INFLUENCES, HISTORIES AND REALITY

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Abstract

It is stressed that any theory of which it is claimed that it is compatible both with standard realism and with the experimental data is subject to severe constraints. One is that it must either incorporate superluminal influences or negate the free will of the experimentalist. The other one is that, in it, it is only at the price of accepting "backward causality" that a measurement can be interpreted as revealing the value the measured quantity had, just before, rather than just after, the measurement took place.

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1 - Introduction

Roughly speaking, there seems to be two ways of understanding physics (there may be more than two, of course), but for shortness sake let us focus on the extremes. One consists in interpreting it - along the lines of standard, or conventional, realism - as directed toward lifting the veil of the appearances and describing reality "as it really is". The other one is to see it merely as synthesizing human experience in the field. Within the first approach the word "reality" is, of course, understood as meaning mind-independent reality. Within the second one it means the set of phenomena, in the philosophical sense of the word, that is, what has been called "empirical reality". Both points of view are tenable. But they are mutually incompatible, so that we should be careful of not inadvertently switching from one of them to the other one in the course of our reasoning.

As long as what is aimed at is a conception of quantum mechanics that should make it instrumental and as free as possible from interpretational riddles the second approach is, of course, the most economical. But the first one is more in line with a tradition in the physical sciences that goes back at least to Galileo and that may be called "standard realism". Standard realism is not aimed at "ontological" knowledge. Galileo strongly criticized the view of many philosophers that basic notions such as those of substance, cause etc. should be totally cleared up before we could efficiently start up with quantitative physics, but it definitely considers physical objects and their attributes their dynamical properties, we would say, as being elements of a mind-independent reality. In view of what follows, let us note one of its distinctive feature, which is that, in it, counterfactual statements are considered as possessing a truth value. In a case, for instance, in which there is a table in the next room, the statement "if I raised my hand there would be a table in the next room" is, in standard realism, considered as meaningful; and, at least when the assumption is made that no influence can travel from this room to the next one, it is, even, considered true.

Be it in virtue of tradition or because of a widespread view that alternative standpoints are absurd, the fact is that standard realism has met within the last decades with renewed favor, even among theoretical physicists, so that theories have been, and still are, developed, aimed at rendering quantum mechanics compatible with it. As is well known, this is no easy endeavour and it is interesting to inquire how and to what extent some notions that naturally fit into it, such as the one of possessed values and the related ones of causality and influences, can be accommodated within the quantum mechanical rules.

Only very partial aspects of this program are taken up here. Section 2 concerns problems related to the notion of influence and Section 3 deals with the question of possessed values and causality.

2 - On superluminal influences

(i) A criterion for superluminal influences.

As is well known, the problem of formally defining in a strict and general way the twin notions of "cause" and "influences" is
fraught with considerable difficulties when it is requested - as it
must be - that the definitions should capture our intuitive idea of
what a cause and an influence is and is not. However, when the
question is just to specify, within standard realism, a sufficient
condition for the statement "in such and such instances superluminal
influences take place" to hold good, the objective is more reachable:
It suffices to identify this condition with a violation of Local
Causality as initially defined by John Bell [1]. Let R₁ and R₂ be any
two spatially separated space-time regions. Local Causality stipulates
that when all the elements of physical reality in the overlap R' of
the backward lightcones in R₁ and R₂ are specified the probabilities
of events taking place in R₁ remain unaltered by specification of what
takes place in R₂.}

In their recent outlines the reasons why this condition is
appropriate are known, but a more precise account of them may be
worthwhile. Firstly, let B A, X be the conditional probability of an
event B occurring if some other events A, X occur here X stands for
some set of events other than A. Even without having a precise
definition of the word influence, we all consider such a definition
should somehow imply that whenever the function B A, X effectively
depends on A this reveals that some influence is exerted, either
directly between A and B, or from some set of prior events C
separately on A and B. In the second case we moreover consider that
the (only) reason why the function B A, X depends on A - if it does -
is that it depends on those C's and these C's influence A. The latter
view implies that no effective functional dependence of (B A, X) on A
is possible when this probability is defined subject to the condition
that the variables specifying the C's are all kept at fixed, given
values; otherwise said, when the set of events X incorporates all
events C. Secondly - and, again, whatever the precise definition of
influences may be - the notion that influences travel with a velocity
not exceeding that of light implies that, if A is in R₁ and B in R₂,
(i) A and B cannot directly influence each other and (ii) for
influencing both A and B the events C should lie within the overlap R'
of the backward lightcones of A and B. Let now B A, C, Y be the
probability of B given A and all the elements of physical reality in
R' (plus, possibly, other data, represented by symbol Y). (B A, C, Y)
considered as a function of A, is one particular instance of the
functions (B A, X) of A considered above. But it is a function of A in
which, by definition, the parameters specifying the C's all have given
values. From what we just noted we must therefore infer that it does
not effectively depend on A, that is, that Local Causality (as stated
above) holds good. It follows of course that any directly or
indirectly established specific dependence of (B A, C, Y) on A implies
the existence of superluminal influences, Q.E.D.

(ii) Consequences

The criterion in question has important bearings concerning all
the theories consistent with the philosophy of standard realism. Any
"realist" theory in this sense must have an answer to the question
"what is real?", concerning the systems it considers. The answer may
be: "the wave function" or "the density matrix" or "the events in the
theory" or "the set of the hidden variables" or whatever. The
requisite just is that the answer be definite, the thus designated
entities being then considered as elements of mind-independent reality
(not just as "human representations" of it). Moreover, in the theory
measurements and measurement outcomes must be real, in the just
explained sense.
Such theories are those to which Bell’s theorem applies\(^1\). And this theorem amounts to stating that if Local Causality holds good and the experimentalists are free to choose at whim the orientation of their instruments, the Bell inequalities are satisfied. Since these inequalities are violated by the experimental data, it follows that in any theory of which it is claimed that it matches standard realism and in which experimenters are not denied free will, local causality is violated and therefore, according to the foregoing argument, superluminal influences are present.

III: What about “consistent histories” theories?

Initially, the consistent histories theories were conceived of by their authors as being “realist” ones, and as being preferable to the Copenhagen interpretation just because they matched standard realism much better. In the face of argumented criticism see e.g. [2],[3],[4] some of these authors watered down this claim. Some now concede (privately at least) that their theory is merely a human (or “UGSian”) representation of reality, that is, something akin to a theory of empirical reality. This removes any specific difficulty since it has been shown that in a theory of such a type local causality and also, therefore, the foregoing Criterion cannot even be stated. But other such authors, particularly in popular books and articles, maintain that their theory does away with the necessity of basically referring quantum physics to human operations such as measurements. Indeed some claim that it is essentially as realistically interpretable as classical physics. And at the same time, they claim it involves no superluminal influences. To quote a specific example, in his book The Quark and the Jaguar [5], Murray Gell-Mann considered, within his theory, the case of a standard EPR-Bohm experiment performed on a photon pair, noted that in a history in which the polarization of one photon is measured the polarization of the other one is specified and claimed both that this case is similar to the one of classical correlation effects he referred to Bell’s “Bertlmann socks” example [6], and that in it no superluminal influence takes place.

In fact, both claims are flawed. While the meaning of the word “similar” is, of course, vague and subject to appreciation, still it is inappropriate to apply it in this example since any similarity with classical physics vanishes as soon as a - totally legitimate - question is asked, namely: what would take place if, instead of the actually measured polarization another one were measured. This is because, in the considered theory, the “history” being different, the direction along which the second photon has a sharp value would be different as well, whereas, in a classical, local theory of a similar experiment (performed on a correlated pair of objects such as, say, oppositely oriented darts: the real, factual situation of the second object would, of course, be totally independent of whatever happens to the first one, and in particular of whether or not a measurement is performed on it). Since the possibility of considering counterfactual situations (such as the one envisioned here) is an essential element of standard realism as we saw, Gell-Mann’s first claim is misleading. As for his second claim it is misleading as well since it is obviously incompatible with the foregoing criterion and the violation of the Bell inequalities. Indeed it could be substantiated only by attributing to the word “influence” a meaning differing from the one explained above and that would basically refer to the well-known fact that the superluminal influences that have to do with the Bell theorem do not carry information. Within a purely operational approach to

\(^1\)It is therefore a serious error (one, unfortunately, often made, see e.g.[5], Chapter 12) to hold that Bell’s theorem applies exclusively to the restricted class of (mostly deterministic) theories known by the name “hidden variables theories”.
physics it could consistently be claimed that therefore, by
definition, such superluminal influences do not exist; and it may
benevolently be surmised that this is the definition Bell-Mann
actually had in mind. But even this idea not, when all is said and
done, makes his position consistent since it amounts to switching to a
purely operationalistic standpoint incompatible, as we noted, with his
own claim to the effect that his theory is no more anthropomorphic
than classical physics.

3 - Possessed values, time reversal and causality

By definition an ideal measurement is a measurement of such a
type that, if it is performed twice on the same system within an
infinite short time interval, the two outcomes coincide. When an
ideal measurement - call it M - has been performed of some observable
A, with outcome a, it is known that if another ideal measurement,
M', of A were made immediately after M its outcome would be a, and
from this counterfactual remark ("counterfactual" since the "other"
measurement is conceived of as not being actually performed: it is
commonly and quite naturally inferred that immediately after an ideal
measurement the measured observable has the value the measurement
indicates (see e.g. [4], Chapter 3). While such an inference sounds
natural, its parallel but "time-reversed" one, based on imagining the
"other" (counterfactual) measurement, M', to be performed just before
M, is so artificial that it is normally viewed as not being valid.

Instinctively (and correctly) we argue that measurement M is performed
with the help of an instrument of some kind, that, even if M is ideal,
the interaction between the measured system and this instrument may
well have rendered 'sharp with respect to a' a statement that was unsharp
before (more precisely: it may have changed the initial state,
whatever it was, into an eigenket of A corresponding to eigenvalue a),
and that there is therefore no ground for considering that, before M,
A had value a. The question here addressed is whether or not some
alternative standpoint may be consistently adopted concerning this. In
fact, in some of the consistent histories theories [7][8] it is stated
that a measurement reveal what the value of the measured quantity was,
just before the measurement took place, or, equivalently, the state in
which the system then was. In classical physics this idea implies no
conflict with causality and is indeed a feature of any good
measurement; so that the prospect of recovering it within a quantum
formalism may sound attractive and natural. Let us therefore inquire
on what it implies within standard quantum mechanics.

Something makes this question a little bit subtle and intricate.
It is the fact, clearly shown by Aharonov, Bergman and Lebowitz [9],
that a completely "time-symmetrical" quantum mechanics - a theory in
which past and future have symmetrical roles - can be constructed, but
does not apply to the problems we normally have to deal with. Here, we
are not interested in such a theory since what we want to investigate
is the set of the various possibilities of interpreting the actual
theoretical formalism: the one that works. Our purpose is therefore to
preserve the validity of the standard rules of quantum mechanics.

With this goal in mind let us consider the simple situation in
which two noncommuting observables A and B both commuting with the
system Hamiltonian and with nondegenerate spectra:

\[ A \Phi_n = a_n \Phi_n \]  \hspace{1cm} (1)

\[ B |\kappa\rangle = b_\kappa |\kappa\rangle \]  \hspace{1cm} (2)

2This section complements and partly modifies Appendix 3 of Ref. [2].
are successively measured, at times $t_1$ and $t_2$ respectively and by means of ideal measurements, on an ensemble $E_1$ of systems $S$. Let us provisionally assume $E$ may be considered initially as a pure case, described by the ket $\phi_n$, and let $q$ be an observable such that

\[ q \phi_1 = \phi_1 \phi_1 \]

The tentative interpretation of the quantum mechanical predictive rules that we consider in this section is based on the following two assumptions:

Assumption a. Just before the $A$ measurement every $S$ had a well defined $A$ value, namely the of the $a_n$ and was therefore in the corresponding state $\phi_n$ hence we may consider that the measurement reveals to us in what state the system was.

Assumption b. The probability that, at time $t_1$, a system having $A = a_n$ goes over into state $\chi_k$ is

\[ P_{n,k} = \langle \chi_k | \phi_n \rangle \]

Contrary to expectation, these assumptions are tenable ones provided that suitable conventions are made.

Convention 1 - In this alternative interpretation, counterfactuality in the usual sense must be given up. As stressed by Bohr [10] giving it up is obviously necessary for the probability rule (4) to make sense. This is because the $\phi_n$ that appear in (4) are the eigensets of $S$ and the set $\{ \phi_n \}$ therefore depends on the choice of the observable $B$:
However, $S$ is measured at time $t_2$, while $P_{n,k}$ is relative to what takes place at time $t_1$. The proposed interpretation therefore makes sense only if "the future is partly given". In it, it is therefore inconsistent even to imagine that, after $t_1$ we could decide to, at $t_2$, measure something else than $S$ or nothing! As we see, Convention 1 refers, in a sense, to a kind of - counterintuitive - backward causality.

Convention 2 (time reversed collapse) - The initial ensemble $E_1$ is a mixture in proportions $P_{n,i} = \langle \phi_n | \psi_i \rangle^2$ of states $\phi_n$. With convention 1 made, convention 2 is consistent. The objection one uses to address to such a description of $E$ is that, observationally, a mixture in the strict sense is not equivalent to a pure case since if, at time $t_1$, instead of measuring $A$, we measured $Q$ we should, according to the description under scrutiny, get outcome $q_i$ with a probability \[ \Sigma_n |\langle \phi_n | \psi_i \rangle|^2 \langle \psi_i | \phi_n \rangle^2 \] whereas, obviously, the correct value of the said probability is 1. But as soon as convention 1 has been made, such an argument cannot be formulated consistently, for the reason that, in contradiction with convention 1, it assumes we are at liberty, when discussing the status of the ensemble before $t_1$, to imagine that the measurement of $A$ at $t_1$ could be replaced by something else. For this reason, the set of conventions 1 and 2 are consistent.

Moreover, it can also be shown that these interpretative conventions are compatible with the standard formula expressing the probability $W_{n,k}$ of getting outcomes $a_n$ and $b_k$ upon successive measurements of $A$ and $B$ performed on $E_1$. This well known formula is:

\[ W_{n,k} = \text{Tr}[P_{k} B_{n} A_{n} P_{n}] \]

\[ = \text{Tr}[\langle \chi_k | \phi_n \rangle \langle \phi_n | \psi_1 \rangle \langle \psi_1 | \phi_n \rangle \langle \phi_n | \chi_k \rangle] \]
and the compatibility just mentioned consists in the fact that Eq. (5) may be derived from the conventions in question. Explicitly, the argument goes as follows:

"Account being taken of the existence, at time \( t_0 \), of the measuring instrument that will serve for measuring \( \mathcal{A} \), ensemble \( \mathcal{B} \), according to Convention 2, may, conventionally, at the initial time \( t_0 \) be identified with a mixture in proportions \( p_{0\mu} \) of systems \( \mathcal{S} \) in states \( \phi_{\mu} \); so that by yielding outcome \( a_\mu \), the measurement of \( \mathcal{A} \) performed at \( t_0 \) on one particular system \( \mathcal{S} \) reveals, in fact, the state in which \( \mathcal{S} \) was. Similarly, after \( t_0 \), each one of the subensembles described by a given \( \phi_{\mu} \) must, because of the existence, at time \( t_0 \), of the measuring instrument that will serve for measuring \( \mathcal{B} \), be considered as being a mixture in proportions \( \langle \psi | \phi_{\mu} \rangle^2 \) of systems in states \( \psi \rangle \). On all of these, the measurement of \( \mathcal{B} \) yields \( b_k \), thus revealing the state in question. Formula (6) follows."

To sum up, within standard quantum mechanics (no "hidden variables") the assumption that quantum mechanical measurements reveal the initial rather than the final value of the measured quantity may be rendered consistent, but, it seems, only at the price of giving up two most intuitive ideas. One is that we have some free choice concerning the future and giving it up implies a kind of - most counterintuitive - backward causality. The other one is that the thus revealed values were preexisting and independently possessed by the system. Indeed, the existence at time \( t_0 \) of a B measuring instrument is here not just merely a circumstance making it possible to know what the value of \( B \) was, on a given \( \mathcal{S} \), just before. It determines the set of the possible \( B \) values and same, of course, with \( A \) and the set of the \( a_\mu \)'s. So that the above mentioned analogy with the classical case is much more apparent than real.

Remark 1

The model is not just a time reversed copy of the standard quantum mechanical rules, in which predictive rules would be replaced by retrodictive ones. Here there are no probabilistic formulas for retrodiction and there is one for prediction.

Remark 2

For "pedagogical" reasons, and in order to keep as close as possible to the standard quantum formalism, a quantum mechanical description, by means of \( |\psi\rangle \), of the initial ensemble \( \mathcal{B} \) was provisionally postulated. However, it should be observed that contrary to the said standard formulation, this one does not allow for any operational definition of such a \( |\psi\rangle \), which therefore is but a redundant algorithm. In the final description of the scheme only the \( P_{\mu\nu} \)'s should therefore appear. It is easily seen that this preserves consistency.

4 - Outlook

Scientists legitimately consider that only objective knowledge is genuine knowledge but, in our times, many fail to realize that the notion objectivity has a wider scope than strong objectivity, that is, the requirements of the philosophical standpoint here called, for
In prevision of the standard realism. Consequently, during the last decades many attempts were made at reformulating quantum mechanics so as to make it compatible with standard realism. Unfortunately, it seems that in a quite a number of these attempts a very basic feature of any kind of realism and in particular, of standard realism, namely counterfactual. was not sufficiently taken into account.

Admittedly, realism is not a necessary ingredient in any theory satisfactorily accounting for the usefulness and success of counterfactual reasoning within both commonsense and scientific practice, see e.g., for an example illustrating this point. But the converse holds. Counterfactual reasoning is a necessary feature of realism. When we claim that some of the contingent relations in our theory are elements of a mind-independent reality, we must take into account that, unobservably to conceive, we need consider judgements concerning what would be the case if the actual, contingent states of affairs were, in some definite respects, different.

What has been shown here is that this necessity constitutes one facet of the obstacles that hinder all attempts at reformulating quantum mechanics so as to make it genuinely, realistically, interpretable as a classical mechanics. In the case of the consistent histories theories this is inevitable, as it appears from the discrepancy, closely related to the more general Bell’s theorem. Admittedly, it may be removed, but within standard realism only at the price of acknowledging the existence of superluminal influences carrying no information. In standard quantum mechanics the necessity of considering counterfactual situations also leads to mismatches with the realistic interpretation, and what we saw here is that, in particular, counterfactual considerations concerning the future turn out to play with the idea that a measurement of a physical quantity reveals the value the quantity had just before.

These results may reasonably be viewed as incorporating the idea that physical theories should not be impacted the precommitment role of yielding a faithful description of the contingent features of mind-independent reality and that their domain of efficiency essentially is the detailed description of just empirical reality.

REFERENCES

6. J.S. Bell, Ref. 1, Chapter 14.