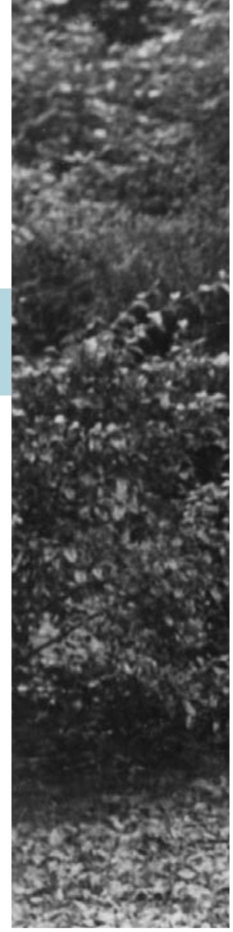
Physics, Philosophy, and Scientific Progress

In this 1950 speech to the International Congress of Surgeons in Cleveland, Ohio, Einstein argued that the 19th-century physicists' simplistic view of nature, illusory as it was, gave biologists the confidence to treat life as a purely physical phenomenon.

Albert Einstein



Let me express my heartfelt thanks for the honorary fellowship that your organization has bestowed upon me, and for your kind invitation to address you on the occasion of the International Congress of Surgeons. While complying with your invitation, I am aware of my inadequacy for this undertaking, on which I should never have ventured on my own.

During the past 20 years, however, I have become enough of an American not to be too much afraid of you. Last year, I even had occasion to experience, myself, how accomplished you have become in the art of making your victim's lot easy to bear. But it is something altogether different that fills me with respect: Specialization in almost all branches of human endeavor has, to be sure, resulted in unprecedented achievements—however, at the expense of narrowing the individual's field of vision. Thus it is hard nowadays to find anyone able to repair, properly, a garment, a piece of furniture, let alone a watch.

The situation is not much better in the professions, and even in research, as every graduate student knows. In medicine too, considerable specialization has become avoidable with increasing knowledge. But in this case, specialization has its natural limits. If some part of the human body has gotten out of gear, a person with sound knowledge of the whole complex organism is needed to put it right. In a complicated case, only such a person can obtain an adequate understanding of the disturbing courses. For this reason, a comprehensive intelligence of general causal relations is indispensable for the physician.

But there are two more requirements for the surgeon: unusual reliability of the senses and of the hands, and an unusual presence of mind. If, after opening the body, an unexpected situation presents itself, a quick decision has to be made as to what to do and what to omit. This is a situation that requires a strong personality. And this commands my deep respect.

Venturing onto the thin ice of philosophy

Such an opportunity as presented to me today, to address scientists in a field far remote from my own, offers itself naturally as an invitation to touch on epistemological questions of a more general character—or, to put it differently, to venture on the thin ice of philosophical deliberations.

If philosophy is interpreted as a quest for the most general and comprehensive knowledge, it obviously becomes the mother of all scientific inquiry. But it is just as true that the various branches of science have, in their turn, exercised a strong influence on the scientists concerned and, beyond that, have affected the philosophical thinking of each generation. Let us glance, from this point of view, at the development of physics and its influence on the conceptual framework of the other natural sciences during the last hundred years.

Since the Renaissance, physics has endeavored to find the general laws governing the behavior of material objects in space and time. To consider the existence of these objects as a problem was left to philosophy. To the scientist, the celestial bodies, the objects on Earth, and their chemical peculiarities, simply *existed* as real objects in space and time, and his task consisted solely in abstracting these laws from experience by way of hypothetical generalizations.

The laws were supposed to hold without exceptions. A law was considered invalidated if, in a single case, any one of its properly deduced conclusions was disproved by experience. In addition, the laws of the external world were also considered to be complete, in the following sense: If the state of the objects is completely given at a certain time, then their state at any other time is completely determined by the laws of nature. This is just what we mean when we speak of "causality." Such was approximately the framework of the physical thinking a hundred years ago.

As a matter of fact, the framework was even more restrictive than it has been sketched. The objects of the external world were considered to consist of immutable mass points, acting upon each other with well-defined forces eternally attached to them and, under the influence of these forces, carrying out incessant motions to which, in the last analysis, all observable processes could be reduced.

From a philosophical point of view, the conception of the world, as it appears to those physicists, is closely related to naive realism, since they looked upon the objects in space as directly given by our sense perceptions. The introduction of immutable mass points, however, represented a step in the direction of a more sophisticated realism. For it was obvious from the beginning that the introduction of these atomistic elements was not induced by direct observation.

With the Faraday–Maxwell theory of the electromagnetic field, a further refinement of the realistic conception was unavoidable. It became necessary to ascribe the same irreducible reality to the electromagnetic field, continually distributed in space, as formerly to ponderable matter. But sense experiences certainly do not lead inevitably to the field concept. There was even a trend to represent physical reality entirely by the continuous field, without introducing mass points as independent entities into the theory.

Summing up, we may characterize the framework of physical thinking up to a quarter of a century ago as follows: There exists a physical reality independent of substantiation and perception. It can be completely comprehended by a theoretical construction which describes phenomena in space and time—a construction whose justification, however, lies in its empirical confirmation. The laws of nature are mathematical laws connecting the

Einstein in 1948, posing for sculptor Gina Plunguian. Courtesy of AIP Emilio Segrè Visual Archives

mathematically describable elements of this construction. They imply complete reality in the sense mentioned before.

A reality independent of observation?

Under the pressure of overwhelming experimental evidence concerning atomistic phenomena, almost all of today's physicists are now convinced that this conceptual framework—notwithstanding its apparently wide scope—cannot be retained. What appears untenable to physicists of our times is not only the requirement of complete causality but also the postulate of a reality which is independent of any measurement or observation.

Let me illustrate what I mean by using light as an example. Let a light beam of a certain color impinge on a reflecting and transparent plate. The beam will be decomposed into one transmitted and one reflected beam. Apparently, the whole process can be completely and adequately described by an electromagnetic field. This theoretical interpretation not only furnishes direction, intensity, and polarization of both beams, but also, with amazing precision, the interference phenomena which are produced if, subsequently, both beams are brought to interaction by a suitable device.

It has been shown, however, that light has an atomistic energetic structure or, as it is usually put, consists of "photons." If an elementary act of absorption occurs in an object which is struck by one of the beams, the amount of energy absorbed is independent of the intensity of the light. We are forced to conclude that this phenomenon has nothing to do with the fact that several photons are involved. A *single* photon is responsible for the ability of the two beams to interfere, as well as for the absorption of light from one of the beams.

It is evident that Maxwell's theory cannot account for this complex of properties of the photon. It does not provide us with any means to understand the atomistic character of the absorbed energy of radiation. But if one tries to picture the photon as a pointlike structure moving in space, it must either be transmitted or reflected by the plate, since its energy is indivisible.

This interpretation leads to two difficulties: Assume that the photon, before reaching the plate, is a simple physical object characterized by direction, color, and polarization. What is going to determine whether, in any single case, the photon will be transmitted or reflected? The existence of sufficient reason for such a decision is hard to envisage, and it is not easy to believe in the existence of such a reason. Second, the interpretation of the photon as a pointlike structure does not admit of an explanation for the interference phenomena which are only produced if *both* parts of the beam interact.

A probability field

In this exigency, the physicists have chosen the following expedient: The wave description of light is retained. The wave field, however, does not represent a real field whose energy is distributed through space, but only a mathematical construction with the following significance: The intensity of the wave field in a given region is a measure for the probability that the photon is localized there. This probability is all that can be tested experimentally, namely by absorption devices.

It has turned out that by replacing the field in the sense of the original field theory by a probability field, a method has been obtained that is by no means restricted to the theory of light, but furnishes also, mutatis mutandis, a most useful theory of the behavior of ponderable matter. The price which had to be paid for the extraordinary success of the theory has been twofold: The requirement of causality, which anyhow cannot be tested in the atomistic domain, had to be given up, and the endeavor to describe the reality of physical objects in space and time had to be abandoned. In its place, an indirect description is used, from which the probability of the result of any conceivable measurement can be computed.

So much about some of the fundamental ideas of physics, as they have developed during the course of the last century. Let us try to realize what has been the effect of this development on biologists, or rather, on their philosophical attitude as far as it is essential to the objective of their research. Physics is, of course, understood here in its widest sense—that is to say, including all the sciences dealing with inorganic nature.

Let us recall, in this connection, the fertilizing influence of the concepts of Newton's celestial mechanics on the development of physics. Newton demonstrated how to understand planetary motion by applying, in a suitable way, the concepts mass, acceleration, and force—regarding the latter as dependent on the configuration of the masses. These concepts seemed so natural, even necessary, that one expected them, with complete confidence, to furnish the key to the understanding of all processes in inorganic nature.

Based on these concepts, a mechanics of continuous media was next developed, wherein the concept of force was extended by the introduction of stresses. In order to complete the theory, though, the thermal concepts temperature and heat had to be introduced. Although the question—whether or not these concepts are reducible to mechanical ones—remained undecided for a long time, it was finally answered in the affirmative by the development of kinetic theory of gases and, more generally, of statistical mechanics.

Just as physics could develop as the younger sister of celestial mechanics, so did biology as the younger sister of physics. A hundred years ago, there was hardly any doubt in the minds of the natural scientists that the mechanistic basis of physics was established for all times. Inorganic processes appeared comparable to a clockwork whose constituent elements seemed to be completely known, even though the complexity of their interaction did not yet permit of a detailed analysis. But it seemed beyond doubt that untiring experimental and theoretical efforts would, step by step, lead to an ever-increasing understanding of all processes.

Since these fundamental laws seemed well established, it was inconceivable that they should fail in the organic field. It seems to me that the unqualified confidence in the foundation of physics during the 19th century was essential to the development of biology—together with the technical tools and methods which resulted, to a great extent, from physical research. For no one plunges into an undertaking of such dimensions without being confident of eventual success.

Confidence resting on an illusion

Fortunately, today biology does not have to look to the foundation of physics anymore in order to find confidence in the eventual solution of its deeper problems. 'Fortunately,' since we now know that the confidence in those mechanistic foundations rested on illusion, and the older sister—in spite of amazing results in details—is not so sure anymore of comprehending the essence of natural phenomena. This is noticeable in the fact that she takes such a lot of pains to philosophize about her job, an attitude that she would have scorned a hundred years ago.

Under the impression of the profound changes that scientific thinking has experienced since Galileo, the question arises: Is there nothing at all that has remained stable in all this change? As a matter of fact, one easily recognizes certain principal features to which science has firmly adhered since those times.

▶ First: Thinking, alone, can never lead to any knowledge of external objects. Sense perception is the beginning of all research, and the truth of theoretical thought is given exclusively by its relation to the sum total of those experiences.

PETER OZSVATH

▶ Second: All elementary concepts are reducible to space–time concepts. Only such concepts occur in the "laws of nature." In this sense, all scientific thought is "geometric." A law of nature is expected to hold true without exceptions; it is given up as soon as one is convinced that one of its conclusions is incompatible with a single experimental fact.

▶ Third: The spatiotemporal laws are *complete*. This means, there is not a single law of nature that, in principle, could not be reduced to a law within the domain of space–time concepts. This principle implies, for instance, the conviction that psychic entities and relations can be reduced, in the last analysis, to processes of a physical and chemical nature within the nervous system. According to this principle, there are no nonphysical elements in the causal system of the processes of nature. In this sense, there is no room for "free will" within the framework of scientific thought, nor for an escape into "vitalism."

Just one more remark in this connection. Even though modern quantum theory contains a weakening of the concept of causality, it does not open up a back door to the advocates of free will, as is already evident from the following consideration: The processes determining organic phenomena are irreversible, in the sense of thermodynamics, and of such a kind as to eliminate the statistical elements ascribed to molecular processes.

Will this credo survive forever? It seems to me a smile is the best answer.

Editor's Note: The Hebrew University of Jerusalem holds the copyright for this speech, which Einstein delivered in English. The original sound recording is available, with other recordings of Einstein in German and English, on the CD set Verehrte An- und Abwesende! *(Honored audience, present and absent!), released by the German firm Supposé (www.suppose.de). We thank Engelbert Schucking for calling the speech to our attention.* ■