Chapter 13
The Uninvited Guest: 'Local Realism' and the Bell Theorem

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13.1 Introduction

The Western philosophical thought has learnt since its very early days that the idea that there is a world out there – a world whose properties are (at least partially) independent from what we might think of them and even from our very attempts to have access to them – has a peculiar status. Although for some the idea of a world out there is too obviously right in order to waste time to argue in favour of it, whereas for others it is too obviously wrong in order to waste time to try to refute it, most philosophers would agree that a more or less sophisticated array of arguments is needed in order to make realism (or anti-realism, or any variant that lies in the continuum between these two poles) a plausible position. This long and honoured story, however, seems to be forgotten when considered from the standpoint of the foundations of contemporary physics. Surprisingly enough, the world-out-there-idea has recently acquired to the eyes of many physicists and philosophers of physics the status of a pathology, to be recognized as such and to be eradicated as soon as possible. In relatively recent times, some highly respected physicists try not only to convince us with qualitative arguments that the world-out-there-idea cannot easily live with our best theory of the microscopic phenomena (a plausible attempt, although controversial), but also to turn such a *philosophical* stance into an *empirical* hypothesis that can be put to test in advanced physical experiments performed in labs and refuted once and for all.

This experimentally flavoured anti-realism seems to be a recent development in the line of what Abner Shimony used to call *experimental metaphysics*, and the completion of such a project would amount to nothing less than – so the story goes – realizing that the Aristotelian theory of motion fails to correctly explain either the physics on the Earth or that of the Heavenly spheres:

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> So, what is the message of the quantum? I suggest we look at the situation from a new angle. We have learned in the history of physics that it is important not to make distinctions that have no basis — such as the pre-Newtonian distinction between the laws on Earth and those that govern the motion of heavenly bodies. I suggest that in a similar way, the distinction between reality and our knowledge of reality, between reality and information, cannot be made. There is no way to refer to reality without using the information we have about it. Maybe this suggests that reality and information are two sides of the same coin, that they are in a deep sense indistinguishable. If that is true, then what can be said in a given situation must, in some way, define, or at least put serious limitations on what can exist. (Zeilinger 2005, 743)

According to views like this, one of the deepest lessons we learn from quantum mechanics would be that we cannot draw a rigorous distinction anymore between 'reality' and 'our knowledge of reality': this is presented as an irreversible scientific achievement, just like realizing that there is only *one* set of mechanical laws governing both earthly and heavenly bodies.

Attractive as it may seem, this project is far from being well-founded, since it rests essentially on an incorrect interpretation of the Bell theorem (and also of the original Bell's motivation for the theorem). In order to see why, it is useful to list the steps the strategy of the project goes through, starting from the EPR argument itself up to the final conclusions: the list will also provide a roadmap for the present chapter.

No-Realism Strategy

1. The EPR argument shows that quantum mechanics either is incomplete or non-local.
2. Bell proposes to locally 'complete' quantum mechanics by the formulation of a hidden-variable (i.e. 'realistic') local theory.
3. The Bell theorem proves that any local realistic theory is inconsistent with the statistical predictions of quantum mechanics.
4. Since a conjunction (Locality and Realism) if refuted, we are left with the choice of the conjunct to be dropped. But:
5. A new class of theories (non-local realistic theories) is introduced, in which realism is preserved but locality is abandoned (Leggett 2003). Within this class, a new inequality is derived and again shown to be inconsistent with quantum mechanics.
6. The violation of the Leggett inequality is experimentally confirmed.

The final outcome is that we should give up realism altogether, since no theory – be it local or non-local – can preserve it and at the same time be consistent with the statistical predictions of quantum mechanics.

In order to show that the project cannot work – and hence that the issue of realism cannot be decided once and for all on an experimental basis – I will adopt the following counter-strategy. After presenting the background of the no-realism project in Section 13.2, I will emphasize in Section 13.3 that the focus of the original Bell proposal was not on hidden variable theories per se, but rather on a hypothetical local completion of quantum mechanics, whatever form such completion might assume: the Bell theorem – that is – should be interpreted as concerning not local realism, but simply locality. As a consequence, there is no choice to be done between locality and realism, and the violation of the Leggett inequality cannot do the job it is supposed to do, namely the ultimate refutation of realism in the quantum domain. In this perspective, the positive input that Bell himself received from the actual formulation of Bohm's theory should not be overlooked: when this is done, it should be clear why Bell could not be seriously interested to a local hidden variable theory in the sense of the anti-realism project. The Sections 13.2 and 13.3 partially read more like a review, but a much-needed one: in more or less recent years several authors (Ghirardi and Grassi 1994, Maudlin 1996, Norsen 2007, Laudisa 2008, Ghirardi 2009) have shown in detail the extent of such misunderstanding, but these contributions do not seem to have even scratched the wall of faith that surrounds it. In the last section, on the other hand, I would like to suggest a more constructive move. Since on the basis of the arguments recalled in the first sections the idea of an observation-independent world is *not* – and *cannot* be – in itself incompatible with any known physical fact, there might be more interesting ways to deal with it. In this vein, I will refer to the possibility of applying the concept of *en-theorizing* (first introduced by Arthur Fine in the 1980s) to the way in which possibly 'realistic' interpretations of quantum mechanics deal with the idea of an observation-independent world.

13.2 'Local Realism' and Its Background

The whole enterprise of eradicating any visible trace of 'realism' from the quantum domain rests essentially on a specific interpretation of the Bell theorem: according to one of *n* similar statements spread all over the main journals in the areas of the foundations of physics and philosophy of science 'John Bell showed that theories of *local hidden variables*, which don't permit any remote influences, cannot explain certain quantum-physical observations' (Weihs 2007, 723, my emphasis). What is supposed to be the focus of the Bell theorem, jointly with the other (obvious) assumption that quantum-mechanical predictions are to preserved, is summarized in the expression *local realism*. A recent instance (out of a rich selection) is the following:

> Quantum theory predicts correlations between spacelike separated events, which are nonsignaling but cannot be explained within local realism, i.e., within the framework in which all outcomes have preexisting values for any possible measurement before the measurements are made ('realism') and where these values are independent from any action at spacelike separated regions ('locality'). (Pawlowski and Brukner 2009, 030403-2)[1]

[1] Other possible references include Fuchs and Peres (2002), Peres and Terno (2004), Aspelmeyer and Zeilinger (2008).

The claim that the refutation of local realism is essentially what the Bell theorem is about has acquired the status of a commonplace and, like with every commonplace, very few still bother to ask about its truth-value. This is the current situation not only in the areas of the foundations of quantum mechanics but also in quantum computation – where virtually *any* paper mentioning foundational issues takes local realism to be the core of the Bell theorem – and other related areas such as quantum optics, quantum field theory and solid state physics. In a recent paper in the latter area, Ansmann et al. (2009) present the violation of a Bell inequality in solid state physics as a refutation of local realism. With reference to some existing loopholes, designed to escape the conclusions of the Bell theorem, the authors state that

> a variety of experiments have shown violations of the Bell inequality, with one or the other of these loopholes closed. With the caveat that no one experiment has closed both loopholes, it appears that quantum mechanics provides a more accurate description than do *local hidden variable theories* (p. 505, my emphasis).[2]

The 'realistic' part of the local realism condition is often formulated, even recently, as the idea that physical systems are endowed with *pre-existing* properties that turn out to be independent of any measurement. Under the assumption of local realism, therefore, and provided quantum mechanics' predictions are taken for granted, a die-hard view takes the Bell theorem to be a result that does not establish non-locality but rather the impossibility of any objective (i.e. observer-independent in principle) account of the quantum phenomena.[3] According to the paper of Gröblacher et al. (2007), appeared on *Nature*:

> Bell's theorem proves that all hidden-variable theories based on the joint assumption of locality and realism are at variance with the predictions of quantum physics. Locality prohibits any influences between events in space-like separated regions, while realism claims that all measurement outcomes depend on pre-existing properties of objects that are independent of the measurement. The more refined versions of Bell's theorem by Clauser, Horne, Shimony and Holt and by Clauser and Horne start from the assumptions of local realism and result in inequalities for a set of statistical correlations (expectation values), which must be satisfied by all local-realistic hidden variable theories. The inequalities are violated by quantum mechanical predictions. [. . .] So far all experiments motivated by these theorems are in full agreement with quantum predictions [. . .] *Therefore it is reasonable to consider the violation of local realism a well established fact*. (p. 871, my emphasis)

In the first quotation, the expression 'Bell's theorem' without qualification refers to the original 1964 formulation by John S. Bell, in which – as is well known – the ideal experimental setting contemplated the emission of pairs of spin-1/2 particles prepared at the source in the spin singlet state. In this ideal setting the source state of the

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[2] In the literature on the Bell theorem and local realism, it is common to find the expressions 'local hidden variables theories' and 'local realistic theories' treated as synonymous, and this is why the above quotation is relevant for my argument. Clearly, equating such expressions is debatable, but the explanation of why might be the subject of another paper.

[3] An 'objective' account would be an account in which we *can* distinguish 'reality' from 'knowledge of reality', even though such account should indeed be able to describe suitably the very processes by which we gain knowledge of reality. For an instructive sample of quotations on the centrality of 'local realism' see Norsen (2007), pp. 312–314, and Laudisa (2008), pp. 1113–1115.

joint system prescribes a *strict* anticorrelation between the measurement outcomes in the two wings of the experimental setting, whereas the measurement outcomes were supposed to be associated with spacetime regions that are space-like separated (Bell 1964). On the other hand, in the 'more refined versions' of Bell's theorem which the text refers to (see later), the strict anticorrelation requirement is relaxed and this in turn paves the way toward an experimentally feasible test of the Bell inequality (Clauser et al. 1969, Bell 1971, 1981; Clauser and Horne 1974).

To be honest, the vast majority of the (more or less) recent literature that takes local realism to be the target of the Bell theorem is not entirely clear on what a realism assumption is supposed to require. If all seem to agree that, in order for realism to hold, the physical systems under scrutiny must be endowed with *pre-existing* properties, it is far from straightforward whether – and to what extent – such properties (i) depend essentially or not on the measurement interactions to which the systems themselves may be subject, (ii) determine or not all the outcomes of possible measurements that can be performed on the physical systems. The main recent defenders of the anti-realism project, who in my opinion completely misunderstand the meaning of the Bell theorem (for instance, Weihs 2007, Gröblacher et al. 2007, Aspelmeyer and Zeilinger 2008, Brukner and Zeilinger 2009), are quite clear in presupposing (i) in a *strong* sense, namely the pre-existing properties do not depend on the measurement interactions in that they are passively *revealed* by the measurements themselves. Far less clear is what they mean by 'determine'. Curiously enough, an interpretation which is light-years remote from the 'local-realistic' one, namely Bohmian mechanics, assumes not only that physical systems have at least *some* pre-existing properties, but also that such properties – jointly with (suitable properties of) the measurement context – determine the measurement outcomes. Clearly Bohmian mechanics does not collapse into a 'local-realistic' interpretation because it is non-local by construction and takes the properties of the physical system to strongly depend on measurement interactions: but a symptom of how confused is the 'local-realistic' interpretation is just the circumstance that those who endorse it wish to free quantum theory from 'realism' without realizing how close some of their assumptions may be to a thoroughly realistic interpretation! But on the counterexamples provided by Bohmian mechanics in several respects I will return later (cp. end of Section 13.3).

Now, on the basis of these controversies one might embark on the enterprise of wondering what sort of constraints realism is supposed to impose effectively, but there is a shorter route to the understanding of how things stands: to realize that the Bell theorem does not include any 'realism' among its assumptions and that the non-locality established by the theorem holds for *any* theory that preserves quantum-mechanical predictions, be it 'realistic' or 'non-realistic'. In view of the nearly universal – but acritical! – acceptance of the 'local realism-breakdown', it appears then necessary to pinpoint the correct logical structure of the non-locality argument implicit in the Bell theorem: in the sequel I will simply recall the essential steps, since this argument has been presented in detail elsewhere (see for instance Ghirardi and Grassi 1994, Maudlin 1996, Norsen 2007, Laudisa 2008).

13.3 The Failure of 'Local Realism': A False Dilemma

In the EPR setting with strict spin anticorrelation, the very existence of definite properties (call them 'hidden variables', 'pre-existent properties', 'objective properties', 'classical properties' or whatever you like) *is a consequence* of the locality assumption. Since in the EPR setting the distant spin outcomes turn out to be anticorrelated, if we require the theory to be local then it cannot be the case that the anticorrelation is explained by the measurement procedure on one side affecting the outcome at the other, far away side. *Therefore*, the only reasonable explanation of the distant spin outcomes being anticorrelated is that there are definite values for the spins already at the source: due to the logical structure of the argument, the only independent assumption is undoubtedly locality (Laudisa 2008, 1118–1123).

But also in the more general EPR setting with *non*-strict spin anticorrelation, the so-called stochastic hidden-variable theories' framework (originally introduced in Bell 1971 and Clauser and Horne 1974), no independent 'realism' assumption plays any role although, once again, conventional wisdom tries its best to include it in the set of the Bell theorem's conditions. In the stochastic hidden-variable theories' framework (we will refer to the BCH framework, since this was originally introduced in Bell 1971 and Clauser and Horne 1974), a typical EPR joint system S_1+S_2 is prepared at a source, so that a 'completion' parameter λ is associated with the single and joint detection counts. Suppose we denote by **a** and **b** respectively the setting parameters concerning two detectors, located at space-like separation and devised to register the arrival of S_1 and S_2 respectively. The model then is assumed to satisfy the following conditions:

- BCH1. The parameter λ is distributed according to a function ρ(λ) that does *not* depend either on **a** or on **b**.
- BCH2. The parameter λ prescribes single and joint detection *probability*.
- BCH3. *Locality* holds, namely the λ-induced probability for the measurement outcomes for S_1 and S_2 separately is such that (i) the detection probability for S_1 depends only on λ and **a**, (ii) the detection probability for S_2 depends only on λ and **b**, (iii) and the joint detection probability is simply the product of the detection probability for S_1 and the detection probability for S_2.

What Bell is interested to in this context is a joint probability distribution P(A, B | **a**, **b**), where each A and B represent given measurement outcomes and **a** and **b** stand respectively for the above mentioned setting parameters (with the obvious interpretation). No mention of what sort of systems are involved need be made, and once (rather) innocuous conditions on the probabilistic structure are assumed, it is easy to show the derivation of an inequality that turns out to be violated by the corresponding quantum correlations. According to one of the recent anti-realistic claims, however, among the assumptions of the stochastic version of the Bell theorem there is still realism, defined as follows:

> *Realism*. To put it short: results of unperformed measurements have certain, unknown but fixed, values. In Bell wording this is equivalent to the hypothesis of the existence of hidden variables (Žukowski 2005, 569).

But, again, such an assumption need not be required. It is obviously true that in the stochastic framework locality does not imply by itself the existence of definite spin properties, because the stochastic framework does not encompass *strict* anticorrelation. Nevertheless, assuming the existence of such properties is unnecessary: the core of the argument lies simply in stating what preventing any action-at-a-distance amounts to, *whatever the factors determining A and B might be*. A realism-flavoured additional assumption, according to which there are some pre-existing properties in the common past of the relevant events at A and B that enhance the correlation, is simply irrelevant:[4] should such an assumption be adopted, it would be obviously sufficient for the existence of local factors, but it would be such a strong requirement as to make virtually empty the class of 'serious' local theories that might be put to test in a stochastic framework. In other words, it is true that the assumption of pre-existing properties for the two systems at the source might well imply locality, but the assumption that only local operations and influences can contribute to fix the single detection probabilities does *not* require the assumption of pre-existing properties (Laudisa 2008, 1123–1127). Again, Bell himself was concerned to emphasize which were the real assumptions in the argument and how general the stochastic framework was intended to be:

> Despite my insistence that the determinism was *inferred rather than assumed* [N.d.R. a new hint at the frequent misunderstandings of this *inference* in the original EPR and in his 1964 paper], you might still suspect somehow that it is a preoccupation with determinism that creates the problem. Note well that *the following argument makes no mention whatever of determinism* [. . .] Finally you might suspect that the very notion of particle, and particle orbit has somehow led us astray [. . .] So the following argument will not mention particles, nor indeed fields, nor any particular picture of what goes on at the microscopic level. Nor will it involve any use of the words 'quantum mechanical system', which can have an unfortunate effect on the discussion. *The difficulty is not created by any such picture or any such terminology. It is created by the predictions about the correlations in the visible outputs of certain conceivable experimental set-ups*. (Bell 1981), in Bell (2004), (p. 150, my emphasis)

Summing up: if the whole point of the Bell argument (also in the stochastic case) is then in fact to show that the correlations between the results A and B are not locally explicable, no matter what the relation is between A and B on one side and some allegedly 'objective' or 'pre-existing' properties corresponding to them on the other, we can safely say that also in the more general (no strict correlation) case, *there is no 'realism' at stake*.

The 'local-realistic' reading of the Bell theorem and its meaning, however, is still around. In a recent review paper on the Bell inequalities and their relevance to

[4] A similar point, although relative to the derivation of the CHSH inequality in Clauser et al. (1969), has been raised by Norsen (2007), p. 319.

quantum information theory, Brukner and Žukowski (forthcoming) depict the situation in terms of the following experimental framework. At two different stations of a typical EPR-like arrangement, stations that are supposed to be sufficiently far away from each other and that we will call A and B, Alice and Bob are endowed each with a display, on which they observe sequences of +1 and -1 appearing. With respect to a selected reference frame, the numbers appear simultaneously and are caused to appear on Alice's and Bob's displays by the activation of a 'source', located in the middle between the two station. Moreover, the two stations have each two possible 'settings': if we denote with $m = 1, 2$ the possible settings at A, and with $n = 1, 2$ the possible settings at B, a random, local procedure is supposed to take place at each station in order to select a specific setting at each station.

Now, according to Brukner and Žukowski, it is reasonable to account for the above situation by a *local-realistic* model, i.e. a model that satisfies the assumptions of *Realism*, *Locality* and *Free Will*, namely:

Realism

Given the eight variables $A_{m,n},\ B_{n,m}$ with n, m ranging over $\{1,2\}$, the expression

$$A_{m,,n} = \pm 1$$

is meant to indicate that the value at A is $\pm$ 1 provided that the setting at A is m and the setting at B is n. This is equivalent to the assumption that a joint probability distribution

$$\mathrm{P}(A_{1,,1},\ A_{1,,2},\ A_{2,,1},\ A_{2,,2};\ B_{1,1},\ B_{1,2},\ B_{2,1},\ B_{2,2})$$

always exists.

Locality

The appearance of a given value on the display at Alice's (Bob's) station in no way depends on what happened at Bob's (Alice's) station. The expression 'what happened' includes both the selection of a given setting and the appearance of a specific value.

Free Will

The selection of a local setting at a given station (be it A or B) in no way depends on the source.

On the basis of these assumption, Brukner and Žukowski show that a CHSH-type inequality can be easily derived (Brukner and Žukowski forthcoming, eq. (23)).

What does the point seem to be about realism, then? The point seems to be the assumption that realism is equivalent to the *existence* of the joint probability distribution

$$\mathrm{P}(A_{1,,1},\ A_{1,,2},\ A_{2,,1},\ A_{2,,2};\ B_{1,1},\ B_{2,1},\ B_{2,2}).$$

But one thing is to define what realism amounts to, and quite another one to assume that the definition is *actually satisfied*: I can well define what a winged horse is supposed to be, without being able to prove that such a thing exists in the world! As a matter of fact, in the above model the characterization of *Realism* as the existence of a suitable joint probability distribution does not imply *by itself* that such a distribution exists: it is exactly *Locality* that imposes on the form of the distribution the very constraint we need in order to be sure that the desired joint probability distribution actually exists. For let us assume that the theory is local. Then

$$A_{m,n} = A_m \quad \text{and} \quad B_{n,m} = B_n$$

from which

$$\mathrm{P}(A_{1,,1},\ A_{1,,2},\ A_{2,,1},\ A_{2,,2};\ B_{1,1},\ B_{1,2},\ B_{1,2},\ B_{2,2}) = \mathrm{P}(A_1,\ A_2;\ B_1,\ B_2).$$

Due to *Locality*, therefore, we are sure that a joint probability distribution like $\mathrm{P}(A_1,\ A_2;\ B_1,\ B_2)$ certainly exists, since we can always set

$$\mathrm{P}(A_1,\ A_2;\ B_{1,}\ B_2) = \mathrm{P}(A_1)\ \mathrm{P}(A_2)\ \mathrm{P}(B_1)\ \mathrm{P}(B_2),$$

where the distribution $\mathrm{P}(A_1)\,\mathrm{P}(A_2)\,\mathrm{P}(B_1)\,\mathrm{P}(B_2)$ is trivially compatible with the distributions

$$\mathrm{P}(A_1\ \&\ B_1),\quad \mathrm{P}(A_1\ \&\ B_2),\ \mathrm{P}(A_2\ \&\ B_1),\ \mathrm{P}(A_2\ \&\ B_2)$$

as marginals, since $\mathrm{P}(A_n\ \&\ B_m) = \mathrm{P}(A_m)\ \mathrm{P}(B_n)$, with $n,\ m = 1, 2$. Also in this framework, that is, realism is justified by locality which turns out then to be the real culprit.[5]

The point can be further clarified by contrast to the situation in Bohmian mechanics, whose existence and consistency directly refute the claims of Leggett and followers. Such theory satisfies in fact a serious form of realism and nevertheless provides a perfectly consistent account for all phenomena that quantum mechanics is able to treat unambiguously (Goldstein 2001), providing in addition a clear and law-governed ontology of particles evolving in spacetime. How can it be? On

[5] An analogous argument can be formulated about Blaylock (2010), which is a recent review paper on the Bell theorem: for a critical reply to Blaylock along lines similar to the viewpoint advocated here, see Maudlin (2010).

the one hand, the measurement outcomes in Bohmian mechanics are determined by pre-existing, measurement-independent properties of the measured system, namely the precise positions of the particles in the system and, of course, the wavefunction.[6] On the other hand,

> in Bohmian mechanics the random variables Z_E giving the results of experiments E depend, of course, on the experiment, and there is no reason that this should not be the case when the experiments under consideration happen to be associated with the same operator. Thus with any self-adjoint operator A, Bohmian mechanics naturally may associate many different random variables Z_E, one for each different experiment $E \to A$ associated with A. A crucial point here is that the map $E \to A$ is many-to-one (Dürr et al. 2004, 1040).

So, Leggett, Gröblacher and the others fail to appreciate that the consistency of Bohmian mechanics is a direct refutation of their approach since they appear to assume that the preexisting properties that determine the outcome must somehow mathematically resemble the eigenstates of Hermitian operators. But that very specific claim is surely no part of 'realism'. One needs to note that standard quantum theory associates physically different experimental set-ups with the same Hermitian operator ('observable'). But it is no part of 'realism' to demand that physically different set-ups be treated alike: the way that the pre-existent positions determine the outcome of an experiment may of course depend on just how the experiment is set up.

13.4 Ways Out of the (False) Dilemma: Possible Prospects for a Quantum Realism?

What can we conclude from the above arguments then? Although the issue will presumably continue to be controversial, there are several morals to be drawn, some in the form of (provisional) conclusions others in the form of future projects.

First, the above sections hopefully have shown how pointless is the move of 'inflating' into quantum mechanics an a priori notion of 'realism', only to 'discover' that quantum mechanics itself cannot possibly host that notion, something that we know no matter whether QM is local or not! (see again Laudisa 2008, 1122–1123). Hence, the question is open whether realism can still play a conceptual role. The problem is: how should we assess that? Certainly not in the line of questions such as the following:

> Irrespective of the validity of quantum mechanics or not, what can we say *from experiment* about the validity, or not, of the concept of realism as applied to the physical world? (Leggett 2008, 2)

[6] See for instance the discussion of exactly how the pre-existent locations of particle determine the outcomes of 'spin measurements' in Albert (1992).

Asking questions like the following does not seem terribly promising as a way to meaningfully investigate about the plausibility of a realistic interpretation of quantum mechanics (whatever this interpretation might be): for this sort of question assumes implicitly that it is meaningful (to try) to answer without precisely defining the resources of the theoretical framework in which the question can be framed, as if the notion of realism 'as applied to the physical world' could live in a conceptual vacuum and still make sense.

A more fruitful route might profit from a proposal that Arthur Fine put forward several years ago to assess the very nature of the Einsteinian use of such notions as 'realism', 'causality' and 'determinism' (Fine 1986). Fine first quotes a letter of Einstein that reads as follows:

> On this account it can never be said with certainty whether the objective world is 'causal'. Instead one must ask whether a causal theory proves to be better than an acausal one. (Letter to H. Titze, January 16, 1954)

After Fine comments:

> The upshot is to move the entire issue of causality out of the empirical realm, where it would be conceived of as more or less separately and directly subject to empirical test. Instead, one gets at the issue of causality by specifying what counts as a causal theory (namely, one with nonprobabilistic laws), and one replaces questions about whether causality holds in nature by questions about which theory is better. (Fine 1986, 88)

Fine coins the word 'entheorizing' to denote the above move. If we apply this viewpoint to our question, the suggestion is to try to *en-theorize* realism, namely investigate how a *realistic* theory might perform with respect to a *non-realistic* one. If 'realism' (in the sense of the 'local realism' arguments) plays no role, a conflict between a(n even) non-local 'realistic' theory and quantum mechanics might hardly tell against the viability of realism in quantum physics. On the other hand, and in the spirit of en-theorizing notions like realism (and possibly others), we might wonder what sort of general requirements should we ask a *realistic quantum theory* to satisfy (at this level, then, it matters little whether we call such a theory 'realistic', 'causal' or whatever you like). I list what I take to be plausible requirements:

1. *Ontology*: A realistic formulation should clearly and unambiguously posit at the outset a domain of entities which are supposed to be the basic objects of the theory (let us call them *T-entities*).
2. *Observer-independence*: A realistic formulation should not need assume the necessity of *observers* for the basic properties of the T-entities to hold, though being able to *recover* observer-dependent notions and results.
3. *Non-vagueness*: A realistic formulation should make sense at all scales, namely no micro-macro or classical-quantum distinction should play any *fundamental* role in stating the basic principles of the formulation.

Should the 'entheorizing' strategy be taken seriously, no experiment might rule out per se a realistic interpretation of quantum phenomena, an interpretation that – at this point – should be evaluated according to its global conceptual virtues and vices: in this vein, no laboratory alone can help us in the dirty job, that of deciding *theoretically* what we require from a physical theory if the latter is supposed to tell some approximately true story about the world around us.

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