against operationalism as a method of defining concepts.* At that time I could not refer to any important physicist who had come out against operationalism; unfortunately it is only now that I have become acquainted with Born's article. Though I understand the importance of this unexpected support for my views, I still wish to record some considerations about Born's remarks on operationalism.

Born's criticism of operationalism consists of a direct reference to the fact that in quantum mechanics there are concepts with which one cannot associate any operation of direct measurement. The essence of this criticism is accordingly that there is empirically established a domain in which operationalism is obviously bankrupt. At the same time a domain is pointed out in which the operationalistic rule is useful; this is classical physics, in which operations of measurement can be directly assigned to concepts.

Here, however, there is still no analysis of the epistemological tendencies of operationalism, and this is necessary, especially in view of the fact that this doctrine is attractive by its appearance of definiteness, which is regarded as a reaction against "verbalism and word fetishism."

Let us inquire what is the meaning of the basic demand of operationalism, that concepts be introduced into science only through a description of an operation of measurement, even if only an imag-

*Cf. e.g.: a) Uspekhi Fiz. Nauk 39, No. 1 (1949); b) Great Soviet Encyclopedia, 2d. ed. article "Operationalism," 1955.

ined one. It means an understanding of the process of cognition, according to which one first defines concepts, by adopting appropriate procedures of measurement, and afterwards one looks for relations between the concepts (of course such as do not contradict experiment), that is, one develops a theory. But only standardized houses are built from prepared bricks and timbers. The development of new theories, especially those of contemporary science, occurs in more complicated ways. We shall not enter at once upon a discussion of these ways, but merely note, what Born also asserts, that the entire development of quantum mechanics shows how at first abstract formulas are gradually established for the compact description of sets of observations and measurements, and "understanding of their meaning follows afterwards." But this way is in obvious contradiction with the method of operationalism. The actual process illustrates the epistemological fact that a concept receives its content only through a verified and substantiated theory, through the useful part that it plays in a theory that reflects an objective process. There is nothing unusual in this, for science has shown that this is just the nature of the relation between the unified whole of any object and the categories subordinated to it, and theories are only the images or shapes of the unified objects.

The great merit of quantum mechanics lies precisely in this, that it taught us to understand the atom, and, indeed, any physical system, not as a mechanical conglomerate of component parts, but as a unity, in which there arises a law characteristic of the definite object (a "specific" law); this law is obeyed by the components, which in doing so change their own nature. Only in this way have explanations been found for such properties of atoms as their stability, saturation, and so on, which prequantum physics was unable to explain.

This sort of connection between a theory and the categories reflected in it manifests itself most prominently in quantum physics precisely because here it is most clearly seen that some of the categories of the theory do not exist at all outside the unity of the theory.

But in the present context it is essential to emphasize that this connection between theory and categories is a general law of cognition, which is manifested in any theory, and consequently also in classical physics. To convince ourselves of this, we examine the concept of temperature, for which Born readily admits the operational method of definition: "it is reasonable to introduce temperature by describing the thermometric operations," he writes. But for the concept of temperature to have physical meaning, it must satisfy a number of conditions. It must be shown that in thermodynamic equilibrium there exists a certain single-valued, monotonically varying function of the state of the system (for example, increasing monotonically with increasing energy of the system). The possibility of measuring the values of this function is determined, firstly by the fact that it must have the property of transitivity, whereas the energy of systems interacting by the exchange of heat has the property of additivity; secondly, by the fact that when the system passes to a new thermodynamic equilibrium there must be monotonic change not only of the required function, but also of at least one of the other parameters of the state of the system. The existence of a function satisfying these requirements is established in thermodynamics.* This function is the temperature, a concept organically connected with all the other categories of thermodynamics. This extremely indirect definition of temperature also makes clear the limits on the use of this concept. Thus when there is no thermodynamic equilibrium, for example in an electric discharge, the concept of temperature cannot be applied; this limit on the domain of application of the concept of temperature cannot be perceived when it is defined in terms of a thermometric operation.

It follows from what has been said that although before the development of the theory it was possible to measure temperature and even have a primitive idea about its meaning (for example, as the "degree of hotness of a body"), the definition of the scientific concept of temperature is given not by a procedure of measurement but by the theory in which the concept appears as one of its features, as a category connected by the theory with other categories. On the other hand, the possibility of measuring the temperature and the very procedure of the measurement bare based on the presence of definite objective properties that provide the conditions for the definiteness and uniqueness of the measurement and define the limits of the usefulness of the concept; consequently this possibility is based on a certain theory that reflects specific objective processes, in the present case the theory of thermodynamics. Similar arguments apply to all other concepts.

We thus see that operationalism is not able to reflect the genuine process of cognition because of its basic shortcoming: being an empirical con-

*Cf. e. g., M. A. Leontovich, Введепие в термодинамику, (Introduction to Thermodynamics), Gostekhizdat, Moscow 1952.

ception, it ignores the part played by theory in the process of the formation and development of concepts.

One more point must be emphasized: operationalism attaches to each concept, once and for all, a definite procedure of measurement; by so doing it restricts the content of a concept that historically has been discovered before others. Every object, however, that is reflected by a concept (or every category inherent in an object) has a multitude of interrelationships with other objects (or categories), which may turn out to be of greater importance than the relation already adopted as the definition of the concept, though they are discovered only afterwards. For example, the concept of mass is not exhausted in its meaning by Mach's operationally motivated fixation of the role it plays in the mutual accelerations of bodies; in fact, mass also has other essential properties and relationships that were discovered later, for instance its connection with energy, or its dependence on relative velocity, and it is scarcely legitimate to suppose that these relations have less significance than the one Mach took as the basis for the definition of mass. With the advance of knowledge it is found that the definition of a concept in turns of that one of the possible measurement procedures that had become known is a limited one from the historical point of view. Such a definition either turns the concept into an extra-historical category given once for all, or else comes to be regarded as purely conventional. It is well known, for example, that Mach, who also identified each concept with a definite operation of measurement, regarded these definitions as no more than conventional stipulations; he based this view on the fact that the historical sequence of discoveries is accidental and by no means uniquely determined. Let us recall the course of one of these arguments given by Mach. Asserting that physics regards heat as motion and electricity as a substance, Mach shows that this difference in the ideas is determined by the methods of measuring them that developed historically. "In studying the discharges of a Leiden jar," Mach writes, "we can use two different operations of measurement: one with the Coulomb balance, constructed in 1785, and the other with the Riess thermometer, invented in 1838; Since the time of Coulomb the result of the first measurement has been called quantity of electricity, and we call the result of the second the potential." "When the electrical discharge of a Leiden jar produces heat, its potential changes, and, as the Riess thermometer shows, the value decreases. But the quantity of electricity, according to Coulomb's measurement, remains unchanged. Now let us imagine that the Riess thermometer was discovered earlier than Coulomb's torsion balance. It is not hard to imagine this, because these inventions do not depend on each other in any way. Would it then not have been more natural if the quantity of electricity contained in a Leiden jar was evaluated in terms of the heat produced in the thermometer? But then the so-called quantity of electricity would have decreased on the production of the heat, whereas now it remains unchanged. Consequently electricity would in that case not have been a substance, but would have been a motion, whereas now it is still a substance. From this it is clear that if we think about electricity otherwise than about heat, this fact has a purely historical and quite accidental conventional basis." In Mach's general conception this conventional quality of concepts is justified by the fact that concepts, according to Mach, are not the reflections of objective categories, to which they must correspond. "In the study of nature," he writes in connection with the arguments given above, "all that is of importance is a knowledge of the relations of phenomena. Whatever we imagine as behind the phenomena exists only in our minds, and has for us only the significance of a mnemonic device or formula, whose form, being arbitrary and immaterial, changes very easily with the state of our culture."*

Mach's position was purely positivistic. A scientist who starts from the existence of an objective world outside ourselves is of course unable to accept this position.

All these considerations lead us to the conclusion that the operationalistic method of introducing concepts into science does not assure the objectivity of knowledge, and therefore is unacceptable; it is unacceptable not only in quantum physics, but also in general, as an epistemological method.

Let us summarize briefly.

Born is right in holding that there are no other ways of knowing the external objective world except by interacting with it. New experience changes old ideas about the world in a compelling way, deepening them and making them correspond more truly to the world. The fact that the development of our ideas is forced on us shows the existence of an objective content in our experience. From this arises the high value given to experience, to experiment, as the source of cognition.

But a reflection of the external world is not con-

*Cf. E. Mach, History and Root of the Principle of the Conservation of Energy (Russian translation from German original, S. Peterburg 1909).

fined to a single isolated experience; the single experience is generalized and given meaning in a theory; relying on experience, man is free to represent the most subtle and complicated relations in the world in terms of abstract theories, which therefore give a deeper knowledge of the world than the single direct experiment. From this comes the value given to theory, as a deeper representation of the external world, in which experience is generalized and given meaning. Practical activity on the basis of the theory thus developed verifies its correspondence to the external world.

Experience, accumulated and generalized in theory, and thereupon in a unified world view, starting from the recognition of an external world and its reflection in human consciousness, enables the scientist to overcome blind expiricism and is his guide in the progressive advance of knowledge. The justified struggle against dogmatism cannot exclude the guiding role of theory and the world view, provided only that they accurately reflect the regularities of the objective world.

These are the inescapable conclusions that must be reached by a scientist thinking about the question of the roles of experiment and theory in cognition.

Translated by W. H. Furry