Title: Quantum Mechanics is Not Non-Local

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Abstract: Bell's inequality is often stated as proving that quantum mechanics is non-local (rather than non-realistic, which apparently shows that physicists have more problems with non-realism than with non-locality). I will argue that the purpose of the use of locality in Bell's argument (in the CHSH form) is to make the classical system as close to the quantum system as possible, not to differentiate it from the quantum, and that non-realism is a more reasonable interpretation than is non-locality.

Locality

Quantum mechanics is often called non-local

Bell's theorem

No realistic local theory can mimic quantum mechanics

Many seems to grab onto the “local” and claim that
Bell's theorem says quantum mechanics is non-local

A, B **C, D**

All observables have values +1 or -1

Statistical theory.-- in successive runs of same experiment
Get different values for any measured value.

For some reason cannot measure A,B together, nor C and D together.

Run millions of experiments in which various combinations Are measured. <A>=<B>=<C>=<D>=0
<AC>, <AD>, <BC>, <BD>.

$$\mathcal{G} \equiv < AC > - < AD > + < BC > + < BD >$$

$$\mathcal{G} =< AC - AD + BC + BD >$$

It is in order to write this that local realism is assumed.
The previous correlation functions were a fair sample of
The distribution.
All quantities, A,B,C,D all had values, even if impossible to
Measure, in all trials.
The trials are unbiased by anything.

$$\mathcal{G} =< (A + B)C + (-A + B)D >$$

A+B and B-A have values or +2, 0 or -2
|A+B| and |A-B| are anti correlated (if one is 2, the other is 0)

$$-2 < \mathcal{G} < 2$$

Quantum

$$\mathcal{G} \equiv < AC > - < AD > + < BC > + < BD >$$

$$\mathcal{G} = < AC - AD + BC + BD >$$

This step is automatic. All the manipulations in classical case
To argue this are automatic for quantum case.
Locality and "reality" are not to differentiate classical from
Quantum, but to make the classical as similar to quantum as
Possible.

What makes quantum mechanics different from classical?

$$\mathcal{G} = < (A + B)C > + < (-A + B)D >$$

If A, B are σ_x, σ_y Then $\sigma_x \pm \sigma_y$ Do not have
Have values 2,0,-2. They have $\pm\sqrt{2}$

Also |A+B| and |A-B| are not anti-correlatied. They are completely uncorrelated. But, by appropriate choice of state we can correlate A+B with C and B-A with D .

$$\mathcal{G} = 2\sqrt{2}$$

The difference between Quantum and Classical is at the single particle level.

Bell's thm has nothing to do with locality. And little to do with Reality-- they are used not to differentiate classical from QM, but to make it as similar as possible.

Key diff. Is that value of sum is not sum of values, and corr. of Non commuting attributes.

Legget's non-locality

Non-local Hidden var theory-- Bell like inequal. Violated by QM.

Polarization of photons u,v Stokes vectors

a,b measurement vectors of apparatus – outcome is +1 or -1

λ is parameter which determines outcomes given u,v and a,b.

A(u,v,a,b λ),-- outcome of measurment.

Constraint:

$$\bar{A} = \int A(u, v, a, b, \lambda)\rho(\lambda)d\lambda = u \cdot a$$

Experimental determined outcome

$$\rho_{++} = \int \delta(A-1)\delta(B-1)\rho(\lambda_{uv})d\lambda_{uv}d\lambda_{uv}$$

$$\rho_{+-} = \int \delta(A-1)\delta(B+1)\rho(\lambda_{uv})d\lambda_{uv}d\lambda_{uv}$$

$$\rho_{-+} = \int \delta(A+1)\delta(B-1)\rho(\lambda_{uv})d\lambda_{uv}d\lambda_{uv}$$

$$\rho_{-+} = \int \delta(A+1)\delta(B+1)\rho(\lambda_{uv})d\lambda_{uv}d\lambda_{uv}$$

$$-1 + |\bar{A} + \bar{B}| =$$

$$-(\rho_{++} + \rho_{+-} + \rho_{-+} + \rho_{--}) + |(\rho_{++} + \rho_{+-} - \rho_{-+} - \rho_{--}) + (\rho_{++} + \rho_{-+} - \rho_{+-} - \rho_{--})|$$

$$= -(\rho_{++} + \rho_{+-} + \rho_{-+} + \rho_{--}) + 2|\rho_{++} - \rho_{--}|$$

$$\leq -(\rho_{++} + \rho_{+-} + \rho_{-+} + \rho_{--}) + 2(\rho_{++} + \rho_{--})$$

$$= \rho_{++} + \rho_{--} - \rho_{+-} - \rho_{-+} = \int AB\rho(\lambda_{uv})d\lambda_{uv} = \bar{AB}$$

F(u,v) – distribution of the internal polarizations.
Average over u,v

$$\int F(\vec{u},\vec{v})(-1 + |\vec{a}\cdot\vec{u} + \vec{b}\cdot\vec{v}|d^2\vec{u}d^2\vec{v}$$

$$\leq \int F(\vec{u},\vec{v})\bar{AB}d^2\vec{u}d^2\vec{v}$$

$$= < AB >$$

If QM Singlet state <AB>= -a.b   What is F(u,v)?

Thus

$$\int F(\vec{u},\vec{v})(-1+|\vec{a}\cdot\vec{u}+\vec{b}\cdot\vec{v}|) \leq -\vec{a}\cdot\vec{b}$$

For all a,b. Chose a=b

$$F(\vec{u},\vec{v}) = \delta(\vec{u}+\vec{v})\mathcal{F}(\vec{u})$$

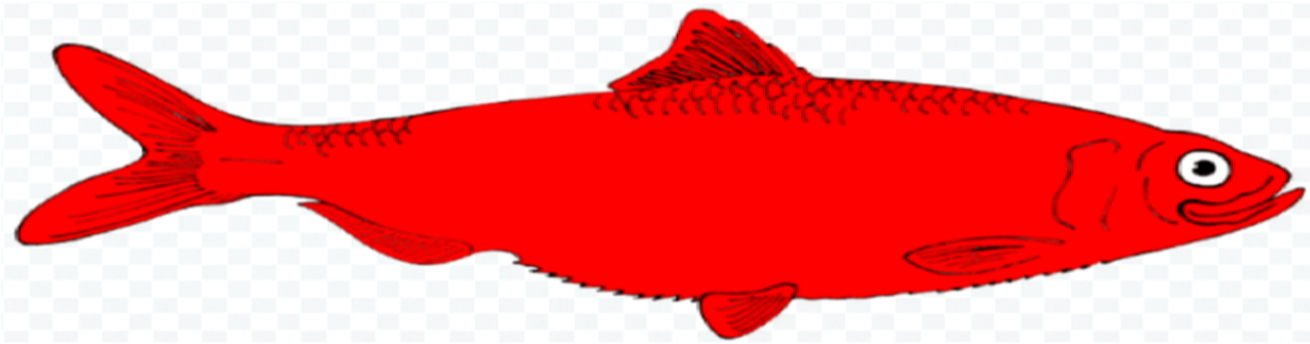
$$2sin(\frac{\psi}{2})(sin((\frac{\psi}{2}) - \int \mathcal{F}(\vec{u})|\vec{e}\cdot\vec{u}|d^2u) \geq 0$$

$$\vec{a}-\vec{b} = 2\sin(\frac{\psi}{2})\vec{e}$$

There always exist a, b such that this is violated by at least 1/8

This crypto-deterministic theory cannot mimic quantum Mechanics, even if it is non-local.

Locality is a red herring as far as quantum mechanics is Concerned. Forget about it. DO NOT use the term.



Stapp-- Has been one of the most persisant in arguing that quantum mechanics is non-local.

Many arg based on counterfactual arguments.

Some: Counterfactual arguments are nonsense.

Peres Mother:
Asher told a story about his mother. One day when she very young, she sat alone in the back yard and asked herself:

> If my father and mother had never married each other whose child would I be?

After much thought and worry, she decided that the question was nonsense, and stopped worrying about it.

We, with our view of genetics, personality, etc would probably agree. Any child of the two new couples would be so different from her that the question would make no sense.

Imagine one lived in a culture in which believed in reincarnation of the soul. Futhermore, that soul is clearly the embodiment of the essence of the person. If one has the soul, one IS that person.
Let us also say that in that culture the transmigration is matrilinear-- the soul travels through the mother's side.

Clearly Peres' mother's question would have a very straightforward answer-- her mother's child.

Counterfactual questions must always be situated in the theoretical framework. They are a way of teasing out theoretical relationships within the theory.

Quantum entanglement is a kind of correlation.- Shares many features with classical correlations.

Classical statistical theory:
I tear a dollar bill in half , place both halves into envelopes and send one half to my friend in Australia. I have no idea which one I sent, and neither does he.
Thus there are two possibilities-- When he opens his envelope, he has the queen's head on his piece of he does not. In both cases, suddenly I have the other half. Collapse of the probability distribution.

One can ask all of the same questions as are usually asked in the quantum case. Does that collapse happen causally or acausally? Can one send signals with that collapse?

Answer: There was a physical fact of the matter, that which half was in the friends envelope was always there. It, or God always knew in which envelope it was. (of couse it cannot know anything, and invoking God is always a questionable philosophical ruse in physical theories)

One has no such option in quantum theory. To see the strangeness in a quantum theory, lets look at what I call Hardy's chain.

Consider two spin 1/2 systems, placed into a state, a non-product state. Call then L and R.

$$|\Psi\rangle = sin(\phi)|++\rangle + cos(\phi)|--\rangle$$

$$L1 = cos(2\mu)\sigma_{Lz} + sin(2\mu)\sigma_{Lx} \quad tan(\mu) = -tan(\phi)^2$$

$$R1 = \cos(2\phi)\sigma_{Rz} + \sin(2\phi)\sigma_{Rx}$$

$$L2 = \frac{1}{\sqrt{2}}(\sigma_{Lz} - \sigma_{Lx})$$

$$R2 = \sin(2\phi)\sigma_{Rz} + \cos(2\phi)\sigma_{Rx}$$

L1=+ ==> R1=+ R1=+ ==> L2=+

L2=+ ==> R2=+

But

L1=+ ==> R2=- with prob. $cos^2(2\phi)$

Classical logic would give

L1=+ ==> R1=+ ==> L2=+ ==> R2=+
implies L1=+ ==>R2=+

The probability that L1 and R2 are non-classically related goes to a 1 as $\phi \to 0$

$\phi = 0$ state is a product state (no entanglement at all)

The probability that L1=+ goes to zero as $\phi \to 0$ as ϕ^2

Ie, this is similar to the Aharonov et al situation, in which "two time" conditions lead to non-intuitive results but the satisfaction of those conditions highly improbable.
In this case, one condition.
Note Max non-classical result if state least entangled.

Stapp: Consider the measurements at R and L, spacelike separated, and measurements are performed on time period small so no part of measurements causally related

Assume that L decided to measure L1 and he found + while R measured R1. He must have gotten +.

In that same experiment, L could have decided instead to measure L2. (freedom of choice. -- Counterfactual) Since R1 in this scheme was +, L2 would have had to have been +

But R also has free will. He could have decided to measure R2 rather than R1. Then R2 must have been + because L2 was.

But we know that L1+ leads (with overwhelming prob) R2=-

Must have non-locality so detectors know what was meas.

Problem: Conterfactual analysis depends crucially on the theory. Can Q M support this line.

What does it mean “In the same experiment, I did Q rather than Q'?

One may be able to buy the counterfactual L2 rather than L1 but even it is pretty shaky. There is no invariance of results in QM under counterfactual substitution. Each situation nees to be analysed on its own. Thus, if L1 or L2 measured, we have different situation. We could perhaps accept R1 pivot as providing a sufficient point of reality to base the counterfact on.

But the second counterfactual subst has nothing to pivot on One has replaced both conditions with counterfactual. There is no reason, unless one accepts “reality” (the values of Operators in an experiment are indep of exper.

Stapp, despite his claims, is using reality to carry forth the arg. not locality.

Q Mech is not non-local. It is local but no-relistic.

Quantum correlations, just like classicla correlations arise from a common cause, entanglement

Quantum Mechanics is fine as it is.

Are there problems?

General Covariance.-- Sort of like Gauge symmetry.
Any two solutions which differ by a coordinate transf. are equivalent.

Generators of coofdinate transformations:

$$\int N_\mu \sqrt{g^2} G_0^\mu d^3x$$

$$\int N^0 H_0 + N^i H_i d^3x = 0$$

Any observable must commute with these==> Only observables are constants of the motion and of space.
How does one represent time developement?

Other issues with locality:

* Non-unitarity
  -- Black hole evaporation.
    (Firewall demonstrating that the folly of black hole Unitarity)
  -- Creation: The universe was small in past, large now
    Degrees of freedom coming into being.
    QM assumes that degrees of freedom always there.
      May have different states, but they always exist.
    (Like political science assuming that "Kingship" always there, just the state (eg, non-existence) changes
    How can we handle degrees of freedom coming into Existence and disappearing from existence?

Q. Mech on its own is local theory. Local operators evolve locally. But once gravity (General Relativity) comes in to play whole idea of locality becomes very problematic.

Locality critical to doing physics-- plays a role in allowing us to break up problems into individual pieces.

If one had to know everything in order to do and analyse anything, physics would be impossible.