(Dr. Schwinger)

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QUESTIONS AND DISCUSSION

University of Delaware (1961)

Question

In classical physics, where we have a statistical type of situation as, for example, the behavior of a gas, we know that we can ascribe this to underlying structural features that we can't account for. Is it not possible that this is also true in quantum mechanics; that there are structural features underlying the particles that we can't account for; that we are stuck with the statistical notion which, if we were able to examine the structural features, we would be able to declare the behavior as a deterministic one rather than a statistical one?

Let me see if I can repeat that, or change it rather. The question is that of course, even in classical physics, we are familiar with situations which are statistical in the nature of their description as in thermodynamics, statistical mechanics, and so on. I gather the question is whether in that case we know that these are associated with the fundamental - - ((with fundamental - - features of motion or structure that we can't really account for because they are just too numerous to))*

Yes, that's right. The usual story in that case is that while in principle, within the framework of classical physics, one could, if one wished to, if one had enough batteries of calculating machines, account in detail for the invoking of the number of particles, the number of degrees of freedom, the complexity of the motion is such that in practice, it is not useful to do so, although classical physics says that in principle, one could.

The question is, when one says that in microscopic physics the laws are fundamentally statistical, is there something similar; that is, could it not be that we are simply not aware of some underlying mechanism which eventually will be disclosed and which at the moment we are not able to control but which if we could, it would make the laws deterministic?

That, of course, is hardly an answer except in the following way that the - - I think the answer to all such questions is always success or failure. You can never prove a theory in physics; you simply can say it has been successful in all of the domains in which it has been tried. And so I would say that the laws of

* Questioner interrupts.

quantum mechanics, which have been erected on the possibility of the statistical nature of microscopic phenomena, is fundamental and not just simply because we are stupid or unable to control some specific event but which has been erected on this, the laws of quantum mechanics, has been overwhelmingly successful in every domain. And that, in a sense, that I think one can show even within its own framework that there would be internal contradictions between supposing that there was this underlying determinism on the one hand, which is what you might hope for, and on the other hand, that the laws of quantum mechanics should still hold because you don't want to sacrifice them, they work.

So, I think the only answer is that in a sense, the success of quantum mechanics is the indication that this cannot be true, leaving, however, still a loophole of high energy phenomena. In other words, we do not know whether or not quantum mechanics fails at sufficiently high energies and sufficiently small distances. It is, therefore, conceivable that the way out, the means of reviving classical physics, could be in this completely opaque world of high energy physics.

I think any physicist would doubt this completely because as we go up to higher and higher energies, more and more non-classical phenomena, things that have no counterpart have come into evidence. To think that the whole day can be saved by something yet still to be found, well, while a logical possibility isn't to be expected, categorically, statements cannot be made about what the nature of future theories will be.

<u>Question</u>

As far as quantum mechanics is formulated then, it is inconsistent with the existence of a deterministic foundation?

Quantum physics is itself not deterministic in an individual sense. It is, however, as I hope I emphasized, statistically deterministic. It is entirely compatible, however, with the individual determinism that we find in the macroscopic realm. There is no difficulty there. It is a perfectly familiar fact that a large enough number of small things becomes perfectly definite in an individual event.

((I was trying to establish whether the answer that you were giving was that if we have to accept quantum mechanics, then we can't accept an underlying nature deterministic in character.))*

If we accept quantum mechanics as holding without modification throughout all the future domains of the exploration of physics, then we must reject any implicit, classical determinism. That leaves the loop-hole that quantum mechanics may fail in some remote region of space but we are then so far from the classical modes of thought and concepts that I find it inconceivable that that would finally turn the tables topsy turvey and we would be back to a classical world. That, of course, is what I think, and I think I'm right.

<u>Question</u>

Now, you suggest this philosophical dichotomy among physicists, one of whom feels that simpler mathematical models are the root, and the other feels that more and more accurate measurements and newer measurements are the root, if it really is a dichotomy - - -

((Dr. Schwinger: Sorry, I'm not sure I recognise myself in what you said.))

*Interruption by Questioner.

(Question continues)

I'm sorry, but that is the way I got what you said; correct me if I am wrong. But if this is what you said, isn't this rather a complementary activity in which the theoriticians develop models which t he experimentalists then prove or disprove?

Yes, may I agree with you - - the way in which this activity is conducted at the moment, and will be for many years, is complementary. The clash is not in what one does but the philosophy in what one things is the ultimate objective. The class of shall we say field theorists believes that the fundamental objective is to find a simple mathematical scheme and labor very hard to draw the mathematical consequences, and in this way explain vast areas of empirical evidence. The difficulty is that the mathematical complexity of field systems, which mechanically are systems of infinite numbers of degrees of freedom - - is that we have, as yet, no real understanding of how to handle this and there is a technical problem and; therefore, this point of view cannot be brought to bear on experimental evidence.

It is a very simple matter to postulate an underlying field system but to test it has been so far impossible. On the other hand, of course, we must make headway with correlating experimental data. And so, there is on the one hand the great activity of studying what comes out of the high energy accelerators, making simple hypotheses, and putting all these facts together. This we must do also. It is, on the other hand, a philosophical contention that this is all we can ever do. Whether they are ever to be accomplished can never be tested. You see, I'm afraid that this philosophical dissension is simply because of the inability to bring either conception to a test. In other words, if the theorists had the mathematical machinery to postulate various simple field systems and draw their consequences and say, yes, this one checks and no, this doesn't, then it would be no problem. But we cannot now, and I suspect not for many years to come, and so this philosophical discussion goes on also.

Question

Last week, Professor Hempel drew a rather distinct difference between a science and a pseudo-science by means of the disconfirmability criteria. Is quantum mechanics, since it is statistical in nature, is it challenged in any way by disconfirmability problems?

Well, as I have suggested, it has been the theoretical foundation that much of the developments that have gone on, for example, in the field of solid state physics, the invention of the transistor, if you like, is an application of quantum mechanics. I can point to many examples which a physicist is always glad to supply. There is no example in which quantum mechanics has ever been known to conflict with experiment in which, within its own conscious limitations of being a statistical theory, to provide the predictions for other possible experiments. It disclaims the ability to predict what can happen in any individual event, and it must be so because these can never be repeated. You take conditions in which you have repeated - - you have reproduced everything possible that you can control, and yet the phenomena will not duplicate themselves. Therefore, the physicist says we are not able - - it is not the purpose of physical theory to make these detailed predictions, but it is its purpose to make statistical predictions and in this domain, quantum mechanics has never failed without exception. It is the most successful theory we have. Much more successful, if you like, than any of the classical theories because it has brought unity into so many different domains of physics and it has united them under one common heading in the sense all of modern physics is applications of quantum physics.

Had such a thing as you mentioned occurred, there would have been an enormous crisis and everybody would be out hunting for a new theory or formula, something that has not occurred. Where there are problems, they are in an entirely different realm of physics - - of high energy physics - - where it is not simply the question of how you describe microscopic phenomena; it is also what are the microscopic phenomena. I mean, one is still finding out what it is you have to correlate and explain and as you go to higher and higher energies, new phenomena appear. There is no end to the process. In other words, it is not probably possible in any clear-cut way to test quantum mechanics without at the same time testing your belief and your comprehension about what the nature of this new world is; they are all tied together in a very complicated way. But in the domains in which quantum physics was set up to explain, ordinary atomic phenomena, it is completely successful.

Question

I was going to ask is the interaction between the measurement and the system being measured a fundamental property of the theory of measurement or a property of our techniques of measurement?

Well, it again comes back to the question: do you accept the statistical nature of these microscopic events as a fundamental aspect of nature, which you must just simply put up with, or don't you? If you do, then any measurement is a physical process. It must be subject to the same microscopic laws and, therefore, the theory of measurement must take into account the way any measurement as a microscopic interaction has to do. And so it is not something - - - I mean, if you ask the question is this simply a temporary limitation of our measurement techniques, you are really asking is there something that will eventually remove this statistical or an atomistic limitation? If I insist that this is the nature - - (this is the way nature is, not the nature of nature - -), then my description of physics, my theory of physics, since physics is an experimental science, it can only deal with those experiments that can be carried out by physical units. So, the theory of measurement must take into account the nature of physical objects. And so I would say that this is the same question.

Question

In the August issue of American Journal of Physics, Landé mounts a rather strong attack on complementarity. Have you seen the article and would you care to comment?

Sorry, I really haven't. Can you quote me the essential attack.

Questioner continues:

Here are two main points, that I remember:
(1) That the classic experiment explained by Duane, as modified by Born, that a statistical particulate interaction of electrons with the lattice vibrations, it is not a matter of wave characteristic rather than particle, it is a statistical collision process basically; and the other
(2) That there is no fundamental uncertainty; the problem is a problem of measurement; in principle the velocities, the momenta, or the positions are precisely exist and the measurement gives rise to the uncertainty.

I think these were his two main points. He doesn't agree with Bohr at all.

controversy is carried out. For example, the idea of the quantized field is something that goes completely beyond whether an electron acts like a wave in some simple classical sense, or is a particle in some simple classical sense. It is a new concept and I think we must throw away the old concepts except, of course, we are stuck with the classical language. It is always with us. But the way in which the theory operates is not in terms of these classical concepts. It is only when you, so to speak, confuse the issue by using irrelevant classical concepts, superimposed on what in fact you actually do, which is not the way the language goes in the course of this conversation, that difficulties appear. So, without having really seen what Landé has done in detail, I think I would disagree. But at least the concept of complementarity, I think, must be accepted by anyone who believes in quantum physics. I think, however, one has to divorce complementarity somewhat from its historical origins. I would prefer to give complementarity an understanding in the light of what I did; that the specification of a state, so to speak, involves half of the quantities of what it would be classically; but you have essentially your choice as to which half that shall be. In other words, you have your choice as to which roughly analogous to a classical description you can use. But once you have picked one, the other is excluded. The latter I interpret simply as the nearest you can come in classical language to this perfectly clear-cut mathematical quantum mechanical situation. And so I would say that all of these difficulties are difficulties of language, not of the theory, but it is a hard subject to discuss.

Question

What relationship does the overthrow of parity have to do with what you are talking about tonight?

Well, first of all, I would say that parity has not been overthrown.

Questioner: I stand corrected.

No, in what you meant, you are correct. Well, perhaps to explain a little bit. Among other things, what one takes, so to speak, at a very fundamental level and attempts to incorporate into the theory is the idea that while the description of nature, with respect to various coordinate systems which in turn are idealizations of the observer and his apparatus, that in a sense that there are all classes of observers who are on the same footing. In particular, the concept of parity lies in the idea that whether the coordinate system that the observer happens to use is left-handed or right-handed cannot have any particular bearing on the phenomena. So one has always believed that the essential equivalence of left and right, that there are no phenomena in nature or at least not that there is no physical phenomenon in nature, at least in the neighborhood of our earth which enables any physical distinction to be made between left and right. One also believed that there was no fundamental distinction between positive and negative charge. Once one had learned, as a result of experiment, that positive and negative charges, so to speak, when we created them instead of taking what happens accidentally in the present - - when we created positive and negative charges that always they are together. What one has to learn as a result of the experiments we mentioned is that the conception of space reflection left to right transition or parity is more sophisticated than one thought. What is now true without exception is that when you interchange, shall we say left and right coordinate systems, you must also interchange what we call positive and negative charge. This is still a parity, only in a more sophisticated sense, but if you like, parity has been retained but the equivalence of positive and negative charges has been destroyed. But the most important point is that before, one believed there were two distinct symmetry principles. Left and right are fundamentally indistinguishable; positive and negative charges are fundamentally indistinguishable. You have to arbitrarily say that that is an electron and then go on from there to label everything correspondingly. But what one knows now is that neither of these is true for all aspects of physics but only when taken together. In other words, when you go from a left to a right-handed coordinate system, if you do not at the same time interchange electrons and positrons, then there will be a discriminate difference but, nevertheless, there is an operation which changes left and right and changes nothing else. But you must also interchange positive and negative charge. So I would say that parity, meaning by that not the conception of parity that one had before this famous experiment but in some sense the indistinguishability of one from another, this is still with us but it has been sharpened, refined - - and other physical phenomena have come into play in a very interesting way because this means that there is now a connection between space and time, as in these equivalence of left and right coordinate systems. And something that we have always believed was outside of space and time, namely, electrical charge - - as a new physical concept, here we see in the face of these experiments, there's that charge again (Note the tape is inaudible at this point.) . . . .

Because before this, one would have hoped that what an electrical charge was, and all the other charges we are just beginning to recognise, one would hope that these could somehow be explained in terms of the overall characteristics of space and time, but as a theoretical question, it is essentially hopeless.

Question

(Note: The Japanese graduate student who asked about Hamiltonian equations did not speak loudly or clearly enough for a definite transcription from the tape. Will transcribe only if essential.)

Well, if I can try somehow to rephrase the question, I think that what you are asking is essentially the question of what do you do when you have a conflict between a philosophical prior conception about what invariance laws should be and the brutal statements of nature of what in fact they are. Philosophy suffers and we must put up with this. I think you must - - I mean, the attempt of theoretical physics is only, after all, to seek simple explanations and simple explanations are usually based upon prior conc e ption about what is simple. When such prior ideas run into conflict with the facts of nature, we must alter what we consider to be simple explanations. The history of what I have just told you about is the fact that passing from the simple laws of classical physics to a new world in which everything seemed paradoxical, incomprehensible, as we finally transmuted it into a beautiful new theory of quantum mechanics and so now we also have reached the stage perhaps of transmigration, so to speak, in which we are learning something new; perhaps not about quantum mechanics but about our belief in the nature of what are the fundamental entities. If we start out with the conception that there should be a symmetry between left and right coordinate systems, and historically one went far beyond what was necessary to state that as a simple requirement, an experiment brings us up short by telling us that we have over-idealised, over-simplified what we thought was that symmetry principle. When you say, what will we do? The answer is accept it. Change our theories to fit, but still always hoping that there will be some unifying symmetry principle. We have all been brought up to believe that a real understanding of unity and simplicity is a conservation law of symmetry principle, but we are slowly learning through the facts of physics precisely what forms these symmetry principles must assume and they are clearly much deeper and much more sophisticated than the elementary primitive attempts had been. And so it will go. Our understanding will adapt itself to the facts of nature and some day somebody will stand on this platform and again give you a history of physics and advance it by perhaps 15 years and he will indicate that a beautiful theory has finally emerged from all this, but it will not be the theories we are now talking about.