Chapter VII

Indeterminism and Nonlocality

John S. Bell

The following contribution is the transcript of a talk presented on 22 January at CERN on invitation of the Center for Quantum Philosophy, Geneva. The text is literally taken from the video-recording of this quite informal colloquium. It has the spontaneity and originality of the spoken word, but misses the final touch and the polishing of a written contribution. The late Prof. Bell could not revise the text himself. On the other hand the editors are not so sure that changes by them would improve the document. Instead we ask our readers to apologise the imperfections, which in some cases are also due to the not always perfect voice recording of the session. We would like to thank R.W. Nowak who did an excellent job in transcribing the text.

Introductory remarks

A. Suarez,
Center for Quantum Philosophy Geneva

About indeterminism we all as students have heard a lot. On the other hand there are still best-sellers of famous physicists that do not include the term nonlocality in the index. Every man who reads the rigorous book of John Bell *Speakable and Unspeakable in Quantum Mechanics*[1] wants to ask the author "Are both indeterminism and nonlocality necessary for a coherent physical theory or only one of these principles - and in this case which? - or neither of them." We are very grateful to Professor Bell for having agreed to discuss with us today this question. The talk will be registered - those who are interested in a copy of the tape can request it at the address of the Center. Please Professor Bell.

The Talk

1. Introduction

Imagine that this is a metal grid made of some very tough metal, and I am shooting bullets at it. Sometimes the bullet will hit the metal and be stopped, and sometimes it will go through the hole. Now imagine that that is made on a microscopic scale, so that I cannot see with my eyes or even with my instruments that it is made like that, that some parts are transparent and some parts are opaque. And what would happen when I shoot my little bullets would be sometimes they would go through, and sometimes not, and I would have a situation of **unpredictability**[2]. My experiment would sometimes give one result 'pass', and sometimes another result 'stop'. And a classical physicist would

---

[1] J.S. Bell:, *Speakable and unspeakable in quantum mechanics*, Cambridge University Press, Cambridge (1987)
[2] Words written down by Prof. Bell on the board are typed with bold characters

understand this situation by saying that the unpredictability arises from the **lack of control**. That although I think I am doing the same experiment each time, I am not doing the same experiment each time, because there are little things which I am not reproducing sufficiently accurately from one time to the next. And for a classical physicist, or let's say nineteenth century physicist, unpredictability simply meant lack of control.

So the unpredictability was in no way synonymous with **indeterminism**. For that classical physicist the unpredictability was a reflection of human weakness, and nature might very well be perfectly deterministic.

Now we have a situation a bit like that when we think of the photons streaming out from this lamp and coming up here, and being reflected towards the blackboard. If I put in some absorbing material, not all the photons get through. And if you did the experiment one photon at a time, you would find that sometimes the result of the experiment would be ‘pass’, and sometimes it would be ‘stop’. And it would be quite unpredictable which was the case. A classical physicist would say: ‘Aha, we don't get the same result every time because we don't know everything, and we don't control everything. There is something out of control in this experiment’.

But the founding fathers of quantum mechanics did not say that, they said we are confronted here with the case of **indeterminism**. Now, when I read history it always amuses me that the founding fathers could come so confidently to that conclusion. Up to then the tradition in physics was that if something was unpredictable, it was because it had not be fully controlled. And for me the natural assumption would be that the situation with photons is like this situation here.

And that was also the natural photon for Einstein, who said: ‘*God does not play dice’*. For him it was always an article of faith that the nature is lawful, and if we could not control it, that was our fault. And so he contemplated that the description given by quantum mechanics was **incomplete**. That it should be supplemented by hypothetical **hidden variables**, which we do not know just by inspection, but we will have to make theories about. And that when these hidden variables were found, at least conceptually, that we would again see that nature was perfectly lawful, that we would have **determinism**.

Now, the piece of absorber that they put there (see Fig. 1) is not just any old material, but it's actually polarising material. And the photons that get through a polarising material have the property that they cannot get through a second piece of the same material, if it is oriented at right angles to the first. Whereas if it is oriented parallel to the first, it gets through again. So that is a property of photons, that they have polarisation, which can be detected by such pieces of material, and that plays a role in the sequel to what I have to say.

Now at first this was simply a working hypothesis of Einstein, and for a few other die-hard classical nineteenth century physicists. But in 1935 he invented an extremely powerful argument, for this position, based on another hypothesis which most people who have not met these phenomena before would accept; the hypothesis of no **action at a distance**, which is sometimes called **local causality** or just **locality**. And he said that there are situations where this hypothesis implies determinism. So in this argument determinism was no longer a hypothesis, but a theorem, but with locality as the axiom.

locality ⇒ determinism

2. The EPR Gedanken-experiment

Now the situation that he[3], and later on in a more simple example David Bohm, the situation which he paid attention to was this: You can make, in a way that I will not go into in any detail, twin photons. You can have a source, which when you press the button, emits a photon going into this diagram, and another photon coming out (see Fig. 1). And you can see whether these photons do or do not pass through pieces of polarisation detecting material. And the twin photon source has the character, that whenever the photon passes here its twin passes there, and whenever this one does not pass here, its twin does not pass there. That's a feature of this particular source. Such sources exists according to quantum mechanics, and have been built experimentally. And that is true no matter which way these things are oriented, provided they are oriented in the same way. And this is a very powerful argument against the idea that the passage of this photon through that polariser is a matter of pure chance. If it was determined by a die being cast over here, this was determined by a die being cast over there, how could they possibly always agree either to pass or not to pass at a given location.

The situation here is rather like one which is extremely interesting to biologists, when you have identical human twins. I believe that all babies are born with blue eyes, but some of them may turn brown, and you might think that was a matter of chance. Interesting to take bets on whether brown or blue was going to come. But it's not a matter of chance. We know that from the phenomenon of identical twins. But even if they are separated before their eyes acquire their final colour, if one turns brown so does the other, and if one turns blue, so does the other. And we don't think "Oh, what a mysterious long distance correlation", we say that's genetics.

And similarly here the reasonable assumption, for any reasonable person, is that we are concerned here with the case of genetics. That these photon unknown to us carry some small packets of information, the same information in the two cases, which dictates that when they meet the same circumstances they will behave in the same way. And that was the Einstein-Podolsky-Rosen (EPR) argument, from no action at a distance to determinism. If you didn't want to accept that hypothesis of determinism, I think you are obliged to accept that in some way things can agree at a distance, without any explanation. And that for Einstein would have been an objection about action at a distance.

---

[3] A. Einstein, B. Podolsky and N. Rosen, *Can quantum-mechanical description of physical reality can be considered complete?*, Phys. Rev. **47**, 777-780 (1935).

3. The Bell inequality

Now, for Einstein then, quantum mechanics was incomplete. The formalism that we are taught is not the whole story, the ‘genes’ are missing. It would be like biology without genes, where things just happen by chance, and it is quite mysterious that sometimes they happen in the same way to identical twins. He supposed therefore, that there must be some variables that we don't know about, which are not under our control, analogous to the genes. And they explained these correlations at a distance, without causation at a distance. Because the causation was transmitted from the source to these objects. Einstein said originally “*God does not play dice*”, but in this argument it was no longer an assertion by itself, it was an inference from the assumption of no action at a distance. And in later years, Einstein was much more concerned about the fact that quantum mechanics was not explicitly free from action at a distance, than he was concerned about determinism as such.

Now it is a great irony that this argument, which I think was an extremely powerful argument, and which the people of today should have accepted, that this argument boomeranged on him. And became an extremely powerful argument against his own position. Now that came about as follows:

We did that experiment, I described the results of that experiment with parallel polarisers (see Fig. 1). But of course you can also do it with off parallel polarisers. Now, let’s start with the parallel case. And then suppose we turn this through thirty degrees. We will no longer get perfect agreement. Sometimes a photon will pass here, and its twin will not pass there, and vice versa. And quantum mechanics gives a formula for the degree of discordance that creeps in when you turn such a device. Now we could turn the other device instead, and there would be some discordance, and we could turn both of them, and there would be another discordance. Now there's a simple relation between those three situations that I have described, turning this one, turning that one or turning both, and it's the following.

Let N be the number of cases in which you have disagreement on the two sides, a yes and a no, or a no and a yes. When the two polarisers are both at zero degrees there is no discordance. It'll always be yes yes, or no no. Never yes no, or no yes.

$$N(0^\circ,0^\circ)=0 \qquad (1)$$

If I now consider the case where both are turned, one minus thirty degrees and the other plus thirty degrees, then it’s easy to see, that on the genetic hypothesis, that this number must be less than or equal to the discordance if just one turned, plus the discordance if only the other turned.

$$N(+30^\circ,-30^\circ) \leq N(+30^\circ,0^\circ) + N(0^\circ,-30^\circ) \qquad (2)$$

And that is indeed easy to see because the programming of this device must be such that a yes, some yes's are replaced by no's, and some no's by yes's, when I turn it. Similarly when I turn that, some no's are replaced by yes's, and some yes's by no's. But now in this case every change in the programming introduces a discordance, because originally I had perfect concordance, yes yes and no no.

So every change here introduces a discordance, every change there introduces a discordance. But not every change here introduces a discordance, because there may be compensating changes in the program on the two sides, a yes may turn to a no, or the no may turn to a yes. And again you will have agreement, and therefore the amount of discordance with the two movements is less than or equal to the amount of discordance with both movements.

Now, if you calculate that according to quantum mechanics, that just isn't so. I don't remember, I think I remember the exact numbers, that this turns out to be 3/8 as a fraction of the total number of trial, that 3/8 of them will be discarded. And here it is 2/8, and here it is 2/8. That's not right. It must be something like that, 1/8 and 1/8.

$$N(+30°,-30°) = 3/8$$
$$N(+30°,0°) = 1/8$$
$$N(0°,-30°) = 1/8$$

Therefore with Eq. (2)

$$3/8 \leq 1/8 + 1/8 \;!!!$$

It just is a fact that quantum mechanical predictions and experiments, in so far as they have been done, do not agree with that inequality. And that's just a brutal fact of nature. The genetic hypothesis, which seems absolutely compelling for parallel devices, simply doesn't work for nonparallel devices. You can't get away with the genetic hypothesis, and therefore the Einsteinian argument fails. No action at a distance led you to determinism, in the case of parallel polarisers, but determinism, in the case of off parallel polarisers, leads you back to action at a distance:

no action on a distance (polarisers parallel) $\Rightarrow$ **determinism**

determinism (polarisers nonparallel) $\Rightarrow$ **action on a distance**

4. Action on a distance

Now, in my opinion, in answer to the question that you posed at the beginning, I don't know this phrase is too strong and active an assertion, I cannot say that action at a distance is required in physics. But I can say that you cannot get away with no action at a distance. You cannot separate off what happens in one place and what happens in another. Somehow they have to be described and explained jointly. Well, that's just the fact of the situation; the Einstein program fails, that's too bad for Einstein, but should we worry about that? So what?

Now, there are three replies to the question “So what?” One is that the whole idea of action at a distance is very repugnant to physicists. If I were speaking for an hour..., I would bombard you with quotations from Newton, and Einstein, and Bohr, and all the other great men, telling you how unthinkable it is that by doing something here, we can change the situation in a removed place. I think that the founding fathers of quantum mechanics did not so much need Einstein's arguments about the desirability of no action at a distance, as they looked away. The whole idea that, either there might be determinism, or action at a distance, was so repugnant to them that they looked away. Well that's tradition, and we have to learn in life sometimes to learn new traditions. And it might be that we have to learn to accept not so much action at a distance, but inadequacy of no action at a distance.

There are two more professional reasons for being discontented with the situation. Now one is relativity. According to relativity, the notion of simultaneity is relative. And events which are simultaneous for one observer are not simultaneous for another. So it does not make sense for very distant situations, to say that one event has occurred before or after another. So if we allow the result at one of these experimental set-ups to depend on what an experimenter does at the other, we have a puzzle, because we would not like what he does here to have an effect there, before it is done here. But if I say that this is affecting that, I can find some observer for whom this comes after that. So if I set up a traditional causal model, which the cause effects are allowed to be nonlocal, in the sense of propagating instantaneously over large distances, in some frame of reference the cause will come before the effect. So we have to be a bit more subtle than that somehow. I have to find some way out of this situation, which allows something somehow to go from one place to another, very quickly, but without being in conflict with special relativity. And that has not been done. We have the statistical predictions of quantum mechanics, and they seem to be right. The correlations seem to cry out for an explanation, and we don't have one.

The other reason is no signals. It is a fact that I cannot use whatever this nonlocal connection is to send signals. When you look at what quantum mechanics predicts, it predicts so long as you look at just one side or other of this experiment, you will simply have no information about what is happening in the other place. No matter what that other fellow does with his equipment, you will not notice anything funny happening in your side. As an analogy of that, I could say, supposing we were tossing coins, I here and one of you people down here. And supposing I had the power to say that your coin will turn an extra time before it falls on the table. Now you are looking at your coins and you see heads tails heads tails. And you don't know when I have exercised my power to turn it once more, because you didn't know whether it was going to fall heads or tails. So we have the curious situation, that to explain the correlations between my results and yours, we have to invoke some such mysterious power. But it is one which I absolutely cannot use to send you a message. I got here a demonstration of that. This is a computer simulation of such an experiment in which people are calling heads and tails. And when it comes up heads I have written ‘H’, and for tails I have written blank, so that you can see it from where you're sitting. And they're a whole series of random heads and tails, you can see it there (Fig 2). Now at some point I exercised my power. My remote power to turn a head to a tail. And here is the result (Fig. 3). So somewhere in there I have done something to the random code. I exchanged heads for tails, but you absolutely cannot see that. This message, as far as you're concerned, is as meaningless as the other. It's only if you have two copies of that, that you can compare it, that you can get something (Fig. 4).

That curious situation has inspired a musical composition. There is a musical composition called `The Bell's theorem blues'. I'm not going to sing it, I'll say the words:

> *Doctor Bell say we’re connected,*
> *He called me on the phone,*
> *But if we’re really together baby,*
> *How can I feel so all alone?*

5. Conclusion

And that is the dilemma. We are led by analysing this situation to admit that in somehow distant things are connected, or at least not disconnected. And yet we do not feel that we are connected. So as a solution of this situation, I think we cannot just say ‘Ohoh, nature is not like that’. I think you must find a picture in which perfect correlations are natural, without implying determinism, because that leads you back to nonlocality. And also in this independence as far as our individual experiences goes, our independence of the rest of the world is also natural. So the connections have to be very subtle, and I have told you all that I know about them. Thank you.

Figures

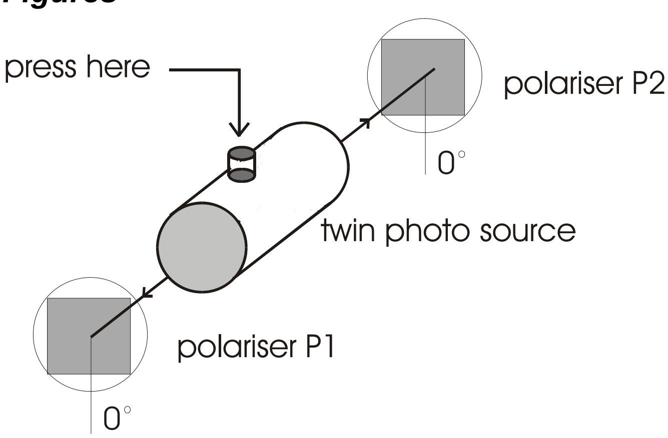

Fig. 1. Experimental set-up for an EPR experiment with twin photons. The polarisers are set parallel at an angle of 0° with respect to the vertical.

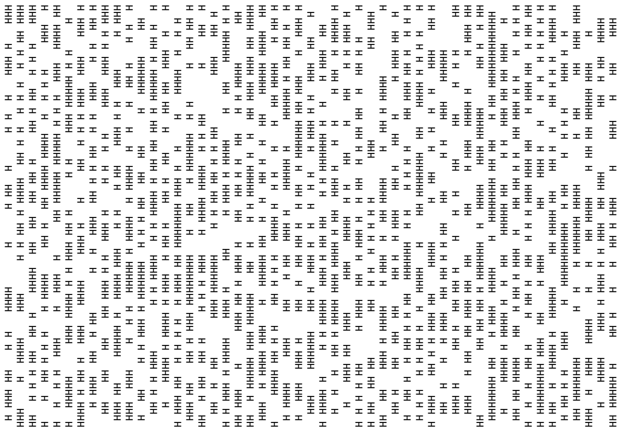

Fig. 2. Result of computer simulation of a random series of heads 'H' and tails (blank)

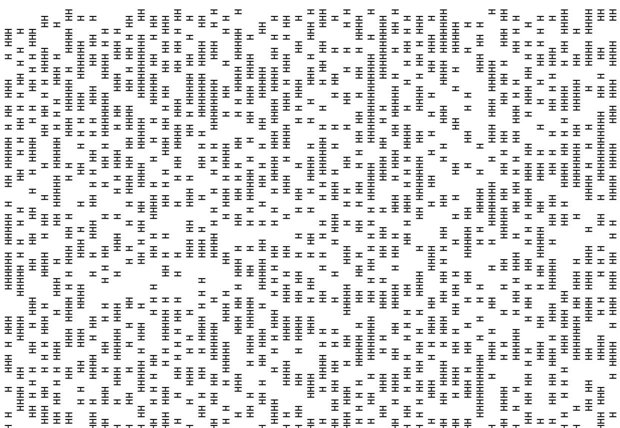

Fig. 3. Inverted display of Fig.2: heads (blank), tails 'H'. In some places the random code is changed.

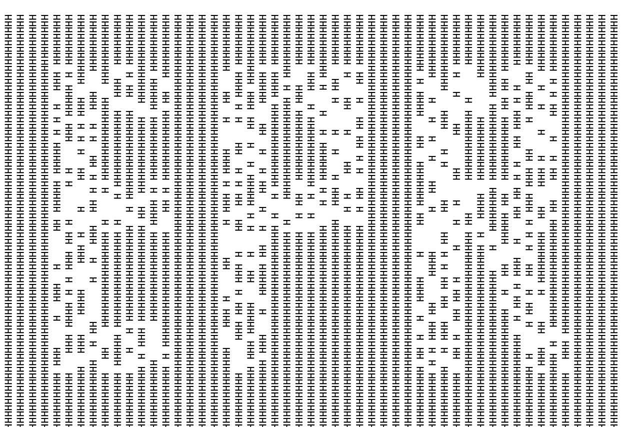

Fig. 4. Superposed images of Figs. 2 and 3 (after B. Julesz)

Discussion

Note:
In the following, a selection of the 60 minutes discussion is given. Professor Bell's speech is presented in plain typeface, all other contributors to the discussion in *italic*. A new section is started for each person talking, with comments made by others presented in parentheses, '(....)'. The typeface rule is maintained even within parentheses. Speech which could not be understood is represented as ' ..... ', this often indicates more than one word. The sections are numbered and run up to 113. We reproduce a selection of sections, which we think are relevant for the subject of this book.

10......., *we have learnt, that there always will be questions in arithmetic that could be undecidable. That is unsolvable by mathematical reasoning. Nonlocality seems to suggest that there are also questions which could in principle be answered by way of mathematical reasoning, but that in fact cannot be answered because information about what is going on in regions far away from us is not available to use. What do you think? Is correct to think this way?*

11. I don't know, I mean you gave your thesis very briefly, and so I cannot judge .. whether you are correct or incorrect. But I do not myself think it is right to use the words 'Gödel theorem' in this discussion. I don't see a connection, except insofar as both subjects are very difficult to us. But, I think you see, with Gödel's theorem we have some kind of permanent boundary to the possibilities of systematic reasoning. But here, I think we have a temporary confusion. It's true that it is sixty years old, but on the scale of what I hope will be human existence, that's a very small time. I think the problems and puzzles we are dealing with here will be cleared up, and we will look back on them with the same kind of superiority, our descendants will look back on us with the same kind of superiority as we now are tempted to feel when we look at people in the late nineteenth century who worried about the ether. And Michelson-Morley .., the puzzles seemed insoluble to them. And came Einstein in nineteen five, and now every schoolboy learns it and feels .. superior to those old guys. Now, it's my feeling that all this action at a distance and no action at a distance business will go the same way. But someone will come up with the answer, with a reasonable way of looking at these things. If we are lucky it will be to some big new development like the theory of relativity. Maybe someone will just point out that we were being rather silly, and it won't lead to a big new development. But anyway, I believe the questions will be resolved. I do not think the questions raised by Gödel will be resolved.

12. *It seems that from what you have shown by that, the concept of an isolated system, is appealing. Nothing is isolated any more from the rest of the whole of the universe. In general I know that in classical physics you can think that influences from outside, the outside world, you can reduce to small as you want. Is that still the situation?*

13. Well, conceptually you could reduce them as small as you liked, but of course we can't, we can't declare that Jupiter does not exist. And so long as it does exist it will affect

the orbit of the Earth, and even the way this piece of chalk falls a little little bit. The chalk falls only roughly the way Galileo said. And to some extent it feels the gravitational field of Jupiter, and of the Crab Nebula, and God knows what, and I can't switch those off.

14. *But how far are we allowed now to describe anything without taking the whole universe in to account?*

15. Well first of all, strictly speaking, you never were allowed to do that. It was always a rough procedure, that for rough work we can neglect much of the universe. But when we looked at what our equations said, Newton's equations include Jupiter's gravitational field acting on this bit of chalk. So that when we looked at what our equations said, we had to remember that it was ... And I think it's about the same. If you are interested only on a limited part of the world, in quantum mechanics you use the so called density matrix, which kind of averages over the rest of the world. And then the density matrix has an equation evolving for itself, and not mentioning the rest of the world. You still have to admit that if you wanted as much precision as the theory could possibly yield, you just have to put things ... What I think is novel is that Einstein gave us a way of switching off the rest of the world outside the light cone. You could say that yes the rest of the world is going to have an effect, but that effect will not arrive before light could propagate. So, that was a way of dividing the world into bits which are relevant, and bits which could not be relevant. And that we don't have any more.

16. *(That is a very important affirmation.) I'm sorry, does that mean that you say relativity and quantum mechanics are not compatible?*

17. No no I can't say that, because I think somebody will find a way of saying that they are compatible. But I haven't seen it yet. For me it's very hard to put them together, but I think somebody will put them together, and we'll just see that my imagination was too limited. Well, as the people in that department work at present, they are not coming to this question, because the superstring is still formulated within traditional quantum mechanics, and you still have the superposition principle which is maybe the root of all these things. But it could be that as they go further into that, they find that it just won't work along the traditional lines, and at some point they'll have to give up the superposition principle. .. in that direction, and occasionally see papers from over there called `How worm holes reduce the wave function.' Haha.

18. *.. that there are no hidden variables. ....*

19. Well I don't know that there are no hidden variables. What we said there was that hidden variables cannot restore locality. But there was still the consideration that I began with, that the classical physicist still thinks repeating the experiment gives different answers. He has not quite repeated the experiment. And you can have nonlocal determinism, nonlocal hidden variables. So I could imagine the situation where we do have hidden variables, and we do have again determinism, but not predictability. Because we won’t be smart enough to get things with sufficient precision. We'd be able to gain

that determinism, and it would be nonlocal. And we see that in some way distant things were connected, and yet not in a way that we could get hold of to send messages.

20. *But if there are hidden variables, somehow we are back in classical mechanics. ..*

21. Well it depends on what you call classical mechanics. You won't be back with the mechanics of Einstein. With the light cone neatly separating what is relevant and what is irrelevant. But you would be back with classical mechanics in the sense that you would have some equations, presumably integral rather than differential equations, and the equations would tell you what is going to happen. Whereas in quantum mechanics it's perfectly obscure whether we have a theory like that. In fact we don't have a theory like that.

22. *Well, .. the principle of free experimentation. (Yes.) That seems important for us. (Right.) Then Bell theorem holds. Is it possible to formulate this experiment in this way: In a world, in which there are human free actions, either action at a distance, in this sense, exist or we must accept that correlated events will not have any rational explanation*.

23. I think that's alright. (*Do you think?*) No, I would not sign that yet. (*laughter*) But certainly it sounds OK what you said. That's the kind of way I think also.

24 *Do you think it is important to say that Bell theorems has something to do with free experimentations*.

25 I eh, that's not what you said. (*Yeah, exactly*) .. Because you in your, in your (*Yeah*) what you said the free action was the hypothesis, and now you're trying to turn it into a theorem.

26. *.... I think. If one admits the principle of free experimentation, the Bell theorems holds. And my question is, is possible to formulate this result in this way. In a world in which there are human free actions, either action at a distance exists or we must accept that correlated events do not have any rational explanation*.

27. *What means free experimentation and free human action?*

28. *Well, free experimentation is the fact that there is, in this sense of what Professor Bell says in his book, no super determinism, in the kind that when I am arranging the setups, this action is not determined from the beginning of the world.*

29. That's correct. It comes into the analysis. When I turn one of these polarisers, I assume that I can consider the same hidden variables in the turned position or in the unturned position. But if my choice was itself determined by the hidden variables, the argument would fail at that point. So I have assumed that there is something outside my field which is quite free, which is not dictated by the parameters, the variables in the theory. Now, it is a fact that if I give that up I have no theory. But I myself do not think

it's a very essential point, in the following sense that you know that there are, if you have random number generators on a computer, you could have a computer here generating random numbers and another one other there, with a different program, generating random numbers. Strictly speaking, they are determined what comes out. But for somebody doesn't know the program, it's unpredictable what comes out. And they are self determined, so that they have nothing to do with the hidden variables that are determining whether the photons do, or do not go through polarisers. So I think that that is enough freedom, the freedom of random number generators. But that's not a theorem, because when you set a random number generator going you have to pick the program, and maybe your choice of program will be determined by the hidden variables, (*laughter*) in your experimental setup. So you have to be very far fetched to make this the escape plan.

32. *I have a question .. . .. . Is it correct to say that indeterminism is not a necessary condition for a coherent quantum theory?*

33. I would agree with that, yes.

34. *OK. But quantum theory is not incompatible with indeterminism. Also, quantum theory is compatible with indeterminism.*

35. I believe that quantum theory is compatible both with determinism and with indeterminism. (*With both?*) With both.

36. *Depending on locality or nonlocality*.

37. That's right. If it's deterministic. Well I think it has to be nonlocal, whether it's deterministic or indeterministic. I think you're stuck with the nonlocality. I don't know any conception of locality which works with quantum mechanics. So I think we're stuck with nonlocality. Whether we're stuck with determinism or indeterminism is another question. I know that if you didn't worry about Lorentz invariance, you can make explicit deterministic models which agree with all the experiments. But they're not Lorentz invariant. You have an ether, in there, and that's hard to swallow. It may be that Lorentz invariance plus quantum mechanics is incompatible with determinism, but I don't know that. That's a possibility.

40. *Because, I mean, I would think maybe all the trouble come from special relativity, which to my mind is anyway only a frame that doesn't contain any physics. For instance if you say that, well, the action is at a distance is not possible. Well, you mention then, with relativity one gets into trouble, one had the trouble with the ether. Special relativity has abolished the ether, but what is producing the action now? So that you can get only by field theories, where you then have field quanta, which in case of gravitation you need the graviton, which means you need, you have to quantise also gravitation. So I think to solve the problem one probably has to go to general relativity and not stick to special. Maybe al.., I don't know, but could be that all the difficulties would disappear if we would forget special relativity.*

41. Well, I certainly agree with you that we should be thinking in terms of general relativity. I think all the difficulties may disappear, but not at once. (*laughter*) There are quite a number of people who have tried to combine general relativity with quantum theory, never mind about hidden variables. It is very difficult indeed.

42. *But I thought the big success of supergravitation..and superstrings is that they show that in principle there exist theories which are mathematically alright.*

43. Well again they have over sold their message to the general public, I would say. When you press them, you find that whereas they are announcing a theory of everything, they only have theories of S matrix elements. That's to say, bodies come in from infinity, and they say nothing until they go out again at infinity. (*laughter*) But we don't refer to infinity. And in order to make a serious theory, including gravity, it must not be an S matrix theory but a field theory, which discusses things at finite times and places. And they can't do it. They have tried very hard and given up. So string theory is not in the state where you could bring it into this discussion.

58. *There is a word .. of language .. which confused me. When .. there is a word interaction, action at a distance, or cause, causality. I think in general this involves a force or a transfer of energy, through a signal. And then you say that is no signal, there is information involved but not energy transfer. Is it right?*

59. There is no energy transfer and there is no information transfer either. That's why I am always embarrassed by the word action, and so I step back from asserting that there is action at a distance, and I say only that you cannot get away with locality. You cannot explain things by events in their neighbourhood. But, I am careful not to assert that there is action at a distance.

60. *.. everything interacts with everything .. but is not interact ...*

61. Well let's say. Let's say, let's change it and say that you cannot account for anything without taking into account everything. And then I have avoided the word interaction. It's true, the word action brings up in your mind force. And one does not want that image to arise, because I don't know of any sense that I could attach to the word force in this context.

66. *Well don't you see the problem already there in classical physics, without having to .. ?*

67. Well you see the problem that things are not isolated. But in classical physics the light cones do determine the separation, which is a status in classical physics that you do not have in quantum physics. As soon as you permit free actions, or effectively free actions, in classical theory their consequences are confined to the future light cone. And that's a concept that we seem unable to fit in to quantum theory.

90. *The next question, another question of more philosophical nature. The question of mind and consciousness. .. some months ago Wheeler, in a talk in Sweden, said to me that he's convinced ... the fundamental role played by the observer. And Wigner also insists very much that man is a central element of the theory. Because of the fact of nonlocality, it seems that mind, .., which constructs the observed world. If a mind constructs the observed world, this mind could not be alone the mind of the human observer.*

91. If two and two are five, what is three and three? I simply do not follow Wheeler, and Wigner, in saying that atomic physics involves the human mind. I see not the slightest trace of the human mind in atomic physics. And here, I am with Bohr rather than with others, although many times I am against Bohr. Bohr insisted very strongly that the only observer that he was concerned with was the inanimate apparatus. He .. insisted that you could not separate atomic processes from the apparatus that was used to amplify those processes onto our scale. But then he insisted that whether somebody was looking at the apparatus or not doesn't matter a bit.

92. *Yes, but he says that this is all right because different observer will always see the same. This conception objectivity is wrong. But I think he eh, his opinion is that the phenomenon occurs in the moment in which I am observing.*

93. That is not Bohr. (*That is not Bohr*.) No. That may be .., and it may be Von Neumann and Wigner and .. and .. and Wheeler, and a whole (*But not Bohr*.) host of people, but it is not Bohr. And I think that Bohr was the sound person on this. It's an enormous extrapolation from the situation in physics, to the idea that being and mind is involved. Now, I can see the motivation for that extrapolation, 'cause when you say the apparatus is playing an essential role, you are asking `Well, how do we divide the world into systems, and apparatus, and the rest?'. And it's clear that any such division is a very shifty thing. So people look for somewhere that a division could naturally be made, they say `Ah! Between matter and mind!' And so they postpone the so called reduction of the wave packet, which is an element of ordinary quantum mechanics. Instead of that occurring in the apparatus, they say let it occur in mind. But that's a conjecture, an extrapolation. There is no evidence in physics for that, and as far as physics is concerned, it can all end at the apparatus level.