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Physics and the Explanation of Life

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It is proposed to consider present-day physics as dealing with a special situation, the situation in which the phenomena of life and consciousness play no role. It is pointed out that physical theory has often dealt, in the past, with similarly special situations. Planetary theory neglects all but gravitational forces, macroscopic physics neglects fluctuations due to the atomic structure of matter, nuclear physics disregards weak and gravitational interactions. In some of these cases, physicists were well aware of dealing with special situations, or limiting cases as they are called in the article; in other cases, they were not. It is pointed out that, even if it were true that present-day physics accurately describes the motion of the physical constituents of living bodies, it would not give the whole story. Arguments are adduced, however, to show that the laws of physics, applicable for inanimate matter, will have to be modified when dealing with the more general situation in which life and consciousness play significant roles.

1. INTRODUCTION

The subject of this article, the relation of life to present-day physics, is not a problem of physics. Since I am a physicist, I may well be told, "*ne sutor ultra crepidam*"—the shoemaker should stick to his last. There are, however, several excuses for my writing on this subject and also on the possible extension of the present area of physics into the science of life. The first is that, if no solid knowledge is available in a field, it is

The present article is a somewhat revised version of the address presented by the writer at the 1969 AAAS meeting in Boston, Mass.

good if representatives of neighbor sciences put forward the views which appear most natural from their own vantage point. The second reason for my taking up this subject is that, since I started to think and also to write on the subject, I have received many letters and verbal comments from colleagues, agreeing, on the whole, with my point of view. This means, I hope, that there is some interest in the subject among physicists and some consensus on it. It also means that much of what I will have to say will not be original but must have been conceived, at least in part, before me. My third excuse for putting forward views which do not have the solid foundation which one is used to expect from a physicist is that many others before me have done likewise. My fourth excuse is simply that the subject is of overwhelming interest and I like to speculate about it.

2. A BIT OF HISTORY

It would be difficult to review here even that small part of the philosophers' thinking on the problem of body and mind, physics and consciousness, with which I am familiar. Let me confine my attention to the ideas of three schools, all of which have had a profound effect on our thinking.

Descartes seems to have been the first in modern times to have devoted a great deal of thought to our question. Descartes is best known to most of us as the originator of the rectangular coordinate system, and for his pronouncement, "*cogito ergo sum*." This saying indicates that he recognized the thought, an evidence of the consciousness, as the primary concept. Descartes was also the first to recognize the nerves as transmitters of sensations and the brain as the depository of our emotions and our memory. He said that the brain is the body's link to the soul.[(1)]

Let me comment only on two characteristics of Descartes' thoughts. The first point to which I wish to call attention is that Descartes considered mind and body to be two separate entities, the body acting on the mind. He did not think of body and mind as fused into an entity. Second, he maintained that only man has a soul; animals are mere machines or automata, devoid not only of thoughts and emotions, but also of sensations. One of his successors, Malebranche, said (quoted by Huxley,[(2)] p. 218): "Thus dogs, cats, and the other animals, have no intelligence, no soul in the sense in which this concept is usually understood. They eat without pleasure, cry without pain, grow without knowing this. They have no desires and no knowledge." This sounds fantastic to us, pupils of Darwin's recognition that man is an animal species. It sounds more fantastic than it should: some insects lack sensations to a surprising extent. A wasp whose thorax was cut off suddenly did not appear to notice this but continued to eat, the food dropping out of the channel leading to the thorax. I shall return later to this illustration of the enormous differences between the inner lives of different animals.

The next philosopher whose ideas I wish to mention is Thomas Huxley.[1] He

[1] Huxley,[(2)] pp. 199 ff. I am greatly indebted to Dr. W. Schroebel for calling my attention to this essay. Ideas similar to those of Huxley were held by many others. Medawar[(3)] mentions, with approval, D'Arcy Thompson's very similar convictions.

recognized the near absurdity of Descartes' view as far as the sharp and absolute difference between the states of consciousness of animals and man is concerned. He did accept, however, Descartes' view that animals are pure automata, and extended this to man. According to Huxley, and many other philosophers who followed him, man's and animals' volitions, their intentions, are consequences rather than causes of the physical circumstances. At first hearing, this appears absurd but, as will appear later on, in the deterministic framework of these philosophers it is more nearly meaningless than absurd. Causation is not a well-defined concept in a deterministic picture of the world—it may not have an unambiguous meaning in any known picture. This statement will be made more explicit and concrete later on; it will also be expressed in the physicist's language.

The last body of thought that I wish to refer to is that of the *Gestaltslehre* of Wertheimer, Köhler, and others (see, e.g., Petermann or Köhler[(4)]). They point out that a steam engine, for instance, would be very inadequately described as a steel cylinder, covered at one end, having a closely fitting but movable disk on the inside and a rod, attached to this disk, protruding on the other side. Rather, in order to describe a steam engine, its purpose and the cooperation of its parts should be given. Similarly, an explanation of an animal in terms of the physical functioning of its parts will be inadequate; it is a whole, much more than the sum of its parts.

The point of the *Gestalt* theoreticians is undoubtedly correct and it is a valuable observation. However, it seems to me to be more a pedagogical than an ontological observation. Surely, we do not obtain a vivid picture of man by just describing his bones and muscles and how they are attached to each other. However, it is possible to describe the functioning of man's organs without answering the question of the relation between his body and soul, his emotions and his physical constitution, his volition and his movements. Hence, it appears to me that the statements of the *Gestaltslehre*, though both true and relevant, really avoid the principal issue which confronts us.[2]

Let me now attack our problem from the point of view of the physicist, the physicist familiar with the fundamental changes which quantum mechanics initiated in the physicist's picture of the world. I shall begin with the part of our title with which I should be familiar—with physics.

Before doing this, let me point out, however, that the present writer is by no means the only physicist interested in our subject. Again, it would be impossible to mention all the thoughts and articles on the subject. Bohr[(6)] was probably the first to have at least skirted it on the basis of the fundamental changes brought into the thinking of the physicists by the statistical interpretation of quantum mechanics. Margenau wrote on it, not only in *The Nature of Physical Reality* but, more concisely, in his *Scientific Indeterminism and Human Freedom.*[(7)] The reader will find references to writings of W. Elsasser, J. H. Greidanus, H. H. Pattee, E. H. Walker, H. Zanstra, Jules Duchesne, and some others (including Margenau) in this writer's article, "Are We Machines?"[(8)] In some ways, the present article is only a condensation of what this writer has learned from others and of his earlier writings.

[2] An interesting account of the views of many philosophers, physicists, and biologists is given by Jaki.[(5)]

3. WHAT IS PHYSICS? WILL IT FORM A UNION WITH THE LIFE SCIENCES?

One often hears the statement that the purpose of physics is the explanation of the behavior of inanimate objects. To most of us physicists, this does not appear to be a very incisive statement. What our science is after is, rather, an exploration of the regularities which obtain between phenomena, and an incorporation of these regularities—the laws of nature—into increasingly general principles (the theories of physics), thus establishing more and more encompassing points of view. I like to quote Bohm[9] in this connection, who said that, "Science may be regarded as a means of establishing new kinds of contacts with the world, in new domains, on new levels." No ultimate explanation is possible and our science is rather a constant striving for more encompassing points of view than the provider of an explanation for one or another phenomenon.

If all this is accepted, it follows that the phenomena of life and mind will form a unit with our regularity-seeking physical sciences if regularities in the behavior of the thought processes can be discovered, and an encompassing point of view developed which embraces both the phenomena of the mind and those of matter. Surely, psychology has pointed to many regularities in our thought processes and has made many, many interesting observations. These are, however, at present entirely divorced from the regularities in the behavior of matter which are the subjects of present-day physics.

My discussion of life and consciousness will be based on the assumption that these phenomena will become, along with ordinary physical phenomena, the subjects of a regularity-seeking science. It will be based on the assumption that a picture will be discovered which will provide us with a view encompassing both mental and physical phenomena and which describes regularities in both domains from a unified point of view. Clearly, these are assumptions for which a proof is lacking at present.

Are there tendencies in the sciences of life to expand in the direction of physics and are there, conversely, tendencies in physics to consider the phenomena of life and consciousness? If the disciplines in question are considered broadly enough, both tendencies are present. It is true that physics, in the true sense of the word, is foreign to basic psychology. However, the life sciences, particularly those dealing with the lowest organisms, are endeavoring to acquire a base in chemistry and physics. They also hope to extend their interest, eventually, to organisms of which consciousness is an essential characteristic. Conversely, the basic principles of physics, embodied in quantum-mechanical theory, are dealing with connections between observations, that is, contents of consciousness. This is a difficult statement to accept at first hearing, and I must hope that most are familiar with it. In essence, it recalls that quantum mechanics is not a deterministic theory.[6,7,10] The formulation of its laws in terms of our successive perceptions, between which it gives probability connections, is a necessity. Classical physics, of course, also can be formulated in terms of (deterministic) connections between perceptions, and the true positivist may prefer such a formulation. However, it can also be formulated in terms of absolute reality; the *necessity* of the formulation in terms of perceptions, and hence the reference to consciousness, is characteristic only of quantum mechanics. In fact, the principal objection which the present writer is inclined to raise against the epistemology of quantum mechanics is that it uses a picture of consciousness which is unrealistically schematized and barren. Nevertheless, there is a tendency in both physics, which we consider as the most basic science dealing with inanimate objects, and in the life sciences to expand toward each other. Furthermore, the tendency is strongest in the modern parts of the two disciplines: in quantum mechanics on the one hand, in microbiology on the other. Each feels it cannot get along by relying solely on its own concepts.

Nevertheless, that the tendencies to which I just alluded will ultimately lead to a merger of the disciplines can be only a hope at present. Neither of them proposes in its present form a more encompassing point of view; both wish to use the concepts of the other only as the basic concepts in terms of which their own regularities can be formulated. That some such basic concepts are unavoidable is, I believe, clear: there must be some things which are the subjects of regularities. It is not clear, however, that these subjects must be either entirely in the realm of orthodox physical theory, or entirely of psychological nature. Nevertheless, it is encouraging that there is a tendency on both sides of the chasm to take cognizance of the other side—even if both sides are forced to do so, or perhaps *because* both sides are forced to do so.

Let me now come to my last subject: the physicist's view of the relation between body and mind. I will try to give a rational discussion of the two alternative roles which present-day physics can play in a future regularity-seeking science the realm of which extends to the phenomena of mind as well as to those of present-day physics.

4. A PHYSICIST'S VIEW ON THE MIND-BODY PROBLEM—THE FIRST ALTERNATIVE

Physics has, at present, no perfect, well-rounded theory which could be applied to all phenomena involving inanimate matter. Nevertheless, most of us physicists feel that such a theory is attainable without delving deeper into the problems of life and consciousness, that the basic principles of quantum mechanics need not be modified in order to arrive at a theory which correctly accounts for all regularities in the behavior of inanimate matter. Even though the present writer is well aware of the cavalier nature of the picture which present quantum-mechanical theory presupposes about consciousness, as long as this theory deals with inanimate matter he would not seek for its improvement by means of a closer analysis of the content of consciousness. To put it in a somewhat vulgar fashion, even most physicists, if unexpectedly presented with the question of the validity of the laws of physics for organic matter, would affirm that validity. On the other side of the chasm, many, if not most, microbiologists would concur in this view. The view does not lead automatically to Huxley's view that we are automata, since the present laws of physics are not deterministic but have a probabilistic character.[7] Furthermore, if we are honest about it, we cannot now formulate laws of physics valid for inanimate objects under all conditions. Hence, the statement which we are considering should be formulated somewhat more cautiously: that laws of nature, for the formulation of which observations on inanimate matter suffice, are valid also for living beings. In other words, physical laws, obtained by studying the traditional subjects of physics, and perhaps not very different from those that physicists are trying to formulate now, will form the basis from which the behavior of living matter can be derived—derived perhaps with a great deal of effort and computing, but still correctly derived.

The assumption just formulated is surely logically possible. It is very close to Huxley's views which were mentioned before. Would it mean that, eventually, the whole science of the mind will become applied physics? In my opinion, this would not be the case even if the assumption which we are discussing were correct. What we are interested in is not only, and not principally, the motion of the molecules in a brain but, to use Descartes' terminology, the sensations which are experienced by the soul which is linked to that brain, whether pain or pleasure, stimulation or anxiety, whether it thinks of love or prime numbers. In order to obtain an answer to these questions, the physical characterization of the state of the brain would have to be translated into psychological-emotional terms.

It may be useful to give an example from purely physical theory for the need for such a translation. The example which I most like to present derives from the classical theory of the electromagnetic field in vacuum, that is, the simplest form of Maxwell's equations. These give the time derivative of the electric field E in terms of the magnetic field H, and the time derivative of the magnetic field in terms of the electric field. Both fields are free of sources. Although the actual form of the equations is not very relevant for our discussion, writing out these equations may render the discussion more concrete:

$$\partial H/\partial t = -c \operatorname{curl} E, \qquad \partial E/\partial t = c \operatorname{curl} H \tag{1}$$

These equations will be called, briefly, Maxwell's equations; actually, they are Maxwell's equations for empty space; c is the velocity of light. If E and H are given at one instant of time, these equations permit their calculation for all later times, and for all earlier times. They will serve as model equations for the discussion which follows—they give both sides of the picture, the electric and the magnetic side, and do not prefer one over the other.

It is possible, however, to formulate an equation for the magnetic field alone. This is again, and should remain, free of sources and its time dependence is regulated by the equation

$$\frac{\partial^2 H}{\partial t^2} = c^2\left(\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2} + \frac{\partial^2 H}{\partial z^2}\right) \tag{2}$$

One can observe now that, if H and $\partial H/\partial t$ are given at one instant of time, (2) permits the calculation of H for all later times—and for all earlier times. Is now this equation, which is just as valid as Maxwell's original equations, a full substitute for the latter? The answer is no. If we want to obtain the force on a small charge at rest, the original form of the equations furnishes this directly: it is the electric field at the place where the charge is, multiplied by the magnitude of the charge. In order to obtain the force from (2), referring only to the magnetic field H, one has to calculate first the electric field in terms of H. This can be done, though the formula is not quite simple:

$$E(r) = -\operatorname{curl} \iiint \frac{\partial H(r')}{\partial t} \frac{d^3r'}{4\pi c \mid r - r' \mid} \tag{3}$$

Equation (3) gives the translation of the magnetic field into the electric one and this is, in the case considered, more relevant than the magnetic field itself. We have, therefore, an example before us in which a theory—Eq. (2) for H alone—is completely valid but is not very useful without the translation which should go with it.

The preceding example also shows that the translation into the more relevant quantity can be quite complicated—more complicated than the underlying theory, that is, Eq. (2). The translation equation is also more complicated than the set of equations, in this case Maxwell's equations, which uses both concepts: the one which turns out to be the more relevant one, that is, E, along with the other, H, which does suffice for the formulation of the time dependence. It is unnecessary to remark that, in the preceding illustration of a future theory of life, H plays the role of the purely physical variables, E plays the role of the psychological variables. In this illustration, the use of both types of variables in the basic equations is much preferable to the use of only one of them—the problem of translation does not arise in that case.

The example just given illustrates also the observation on the meaningless nature of the concept of causation in a deterministic theory—such as Maxwell's theory of the electromagnetic field in vacuum. Looking only at Eq. (2), and the translation Eq. (3) thereof, one will conclude that the magnetic field is the prime quantity, its development is determined by its magnitude in the past. The electric field will appear as a derived quantity, caused and generated by the magnetic field. Maxwell's original form of the equations shows, on the other hand, the possibility (and, in the opinion of the physicists, the desirability) to consider the two to have equal rank and primitivity. As a matter of fact, relativity theory teaches us that the three components of E and the three components of H are all components of a single tensor, the electromagnetic field tensor. The fact that they appear in Maxwell's equations as equals was helpful when the special theory of relativity was first formulated.[11]

I believe I have discussed the assumption that the laws of physics, in the sense described, are valid also for living matter. We also saw that this assumption need not imply, as is often postulated, that the mind and the consciousness are only unimportant derived concepts which need not enter the theory at all. It may even be possible to give them the privileged status. Let us now turn to the assumption opposite to the "first alternative" considered so far: that the laws of physics will have to be modified drastically if they are to account for the phenomena of life. Actually, I believe that this second assumption is the correct one.

5. THE SECOND ALTERNATIVE: LIFE MODIFIES THE LAWS VALID FOR INANIMATE NATURE

I wish to begin this discussion by recalling how wonderfully actual situations in the world have helped us to discover laws of nature. The story may well begin with Newton and his law of gravitation. It is hard to imagine how he could have discovered this, had he not had the solar system before him in which only gravitational forces play a significant role. The discovery, also due to Newton, that these forces also determine the motion of the Moon around the Earth, and the motion of freely falling bodies too heavy to be much affected by air resistance, was a wonderful example for science's power to create a unified point of view for phenomena which had, originally, widely differing characters. Newton, of course, recognized that there must be other forces in addition to the gravitational ones—forces which, however, remain of negligible importance as far as the motion of the planets is concerned.

Newton's discovery was followed by the discovery of most laws of macroscopic physics. Maxwell's laws of electromagnetism—the ones which were just considered in the special case of absence of matter—are perhaps the most remarkable among these. Again, these laws—those of macroscopic physics—could not have been discovered were not all the common objects which surround us of macroscopic nature, containing many millions of atoms, so that quantum effects, for instance, play no role in their gross behavior. Again, the unifying power of science manifested itself in a spectacular way: it turned out that Maxwell's equations also describe light and, as we now know, all electromagnetic radiation from radio waves to X-rays.

The next step of comparable, perhaps even greater, importance was the development of microscopic physics, starting with the theory of heat and soon leading to quantum theory. Most of this development took place in the first half of our century but, in some regards, the development is still incomplete. If we assume that it can and will be completed—most of us believe this—the question which we should face is whether our present microscopic theories also presuppose some special situation, the absence of certain forces or circumstances. The point of view which we are discussing maintains that this is the case. Just as gravitational theory can describe only the situation in which no other but gravitational forces play a role, and macroscopic physics describes only situations in which all bodies present consist of many millions of atoms, present microscopic theory describes only situations in which life and consciousness play no active role.

Similarly, just as macroscopic physics contains gravitational theory as a special case, applicable whenever only gravitational forces play a significant role, and just as microscopic physics contains macroscopic physics as a special case, valid for bodies which contain millions of atoms, in the same way, the theory which is here anticipated should contain present microscopic physics as a special case, valid for inanimate objects. Thus, each successive theory is expected to be a generalization of the preceding one, to recognize the regularities which its antecedent postulated, but to recognize them as valid only under special conditions. This should apply also to the theory postulated here, in the form of the "second alternative."

Naturally, the preceding story does not *prove* that the present, microscopic physics will also have to be generalized, that the laws of nature as we now know them, or try to establish them, are only limiting cases, just as the planetary system, macroscopic physics, were limiting cases. In other words, it does not prove that our second alternative, rather than the first one, is correct. Can arguments be adduced to show the need for modification? There seem to be two such arguments.

The first is that, if one entity is influenced by another entity, in all known cases the latter one is also influenced by the former. The most striking and originally least expected example for this is the influence of light on matter, most obviously in the form of light pressure. That matter influences light is an obvious fact—if it were not so, we could not see objects. The influence of light on matter is, however, a more subtle effect and is virtually unobservable under the conditions which surround us. Light pressure is, however, by now a well demonstrated phenomenon and it plays a decisive role in the interior of stars. More generally, we do not know any case in which the influence is entirely one-sided. Since matter clearly influences the content of our consciousness, it is natural to assume that the opposite influence also exists, thus demanding a modification of the presently accepted laws of nature which disregard this influence.

The second argument which I like to put forward is that all extensions of physics to new sets of phenomena were accompanied by drastic changes in the theory. In fact, most were accompanied by drastic changes of the entities for which the laws of physics were supposed to establish regularities. These were the positions of bodies in Newton's theory and the developments which soon followed his theory. They were the intensities of fields as functions of position and time in Maxwell's theory. These were replaced then by the outcomes of observations (the perceptions referred to before) in modern microscopic physics, that is, quantum mechanics. In the development which we are trying to envisage, leading to the incorporation of life, consciousness, and mind into physical theory, the change of the basic entities indeed appears unavoidable: the observation, being the entity which plays the primitive role in the theory, cannot be further analyzed within that theory. Similarly, Newtonian theory did not further analyze the meaning of the position of an object, field theory did not analyze further the concept of the field. If the concept of observation is to be further analyzed, it cannot play the primitive role it now plays in the theory and this will have to establish regularities between entities different from the outcomes of observations. An alteration of the basic concepts of the theory is necessary.[3]

These are the two arguments in favor of the second alternative, that the laws of physics which result from the study of inanimate objects only are not adequate for formulating the laws for situations in which life and consciousness are relevant parts of the picture.

6. CONCLUSION AND SUMMARY

Clearly, the hope expressed in the last two sections, that man shall acquire deeper insights into mental processes, into the character of our consciousness, is only a hope. The intellectual capabilities of man may have their limits just as the capabilities of other animals have. The hope does imply, though, that the mental and emotional processes of men and animals will be the subjects of scrutiny just as processes in inanimate matter are subjects of scrutiny now. The knowledge of mind and consciousness may be less sharp and detailed than is the knowledge given by present-day physics on the behavior of inanimate objects. The expectation is, nevertheless, that we can view mind and consciousness—at least those of other living beings—from the outside so that their perceptions will not be the primitive concepts in terms of which

[3] This observation was also made by G. G. Harris (unpublished).

all laws and correlations are formulated. As to the loss in the sharpness and detail of the laws, this is probably unavoidable. It has taken place throughout the history of physics. Newton could determine all the initial conditions of the system of his interest and could foresee its behavior into the indefinite future. Maxwell's and his contemporaries' theories can be verified only by creating conditions artificially under which a verification is possible. Even then, it is possible only for limited periods of time. The laws of quantum mechanics, finally, neither make definite predictions under all conditions, nor have its equations of motion been verified in any detail similar to those of macroscopic theories. A further retrenchment of our demands for detail of verification is probably unavoidable whenever we extend our interest to a wider variety of phenomena.

As to the usefulness of the preceding considerations, I must admit that I do not see much of it. This may well be the reason for the lack of a more acute interest on the part of physicists in the questions discussed. Even if not useful, I would like to summarize them in concluding this article.

I believe that the present laws of physics are at least incomplete without a translation into terms of mental phenomena. More likely, they are inaccurate, the inaccuracy increasing with the increase of the role which life plays in the phenomena considered. The example of the wasp which does not seem to have sensations may indicate that even animals of considerable complexity are not far from being automata, largely subject to the present ideas of physics. On the other hand, the fact that the laws of microscopic physics are formulated in terms of observations is strong evidence that these laws become invalid for the description of observations whenever consciousness plays a decisive role. This also constitutes the difference between the view here represented and the views of traditional philosophers. They considered body and soul as two different and separate entities, though interacting with each other. The view given here considers inanimate matter as a limiting case in which the phenomena of life and consciousness play as little a role as the nongravitational forces play in planetary motion, as fluctuations play in macroscopic physics. It is argued that, as we consider situations in which consciousness is more and more relevant, the necessity for modifications of the regularities obtained for inanimate objects will be more and more apparent.

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