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AIMING AT DESCRIBING EMPIRICAL REALITY

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Abstract

The interpretational difficulties besetting Quantum Mechanics can to a large extent be circumvented by adopting the view that the referent of the theory is merely Empirical Reality, that is, the set of the phenomena, in the philosophical sense of the world. One possible materialization of this idea, partly based on the consistent histories approach, was described elsewhere [1]. An alternative one - called the operational theory - is put forward here. The explanatory power of such a quantum theory of Empirical Reality is shown to equal that - based on causality - of more realistic theories. The new theory of Empirical Reality is compared with the earlier one as well as with the consistent histories models. Finally, recent findings concerning our inability at truly explaining observed classicality are turned into a novel argument strengthening the (Kantian) conception that the fact we apprehend the World as classical (and probabilistic) is of an irreducible nature.

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1 - INTRODUCTION

I first met Abner in 1970 at the Enrico Fermi Summer School on the Foundations of Quantum Mechanics. He told us, of course, of the spectacular generalization of the Bell inequalities that he, Clauser, Horne and Holt had published the year before. But we also had several opportunities of exchanging ideas, either in corridors or in trattorie looking on the lake of Como. I was doubly impressed by him. One reason was that, until then, I never had met a physicist-philosopher. I vaguely thought the neuronal networks of the two races were different so that I was surprised getting from Abner - on philosophy - understandable and valuable information. The other reason was that I discovered a new kind of person on this occasion. Most people never listen. Abner does. I now try to listen also.

Abner and I are interested in the same - momentous! - problems of Reality and Intelligibility. These questions however do not constitute as such the subject matter of the present paper for my overall views concerning them were already explained at length in a recent book [1]. In a way, this article is just a sequence to the said book, developing in detail one or two rather particular points - concerning interpretation of quantum mechanics - that I considered in the same.

In it, a rough classification of such tentative interpretations was proposed. Schematically, they fall within two great categories: that of the "ontologically interpretable" theories and that of the theories that "save the appearances". What makes the matter subtle (and attractive) is that each one of these two general approaches encounters difficulties acute enough to justify taking the other one quite seriously into account. These difficulties were explained in detail in the book in question - together with the substance of the most important theories in the two families - and there would be no point in developing the subject again here. In fact, the investigations to be reported on in this article only bear on the theories of the second kind, those that are aimed at "saving the appearances", and on but some aspects of these.

"Saving the appearances" is seen as the ultimate goal of physics not only by the - avowed or crypto - idealists, but also by some people who are convinced we cannot dispense with the notion of a Mind-Independent Reality but who, at the same time, consider physics does not lead to a scientifically reliable ontology. For these persons - among whom I rank - the word "reality" has two meanings, that I proposed to distinguish by appropriate epithets. There is on the one hand Mind-Independent Reality, or Being: a Reality that, according to these views, is not scientifically knowable (at best: it is veiled), and on the other hand Empirical Reality, which is just the set of what philosophers call the phenomena, that is, images of Mind-Independent Reality as seen through the distorting glasses of our human faculties at apprehending and thinking. For the persons in question, the essential goal of physics, and, in particular, of quantum physics, is to describe this, human centered, Empirical Reality. This is the standpoint - called, for short, the "Veiled Reality conception" or the "Empirical Reality approach" - that, for the sake of the argument, is adopted in what follows. As shown in [1], such a standpoint disposes of most of the difficulties burdening the conventional, von Neumann-like approach to quantum theory. In particular, it removes an essential difficulty concerning the wave function collapse. In it, since the instruments are "automatically" classical (just because we make use of them as instruments) the wave function can consistently be considered as just being a tool that serves at determining the probabilities we have of observing this or that. It is therefore not surprising that it should be relative to us and should change abruptly when our information increases (for details on all this, see Ref.[1]).

It will be observed that the Veiled Reality conception does not boil down to plain operationalism. This is because we have to explain why classical predictive rules work. It is also due to the fact that even predictive rules must, at some place, make use of such primitive verbs as "to have" and "to be". In Sections 2 and 3 an operational definition of these verbs is put forward, and a corresponding analysis of the notion of truth is made. This leads to, in Sections 4 and 5, a new theory of Empirical Reality, called the Operational Theory. This theory is compared with classical physics in Section 6, is shown to match our commonsense notion of cause in Section 7, and is compared with consistent histories approaches in Section 8. The main results are summarized in Section 9.

2 - EPISTEMOLOGICAL (ALIAS: WEAK) SENSE OF THE VERBS "TO HAVE" AND "TO BE".

As Shimony et al. have stressed [2] (see also [1]), the EPR criterion of reality is ambiguous since, in it, the phrase "can be known" may be understood in two different ways: meaning either that "data are available" or that "data could be made available" for prediction. It is only if the second sense is implied that the EPR argument goes through, with the consequence that the observed violation of the Bell inequalities then implies the existence of some sort of an influence at a distance. When only the first sense is taken up - and care is taken not to inadvertently go over from it to the second sense! - this conclusion cannot be drawn. The criterion can then be reformulated so as to yield an operational definition of the meaning of the verb "to have" that reads as follows (for future reference let us call it the "operational definition").

Operational Definition

If - due for example to some previous measurement - data are actually available that make it possible, without in any way disturbing a system, to predict with certainty what the outcome would be of a future measurement of an observable pertaining to this system, then it can be said that, on this system, this observable has the value in question.

This is what has been called [3] the "epistemological" (or "weak") sense of the verb "to have". Being operational, this definition of "to have" is well suited for being made use of in a theory of empirical reality (the other conceivable sense, the ontological one, does not directly concern us in this article). Since this definition refers - via the "would" it contains - to a "future measurement" that is not assumed actually performed, it corresponds to a counterfactual, operational meaning of the verb in question.

The operational definition yields a meaning to the verb "to have" occurring in the sentence: "immediately after an ideal measurement of an observable A yielded outcome a, observable A has, on the system, value a". Admittedly this does not bar the possibility of alternative partial definitions of that verb, referring, not to the stated operational definition but to something else. In particular, a kind of "time reversed" partial definition could be considered according to which the data recorded by an instrument would inform us of the value the measured observable had before the measurement took place. But it must be stressed that the two definitions cannot be made use of at the same time. This is apparent as soon as we consider the

case of the successive measurements, at times t_A and t_B respectively, of two noncommuting observables A and B with nondegenerate spectra. The foregoing definition shows that, within the time interval (t_A, t_B) , A has value a_n while the "time reversed" definition would show that B has, within this same time interval, value b_k , which is impossible. Hence a choice must be made, once and for all. It can however be shown [4] that the time reversed definition implies a form of backward causality that is extremely counterintuitive. Hence we shall favor the "normal" (non-time reversed) choice: the one that consists in considering that it is just after - and not just before - the measurement that the measured observable has the value registered by the instrument.

3 - E-TRUTH.

Within the veiled reality conception the purpose of science, and of quantum physics in particular, is not - to repeat - to provide us with an ontologically true description of Reality but merely to yield a systematic account of human collective experience. This implies that, in this approach, the basic elements of the said collective experience - essentially such elementary sense data as "seeing a green light" or "seeing a red light" on an instrument - are taken as the, unanalysed, building stones of the theory. Propositions concerning them are taken, by definition, to be true (or false): Not "ontologically" true of course but empirically true, or, for short, E-true. In fact, this class of propositions can be enlarged without much ado to, practically, all those of classical physics. At least it can to all of them that only involve what we call macroscopic objects: for in this approach it is consistent [1] to adopt a human centered definition of the concept of a macroscopic object and say that a macroscopic object is one on which we can - or care to - perform classical measurements only.

In principle, the whole of physics could be described just with the help of E-true statements bearing on macroscopic objects, plus suitable rules of calculation making it possible to predict future observations - performed on these objects - on the basis of past ones. However, in practice this does not work: we also need express, in some sort of a realist language, some propositions bearing on microscopic objects and their properties. It is tempting to try and extend to such propositions the notion of E-truth (or falsity). The question is: how is this to be done in a consistent way?

The authors of theories of the "consistent histories" type - essentially, Griffiths, Gell-Mann and Hartle and Omnès - have developed ideas that have some relevance to this problem. "Some" only, for these theories are considerably more ambitious than the one contemplated here since they aim - or seem to aim - at describing, not just empirical reality but, in some sense, reality itself (at least, this is what appears to follow from a number of the motivations they present). The question whether or not they do actually achieve such an end is a delicate one, which will be touched upon only in Section 8. But anyhow this objective clearly underlies their investigations to an extent large enough to induce them not to set the notions of measurement, instruments etc. in the forefront.

In the "Empirical Reality approach" I am trying to develop here, the situation is, of course, different because of its avowed purpose of merely describing (collective) human experience. As a consequence, this approach should take the E-true statements bearing on (observed) pointer positions and the like as primary ones; and if any pseudo-realist statement bearing on a microsystem happens to be, in it, of some practical use it should only be viewed as a convenient language convention.

Two possible ways of defining the meaning of the latter statements are then open. Either (i) we try to define it abstractly,

as Omnès did [5],[6], by specifying logical composition laws etc. within the set these statements constitute, and leave it for later to specify any relationship they may have or not have with experience, or (ii) we define it operationally, by ultimately referring to the propositions bearing on pointers and so on.

In any attempt at building up a "theory of Empirical Reality" purporting to exploit possibility (i) the set of the E-true (or false) propositions bearing on quantum systems must of course be severely limited, same as they are in Omnès theory. Valid propositions may then be defined in an abstract way, same as there, but, just as there, most of them are only reliable (or E-reliable, as we may also say). In Ref.[1] I proposed a theory of empirical reality based on such general ideas. For later reference, let it be called here Theory A. Its most significant feature is that, in it, just as in Omnès' theory, there is no sense of the words "true" (or "E-true"), in which it could be said that, at some finite time after we have measured a quantum property of a microsystem, that property is a true attribute of the system. In other words, in this version of the theory statements of the "A has value a" type that are based on some previous (direct or indirect) measurement of A are, in general, only E-reliable statements, which, of course, precludes applying the EPR reasoning. Independently of any other possible argument to the same effect, this one remark suffices, as stressed in [1] in particular, to show that according to Theory A none of the consequences usually drawn from the EPR reasoning - Bell's theorem and nonlocality in particular - apply to empirical reality.

Possibility (ii), on the other hand, is also well worth being explored. At first sight, its operationalistic character even makes it more consonant with the general spirit of the empirical reality approach. The alternative it constitutes is the main subject matter of this article. Let the prospective theory hopefully to be constructed along these lines be called for short the Operational Theory.

4 - MAIN LINES OF THE OPERATIONAL THEORY.

The most elementary interpretation of nonrelativistic quantum mechanics consists in considering that the wave function of a system of N particles is a "real" stuff, immersed in some "real" 3N-dimensional space, and that at the quantum level it is the only real stuff. Collapse is then considered as a real, nonlocal phenomenon, taking place whenever a measurement is performed.

This elementary picture has some virtue of its own. For example, it disposes of the "delayed choice" paradox (according to it, in the two slits experiment a "particle" (i.e. the corresponding wave) always passes through the two slits, even if a counter is in place behind each slit: nonlocality of collapse accounts for the fact that only one counter clicks]. But of course it encounters a host of well known - and insuperable - difficulties of quite an elementary nature.

It is however worth noticing that these difficulties of the theory are mainly attributable to its tight embedment in realism. As noted in the Introduction, restricting - as done here - the "ultimate goal" of physics, and especially of quantum physics, to a mere description of Empirical Reality alleviates many of the difficulties the various interpretations of quantum physics are burdened with. In particular, let it be reminded [1] that, within such a conception, the wave function being just a tool, neither completeness (in EPR sense) nor collapse are conceptual problems. Consequently, it seems reasonable to try and build up the Operational Theory along the lines of the afore-mentioned "naïve" theory but with all ontological overtones removed.

In such a program we are faced with questions already met with in Theory A. They are as follows:

(i) *Consistency*. This is essentially the old Schrödinger cat paradox. In a general measurement-like process, if the initial state $|\Psi(0)\rangle$ of the overall system (measured system, plus apparatus, plus environment) is a pure state it will remain a pure state $|\Psi(t)\rangle$ at any time. It is true that, due to decoherence etc., no interference terms will be observed in a measurement performed at time t of a macroscopic observable. But there are many Hermitean operators - call them M - that do not correspond to macroscopic (hence practically measurable) observables; some of them are such that $\langle\Psi(t)|M|\Psi(t)\rangle$ contains interference terms, and there exists no argument showing that none of these correspond to a quantity that in principle (if we had powerful enough instruments etc.) could be observed. By measuring such an observable one would exhibit the existence of a surviving quantum superposition of macroscopically different states. Omnès (Ref.[5], Ch.7) criticized this argument by claiming that it relies on the - most questionable - axiom that every Hermitean operator is measurable¹. Strictly speaking, this claim of his is incorrect. Obviously, the argument in question remains valid even if many Hermitean operators correspond to no observables. It merely relies on the fact that there may exist some operators M endowed with the above said properties and that are measurable, at least in principle. And indeed, at least in simple models of quantum measurement processes (the Zurek model in particular), such M 's do exist, as I showed explicitly by producing one [8],[1].

For this reason, the idea of treating the instruments classically qua instruments is consistent with the general rules of quantum mechanics only if an "Axiom of Empirical Reality" [3] is set forth, according to which some quantum mechanical operators that correspond in principle to observables (measurement procedures concerning them can be stated) are declared by fiat not to correspond to elements of Empirical Reality. Of course these "sensitive observables" (as I called them) must be unobservable in practice. The question we are then faced with is whether an observable that, at a given time, is sensitive will remain sensitive (i.e. unobservable in practice) at all other times. This question was considered in [1] and answered positively: because, in particular, of decoherence, an observable that is sensitive at some time does remain sensitive at later times. The validity of this answer does not hinge on whether we choose to exploit possibilities (i) or (ii) above, so that it holds good also with respect to the operational theory.

(ii) *Locality*. As is well known, nonlocality does not make superluminal signalling possible. A satisfactory theory of Empirical Reality should allow for this, that is, it should be such that none of the Bell theorems applies to it. Bell 2 (see Ref.[1] for definition) clearly does not, since it is avowedly based on ontological considerations (the "complete specification" of all the "beables" in the intersection of two lightcones). But the case with Bell 1 is a little bit more intricate. In view of it, if we want the observed violation of the Bell inequalities not to imply superluminal influences we must, concerning microsystems, renounce the kind of counterfactuality that leads to the EPR Criterion of Reality. As shown

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¹In fact, surprisingly enough he even attributed this questionable view to me! In a footnote to [5] he stated that, in Ref.[7], I introduced the axiom in question as a rule in the formalism. Let me seize the present opportunity for informing Omnès's readers that this I definitely never did, as every reader of my books will know. Unfortunately Omnès, as he now privately acknowledges, had misunderstood some clear sentences in the latter.

in [1] this is possible provided only a part - called Reality Criterion 1 - is kept of the EPR criterion. The there stated Reality Criterion 1 essentially coincides with the "Operational Definition" of "to have" stated in Section 2 and can therefore be considered as a (partial) operational definition of the meaning of this verb, called its "weak", or "epistemological", meaning. Intuitively we tend to go over from Reality Criterion 1 to Reality Criterion 2 (essentially the EPR criterion proper) which implies that observable A would have, on system S, the value in question, also under the weaker condition that "data could be made available that would make it possible etc." In other words, we tend to go over from the epistemological meaning of "to have" to the conventional - that is tacitly ontological - meaning. In a theory of Empirical Reality we, clearly, must refrain to do so if, for the reasons just given, we want to preserve its "local" character.

In Theory A this "refraining" is almost automatic, since, in it, the above derived proposition "observable A has value a" is, as noted, not E-true but merely E-reliable. But, in contrast to what takes place in the case of "Consistency", this feature of Theory A cannot be just simply carried over to the Operational Theory. This is because, in an Operational Theory closely inspired from the naive theory (only with ontology wiped off), there is no reason to drop the standard view according to which, in suitable circumstances, the outcome of a measurement informs us of the (E-)truth of the assertion that the measured physical quantity has the observed value, even at times finitely different from the measurement time. A natural question then arises, namely: "since these propositions are now said to be E-True, is there not a risk that nonlocality will reappear, also within Empirical Reality? But actually this question was already answered in the first paragraph of Section 2. The operational definition (stated there) essentially coincides, to repeat, with Reality Criterion 1, otherwise said, it defines the "epistemological sense" of the verb "to have". And, even though we are now considering the propositions under study as being E-true, nothing forces us to consider them as being ontologically true, that is, nothing compels us to go over, concerning them, from Reality Criterion 1 to Reality Criterion 2. Hence, in principle, deciding not to accept Reality Criterion 2 should be sufficient for making Empirical Reality free from any admixture of nonlocality.

For convenience, let us call "SE-true" ("strongly empirically true" the propositions of the type "A has value a" that can be interpreted not only in the sense of Reality Criterion 1 but also in the sense of Reality Criterion 2. Which means that for all practical purposes we may argue as if, in them, the verb "to have" had its usual, ontological sense (here "for all practical purposes" means we do not thereby run the risk of making false predictions). And let us call "EE-true" ("epistemologically empirically true" the propositions of the type explained above, that is, those in which "to have" has its epistemological sense only. Then the essentials of the Operational Theory may be summarized as follows. We describe to each other our collective commonsense experience by making use of such notions as those of macroscopic systems and macroscopic (classical) physical properties possessed by these systems. These notions are carried over in the Operational Theory. In it, the macroscopic systems have E-existence and the propositions stating the dynamical properties they possess at such and such times are SE-true. As for our scientific experience, we also ultimately express it in terms of the just mentioned SE true propositions. But for (statistically) predicting the details of it, we need theories. And a number of intermediate statements in these theories are most conveniently expressed in a pseudo-realist language, in which theoretically defined dynamical physical quantities are attributed values. Such statements are EE-true propositions.

5 - COLLAPSE

As already noted, in the Veiled Reality conception, and in particular in the Operational Theory, the wave function and the state operator (density matrix) are just tools, so that their collapses subsequent to a measurement do not raise the conceptual problems they do raise within the standard von Neumann-like conception. The difficulties associated with the necessity of physically defining the quantum-classical cut vanish due to the fact that the cut in question is not "physical" in this theory. Similarly the difficulties concerning the collapses-at-a-distance (induced on one element of an EPR correlated pair by measurements performed on the other element) and the fact that they seem to imply influences at a distance, vanish, as explained in Section 4, due to our choice of a weak (or "epistemological") definition of "to have", that parallels Reality Criterion 1 but not the full-fledged EPR reality criterion (Reality Criterion 2). Consequently, in a case in which a measurement of some observable A belonging to some system S has yielded a certain outcome a, it is, in the Operational Theory, a fully justified move to consider that, immediately afterwards, S is "in the state" described by the corresponding state vector or density matrix.

6 - THE OPERATIONAL THEORY AND CLASSICAL PHYSICS

Two of the basic ideas of the Operational Theory are, to repeat: (i) that the reason why we apprehend "the world outside" in terms of space, time, and localized macroscopic objects obeying classical physics is that the very structures of whatever - inside us - enables us to feel and think forces us to do so; and (ii) that the mind-independent reality underlying this built-up representation of ours essentially lies beyond our reach. Hence, there can, of course, be no question of "explaining" the macroscopic appearances in terms of the structures of the underlying reality, that is, of "deriving" classical physics from some - nonexistent! - quantum "ontology". And it even is questionable that the less ambitious question: "can we predict that we shall continue to apprehend a classical world?" can meaningfully be kept (more on this in Section 3). But this is not to say that, in the Operational Theory, the coexistence of classical and quantum physics does not raise any question whatsoever. It does for several reasons. The main ones are that:

(a) While a macroscopic system is defined as "classical" by the very fact that we apprehend it that way, still we are free to think of it otherwise and consider what we could predict by means of quantum mechanics concerning outcomes of possible measurements performed on it.

(b) Our classical apprehension of objects is not just merely descriptive. In it, we also use to 'explain' events by means of 'causes', that is, we make use of a classical type of determinism, which works quite differently from the Schrödinger-like "determinism of the wave function" since, within the latter, the causes and effects we refer to when we apply the former cannot even be considered as always possessing full fledged existence. Not all of them can, for example, when the Schrödinger time evolution is applied to a several step process the first step of which involves branching (by 'full fledged' existence one is meant that entails all the, possibly counterfactual, consequences normally implied by the fact that a system has such and such a property).

Consequently, even within the Operational Theory the problem of checking the compatibility of quantum and classical physics has a meaning. Fortunately, this problem is, by far, not a new one.

Milestones concerning it are the Ehrenfest theorems, the BKW method and Jauch's notion of "macrostates" [9]. More recently, thorough investigations were performed, especially by the "consistent histories" theorists, and in particular by Omnès [6], of the main questions that hinge on it. Fortunately, the analysis these theorists made of this point is essentially independent from the postulates that make their theories differ from standard quantum mechanics, so that their results can be taken over here. In particular, those of Omnès imply that, in the circumstances this author considers, the classical procedures for predicting future observations will work. For practical purposes it is therefore unobjectionable, in such cases, to make use of the ontological language we are familiar with. In other words, we may then, without qualms, attribute a "sham-ontological" sense to statements - such as "At time t , A has value a " - whose meanings we, up to this point, defined merely operationally. From these statements we may then classically infer statements concerning later times t - such as "At time t A has value a " - and use these statements in the usual way for predicting observations.

7 - CAUSAL PREDICTIVITY AND EFFICIENT CAUSES

The foregoing result goes a long way towards removing what, in the Veiled Reality conception, may be called "the riddle of causal predictivity". This expression refers just to the cause-effect relationships linking some phenomena with one another. As is well known, the existence of such relationships is considered by some upholders of conventional realism as constituting a strong argument in favor of their conception. Their point (see e.g. Ewing [10]) can be summarized as follows. It is universally recognized, they note, that if we can make a great number of predictions from a scientific hypothesis, and the predictions are fulfilled, this is quite a strong argument that the hypothesis, or something like it, is true. Now - they go on - an immense number of predictions are constantly being made on the basis of the hypothesis that physical objects exist quite independently of us and have, as a rule, the properties that are observed: and a proportion of them extremely close to 1 come off. Hence - the realists in question claim - the hypothesis is scientifically confirmed to within an extremely small margin of error. Since this hypothesis is just the one that the Veiled Reality conception rejects, the argument could, *prima facie*, be considered as constituting quite a strong objection to the latter. The foregoing shows however that this is not the case. In the Operational Theory it is definitely not assumed that physical systems exist and have, at any given time, definite properties that are independent of us; but nevertheless, as we saw in the foregoing section, it is a theorem of the theory that - within some specified time and in specified circumstances - all the predictions we make by pretending this to be the case must come out right. Under these conditions, the fact that these numerous predictions do come out right is no indication that the "realist" theory is the better one.

Remark

For the explanatory power of the Operational Theory to be, in the considered field, truly comparable to that of the classical, ontologically interpreted, theory, it is necessary that this theory should be extended to imaginary, or "just possible", situations in the way in which classical theory normally is. Our actions, and even, just simply, our predictions, are not merely based on what we now observe. They also take into account our knowledge that if such and such event took place - or does take place in some future - such and such other event would - or will - follow. Can the Veiled Reality conception account for knowledge of such a kind? The answer is yes, provided only

that the operational definition of Section 2 is (trivially) extended to the future and the counterfactual, say in the form:

Operational Definition(')

If - due for example to some previous measurement - data are - or will be, or were - actually available that make - or, respectively, will, or would, make - it possible, without in any way disturbing a system, to predict with certainty what the outcome would be of a future measurement of an observable pertaining to this system, then it can be said that, on this system, this observable has - or, respectively, will, or would have - the value in question.

Note the word "actually", which differentiates Operational Definition(') from any statement paralleling Reality Criterion 2 or the EPR Reality Criterion. It seems that the range of the thus extended Operational Theory is - in the field of predictions concerning macroscopic systems, collective variables etc. - essentially the same as that of our ontologically interpreted commonsense, supplemented with classical physics.

On the other hand, and still concerning these types of systems, a notion that *prima facie* seems primeval within both commonsense and (to some extent) classical physics, gets blurred in the Veiled Reality conception - and in the Operational Theory in particular. This is the notion of (Aristotelian) past, contingent, ontologically interpreted, efficient causes. We normally explain the existence of U shaped valleys by referring to the Ice Ages glaciers etc. In other words we explain present data by referring to causes whose nature is that of events that did objectively exist, in the strong sense of this word. Clearly, such a notion is incompatible with the Veiled Reality conception, in which no statement bearing on contingent facts can be objective in the strong - ontological - sense. I claim, however, that this does not constitute a deficiency of the theory. The reason is to be found in the well known fact that the very notion of past, efficient cause is by far not so clear as it, *prima facie*, seems to be. Indeed, thanks to the advance of physics and the many critical analyses of the cause-effect relationship that were carried out since Hume's time, we now know that, for the purpose of explaining, the use of the notion of cause is, as a rule, advantageously replaced by the use of that of natural laws. In fact, the only aspect of the cause-effect relationship that does not merge into the more comprehensive notion of basic natural laws is the distinction that - contrary to the latter - the former expresses between future and past: the necessity of taking into account the fact that the past is closed whereas the future is open and that the future has no influence on the past. Now, the Operational Theory does take this distinction most seriously into account, as we saw. It is true that it does away with the "ontological flavor" often attached to the concept of physical laws. But, as pointed out in the foregoing Remark, it has exactly the same predictive power as the latter. Now, clearly, when (as here) any reference to ontology is barred out (or rather is transferred to the notion of "extended causality", see [1]), "to explain" reduces to "to point to means of predicting". It therefore follows that the Operational Theory "explains" the data to the highest degree we may expect from an explicitly nonontological theory.

3 - COMPARISONS

It is now time that we compare with one another some of the theories put forward or mentioned in this article.

1) Comparison with respect to the notions of truth and locality.

As we know, the basic elements of the "consistent histories" theories of Griffiths and Gell-Mann and Hartle as well as of Omnès's "consistent logics" theory are propositions of the type: $P =$ "at time t , A has value a ", where A is a physical quantity; and the projectors that appear in the basic Wigner probability formula for successive observations (a formula the theories in question make an essential use of) can be interpreted as corresponding to such propositions only if some "consistency conditions" are satisfied. Hence, clearly, these consistency conditions are necessary for such a use of the verb "to have" as made in P to be possible. Are these conditions sufficient? This is not obvious for internal consistency does not, by itself, guarantee meaningfulness. We still have to face the question met with in the foregoing sections: "What, after all, is the meaning of that verb - or, equivalently, of "to be"?". Omnès explicitly considered this question and his answer ([6], Chapter 3) was that it is not necessary to define the meaning of these verbs if only we know how to use them when they occur in the statement of a property; and that this indeed is quite simple since the rules for using them are just the rules for using a projector as a mathematical entity. While this approach is interesting and mathematically satisfactory, still it can be objected to, on the ground that it fails justifying any relationship between mathematical algorithms and experience as conveyed by sense data.

Here however, for the sake of the argument, let us follow Omnès in assuming that the consistency conditions are sufficient, and, again, let P be the proposition " A has value a ". The answer to the question: "is P meaningful?" ("does it have a definite, truth or reliability value?") is then totally context-dependent in the sense that it depends on how P happens to be mentally associated with other propositions. If P is an element of a set L of propositions that constitutes a consistent logic (or "histories set"), then "in this logic" P does make sense, and it goes on making sense if L is augmented (say, in the future) by adding other propositions to it, provided that the new, augmented set still be a consistent logic. But P gets meaningless if the additional propositions are so chosen that the augmented set is not a consistent logic. For example, in a two-slit experiment let us consider histories with two times only: the time, t_1 , when the "particle" leaves the source and the one, t_2 , when it gets through the diaphragm. As is well-known, all logics with two times only are consistent. The set of the two histories in which the particle is considered as going through one definite slit and through the other slit respectively is therefore a consistent set, so that the proposition P : "the particle goes through the upper slit" is meaningful. In the language of the theory it describes an "event", that, much as in classical physics, has such and such a probability of occurring. But if we now want to supplement these histories by also considering what happens next to the particle, and if what happens next is that it falls, at time t_3 , on a screen, the thus augmented histories are not consistent any more. Accordingly, Proposition P becomes meaningless. What was an "event" in our first manner of thinking is not one any more when we show this new interest. This particular kind of dependence of the meaningfulness of a proposition on its context is new and worrying. It shows that the use that is made of the word "event" in the theory is not the commonly accepted one and is, in this sens misleading.

But the problem concerning truth proper is even more disconcerting. We normally consider that whether a proposition P concerning the physical world is true or not does not depend on us, viz, on how we choose to mentally associate P with other propositions. However, as already noted, in Omnès's theory this condition could only be fulfilled by introducing, as this author did, an additional requirement which, when all is said and done, essentially limits the class of true (or false) propositions to those bearing on "actual facts". In theory A the same requirement was adopted concerning the class of the propositions to which a definite E-truth value can be ascribed and the same limitation ensued.

In the Operational Theory, the situation is altogether different. This theory does not refer to the notion of consistent logics. Correlatively, in it the answer to the question "is P meaningful?" (where P is defined as above) is not "context-dependent": it depends in no way on what other propositions we care to mentally associate with P (in, e.g. the case that the projector corresponding to P commutes with the Hamiltonian, what this answer depends on is merely the fact that the validity of P has, or has not, been established, at some previous time, through a measurement). Hence the above explained conceptual difficulty simply is not there. In the Operational Theory, therefore, the class of the E-true propositions is not as severely limited as it is in Theory A: Along with propositions bearing on "actual facts" (e.g. on pointer positions subsequent to measurements: these are the propositions we called SE-true in Section 4) it may also contain propositions (called EE-true in Section 4) concerning quantum systems and bearing on the values at a time t of properties of these systems measured at a time t_0 finitely anterior to t .

A simple illustration of this difference is obtained by considering a spin $1/2$ particle P whose S_x and S_z spin components are measured at times t_0 and t_1 respectively, with outcomes $+1/2$, say, in both cases. Within the time interval (t_0, t_1) , proposition " $S_x = +1/2$ " can, according to Theory A, be E-true only at a time infinitely close to t_0 . At any other time t' it is merely "E-reliable", for we could always insert, at times between t_0 and t' , propositions that would make the thus augmented logic inconsistent (a parallel remark holds as well, of course, concerning t_1 and proposition " $S_z = +1/2$ "). In contrast, according to the Operational Theory proposition " $S_x = +1/2$ " is true within the whole open interval (t_0, t_1) (and proposition " $S_z = +1/2$ " is not). Note that, as pointed out at the end of Section 2, the fact we have chosen one definite direction of time for defining the meaning of the verb "to have" is essential here. With the reservation explained there (backward causality is counterintuitive) we could also have chosen the alternative possibility, and then it would be the proposition " $S_z = +1/2$ " that would be true within (t_0, t_1) . But obviously we can not use both definitions together. If we did we should encounter the same objection as was expressed [11] against the first version of Griffiths's theory, namely that, at a time such as t' , both propositions " $S_x = +1/2$ " and " $S_z = +1/2$ " would be E-true, which is incompatible with the fact that S_x and S_z do not commute.

2) Comparison with respect to the notion of Reality.

As noted in Section 3, the consistent histories theories are, in a way, considerably more ambitious than the Empirical Reality theories since their authors do not distinguish between Mind-Independent Reality and Empirical Reality: At first sight they therefore give the impression that their aim is to describe "reality as it really is." In ref.[12], for example, Gell-Mann stated that in an EPR experiment with two photons in which the polarization of one of them is measured the polarization of the other one "is specified", and claimed that this is

quite similar to the classical case of "Bertlmann's socks" (See Bell [13]). However, in the socks case it is meaningful and true to assert that the color of the unseen one would be definite also if the one that is in sight had not been observed. In the Gell-Mann and Hartle theory the corresponding statement concerning the unmeasured photon polarization is either meaningless or untrue, so that, contrary to Gell-Mann's claim, his theory definitely parts with conventional realism.

A more thorough approach to the question of reality is Omnès's [6]. This author identified the idea with that of "actual facts", a notion he defined only implicitly, by referring to "the actual facts of experimental physics", which can "be described in terms of classical concepts, registered, later remembered or recovered from a record". Now, some reflexion shows that following him along these lines soon sets one on the horns of a dilemma. Either the identification in question is taken as a full-fledged definition (of facts, and therefore of reality) or it is just a criterion, by means of which we are supposed to recognize real facts and discriminate them from mere appearances. If we consider we have to do with a genuine definition, this implies that the data we register etc. are the very constituents of reality, that is, that there is no reality apart from what we register (idealism). If, on the other hand, we consider we have to do with a mere criterion, we must immediately grant that it must be an incomplete one: why should everything that exists be classically describable etc.? Can it be that particles, quantum fields etc. partake of no reality? Clearly, if the program is to make physics a description of some reality underlying mere appearances and if the criterion for real facts considered here is an exhaustive criterion of reality, the program in question is simply not fulfilled concerning quantum physics. The only sword capable of cutting this Gordian knot without falling into idealism (Einstein would have said: "solipsism") is, I believe, the following one. We must come back to the idea that "actual facts" define 'a' Reality, but we must say that this is just Empirical Reality, the set of the phenomena, not (whatever this means) "what exists", Mind-Independent Reality. Clearly, if such a solution is taken up, then Theory A is essentially an interpretation - in fact the correct interpretation - of Omnès's theory, with the SE-true propositions corresponding to "actual facts" and the EE-true propositions to Omnès's "merely reliable" propositions.

Another conceivable way - intermediate between ontological and radically empirical objectives - of making some connection between the formalism and the subject matter of physics was however also explored - implicitly at least - by the consistent histories theorists. It consists in considering that physics is merely interested in the structure of our human experience, but that it should aim not only at describing but also at explaining it; and particularly that it should account for the fact that this experience is describable, and presumably will continue to be describable, in quasiclassical terms. It is worth noticing, of course, that, if this really is the purpose - and the sole purpose - of physics, then, again, physics boils down to an explanation of just Empirical Reality. It turns out however that requesting quantum physics to provide such an explanation may still be demanding too much. Indeed - setting here the "reality" question apart - Omnès expected his theory to fulfill this very program. But Dowker and Kent [14] argued that, in fact, such an explanation of past and future quasiclassicality of observation does not follow from Omnès's theory and his definition of the word "true". For a detailed description of their objection - which, with suitable changes, they also extend to the other consistent histories theories - the reader is referred to their article. Here, let it simply be observed that as soon as it is explicitly acknowledged that the referent of the theory

is merely Empirical Reality, it becomes natural to replace the still rather ambitious goal of explaining and predicting quasiclassicality of macroscopic experience by the more modest one of showing that the quasiclassicality in question is compatible with the quantum laws: a goal that, indeed, thanks to recent works, seems now to have been attained, as recalled here in Section 6. One point worth noticing in this respect is that the Empirical Reality approach has, as one of its axioms, the idea that we can "see" basic Reality only through some inbuilt "distorting glasses" of ours, which include apprehending instruments classically etc.: So that science does not have to explain quasiclassicality. Technically this means that when we consider what Omnès calls "sensible logics", that is, consistent logics incorporating actual facts, we should not start with sensible logics containing only present actual facts and try to infer the existence of past and future actual facts (which, again, is what he and the consistent historians seem to have a hard time achieving). Rather, we should consider sensible logics incorporating all present, future and past actual facts (all of them being prerequisites for human apprehension) and rest content - to repeat - with having proved their compatibility with the quantum rules. This certainly alleviates the difficulties pointed out by Dowker and Kent, and it even may remove them. When, above, it was mentioned that Theory A is the correct interpretation of Omnès's theory, this statement was implicitly to be understood in the restrictive sense just explained.

Finally, let it be noted that giving up the idea of explaining quasiclassicality seems to also make away with the hope [6] of theoretically explaining the unicity of actual facts, but that, within the Empirical Reality approach this is in no way a defect. Again: this unicity is a prerequisite for human apprehension. Moreover, it does in no way conflict with quantum theory [1] since, in the approach in question, completeness in EPR sense cannot even be defined and the "and-or" problem see [1] does not arise.

9 - OUTLOOK

For reasons explained at length in Ref.[1] I claim it is essential to distinguish between the two notions of Mind-Independent Reality and Empirical Reality, and consider that, while physics may give us some glimpses on the overall general structure of the former, its true domain is the description of the latter. This view was essentially inspired by the fact that, in virtue of the Bell theorems, no tentative description of Mind-Independent Reality compatible with Local Causality can match the experimental data, whereas, in contrast, no explicit violation of local causality ever appears in the usual - or even in the scientific - descriptions of the phenomena. Unquestionably the latter fact strongly favors descriptions of Empirical Reality in which it can consistently be said that Empirical Reality is "separable" or "local". Such is the case concerning Omnès's theory - interpreted as an Empirical Reality theory - provided that, in it, the only propositions viewed as referring to the said Reality are the "true" ones. This is why, in Ref.[1], Theory A was put forward as a possible candidate for describing Empirical Reality. It remains suitable for this purpose. However, the observations reported on in the present paper suggest that the detour through such notions as (abstract) "events" (projectors), consistent logics, contextuality of meaning of propositions etc. constitutes a complication that can be avoided and is therefore unwelcome. It is in this spirit that the Operational Theory is here proposed as an alternative for describing Empirical Reality.

Clearly, the choice between Theory A and the Operational Theory is to some extent a matter of taste. But let it be pointed out that, independently of this choice, there is a lesson to be drawn from the discussion carried out in Section 3, and especially from the fact, stressed, as we saw, by Dowker and Kent, that the available theories do not explain why, in all circumstances, we observe quasiclassicality. If such a basic fact could be explained from first principles this would go a long way towards proving Kant's assertion that we can "see" basic reality only under through some "distorting glasses": which means it would reduce the status of this assertion from that of an axiom to that of a mere theorem, derived from our knowledge of even more fundamental things. In contrast, the fact that such an explanation cannot be given strongly indicates that the assertion in question is to be considered (as Kant himself did) as an irreducible axiom, which shows that the veil covering (Mind-Independent) Reality is really thick.

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