A note on Measurement

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Abstract

Grounded on the quantum measurement riddle, a general argument against the universal validity of the superposition principle was recently put forward by Bassi and Ghirardi [1]. It is pointed out that this argument is valid only within the realm of the philosophy of "objectivistic realism" which is not a necessary part of the foundations of physics, and that recent developments including decoherence theory do account for the appearance of macroscopic objects without resorting to a break of the principle.

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How do we know that there is a stone on the path, or a tree in the courtyard? Obviously (as many philosophers have kept stressing) by having a look. So that, if we were extremely cautious not to make unwarranted statements we should not bluntly say that there is a stone on the path (or a tree in the courtyard). We should say: "We know that if we had a look at the path, to check whether or not we have the impression of seeing a stone, we should actually get the impression in question". As long as we remain within the realm of pure thinking, this remark does not amount to taking an option for or against objectivistic realism. It is just a matter of cautiousness, that is, of taking care not to make unjustifiable claims. It may be that objectivistic realism is true. But, since it is unprovable, it may also be that it is not. So, we keep on the safe side by not implicitly postulating it.

In ordinary life making use of such long, intricate sentences is quite impossible. For all practical purposes we are therefore fully justified - even if we are not diehard realists - in using the shorter, so called "realistic", sentences, that describe objects as "really being" here or there. In the quantum mechanical realm the situation, however, is different. As everybody knows, this is a domain in which too "realistic" sentences, implicitly postulating that all the quantities of interest always have values, would lead us astray. And we may well suspect that, when we assume quantum mechanics is universal and apply it to macroscopic systems, something similar may be true also concerning some sentences bearing on such systems. But still: even in the realm of atomic and subatomic physics there is at least one circumstance in which the use of "realistic" sentences - involving the verbs "to have" and "to be" - is both harmless and convenient. This is when we know (for sure) beforehand that, if we measured an observable B on a system S, we would get eigenvalue b_k of B as an outcome. In that case we may assert that system S is in a state described by one of the eigenvectors of B corresponding to eigenvalue b_k (when S is entangled with other systems what we may assert is, more precisely, that the overall composite system is in an eigenstate of $B\otimes 1$ corresponding to eigenvalue b_k, where $B\otimes 1$ stands for the extension of operator B to the Hilbert space of the whole composite system).

Similarly, when, as with the example of the stone on the path, we know for sure that if we looked we would have the impression of seeing a certain physical system lying within a given region of space instead of outside it, we are allowed to consider this knowledge as enabling us to make some definite statements concerning the quantum mechanical description of this system. For instance, when the system in question is an electron we are allowed to infer from such a knowledge that the state vector of the electron (or, better to say, of the whole Universe including the electron) is an element of a certain set of vectors. Or, to take another example, consider the well-known explicit model of a measurement process that was given by von Neumann and which just consists of a "spin" and a one degree of freedom apparatus (see [2], Chapter VI, §3 or [3], Section 14.3). When the initial spin state is given and is an eigenstate u_k of the quantity S_z that the instrument has been instructed to measure, we can derive from the Schrödinger equation the certainty that if, after the interaction, we had a look at the position B of the pointer we would get the "outcome" b_k. Then, according to the above,we are allowed to infer from this knowledge a definite statement concerning the pointer final state, namely that it is the state φ_k corresponding to b_k. However a problem arises when we assume that initially, the spin state is not an eigenstate of S_z. This problem - a conceptual one! - bears on the question whether or not we should still assert that the pointer lies at some definite place, corresponding to one of the b_k, and that its quantum state is therefore an element of one or other of the corresponding definite sets of vectors.

More precisely, the problem consists in the fact that the above described general approach can be applied in two different ways, depending on the amount of initial knowledge we consider we have, and that these two ways lead to different conclusions.

One of these "ways of arguing" - call it "option A" - consists in clinging to the realist philosophy, which claims that the reason why we see macroscopic objects as having definite forms and definite localizations in space is that they really exist as such, quite independently of us, that is, of our sensorial and intellectual equipment. We see them at definite places because they are at definite places. Hence we know beforehand that a pointer, say, cannot be at the same time in two macroscopically different states and of course this - very general but, nevertheless, quite certain - knowledge must be taken into account when we apply the above described procedure in order to determine the final state of the pointer or, better to say, in order to state some general conditions that the state in question must fulfill.

The other "way of arguing" - call it "option B" - consists in keeping close to a standpoint taken by a number of ancient Greek philosophers (Plato foremost), adopted as a "starting point" (though finally dropped) by Descartes and forcefully argued for by Kant. Roughly, this is the view that, quite generally, the testimonies of our senses are deceitful and should not be taken at face value. More precisely, it consists in claiming (contrary to Galileo, Descartes and Locke) that, when all is said and done, the "qualities" Locke called "primary" (shape, position, motion, etc.) should be considered as being man-dependent precisely in the same sense as are those he called "secundary" (colour, taste, smell, etc.: the taste of a fruit depends on the fruit but it also depends on us). According to this trend of thought (considered the most reasonable one by, perhaps, the majority of contemporary philosophers), the fact that we perceive such "things" as macroscopic objects lying at distinct places is due, partly at least, to the structure of our sensory and intellectual equipment. We should not, therefore, take it as being part of the body of sure knowledge that we have to take into account for defining a quantum state.

The branch of study conventionally called "measurement theory" almost entirely developed within option A and was an attempt at showing that the said option is compatible with conventional quantum mechanics and the completeness assumption. In their recent article [1] Bassi and Ghirardi referred to a book [3] in which I reviewed and discussed the main proposals that were put forward to that end and pinpointed the considerable difficulties they all must cope with. The main one of these is of course that when the system S on which a quantity B is to be measured is not, initially, in an eigenstate of B, if a state vector is initially attributed to the pointer the Schrödinger time evolution leads, for the overall system Σ composed of S and the pointer (or of S and the rest of the world if, along with the pointer, we take the environment into account, as we should), to a state that is a superposition of macroscopically distinct states; a result which is incompatible with option A as noted above. In order to overcome this difficuly it was stressed in [3], in particular, that initially describing the pointer (or the pointer-environment system) by means of a state vector is a considerable idealization, and that, because of our ignorance of its detailed atomic structure and so on, it should actually be represented by a density matrix, with the consequence that the final state of Σ would also be represented by such a matrix. In view of the fact that, in general, a given density matrix corresponds not to one but to infinitely many proper mixtures it could then a priori be hoped that, among the latter, some would be composed of states fulfilling the condition of not being superpositions of macroscopically distinct states. The specific difficulty mentioned above would then be removed (even if other ones conceivably remained). Also - let this be added here - it could be hoped that, somehow, the apparent violation of determinism characterizing such measurement processes could be reconciled with the deterministic nature of the Schrödinger time evolution by invoking the ignorance probabilities inherent in proper mixtures. However, as pointed out in [3], the result of the investigations in question was that the first of these two hopes is, in fact, unfounded, in the sense that, concerning the final state of Σ, in the considered situation proper mixtures with the requested properties do not exist. Now, Bassi and Ghirardi gave a new proof of this, and it may be considered that theirs is both simpler and more general. It is true that they did not explicitely consider proper mixtures but it could be argued that their proof applies separately to every component of such mixtures. Also, they did not explicitely consider the question of determinism… but after all, neither did I.

From their result Bassi and Ghirardi inferred that "to have a consistent picture one must accept that in a way or another the linear nature of the dynamics must be broken". Now, is this conclusion inescapable and general (at least within a genuinely quantum description, with the completeness assumption made)? This is the question that must now be addressed to.

Within Option A the conclusion seems inescapable indeed. But on the other hand none of the schemes that materialize the break is as yet considered, for various reasons, as being fully convincing. In particular, the one that was developed by Ghirardi et al. [4] offers no other motivation for the proposed modification than the one just explained above, namely the "necessity" we think we are in of describing macroscopic systems as never being in superpositions of macroscopically different states. But, as the forgoing already indicates, this is merely a philosophical requirement. In fact, scientists most righly claim that the purpose of science is to describe human experience, not to describe "what really is"; and as long as we only want to describe human experience, that is, as long as we are content with being able to predict what will be observed in all possible circumstances, it must be granded that Option B is enough. We need not postulate the existence - in some absolute sense - of unobserved (i.e. not yet observed) objects lying at definite places in ordinary 3-dimensional space. Consequently we have no need for such a break in the linear nature of the dynamics as the one Bassi and Ghirardi suggest. To introduce such a momentous change in the scientific description merely on the basis of a philosophical conception of our relationship with the World is a procedure that may be considered as far removed from normal scientific practice.

In view of all this (combined with such experiments as the one of the Haroche group [5], which plead convincingly in favor of the universality of the quantum mechanical predictive rules), taking up Option B seems more advisable than taking up Option A. Within the realm of Option B it is, to repeat, not at all considered certain that, independently of ourselves, macroscopic objects exist "out there" as we see them (with precise locations and so on). What is considered certain (or at least "well established") is a set of predictive rules that enable us to foresee what we shall observe. This set involves, in particular, the rules - call them "the M rules" - that apply within the so-called macroscopic domain and it so happens that these rules can be translated in the language of the descriptive laws of classical physics, that is in terms of statements interpretable as bearing on objects existing "in the outside World". It is then, to repeat, most convenient to make use of such a language, but we should not infer from this that the language in question necessarily describes elements of anything that could be referred to as "man-independent reality". Perhaps it does but perhaps it does not. Now, in this field the most significant recent development consists in the fact that, due to the (universally existing) interaction between a macroscopic system and its environment (including its "internal" one, that is, the set of its atomic variables), it could be shown (i) that the (predictive) M rules follow from the (predictive) basic quantum rules (see [6], Chapters 6 and 7) and (ii) that, for macroscopic systems, the appearances are those of a classical world (no interferences etc.), even in circumstances, such as those occurring in quantum measurements, where quantum effects take place and quantum probabilities intervene (see e.g. [7]). This is the true significance of decoherence theory. In other words, this theory has no meaning within objectivistic realism and should not therefore be understood as signifying that a "real" collapse occurs, when "real" is understood in the sense it has within the philosophy in question. But it remains true that decoherence explains the just mentioned appearances and this is a most important result. It may be considered as implying that, from a quite strictly scientific viewpoint, the above mentioned Bassi and Ghirardi claim is not justified. As long as we remain within the realm of mere predictions concerning what we will observe (i.e. what will appear to us) - and refrain from stating anything concerning "things as they must be before we observe them" - no break in the linearity of quantum dynamics is necessary.

On the other hand, this conclusion should not be interpreted as meaning that investigations bearing on the so called "measurement theory" have proven nothing. What they proved (within the realm of the completeness assumption) is that we must either accept the break or grant that man-independent reality - to the extent that this concept is meaningful - is something more "remote from anything ordinary human experience has access to" than most scientists were up to now prepared to believe (although science formerly contributed decisively to making plausible the idea that Reality is not at all what it looks like). This is an important result, to the derivation of which the Bassi and Ghirardi paper unquestionably brought a very significant contribution.

APPENDIX

Now, in thus comparing options A and B, was I unfair to the former? After reading a preliminary version of this article Prof. G.C.Ghirardi reminded me that also option B has its limitations, an important one proceeding from the fact that a (nonpure) density matrix corresponds to several proper mixtures. Consequently (as pointed out by Joos [8] and rediscovered independently by myself [9]) when, for example, decoherence is applied to the localization of macroscopic objects (dust grains, say) it does not suffice, by itself, to prove that in an ensemble of such objects each element occupies - or will be seen as occupying - some definite place. In other words, the localization process is not just a consequence of the formalism. It is also due to our human way of perceiving so that, if we stick to the conventional notion of "states" (states of " systems" or of "the World") we have to grant that within option B perceptions are linked in quite a loose way with the said states (as described by density matrices). As Prof. Ghirardi stressed to me, there is, after all, no considerable difference between such a state of affairs and the ancient view of London and Bauer and Wigner, according to which the wave function is reduced by an individual conscious act of perception.

There is, I must admit, substantial truth in this remark*. On the other hand, I claim that this disadvantage of the decoherence approach is, if not completely removed, at least considerably alleviated if option B is understood as centered on predictivity, as sketched in the first paragraph of the present article. More precisely, although, personally, I tend to view physics without metaphysics as being conceptually incomplete, I consider nevertheless that we should be careful not to include some admixture of the latter in the technicalities of the former. In particular (as already stressed in [3]), physicists should be cautious when using the notion of "state", which, because of its role in ordinary language, has questionable metaphysical implications. I observe that if, as physicists, we only worry about predicting what are our chances of observing this or that, and if, correlatively, we impart to the word "state" no other meaning than that of designating a mathematical tool allowing for such predictions, we meet with no ambiguities whatsoever. In particular, I am happy to know (from decoherence theory and so on) that, for the said purpose, I can, without running into inconsistencies, allegorically use in my daily life the descriptive language of classical physics and commonsense. I claim that many of our (conceptual) worries in quantum mechanics proceed from the fact that, since the descriptive language is simpler and more congenial than any conceivable predictive one, we use it whenever possible and then interpret it metaphysically (and erroneously), as describing "what really is".

Now, some philosophers would carry such a "radicalism" to its bitter end. They tend to reject any notion of a reality not identified with the set of our impressions and predictions. Clearly, we should not go that far. And I grant that option B does have one inconvenience at least: that of suggesting going over from Platonicism to neo-Kantianism. Existence is prior to anything else, reference, prediction etc. But existence as Being, not the existence of objects. The trouble is that, while, through physics, Being informs us quite definitely of what it is not (e.g. it is not composed of localized elements), it seems reluctant at letting us know what it truly is.

* Although we should not underestimate the considerable conceptual difference there is between the notion of an individual action modifying reality and the one of a collective way of perceiving reality (added note).

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