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FOCUS

The ontological deficits of quantum reality

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Before entering into any deeper philosophical discussions, our immediate intuition is that our world is comprised of our own consciousness, with its contents and varying states, and an outer world that is independent of our consciousness. Take, for example, a table and the image and idea we have of that table. Let's say the table is brown. Yet, what is brown? The table, you reply, which even had it been red or green would still be a table. This table is also, to a greater or lesser extent, hard to the touch. So, let's try again. What is this hard, brown object? The very table under discussion, at all times the table, which moreover occupies a given place and has certain dimensions. The table, that if I close my eyes disappears from sight, but returns if I open them. This table is the object of somebody else's comments, (oh, that memorable meal we had on it one day!) and my expectations (now, I leave, but when I come back tomorrow, I know I will find it in the same corner of the room). Yet it seems that this table, the real table, whatever be the significance of this assesment, is not the brown colour I perceive, nor the tactile sensation, nor its environment, nor its apparent size in my eyes, nor the comments I have heard about it, nor the memory I keep of it, nor the expectations to which it gives rise. From the beginning, it is none of these, nor can it be accounted for by the most complete series of characteristics that we might predicate. At the level of our immediate intuition, the table is something which is previous to this and concerning which we can predicate all the elements in that complete series. What then is the nature of this enigmatic previous object, if such a question has any meaning?

Perhaps it is worth pointing out at this point that the set of sensations, opinions, judgements, memories, expectations, etc. in relation to the table is endowed with a certain standing, structural and global existence, which is separable from the complete set of sensations, opinions, etc.,that constitute the entirety of our conscious life. For example, we can predict that, if standing alongside the said table, we reach out a hand, we will experience a clearly defined tactile sensation-that of touching the table; if we drum our fingers on its surface we will receive an unmistakeable sound sensation; if we draw close to the table the image we have of it will grow in size, and if we move away from it, the table becomes smaller, etc., etc. So, the set of experiences in relation to the table has a given structure: This structure, the stable set of specific experiential interrelations, forms a part of the object «table». If we were unable to perceive these interrelations, if the only thing we perceived was an indifferentiated magma of table-experiences, un-separated in our inner conciousness from the rest of our mental experiences, we would be diagnosed as suffering a clinical madness: a chaos of sensations devoid of the richness of distinction and order that caracterises our subjective lives. But, this consideration a part, the claim I am making is that the «stable set of specific experiential interrelations» forms a part of this object. I could perhaps take this one step further and argue that the structured series of table-experiences is the very object under discussion. Without it, the object no longer exists and after analysing the object and my perception of it, as we have just done, nothing additional has appeared. Nevertheless, if seeking to be coherent with the result of this analysis, one attempts to move forward and to dissolve the object (i.e., the thing for which we predicated each of the elements in the series «table») within its structured series, then, it raises in our inner consciousness the basic intuition that the object exists independently of ourselves, that behind the above structure lies something more, without entailing that this supposed reality adds anything new to our experience, nor calls into question our experience. We might see it as a sort of useless unattainable ontological patch, to which we cannot, however, renounce and which perhaps give us a basic reliance on our inner life.

Quantum mechanics takes the stage

All this is well known and forms part of the history of philosophy, but, as regards our perhaps useless ontological patch, there does not seem to have been any news during the last two and half millenia. This takes us up to 1927, the year when the basic formulation of Quantum Mechanics was completed. But what does this theory tell us? Let us go back and see its basic lines [1]:

In Quantum Mechanics all we can know about a physical system, in a given state, is necessarily included in what is

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known as its wave function, Ψ, in this state. Let us consider a measurable property of the system, that is, a magnitude. Take, for example, energy. Given Ψ, that is, given the system in a certain state, measuring a magnitude will provide us with a number of possible values. In general, Quantum Mechanics cannot predict with certainty which of these values will be obtained. The theory merely allows us to identify the possible results for the measure of the magnitude and the probability of obtaining any of these values, although in special cases it is possible to predict accurately the result of a given measure. The theory does not allow us to say anything more about the system, even though we can suppose a complete knowledge of the state, Ψ, of the system. This means in practise that we can say even less as frequently our knowledge of Ψ is incomplete. I should perhaps clarify that, in the framework of Quantum Mechanics, the impossibility of predicting with certainty which of a range of possible values will actually occur, when measuring is undertaken, does not derive from our ignorance concerning the nature of the system and its state, an ignorance which we could, in principle, correct. On the contrary, as we have said before, in Quantum Mechanics, all that we can know about a physical system is contained in its wave function. This means that if the overall knowledge of Ψ, that is the complete knowledge of the system and its state, does not allow us to predict when one will obtain a given result, then this relative indefinition forms part of the reality, an ontological deficit, and not the avoidable insufficiency of *a* knowledge provisionally incomplete.

Quantum reality is, therefore, affected by a radical indefinition—the possible results of a measurement—which is settled in favour of one or another at the moment of measurement. It is as if there were a deficit of reality, which is only compensated for by the act of observation. So it appears that the observation of the object creates part of the same reality. Then, the quantum object moves away from this ontological patch; a patch, which, unlike the quantum object, is unattainable and unchallengeable by experience.

The measure of what is called «spin» in Quantum Mechanics illustrates the partial creation of which the measurement act is capable. Imagine this spin as being like an arrow of constant length, with a variable direction according to the state of the system. More specifically, let us consider a particle of spin 1/2. In this case, the length of the arrow is 1/2 in a given system of units. Experiments allow us to measure the projection of this arrow in any direction. Our ordinary intuition tells us that the result of such a measure would be any value between the two extreme values of 1/2 and –1/2. These two extreme values would be obtained when the direction measured is the same as direction of the spin, which is supposed to exist prior to the measurement act. But, this is not what is observed: the measure of the projection of the spin in any direction is always either 1/2 or –1/2. Just as if the measurement act of the projection itself created the adequate direction of spin, spin which previously only partially existed.

That the measurement act should disturb the quantum system in a not totally predictable way is the essence of Heisenberg's uncertainty principle. However, in the case of the measurement of spin, it is not the type of disturbance which fades the clear edges of the reality: here, the disturbance is an act which might be considered as partially creating the reality. In both cases, the idea of a reality independent of the observer breaks down visibly and we are again faced by what before, and in the title of this paper, we have called an «ontological deficit of quantum reality».

The well-known experiment conducted on a double slit provides us with a new stage on which we can see this ontological deficit acted out. Here, a light monochromatic plane wave is incident on a screen after passing through two convenient slits. On the screen one does not observe two brilliant images corresponding to the two slits, but rather the succession of several alternatively bright and dark fringes; known as the interference pattern. This pattern can be explained by supposing that light is an extended wave in the space in which it propagates. The problem is that, when one tries to explain how the light is absorbed by the screen to produce the interference pattern, one must imagine light as being formed by particles known as photons. So, while light propagates like a wave, it is absorbed as a set of particles. There is no need to point out that the joint images of wave and particle are incompatible. Therefore, the only way to avoid this contradiction is to accept, as does Quantum Mechanics, that light is neither one thing nor the other. When one conducts a certain kind of experiment, light behaves like a wave, and when one conducts another kind of experiment, it behaves like a particle, since in general the measuring device forms part of the same quantum reality, and the experimental device used is not the same when one conducts an experiment in order to exhibit the wave properties of light as when one wishes to exhibit its particle properties.

Thus, the question might reasonably be raised as if to whether it would not be more sensible to adopt a radical point of view and to accept that Quantum Mechanics is not concerned with the quantum «reality», but only with the results of measurements. Therefore, the reality of quantum objects would be reduced to the measurement of their properties, or more accurately to the results of these measurements [2]: a doctrine similar, in the quantum domain, to the old philosophical attitude known as «epistemological idealism», according to which the reality of all things could be reduced to the corresponding contents of our consciousness. One could even argue that never, in the history of human thought, has this idealistic thesis found such strong support as it currently holds in the realm of the microscopic world because of Quantum Mechanics, as we have just explained in two well-known cases (the measure of spin and the double slit experiment). On the other hand, the macroscopic epistemological idealism is a somewhat unusual opinion, even if there is no doubting of its internal logical coherence. We will never find either any logical inconsistency in the case, presented before, of the reduction of the quantum world to the measurements carried out on it. But also in this case, this reduction quickly leads to a description of this world and of its knowledge unnecessarily complicated and strange, as we see it if we examine the well-known ideal experiment of «Schrödinger's cat». This imaginary experiment was described by Schrödinger [3] in 1935 and goes as follows: inside a sealed cabin there is a cat and a radioactive atom. When the atom decays it emits a photon which falls upon a device. Then, a poison is given off, killing the cat. Here the atom is the quantum system and the cat the measuring apparatus (a truly awful scenario, but such was the story written, more than 60 years ago). As a given quantum system in a given state, the atom has its wave function, Ψ, which contains all that we know about the atom. This wave function carries away the radical ontological indefinition of the atom as a quantum object, that is, the different possible results in each measurement and, in particular, the two results: the entire atom and the decaying atom.

Let us now consider an observer inside the cabin who is studying the cat. As long as the cat is alive, he infers that the atom remains complete, but as soon as the cat dies he deduces that the atom has just decayed. How would an observer outside the cabin, yet knowing its contents, consider the situation? If we adopt the above reasoning, according to which the reality of the quantum objects reduces to the results of the measurements carried out on it, the situation would be as follows: since the outside observer does not undertake any measurements (the cabin is sealed and so the observer does not know if the cat is alive or dead), he will assume the atom never decays and consequently the atom, as a quantum system, finds itself in this sort of indefinite existence, in that double potentiality, so specifically quantum-like, entire atom-decayed atom. The two observers, the one inside and the one outside, see two very different realities: the former will «see» the indefinite atom, between integrity and decay, until the cat dies when he will know that the atom has just decayed. In contrast, for the second observer, the atom always comprises that indefinition. As in the more general case of the ordinary, non-quantum, epistemological idealism, there is no logical contradiction here: it is not the same observer who sees different and unreconciliable phenomena; they are two different observers who see different things which do not need to be reconciled. All the same, we cannot deny that we have a particularly cumbersome description, in its extreme relativism, of quantum reality. It is comparable to the relativism that allows, in the macroscopic world, and whitin the best idealistic tradition, to say that the moon exists for he who looks at it, at the moment that he looks at it, and that it does not exist for that person who does not look at it, nor considers it, nor evokes it.

New epistemological idealism, reduced to the field of quantum reality, excluding the ordinary macroscopic reality, would find its specific justification in the ontological deficits we have above commented, which are exclusive of that quantum reality. But the problem with this new restricted idealism is that it cannot be limited to quantum reality as it also inevitably encompasses the macroscopic reality. Let us return to the experience of Schrödinger's cat and to what the outside observer «sees». This observer has in front of him a global physical system comprising the atom and the sealed cabin with its devices, including the cat. This global system is a quantum system since part of it (the atom) is quantic. Now, the outside observer cannot perform any measurements on this system and consequently, for him, the atom stands indefinitely in that sort of sui generis existence, between integrity and decay. But the problem is that in this global system, the destiny of the cat is linked to the state of the atom. So it is not only that the two observers see the atom differently, a quantum system (the inside observer sees the decayed atom, and the outside observer sees the atom concerned with an essential indefinition), but that the two observers see the cat, a macroscopic system, very differently: the first observer sees the cat alive or dead, while the second always finds the cat in a sort of ambiguous existence between both possible states, living cat, dead cat, associated necessarily with both coexisting atom states, standing atom, decaying atom. Yet, that two different observers see the same macroscopic object, such as a cat, in such radically different ways, cannot be accepted unless one assumes the traditional doctrine of epistemological idealism in the field of the ordinary macroscopic world (actually, an esoteric doctrine in spite of its venerable philosophical past). Furthermore, we cannot ignore the not insignificant question as to the meaning of a physical cat state, where this cat is neither alive, nor dead, but in a certain sense both things at the same time. Needless to say that in real life, cats show a consoling prosaic nature and they agree without any difficulty to appear before us exclusively alive or dead.

This relativism disappears if we accept that quantum reality is provided with a minimal existence, independent of our perception. From this realistic point of view, the decaying atom is certainly a partially non-predictive event, but it happens objectively, whether is observed or not [4]. The cat lives or dies depending on whether this objective decaying has already occurred or not. His life does not depend on the type of observer-inside or outside-considering the situation.

We cannot reduce quantum reality to the result of the measurements performed on it if we are not prepared to pay the enormous price of also reducing the reality of the macroscopic world to the mere observation of its properties. Then, as to whether or not we can postulate an ontological patch, or a minimal ontological patch, there is not much difference between quantum reality and ordinary physical reality, since both realities are closely connected here: the only difference-and this should be stressed-is that in the case of quantum reality we can speak, in the terms of this paper, of some serious ontological deficits which are not present in the ordinary reality, as I have sought to explain above.

Realistic theories and Bell's inequalities

The ontological deficits commented on above, in the same way as the partial, yet essential, unpredictability, entailed by Quantum Mechanics, make this theory, among all theories referring to the natural world, an extreme case of violation of our ordinary intuition. This is why, since its creation in the twenties and even today, various authors have sought to include Quantum Mechanics in more «complete» theories, the so-called «realistic» theories [5], which are compatible with ordinary intuition. In these theories, unpredictability does not derive from a basic lack of exhaustive causation, but is rather the banal result of a lack of knowledge of some «hidden» variables when attempting to define the state of the physical system. This is what happens in other fields of classical Physics, for example, statistical mechanics. It is worth remembering that no experiment has been described which contradicts the predictions of Quantum Mechanics. Quantum Mechanics is, today, one of the best tested basic theories, with an impressive array of agreements between theory and experiential evidence. This means that the «realistic» theories, alternatives to Quantum Mechanics, need to account for all these agreements also.

So, in the «realistic» theories and in accordance with our ordinary intuition the magnitudes of a physical system preexist its measurement, and if in practice the result of a measure is in part non-predictive, this does not derive from its non-existence or from a deficit of existence of this magnitude or of the physical system as such, but from a partial lack of knowledge of the state of the system we are measuring. It was the great merit of John S. Bell [6], in 1964, to clearly state that the statistical predictions of Quantum Mechanics, on the one hand, and those of «realistic» theories so-called local theories, on the other, do not always coincide. In this way, he shifted the question of epistemological realism into the realms of experimental testing, a remarkable turn of events in the history of philosophical thought.

We have just used the expression «local theories». Here , local theories are those in which the effects of a new physical action cannot propagate faster than light. Now, it must be remarked that there are realistic non-local theories which are able to make the same statistical predictions of Quantum Mechanics, but, of course, these theories contradict the theory of relativity and the copious experimental evidence which supports it. So, these non-local theories represent too high a price to pay in order to overcome the nonintuitive contents of Quantum Mechanics.

Let us then return to the local realistic theories, that are compatible with the theory of relativity. We will clarify, in one particular case, one of the above statistical predictions of the local realistic theories which contradicts certain predictions of Quantum Mechanics.

Let us consider a spinless particle (remember what we have said before about spin) at rest in the laboratory, which decays spontaneously in two 1/2 spin particles E and P (E from «electron» and P from «positron»). Since the original particle is at rest, both decaying particles will move away with equal opposed velocities. On the other hand, the spin is a physical magnitude which is conserved for an isolated system and our decaying particle is just one of these isolated systems. Suppose that an attempt is made to measure the spin of one of the decaying particles, for example, the measurement of the spin of particle E, in a direction, A; suppose that the result of the measurement is, let us say, 1/2 (remember that the result of the measurement of the spin of 1/2 spin particle, in any direction, can only be 1/2 or –1/2). Then, the measurement of the spin of particle P, in the same direction A, can only give –1/2, in such a way that the total spin of both particles, E and P, is always zero. This must be the case since the spin of the original particle, before decaying, was zero and, as we have said, spin is conserved for an isolated system.

Now, let us suppose that new decaying processes, similar in all respects to that we have just described, occur again and again, that is, in each case a similar new spinless particle decays in two particles, E and P. For every decaying process we measure the spin of these two particles, E and P, in any of three fixed at random directions A, B and C, though not necessarily the same direction for E as for P. In evident notation, the possible results of these measures on particles E and P are A^+, A^-, B^+, B^-, C^+, C^-. Let us now make two apparently inoffensive hypotheses:

a) We assume a realistic point of view and so we assume that the spin components along directions A, B, and C, whose components manifest themselves in the experiment, exist previously to their measurement in the form of a special particle arrangement. In each case, the special arrangement implicitly contains the corresponding spin components.
b) For every electron-positron pair, after the corresponding decaying, we assume that both measurements of the spin are practically simultaneous. Then the measurement on the electron cannot affect the measurement on the positron, and vice versa, since, according to the theory of relativity, there are no physical signals which propagate instantaneously.

Now, from these two natural hypotheses, one can prove in an elementary way a well-known inequality, known as Bell's inequality, in honour of its discoverer, the physicist John S. Bell. This inequality can be written in our case as follows [7]:

$$n(A^+B^+) ″ n(A^+C^+) + n(B^+C^+)$$

Here, $n(A^+B^+)$ is the number of pairs of measurements where we have found positive both spin components, of the electron and positron, on the A and B directions, respectively. Every pair of measurements refers to each one of the decay processes under consideration. A similar definition stands for $n(A^+C^+)$ and $n(B^+C^+)$.

Now, our great surprise is this: in spite of the fact that Bell's inequality has been deduced from such an evident or apparently evident hypothesis, the experiment shows that, according to the predictions of Quantum Mechanics, Bell's inequality is violated [8]. Then, in this case, local realistic theories are not experimentally viable, while Quantum Mechanics is. So, as much as this theory runs contrary to our intuition, it seems that its strangeness is the strangeness of the same reality. In particular, the lack of exhaustive causation of the theory is the lack of exhaustive causation in the physical reality as such. In this way, reality becomes something more than Laplace's mechanical world, alien to any newness and to any real production; a mechanical world where there is no place for any kind of freedom. Actually, the world of classical Physics, where the future is determined in all its details, is much stranger than what is frequently recognised. Were it not for any other reason (but many more could be cited), given this last consideration, if Quantum Mechanics did not already exist, it would be necessary to invent it.

Notes and references

[1] See any text book on Quantum Mechanics. In R. Penrose, «The emperor's new mind», Oxford University Press, New York, 1989, the laymen will find a non-technical consideration of all quantum items discussed in this paper.

[2] Historically speaking this has indeed been the posture adopted by most of the creators of Quantum Mechanics. Others, including E. P. Wigner, have argued that it is only when the observer becomes conscious of the result of the measurement that the quantum system jumps to a new state as a consequence of the measurement act (E. P. Wigner, «Remarks on the mind-body question», reedited in «Quantum Theory and measurement», ed. J. A. Wheeler and W. H. Zurek, Princeton University Press, 1983).

[3] E. Schrödinger, «Die gegenwartige Situation in der Quantenmechanik», Naturwissenchaften, 23, 807-812, 823-8, 844-9, 1935. (Translated into English in the above reference from Wheeler and Zurek, ed.). See also the above reference from Penrose, for a non-technical discussion of the «Schrödinger's cat».

[4] A more or less «ontological» vision of quantum reality is common place in all the literature. See, for example, Karl R. Popper, «Quantum theory and the schism in physics. Postcript to the logic of the scientific discovery», Vol III, Hutchinson, London, 1983, and also H. A. Stapp, «Quantum propensities and the brain-mind connection», Foundations of Physics, 21, No.12, 1991, and references therein.

[5] One can find basic references on these «realistic» theories in J. S. Bell, «The speakable and unspeakable in quantum mechanics», Cambridge University Press, 1987.

[6] J. S. Bell, «On the Einstein-Podolsky-Rosen paradox», Physics, 1, 1964.

[7] B. D'Espagnat, Scientific American, 241, 128, Nov. 1979.

[8] A. Aspect, P. Grangier, «Experiments on Einstein-Podolsky-Rosen-type correlation with pairs of visible photons», in «Quantum concepts in space and time», ed. R. Penrose, C. J. Isham, Oxford University Press, 1986.