Contextual objectivity and quantum holism.

Philippe Grangier

Laboratoire Charles Fabry de l’Institut d’Optique, F-91403 Orsay, France

I. INTRODUCTION

In our effort to restate a “realistic” approach to quantum mechanics, that would fully acknowledge that local realism is untenable, we add a few more questions and answers to the list presented in quant-ph/0203131. We also suggest to replace the very misleading wording “quantum non-locality” by “quantum holism”, that conveys a much better intuitive idea of the physical content of entanglement.

II. MORE QUESTIONS (AND ANSWERS)

Q: What about the following statement, taken from [4]: “If you believe that the quantum state is rigidly (or even loosely) connected to reality, then you will never find a way out of the conundrum of “unreasonableness” associated with state-vector collapse at a distance. I.e., our community will always be left with a search for the mechanism that makes it go. Our community will always be left with the embarrassing questions to do with its clash with Lorentz invariance. And, maybe most importantly, we will be left with the nagging question of why we can’t harness this mechanism for more useful purposes.”

A: If we simply admit that there is nothing like hidden variables, then Bell’s inequalities (BI) can be violated without invoking anything like an action at a distance, because without the “λ’s” the standard demonstration of these inequalities does not hold. Then in a classical view there should be no correlations either, but this only proves that classical theory does not work.

The apparent “action at a distance” only results from the effort of attributing a - non-existent - “reality” to the state of a sub-part of a system. The conclusion taken in the quotation above is that “one cannot connect the quantum state to reality”. But this is not correct : the correct conclusion is that a subpart of the system has no quantum state, while the overall system (the pair) certainly has one, because it has a full set of properties that can be predicted with certainty. To state it again:

- let us admit that there is a “reality” attached to the pair of particles, but that there is no “reality” attached to each particle (here “reality” simply means a quantum state according to our definition).

- the “reality” attached to the pair makes no problem with Lorentz invariance, because it was created when the two particles interacted, and it simply follows them if they move very far away. The same conclusion apply to more fancy schemes like entanglement swapping, that requires classical communications to effectively prepare the remote entangled state.

- since there is no “reality” attached to each particle, Bell’s inequalities do not hold! All the job is done by the fact that the individual particles have no quantum state, or no other property whatsoever that would decide on the result of the measurement. Then “action at a distance” simply vanishes: if a measurement if performed on one side, absolutely nothing happens on the other side.

As far as “action at a distance” is concerned, the situation is just the same as in the classical example where I mail a red and a white paper in two envelopes, one to New Jersey and the other one to Australia : if everybody trust my “state preparation” (many witnesses can swear that it is “real”), the guy in Bell Labs will know immediately the colour of the other paper when opening his envelope. The shocking question is : but “what” carries the correlation if the “papers” have no “colour”, as it is the case in QM ? The answer is : the correlation is carried by the quantum state of the pair, that is real and that propagates causally. All the trouble here comes from the desperate attempt to map this quantum evidence on a classical picture, that is out of the game.

1 The set of quantities is complete in the sense that the value of any other quantity which satisfies the same criteria is a function of the set values, see [1] for details.
Actually, what I am saying is old hat : there is a well known quotation by Einstein (in approximate form) 
“there is no doubt that the physicists who adhere to QM
will react in the following way : they will give up the require-
ment of the separate existence of physical reality in
different parts of space; they will be right to say that QM
makes no explicit use of this requirement”. Then
Einstein wrote that this was unacceptable to him, and
maybe this is still so difficult to accept because it was
said many time that the price to pay is giving up physi-
cal reality. But this is wrong : in our point of view local
realism was an inheritance from classical physics, that can
be abandoned without giving up neither locality (in the
sense of relativistic causality), nor realism (in the sense
of the existence of an objective physical reality). We can
thus admit now that local realism is dead, but that phys-
cical realism can do quite well without it.

What next ? QM is a fantastic theory, and it seems
relevant to ask: why is it working so well ? Actually, QM
was invented 75 years ago in a somehow anarchic way, as
an attempt to understand atomic spectra. We may thus
speculate the following: QM is actually the answer to a
question that was never clearly formulated. We have the
answer, what about finding the question ?

Q: What about nonlocality without entanglement [5]?
A: In [5] the authors present a set of orthogonal prod-
uct states of two three-states particles, that cannot be
reliably distinguished by a pair of separate observers who
are given one particle each, and who are ignorant of which
of the states has been presented to them (the separate
observers are allowed any sequence of local operations
and classical communications). This was termed “quan-
tum nonlocality without entanglement” in [5], and “EPR
paradox without entanglement” in [6]. This latter paper
states that “negation of local realism is roughly called
non-locality”, and that “informational local realism” is
the concept that is at stake in this example.

First we don’t fully agree with the statement “neg-
tion of local realism is roughly called non-locality”. As
said above, the negation of local realism is that it is not
possible to define objectively the quantum state of a sub-
part of a quantum system; there is no need, and it may
even be misleading, to call this non-locality. We fully ac-
knowledge however that the most straightforward way to
demonstrate that local realism is contradictory with QM
is by using Bell’s inequalities, that use entangled states
(on the quantum side) and locality (on the classical side).
But once it is admitted that QM has nothing to do with
local realism, there is no reason to restrict this property to
entangled states. The situation considered in [5] gives
a striking example that the joint state of a quantum sys-
tem can be given more “reality” (i.e. more predictability
and reproducibility) than the “states” of its parts. The
state of the joint system can indeed be determined with
certainty by performing a joint measurement (in the ap-
propriate measurement basis), while separate measure-
ments done on the parts cannot provide an equivalent
result, whatever is done on both sides.

Q: Can contextual objectivity say anything about the
quantum state of the universe in a cosmological sense?
A: Quantum cosmology is a subject that is far beyond my
area of knowledge. However, here is an example of
statement (taken from [7]), that enters in contradiction
with contextual objectivity: “The first important ques-
tion is this: is the universe a complete quantum system
or not ? By complete we mean that there are no external
observers or classical agencies not subject to the laws
of quantum mechanics. The observation of Bell-type corre-
lations and violations of Bell-type inequalities together
with a vast amount of empirical evidence for the univer-
sal correctness of quantum principles strongly suggests
that the answer to the first question is yes. This an-
swer excludes from further discussion all paradigms and
models based on any sort of classical hidden variables.
We assume henceforth that the entire universe is a vast,
self-contained quantum automaton”.

In our view, the authors’ conclusion is unwarranted.
Bell’s theorem proves that there are no “classical hidden
variables” to be looked for “below” or “inside” quantum
mechanics (QM). But it does not prove that QM is an
“embedding theory”, i.e., that “the universe a complete
quantum system” in the authors’ sense. There is another
possible conclusion, i.e. to say that the universe has both
classical structure and a quantum sub-structure. But it
may have neither a classical sub-sub-structure (hidden
variables), nor a quantum super-structure (multiverse or
other versions of a fully quantum universe).

This may be shocking in the sense that we as physicists
are strongly tempted to say : “if QM is right, then it
must be universal”. But one has too look carefully at
what “universal” means. It certainly means that every
time one looks at a quantum system, i.e. a system where
quantization plays an important role, then this system
appears to be quantum. But it certainly does not mean
that linear superpositions and so forth are an obvious
feature of our everyday’s environment. It may be possible
to claim that “we cannot see such superpositions, but
even if they have undergone a decoherence process they
must remain around there, because the overall evolution
must be unitary”. Our approach is still different, since we
claim that QM is universal, in the sense that it provides
the only way to relate our classical environment, that is
essentially based upon continuity, and its quantized sub-
structure [2]. In other terms, QM is basically an
interface tool.

We don’t conclude either that a quantum state is
“purely subjective”, or “a state of our mind”, or what-
ever similar. A (pure) quantum state is a fairly objective
status for a quantum system, in particular because there
is no “ignorance” left (a pure state has zero entropy).

So there is clearly some conflict between contextual
objectivity and the more theoretical view that “QM is
either everything or nothing”. I am not able to spell
out whether or not the present approach may have some
implications for cosmology or quantum gravity, but hope-
fully it may interest people competent in these fields.
Q: What about “quantum holism”?
A: For explaining to the layman what is quantum entanglement, you may say either:

(i) when two remote particles are in an entangled state, there is some kind of mysterious influence or instantaneous action-at-a-distance between them, as it is proven by the observed violation of Bell’s inequalities. Though this action-at-a-distance cannot be used for superluminal signalling, it is a clear evidence for quantum non-locality.

or:

(ii) quantum entanglement is the fact that in quantum mechanics it is possible to attribute definite predictable properties to an ensemble of several particles, while it is impossible to do so for each of the particles taken separately. This impossibility contradicts the classical assumption that the state of a given composite system can be defined from the state of its parts.

It should be clear to the reader that in our approach, (i) is misleading and even wrong, while (ii) is perfectly fine, and moreover is in perfect agreement with the mathematical content of the quantum formalism. But for an unknown reason, (i) usually generates a lot of excitement, while (ii) will generate no excitement at all - simply a glance of deep misunderstanding (you may try it, I did).

Therefore I propose to use the words “quantum holism” to convey the idea that (ii) is strange, interesting and very far from classical physics. This wording expresses the ability of the quantum formalism to attribute “more reality” to a composite system than to its parts. Then (ii) can be rewritten as:

(iii) quantum entanglement is the fact that quantum mechanics can attribute fully predictable properties to an ensemble of several particles, in such a way that knowing these properties is contradictory with knowing predictable properties for each of the particles. This “quantum holism” strongly contradicts the classical assumption that the state of a given composite system can always be reconstructed from knowing the states of its parts.

From the experience of anyone who has been reviewer and editor of scientific papers, or simply reader of broad-audience essays about quantum mechanics, the number of irrelevant or even wrong discussions that have been triggered by the wording “quantum non-locality” is simply astonishing. So it may be worthwhile to give a try to “quantum holism”, that has essentially the same content for those who know and use quantum mechanics, but may convey quite different ideas. And it does say what we wish to say: quantum mechanics has no conflict with causality or relativity, but it gives a holistic description of the state of a physical system. Quantum holism is the true “quantum scandal”, that is at the heart of entanglement, EPR paradox, violation of Bell’s inequalities, and decoherence. After 75 years of quantum mechanics it probably deserves some recognition.

Q: Are not you unfair to Chris Fuchs’ position?
A: The sentence from [4] used as the first question of the present paper may be quoted in an inappropriate way indeed: its initial purpose was to illustrate the state of affair before Bell’s theorem, and not to express Chris Fuchs’ personal views on quantum mechanics (thanks to David Mermin for pointing that out).

Nevertheless, if I remember well a discussion about Chris Fuchs’ position [8], the conclusion was that a quantum state is not objective, but that it is not less objective than a classical state. If this is the case, the debate vanishes: my point is not to do philosophy about the ultimate nature of reality, neither to be unfair to Chris Fuchs, but to criticize and if possible to dismiss the often-heard statement that classical physics is the domain of realism and objectivity, while quantum physics would be the domain of fogginess and subjectivity [9].

I do that by claiming that the EPR criterion of reality is (almost) valid in QM, with the caveat that it cannot be applied to all physical quantities simultaneously, but only to a subset of them. Nevertheless, this is strong enough to attribute (contextual) objectivity to a quantum state. The characteristic feature of an entangled state is that “reality” can be attributed only to joint physical properties, and not to individual ones. This is why I think that the usual wording of “quantum non-locality” that is attributed to entanglement is very misleading, and should be replaced by “quantum holism”.

Actually, Bell’s theorem proves that if a “classical” theory (i.e., a theory where all particles have definite physical properties, that may be unknown to us) wants to reproduce QM and be in agreement with the experiments, then it must be non-local (i.e., it must include “instantaneous action at a distance”). But does that imply that QM itself requires anything happening instantaneously at a distance? My answer is definitely no.

It is certainly generally admitted that QM does not allow super-luminal communications. But then it is often said that QM include mysterious “non-local influences”, often by invoking the “instantaneous reduction of the wave packet”. This is nonsense. Bell’s inequalities are violated because the first Bell’s hypothesis fails, i.e., that, in contradistinction with classical physics, QM is able to describe global properties that are not carried by properties of individual particles: this is what I call quantum holism.

But is not quantum holism simply the same thing as “quantum non-locality”? Yes indeed, if “quantum non-locality” is understood correctly, recognizing that it has nothing to do with anything “instantaneous at a distance”. But if the meaning of “quantum non-locality” is unclear to you, quantum holism has the huge advantage that it does not suggest any kind of “instantaneous transmission”, but explicitly refers to the existence of global properties that are not contained in the properties of the subparts. This is in my opinion the correct physical view that is underlying entanglement, EPR paradox, Bell’s inequalities and even decoherence.
An even worse statement is that the only possible way to make QM understandable would be to make it “classical-looking”, either by re-introducing some kind of hidden variables, or by showing that Bell’s theorem is “wrong”.

[1] Philippe Grangier, “Contextual objectivity: a realistic interpretation of quantum mechanics”, European Journal of Physics 23, 331 (2002); see also arXiv:quant-ph/0012122
[2] Philippe Grangier, “Reconstructing the formalism of quantum mechanics in the contextual objectivity point of view.”, arXiv:quant-ph/0111154
[3] Philippe Grangier, “FAQ about the contextual objectivity point of view.”, arXiv:quant-ph/0203131
[4] Christopher A. Fuchs, “Quantum States: What the Hell Are They?”, preprint (see also the last section of this text).
[5] C.H. Bennett et al , Phys. Rev. A 59, 1070 (1999)
[6] R. Horodecki et al , Phys. Rev. A 60, 4144 (1999)
[7] Jon Eakins and George Jaroszkiewicz, “The Quantum Universe”, arXiv:quant-ph/0203020
[8] with Steve van Enk
[9] An even worse statement is that the only possible way to make QM understandable would be to make it “classical-looking”, either by re-introducing some kind of hidden variables, or by showing that Bell’s theorem is “wrong”.