Realism And Empirical Evidence

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Abstract

We define realism using a slightly modified version of the EPR criterion of reality. This version is strong enough to show that relativity is incomplete.

We show that this definition of realism is nonetheless compatible with the general principles of causality and canonical quantum theory as well as with experimental evidence in the (special and general) relativistic domain.

We show that the realistic theories we present here, compared with the standard relativistic theories, have higher empirical content in the strong sense defined by Popper's methodology.

1 Introduction

The violation of Bell's inequality [2] predicted by quantum theory shows an incompatibility between classical realism, causality and relativistic quantum theory. Thus, if we use a strong enough axiom system for realism, we can prove that Einstein causality is false. In the first section we give such a definition of realism, based on a minor modification of the EPR criterion of reality.

Thus, we have a conflict between our definition of realism and relativity. One very popular solution of this conflict is that this definition of realism is too strong and should be weakened. But there is also another possibility: to prefer realism and to accept that relativity is incomplete.

It seems, the preference for the first solution is supported by a lot of very different arguments as well as esthetic preferences, not by objective comparison criteria. In this paper, we apply Popper's scientific methodology [8] to compare above variants. The advantage of this methodology is that we do not have to rely on uncertain notions like simplicity, beauty and so on, but have certain, well-defined criteria: empirical falsification and empirical content.

Thus, at first we establish that our strong notion of realism is not in contradiction with experiment. This is done by the explicit presentation of realistic theories for all important domains.

In the first step we present realistic Galilean invariant theories for the relativistic domain. This is the well-known Lorentz ether theory in the domain of special relativity and a generalization named post-relativistic gravity in the domain of strong gravitational fields.

What remains is the canonical quantization of Galilean invariant theories. But for classical canonical quantum theories we have a realistic hidden variable theory — Bohmian mechanics. Thus, the compatibility of the related quantum theories with realism is not problematic.

Once we have found that realism is compatible with all empirical evidence, to show the advantage of realism in predictive power is simple. For this purpose is seems sufficient to look at the definition of realism we have given and to estimate how often we use these axioms in everyday reasoning. To reject one of the axioms means that all these considerations become invalid.

By comparison between these realistic theories with their relativistic competitors we find also some other places where the realistic theory makes stronger predictions. For example, non-trivial topology of space-time is forbidden, the part behind the horizon of a black hole cannot be reached. These differences in empirical content are not very essential, they are only of theoretical importance. But it is remarkable that they all are in favour of realism. There are no experiments which allow to falsify relativity without falsification of these realistic theories too. Thus, the comparison of empirical content shows a clear advantage of realism.

2 The Definition Of Realism

For the purpose of this paper, we give a definition of realism based on a minor but essential modification of the EPR criterion of reality. We specify that the disturbance of the state mentioned in the EPR criterion should be a real disturbance, thus, also an "element of reality". As a consequence, the EPR criterion allows to prove the existence of some "element of reality" — if not a hidden variable, than a hidden causal disturbance.

The modified criterion is strong enough to falsify Einstein causality and to prove the incompleteness of special relativity based on the violation of Bell's inequality. Note that this is not a non-trivial conclusion, but simply a reformulation of the well-known incompatibility of local realism with the violation of Bell's inequality. The possibility to define realism in such a way is de-facto a tautology — all we have to do is to close all "loopholes" introducing new axioms. Thus, the only interesting point of this section is the natural and simple character of our set of axioms and their agreement with the common sense notion of realism.

2.1 The EPR Criterion Of Reality

First, let's reformulate the well-known EPR criterion of reality. The original formulation is the following [5]:

"If, without in any way disturbing a system, we can predict with certainty ... the value of a physical quantity, than there exists an element of physical reality corresponding to this physical quantity."

The central objection in Bohr's reply was that the EPR reality criterion "contains an ambiguity as regards the meaning of the expression 'without in any way disturbing a system'. Of course, there is ... no question of a mechanical disturbance ... But ... there is essentially the question of an influence on the very conditions which ... constitute an inherent element of the description of any phenomenon to which the term 'physical reality' can be properly attached ..." [4].

Our objection is very close. We also feel some ambiguity in the expression "in any way disturbing a system". We are interested in a description of this disturbance in terms of realism. The simple solution is that this disturbance is also an "element of reality", only of a slightly different type — not an object, but a causal relation.

Thus, we have a measurement A which returns a value, we have a prediction (also a measurement) B which also returns a value. Now, let's introduce the following denotations:

$A \equiv B$ denotes the observable fact of a 100between the values returned by A and B.

$\exists A \to B$ denotes the existence of a real disturbance of the measurement B caused by A — an "element of reality". The phrase "without in any way disturbing a system" we translate as $\nexists(B \to A)$.

$\exists v(A)$ denotes the existence of an object, the "element corresponding to" the observed value. This element is predefined, independent of the choice of measurement A and B, that means, independence axioms of classical probability theory may be applied.

Now note that B is named 'prediction", that means $t_B < t_A$. Applying causality, we can conclude that A cannot disturb B too, thus, $\nexists(A \to B)$ too. After this observation, the reference to time ordering may be omitted.

Last not least, we put the two term $\nexists A \to B$ and $\nexists B \to A$ on the other side. We obtain the following reformulation of the EPR criterion:

$$\textit{If } (A \equiv B) \textit{ then } (\exists(A \to B) \textit{ or } \exists(B \to A) \textit{ or } \exists v(A)).$$

2.2 Completeness Of A Theory

This formulation of the EPR criterion has a simple form: on the left side we have the result of an observation. On the right side we have claims about existence of some objects or relations. We have three different possibilities. Nonetheless, in any case from the observation follows the existence of some "element of reality" — an object or a relation between objects. In other words, the EPR criterion tells that a *realistic explanation* of every observable correlation exists. This suggests a simple and natural criterion of completeness of a realistic theory:

A theory is complete if it gives a realistic explanation for every observable correlation.

The property of being a complete realistic theory has non-trivial empirical content in Popper's sense. Indeed, if the theory does not describe any of the three alternative explanations, the theory predicts no correlation for the related observation. Nonetheless, for a reasonable definition we have to add some axioms about existing objects and relations:

All axioms of classical logic and classical probability theory may be applied to existing objects and relations.

Indeed, without these properties it would not be justified to use the notion "existence" in the common sense of realism.

2.3 Bell's Theorem

With this definition, we have included all properties of the "hidden variables" we need to prove Bell's inequality or one of it's various variants:

If $\exists v(A)$ then Bell's inequality is fulfilled.

We do not consider here the details of this proof and the possibility of loopholes of the existing experimental tests and assume that — as predicted by quantum theory — Bell's inequality is violated in reality even if the observations A and B are space-like separated. Thus, it follows that $\nexists v(A)$. That means, the EPR criterion proves that

$\exists(A \to B)$ *or* $\exists(B \to A)$

Relativity does not describe such causal relations. It follows immediately that Einstein causality is wrong. Thus, if we want to hold causality as a law of nature, we have to reject relativity. Moreover, even if we reject causality, relativity is not a complete realistic theory. This immediately follows from our criterion of completeness and the previous result.

Note that we have not used a theory of causality here — all what we have used from causality is the notion $A \to B$ for a causal relation and the concept that such a causal relation is an element of reality.

3 Compatibility Of Realism With Empirical Evidence

Now, let's show that realism is compatible with all available empirical evidence.

3.1 Lorentz Ether Theory

Once we accept realism and the violation of Bell's inequality and do not believe into closed causal loops, we can de-facto derive Lorentz-Poincare ether theory [7], that means special relativity with a hidden preferred frame - the rest frame of the Lorentz ether.

Indeed, let's assume that for almost all pairs of events A and B we have $\exists(A \to B)$ *or* $\exists(B \to A)$. Moreover, let's assume the elementary properties of causality like transitivity and the absence of closed causal loops.

Now, let's define absolute future and past in the following way: For an arbitrary event B we test the violation of Bell's inequality. After this, we know $\exists(A \to B)$ or $\exists(B \to A)$. Because the closed causal loop $A \to B \to A$ is forbidden, only one of the two can be true. Now, if $A \to B$ then B is in the future of A, and if $B \to A$, then B is in the past of A.

If there are no closed causal loops, Bell's inequality should be fulfilled at least in the degenerated case — contemporaneity. But the uncertainty of time measurement leads to some difference in absolute time. Thus, this degenerated case does not leads to observable effects.

Note that we cannot measure absolute contemporaneity — we have no way to detect what is the correct choice — but, if we accept realism, we have a proof of it's existence. Thus, a complete realistic theory should define the behaviour of these hidden variables.

In the case of special relativity, this choice is simple: we assume that absolute time coincides with coordinate time of some preferred inertial system. We obtain a well-known classical theory — Lorentz ether theory.

3.2 Theory Of Gravity

A generalization of Lorentz ether theory to gravity named post-relativistic gravity has been defined by the author [10], [11], [12]. The theory is a Galilean-invariant ether theory, with an ether described by positive density $\rho(x,t)$, velocity $v^i(x,t)$ and a positive-definite stress tensor $\sigma^{ij}(x,t)$. Interaction with the ether causes an universal time dilation defined by the following Lorentz metric:

$$g^{00}\sqrt{-g} = \rho$$

$$g^{0i}\sqrt{-g} = \rho v^i$$

$$g^{ij}\sqrt{-g} = \rho v^i v^j - \sigma^{ij}$$

The equations of this ether theory are the classical Einstein equations and the harmonic coordinate equation:

$$\partial_i(g^{ij}\sqrt{-g}) = 0$$

which defines the classical conservation laws for the ether. Thus, the ether is no longer stationary, but is influenced by the matter. This solves a conceptual problem of Lorentz ether theory. It also allows to define local energy and momentum densities for the gravitational field, thus, solves a problem of general relativity.

This theory coincides in almost all predictions with general relativity. A solution of post-relativistic gravity defines a solution of general relativity. This solution defines all classical observables of the post-relativistic solution. Thus, in the classical domain the empirical content of general relativity is not greater: An observation which cannot be described by general relativity cannot be described by post-relativistic gravity too.

On the other hand, there are some interesting additional predictions of post-relativistic gravity. Solutions with non-trivial topology are forbidden. Moreover, the notion of completeness is different. There is no reason to assume that the "metric" defined by the ether should be complete. It may be incomplete, and in interesting cases like the collapse into a black hole it is really incomplete as a solution of general relativity: the complete post-relativistic collapse solution does not contain the part behind the horizon — the collapse stops in absolute time immediately before horizon formation.

Thus, the generalization of Lorentz ether theory to gravity is possible, leads to a Galilean invariant ether theory which is in agreement with experiment as well as general relativity. Compared with general relativity it has more empirical content.

This theory is obviously compatible with classical realism and classical causality as well as Lorentz ether theory.

3.3 Canonical Quantum Theory

Because we have found classical realistic Galilean-invariant theories for the relativistic domain too, we only have to consider the quantization of classical Galilean invariant theories. Thus, the canonical quantization scheme may be used.

But in this case, the compatibility with realism is not problematic. To prove this, it is sufficient to remember about the existence of Bohmian mechanics [3]. This is a deterministic hidden variable theory for classical quantum theory. It is obviously compatible with realism.

Thus, realism becomes problematic during quantization not because of compatibility problems with quantum theory, but because incompatibility with relativity.

This remains valid for the case of generalized Hamiltonian systems. Indeed, they are normal Hamilton systems on a subspace, and that we prefer to choose other coordinates is our choice, not a conceptual difference between the theories. That means, this generalization does have any influence on the question we consider here — compatibility with realism.

An infinite number of steps of freedom is of course a technical problem, but also orthogonal to our question. The general problem of ultraviolet infinities in field theories we discuss below for quantum gravity.

3.4 Quantum Gravity

The quantization of post-relativistic gravity does not have the conceptual problems of the quantization of general relativity, like the problem of time [6], topological foam, information loss for black holes, absence of local energy and momentum densities for the gravitational field.

On the other hand, it leads to ultraviolet problems as well as general relativity. From point of view of the ether concept, this can be easily explained with an atomic structure of the ether. But this is not the place to speculate about atomic ether models.

Indeed, we are interested here in compatibility questions. What we want to show is the compatibility of empirical evidence and realism. For this purpose we can use some very easy Galilean-invariant regularization of post-relativistic gravity, for example a simple regular lattice regularization. To quantize this theory, we can apply standard canonical quantization [12]. The resulting theory, beautiful or not, is compatible with empirical evidence. It is also compatible with realism.

4 Discussion

Thus, we have shown the compatibility of realism with all available empirical evidence. We have proven this by the presentation of realistic causal Galilean-invariant theories for all domains up to quantum gravity.

The empirical content of the presented theories is at least equal than the empirical content of their relativistic competitors. We have found some non-trivial additional predictions. Thus, following Popper's theory, we have to prefer realism as the theory with more predictive power.

It can be said that the additional predictions are only of theoretical importance. Indeed, the advantages of post-relativistic gravity become obvious only in the quantum domain, but quantum gravity effects are far away from our experimental possibilities.

But to save relativity we have to weaken our definition of realism. This leads obviously to a very serious and important loss of empirical content: we use all our axioms of realism in everyday reasoning. If we reject on of these axioms, we have to reject any argumentation which uses this axiom too.

There is no necessity to consider the various different possibilities to weaken some of our axioms of realism and causality to show that each of these possibilities leads to less predictive power. We can simply use the fact that Bell's inequality is no longer valid in any of these weaker theories to show that the predictive power of the weaker notion of realism is really a weaker theory in the sense of Popper's criterion of empirical content.

Indeed, if telepathy is possible, this will be in contradiction with realism. Telepathic effects may be observed by establishing correlations which cannot be explained without such telepathic possibilities. But a special case of such a correlation is a correlation which violates Bell's inequality. Thus, if some correlations between claims of two persons in different, isolated rooms show a pattern which violates Bell's inequality, the realistic theory is falsified. But the theory with the weaker notion of realism is not falsified, because Bell's inequality cannot be proven in this theory. This proves that the predictive power of realism is greater.

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