SONDERDRUCK

aus

PHILOSOPHY
OF THE NATURAL SCIENCES

PROCEEDINGS OF THE 13th INTERNATIONAL WITTGENSTEIN SYMPOSIUM
14th TO 21st AUGUST 1988, KIRCHBERG/WECHSEL (AUSTRIA)

PHILOSOPHIE
DER NATURWISSENSCHAFTEN

AKTEN DES 13. INTERNATIONALEN WITTGENSTEIN SYMPOSIUMS
14. BIS 21. AUGUST 1988, KIRCHBERG/WECHSEL (ÖSTERREICH)

WIEN 1989
VERLAG HÖLDER-PICHLER-TEMPSKY

NONSEPARABILITY AND SOME VIEWS ON REALITY

Bernard d'Espagnat
Laboratoire de Physique Théorique et Particules Elémentaires, Université de Paris

Some philosophers of science sometimes confess to me in private talks that they do not see any real basic difference between quantum mechanics and, say, classical electromagnetism. In both cases, they say, we have to do with waves. In both cases these waves obey a differential equation. It is true that the Schrödinger equation differs from the Maxwell equations but this, they say, is merely a technical matter, with no philosophical significance.

In fact these philosophers have had their attention directed to the wrong point. The philosophically meaningful difference between quantum mechanics and classical electromagnetism is not at all that the equations are not the same. It is that classical electromagnetism is a realistically interpretable local theory, whereas quantum mechanics is not.

Classical electromagnetism is a realistically interpretable local theory in the sense that the electric and magnetic fields (which are its basic ingredients) are what we call "one point functions". This means that even in arbitrarily complex situations - think for example of several wave-trains coming from different directions and interfering - there always is at any given time a definite value of the total electric field (or more precisely of its three space-components) attached to each space point. It is just the algebraic sum of all the fields from each wave train. The same holds for the magnetic field of course. This allows us to think of these fields as *locally* having a (time dependent) real value.

In quantum mechanics the situation is, in this respect, qualitatively different. If we have to do with several - say *n* - particles coming from different directions, and if we decide to describe these particles by wave-functions, what we must do in order to describe the composite system they constitute is to build up the *product* - mind you, not the *sum*! - of all these functions. And then, when the interaction takes place and even after it has ceased, we have, for describing the system, a function of n points (or 3n variables) that cannot any more (in general) be written as a product of n functions of one point. Consequently we cannot then speak of *the* wave-function of particle 1, of *the* wave-function of particle 2, and so on. If we want the wave-functions to be "real things" then, after the interaction, we have *only one* such real thing, namely the total wave-function, and it is not attached to any point. In other words it is *meaningless* to speak of its value at a given point. In this sense it constitutes an unanalysable whole. We say that it is *nonseparable*.

Up to this point what I have shown is that indeed classical mechanics and quantum mechanics are structurally quite different things. I have also shown that the *wave function* is nonseparable.

But did I show that *physical reality* is nonseparable ? Not yet. For wave functions might well *not* be what we call *physically real things*. They might, for example, merely describe our information about things, as ordinary probability functions do, in classical physics. Alternatively they might be physically real but *derived* quantities. I mean, quantities similar to potential energy. Even in classical physics, where all *basic* quantities, fields, forces, matter-density and so on, are one-point functions, the potential energy between several matter-points is a multi-points function, namely a function of these points. At this stage we therefore merely have a *hint* that, contrary to what classical physicists had thought, physical reality is nonseparable.

Hence to decide whether or not contemporary physics has brought a philosophically significant modification of outlook on this question we obviously need a more precise definition of what we call separability and nonseparability. And of course we need one in which separability is obeyed in classical physics and is violated in contemporary physics; remaining in both cases within the standpoint of realism.

In order to construe such a definition let me make use of an intermediary step based on two remarks. The first remark is that in quantum mechanics a mathematical device exists that, for partly historical reasons, we call the "statistical operator" (although there are uses of it in which this name is misleading). For many purposes the statistical operator is an adequate substitute to the wave function but it is such that, in a situation such as the one we are considering, a "statistical operator" *can* be defined for *each* of the n particles in question. And the second remark is that, under the conditions I have described, if we act on one particle and change thereby its "statistical operator" we thereby automatically also change the statistical operator of the n - 1 other particles, however distant.

This might suggest that we should define nonseparability as the existence of such effects at a distance. However the condition that separability should be obeyed in classical physics prevents us from identifying separability with just the vanishing of long distance forces: for space probes follow classical physics; it is by means of classical electromagnetism that we communicate with them; and still they obey orders sent from the Earth even when they are extremely far away. But let us imagine two space probes, one near Mars and one near Venus, obeying one and the same individual electromagnetic signal. So: they are strictly correlated. Well even then, clearly, if some hypothetic Martian did, or observed, something on the Mars probe this could not induce any material change on the Venus probe. Well this is the *essence* of the working hypothesis that we shall call the "principle of separability" (often also called the "principle of locality"). Let me spare you here mathematical formulae. By definition, if the principle of separability as we mean it were true also for subatomic particles then, in a case in which two particles U and V, simultaneously emerge from a source S and propagate in different directions the probability of observing some definite thing on V *when the objective state of the U + V pair is fully specified* (this condition is essential) would not depend on what is made, or observed, on U.

When one speaks of probabilities he should not go too fast. So let me dwell a little on this point. If I had not inserted the condition of which I just said it is essential the "principle of separability" would be trivially violated - in classical physics as well as in quantum physics - so that "nonseparability" would be quite a trivial and uninteresting affair. The reason why the principle would be violated is just that a measurement made on U would then increase our information also *concerning V* (because of the correlation generated at the source between the two particles) so that our knowledge concerning the objective state of V would increase. Clearly this would in general induce a change in our probabilities of observing such and such things on V. But when, as here, one considers the "probability of observing such and such things on V, the objective state of the pair - and hence, in particular, the objective state of V - *being given*", then this argument cannot be applied. To understand why notice that, above, what the observation made on U was expected to do was to selectively reduce the set of the objective states of V used for defining the considered probability. Since our new probability is already defined on an even more restricted set such information should normally be expected to be redundant. In other words, under such a condition for defining the probability the "principle of separability" is normally expected to hold true. And a moment of reflection shows that indeed it *is* obeyed in all situations of classical physics.

But is it obeyed in the microscopic world of particles and so on ? Well *no*. It is not, at least if we cling to the realist standpoint. First of all, if we identify the objective state with what, in our jargon, we call the quantum state, that is, essentially with the overall wave-function, separability is plainly violated. The probability for such and such measurement result on V depends on what is observed on U. But it might be argued that this is simply due to the so called quantum state not being a complete description of the objective state so that the condition of complete description would not hold. A well-known and quite remarkable theorem due to John Bell shows it is not so: independently of any assumption on the completeness of the quantum state it so happens that *even when the objective state of the pair is fully specified* the probabilities relative to measurements on V must depend on what is made or observed on the far-away U. At least this must be so if the predictive rules of quantum mechanics are correct. Moreover these changes in the probabilities must occur even if the two measurement events on U and V are separated by a space-like interval, which means that, when interpreted realistically, the accepted form of special relativity must be violated.

I shall not give you here a proof of the Bell theorem. This proof is simple in its principle but, if given, it should, as any proof, be given with all due strictness. Unavoidably this would take time; more time indeed than we have here at our disposal. Moreover the Bell theorem came forth 23 years ago so that it is by now an old affair. Proofs of it have been published many times[1] and have been thoroughly discussed by the experts. To give one of them once again here would I guess be boring for most of you.

Philosophically speaking the important point in this theorem is its generality. It is not at all *based* on the basic concepts of quantum theory. It merely refers to the *predictive rules* of that theory. And this makes a lot of a difference. The point is as follows.[2] It is by now a recognized fact that great theories are in no way immortal. Even a theory such as Newtonian mechanics, which was considered as an absolute truth for more than two centuries, was eventually superseded by the more comprehensive relativistic mechanics. And what is most remarkable is that in such cases the basic concepts of the new theory are in general quite different from those of the superseded one. Of course the philosophers did not fail to notice this. In fact many of them seem to have taken such a state of affairs as an argument for not worrying too much about the conceptual problems that may be raised by the currently accepted great theory - specifically, at present, by quantum theory. For, they say, the great theory in question will presumably be superseded in due time by some other theory and this new theory will presumably be based on a set of quite different fundamental concepts, so that the conceptual problems raised by the basic concepts of the presently accepted theory will vanish. Hence - they say - let us not worry.

This argumentation is in general quite correct. But, thanks to the Bell theorem it does not apply to nonseparability. The reason is that, as I said, this theorem is not based on the fundamental concepts of quantum physics but merely on its predictive rules. Now, when a great theory is replaced by another one the fundamental concepts do change but, within their domain of validity, the predictive rules of the older theory remain valid. For example newtonian mechanics still predicts eclipses quite correctly and it is in fact used in order to steer the space probes. Similarly, if and when quantum theory gets replaced by some more comprehensive theory, the predictive rules of quantum theory will *remain valid* within their present domain of validity, where they have been checked by appropriate measurements (including measurements on "U+V pairs": these are the famous Clauser, Fry, Aspect experiments[3] which, by the way should, in my opinion, never be discussed apart from such a theoretical context). Hence the basis for nonseparability (Bell's theorem) will remain. For this reason nonseparability is immune to the skeptical argument I just recalled. It will remain true even within the "future theory". It is therefore well worth the interest of the philosophers.

Let me now go over to the second part of my talk, which has to do with some possible views on physical reality. In fact philosophy has taught us since long that 'reality' is an ill-defined concept, so that the question at hand is tightly linked with that of the meaning we ascribe to the very word 'reality'. Here I shall try to convince you that what I said up to now, *plus* other general facts concerning present day physics, make it suitable to consider *two* distinct conceptions of reality.[4] I shall call them independent reality and empirical reality respectively. Admittedly this splitting may make you think of the age-old split between realists and idealists and there is some point in that. But quantum mechanics renders the thing a good deal subtler. In fact the split I favor makes it possible, in my opinion, to build up a unified conception that partakes both of realism and of idealism while being appreciably different from the classical forms that the two viewpoints took in the past.

I shall not venture to define the two reality concepts I have in mind right from the start. Rather I shall progressively outline them by specifying the meaning that such terms as probability, propensity, isolation, influence at a distance may be given in each of them.

First consider classical physics, including newtonian mechanics, classical electromagnetism and even special relativity. This is an example of a realistically interpretable theory and if so interpreted, then the reality it refers to is what I call *Independent Reality*. 'Independent' means that at least its *existence* is considered as being quite independent of *our* existence. It does not mean of course that we cannot act on it, but we do not create it.

What is the status of the concept of probability within classical physics? Well, classical physics is a deterministic theory so that the only probabilities that come up in it are *subjective* probabilities referring to our ignorance of details. This has the important implication that we can change the value we attribute to the probability of such-and-such-an-event-occurring-on-a-physical-system, without acting in any way on this system. Think, say, of the example with the two space-probes. Suppose we do not know the details of the command procedure. We measure something on U; the probability concerning V suddenly changes because of the correlations between U and V, although V, at that time, remains unchanged.

Viewed as a basic universal theory classical physics has failed as you know. But other theories or 'models' have appeared, explicitly aimed (which is not quite the case with quantum physics) at describing what I have called *independent reality*. The best known one is also *deterministic*. It is the *pilot wave model*, put forward by Louis de Broglie in 1927[5] and rediscovered and developed by David Bohm.[6] A much more recent one is the Ghirardi, Rimini, Weber (G.R.W.) model.[7] Being aimed at describing independent reality these models must give to the concept 'objective state of a system' a meaning that transcends mere operationality. Consequently as I showed in the first part of this talk, all these models must violate the accepted forms of special relativity. And indeed they do, as an inspection of their formulae easily shows.

Must all of them be deterministic? Obviously not. Indeed the just mentioned G.R.W. model is not deterministic. And there are other examples. A model of independent reality that is *not* deterministic must make use of a novel kind of probability that we may call intrinsic probability or more conveniently 'propensity'. Propensities are potentialities of completely specified physical systems to react in such and such a way, for example to some given stimulus. The important point is that they have nothing to do with "us", I mean with the community of observers and what they know. They are real *properties* (or *attributes*) of the physical systems and of them alone. Nondeterministic propensity models, being aimed at describing independent reality meet the conditions of the Bell theorem. Hence, as I just said, they must violate special relativity in its accepted form. This distinguishes them from standard quantum mechanics, the case of which is more subtle, as we shall see.

Let me say one thing more about the notion of propensity. From a realistic point of view propensities have to be considered, I repeat, as just being physical attributes of the systems they are attached to. But from an observational, or operationalist, point of view they have something quite special. Contrary to normal 'attributes' they cannot be measured on just *one* system. In order to know their value we must obviously make measurements on a whole statistical ensemble of systems. Now this has a consequence which, I think, is well worth the attention of the philosophers of science, and which is the following one. Suppose we have a whole ensemble of systems at our disposal, and suppose we change *individually* the propensities of *each* of them without changing any other attribute it has. Well, these individual changes can be choosen in many ways of course. But it can be shown that in many cases there is *one way at least* in which the result is *unobservable to any "third party"*. Suppose for example that each element in the ensemble is to go through a filter and that a physical quantity pertaining to it will then take one definite value out of two possible ones. Suppose the corresponding propensities (which we assume are the same for all the members of the ensemble) are, say, one third and two thirds. On the ensemble, and concerning the said quantity, we obviously shall not change anything that could be observed after the traversal of the filter if before this traversal we replace each system by one that has one definite possible value of the quantity in question, provided that we do this in proportions: one-third/two-thirds. Now, in propensity theories that reproduce the quantum-mechanical predictions this is just what happens *automatically* when the physical systems constituting our ensemble are one-to-one correlated with other far-away systems (because of previous interactions) and we make measurements on these other systems. This, for example, is what happens to the propensities attached to system V when, in our example, we make a measurement on the far-away system U. Moreover it can also be shown that in this case such a propensity-change changes nothing observable concerning any other attribute of V.

Under these conditions what can we say about the isolation or non-isolation of system V when this procedure is applied? Well, it depends. It is a philosophical question. If we stick hard to the independent reality concept we must of course say that system V did *not* remain isolated since one at least of its properties, namely one of its propensity, *was* changed by some external action (I mean the act of making some measurement on the far-away U). Under suitable conditions such "instantaneous" effects-at-a-distance will even violate special relativity. But on the other hand, as I said, these effects are unobservable to those people I called the "third party", that is (in the actual case) to the community of observers. In truth, they are quite strictly unobservable. In the G.R.W. model for example, where the wave function is the only reality, we do change the wave function at the place where V is observed, when we measure something on U. But this change is unobservable to any observer of V so that this influence at a distance is fully unobservable. Now is it scientifically sound to consider as *"real"*, effects (here the "influence" V is submitted to) of which it can be proved that they are, and must remain, totally unobservable according to the very rules of the accepted theory? Undoubtedly many philosophers, perhaps the majority of them, would answer *no* to this question. Foremost among them are the positivists of course, and more generally all the philosophers who hold that good predictive rules are all there is to science and to knowledge in general. But it seems to me that this "*no*" answer would also be given by philosophers of a "milder" kind. I mean by philosophers who do not make operationalism their *a priori* guiding rule but who, at the same time, are anxious to keep some proper demarcation line between science and metaphysics. For them, "reality" is a valid concept ; but they are reluctant at including in it effects of which it can be proved that they are unobservable, and which can be defined only when the concept of a fully specified "objective state of a system" has been introduced. For indeed this concept is perhaps debatable after all. It cannot be given any operational definition of course. In fact its meaningfulness depends to a higher degree than any concept in physics on the standpoint called "metaphysical realism" in the literature. And the very precise use that is made of it in the deterministic and propensity theories may therefore arise some disquietness. Those philosophers should, I hope, feel sympathetic toward the expression "empirical reality" which I coined to refer merely to stable reproduceable phenomena (in the philosophical sense of "phenomenon") *not* including all these strange, relativity violating *and unobservable*, actions at a distance. Of course a diehard realist might here object that the "reality"-label should not be given to what is admitted to be a mere set of appearances. But I think that he would thereby overlook *another* conventional meaning of the word "reality". Think of what we said at the beginning concerning two systems that have once interacted. The difficulty we then had at considering *each* system as having *real* properties was due to the nonseparability of their wave function. This shows that there is a sense of the word "real" that tightly associates reality with separability. It is in *this* sense that I speak of an empirical reality. Then quantum mechanics (in its conventional forms at least) forbids us to identify empirical reality with independent reality.

Indeed this notion of empirical reality should, in my opinion, be considered as the one implicitly underlying the whole of standard quantum physics, including solid state physics, elementary particle physics and so on. Remarkably, the authors of most textbooks on such matter do not worry at all about the way quantum mechanical probabilities are changed at a distance. They should, if these probabilities are propensities, that is attributes. But they don't. Their relativistically covariant formalism is entirely based on the man-centered notions of "preparation of systems" and "measurement of observables", and they are satisfied to check that *usable information* cannot travel faster than light. In this they behave as strict positivists. From realism, nay even from determinism they tacitly borrow the idea that probabilities, when subjective, *can* be changed at spacelike distances as we saw. But this is not *consistent* realism in any conventional sense since the probabilities they consider *cannot* be purely subjective. In other words they choose to simply ignore the conceptual problems raised by the changes in probabilities whenever science is supposed to describe independent reality; which confirms that whatever reality they implicitly refer to, *must* be empirical reality only.

So standard contemporary physics, I mean the branches of physics that are useful for interpreting experiments and so on, deal with empirical reality only. To the extent that we consider these physical developments as being more than just good recipes - after all they *explain* the properties of superconductors, of pulsar stars and what not - we must say that empirical reality is something more than a collection of recipes. And a moment ago I just gave you another reason to say the same. Nevertheless it is *not* independent reality. That we just saw. Then, what is it?

I think it is *a view* that human beings take on independent reality. In my opinion (I shall come back to this point) the notion of an independent reality cannot be dismissed altogether. In other words I reject solipsism and - by extension - I also reject a kind of collective solipsism (if I may be allowed to make use of that expression) consisting in considering that only human beings exist and that all they apprehend ultimately is mere appearance in their mind. In this I take sides with most scientists and, I think, also with a growing band of philosophers.

This implies that independent reality is not utterly unknowable. If we had not even a glimpse of it then the predictive rules of physics would only be those of a man-created game. That is, they would be completely arbitrary, subject only to consistency. But we know this is not the case. We know that experiment often disproves even highly consistent theories.

Should we then go to the opposite end and say that independent reality is *knowable-as it is*? Should we say that science is indeed in the process of discovering it *as it is*? If true, this view implies as we saw that standard "useful" modern physics - elementary particle theory and so on - is somehow leading us astray and that the correct direction of research is given by one of these models I mentioned that consistently claim at describing independent reality. But then: which model? It seems that our usual scientific-selection-criteria do not work properly in this problem. Indeed, although I am personally quite interested in these models I tend nevertheless to consider them somewhat as metaphysical constructions. I view them more or less as the kind of metaphysical constructions that should naturally occur to the mind of physicists, just as other types of metaphysical constructions naturally occur, or occurred, to the mind of people with other cultural backgrounds. For these reasons I consider that independent reality is neither knowable nor unknowable. Truth lies somewhere between these two extremes. This can be expressed by saying that this reality is *veiled.*

Now, I am aware that what I have been saying during the last few minutes - I mean that talk about independent and empirical reality and the distinction between them - may well have seemed somewhat strange. Many of you probably remain skeptical about the relevance of such a distinction. So I feel that I should come back a little, and be somewhat more explicit.

Well, my first point will be that in fact there is nothing new in this duality of meaning of the *one* word *reality*. In fact it always was with us. On the one hand the word reality has always been understood as referring to *what is*; to *what exists*; to, if you like, the Substance of Spinoza. But on the other hand the notion of a real attribute of an object was also always associated with the possibility of thinking of that object separately from other objects. And indeed it seems that we cannot do otherwise. If we cannot even have a mind-representation of an object as distinct from some big comprehending whole how could we think of attributes attached to it? But, in the age of classical physics, that is, roughly, from Galileo and Descartes to Bohr, this distinction between the two meanings of the word "reality" remained in a stage of latency because it seemed that the things science discovered were real in *both* senses. Well I think we have now overwhelming proofs that this was just an illusion (at least we have proofs that not *all* basic real entities are local). But then, to make the distinction quite explicit is *not* a mere delicacy or flourish. It is a well known story (or fable, I do not know for sure) that the Aegyptians of Antiquity, who knew only one river, namely the Nile, had only one word for the two concepts of North and Downstream. And that they got entangled in all sorts of obscure quarrels when they discovered the Euphrates. I think that some of our learned disputes about the concept of reality have a very similar origin. As I just made clear this word has two distinct meanings and it is *not* true any more that the phenomena we deal with can all be called real (or not-real) in both acceptations at the same time. So, for clarity sake, it seems that we *must* make the distinction explicit, by introducing some distinctive epithets. Those of "independent" and "empirical" have their virtues and their defects. I would not fight to death for them. But I maintain that it is a point of logic that distinct labels should be introduced since the concepts are different.

This being said, the concept of empirical reality needs no further justification. At least it certainly has a referent, namely the set of all that science tells us. But the pertinency of the concept to which I gave the name "independent reality" may be disputed. And the idea that it is not utterly unknowable - that it is but "veiled" - may *also* be disputed. Some minutes ago I outlined to you the substance of my own answer to these objections. Let me now be a little more precise on this.

The first objection - that the independent reality concept may have no referent at all - is essentially the one that would be put forward by the strict phenomenalists or idealists. But I must say I never understood strict phenomenalism. Does it coïncide with what I called "collective solipsism" a moment ago? Most of its supporters would indignantly reject such an identification. They take a position which in their opinion is a more subtle one, and which consists in saying that what science describes is nothing else than mere human experience, or alternatively that it is just a set of relations. Well, I tend to agree (more or less with both views). But at the same time I consider that we simply cannot *stop* at such statements. We must ask: "experience of what?", "relations between what?". If it were merely experience of, or relations between, our own - individual or collective - feelings, impressions and so on we would be back to - individual or collective - solipsism or to something very akin to it. Having rejected that view we *must* grant (this is just a point of logic) that this human experience has also some other ingredient in it. The expression "independent reality" is just meant as a name for that other stuff.

The second objection - that this independent reality is utterly unknowable, in the sense that any of its "message" is hopelessly "blurred" - is perhaps the one that would be put forward by some Kantians. But this objection can be rejected on several grounds. First of all, as I said, science is not pure theory. Something resists us. Experiments sometimes tell us that our conjectures were wrong. And in such cases, though we are disappointed, we nevertheless strongly feel that indeed we did learn something. This, of course, is mere *negative* knowledge. But it is knowledge all the same, and what can it bear on if not - ultimately - independent reality ? Another significant point is, I think, that Kant's conjecture that "our basic scientific concepts are a-priori modes of our sensibility" seems to be wrong. Curved space-time is certainly not a mode of our sensibility. In a sense it is *one* a-priori mode of our intellect. But it is certainly not an a priori element of our "mind-structure" that we should use *space-time* instead of good old space and time. So, here again, independent reality seems to crop out.

Well, I shall not say more on this. Instead of insisting on my own views on veiled reality I prefer to conclude by stressing the importance of nonseparability as regards whatever views we try to form on physical reality. As I already said, the most essential point about nonseparability is that thanks to the Bell theorem it is independent of the set of basic concepts of the presently accepted theory. It should therefore survive any so-called "paradigm change". Its discovery is, so to speak, that of a fixed point in the moving seas of thinking. It irretrievably bars such simplistic views as those of atomistic materialism, of which separability was an unspoken but quite essential ingredient. It certainly is not sufficient to inform us about what reality *is*. Indeed, by making it stranger than initially thought it increases the mystery instead of decreasing it. But at the same time I think it offers a serious basis for the renewal of some essential problems of philosophy. The notion of "object", for example, is so much linked with separability and locality that it cannot remain unaffected by these developments. Hence most of the old classical forms of realism will have to change. And it may be suspected that these changes in realism will induce, by a kind of action-reaction effect, also some changes in idealism. My own intuition is, as I already said, that when thus modified these two opposite doctrines will not remain as opposite as they used to be up to now. In their modified form they - I hope - will become complementary.

NOTES

[1] J.S. Bell, *Physics*, Vol. 1, p. 195 (1964) ; see also, for example, J.S. Bell, *Speakable and Unspeakable in Quantum Mechanics* (Cambridge/New York, 1987), B. d'Espagnat "Nonseparability and the Tentative Description of Reality" *Physics Reports*, Vol. 110 (1984), and ref. 2).

[2] B. d'Espagnat, *Physical Review* D11 (1975), p. 1424.

[3] S.J. Freedman and J.F. Clauser, *Physical Review Letters* 28 (1972), p. 938; E.S. Fry and R.C. Thompson, *Physical Review Letters* 37 (1976), p. 465; A. Aspect/P. Grangier/G. Roger, *Physical Review Letters* 149 (1982), p. 91.

[4] B. d'Espagnat, *In Search of Reality* (New York/Berlin, 1983); *Reality and the Physicist* (Cambridge/New York, 1989).

[5] L. de Broglie, *Journal de Physique* 5 (1927), p. 225.

[6] D. Bohm, *Physical Review* 85 (1952), p. 166.

[7] G.C. Ghirardi/A. Rimini/T. Webber, *Physical Review* D34 (1986), p. 470.

* * *