Title: Quantum Mechanics and Spacetime

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Abstract:

Quantum Mechanics and Spacetime

Based on Paper in **Minkowski Spacetime: A Hundred Years Later**
Ed V. Petkov (Springer 2010) p133

Some common problems with Q Mech and why they are not problems.

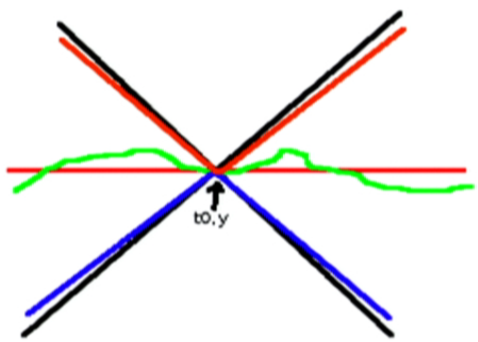
* Collapse of wavefunction, and its Causal structure
* Particle theory, Field theory and causality
* Bell's Theorem and Non-locality

Wave function collapse

ψ (t,x)-- represents the Probability (via square) that the

Particle is at point x.
If particle found to be at y, then it is no longer possible
It is at x.
After discovering at time t_0 that it is at "y" the wave
function must change.

Along which timelike hypersurface does ψ change?



How can wavefuction collapse be consistent with Relativity?

Misconception of what the wavefuntction is.

Schroedinger made great diservice to physics by inventing His quantum mechanics.

Obviously not calculationally-- his approach is far more Useful for calculating than Heisenberg's. Interpretationally however it becomes incredibly Misleading.

ψ (t,x) – looks like something that exists in spacetime

Reification of the wave function.

ψ (t,p) – lives where? Everywhere?

Heisenberg representation

Particle does not live inspacetime. Instead particle has Attributes at some time time t. --X,P, X+P, XPX,....

$$\frac{dX}{dt} = i\,[X, H]\,, \qquad \frac{dP}{dt} = i\,[P, H]$$

All dynamics lies in the dynamic variables.

ψ -- represents our particularizing to what we know of the world. Constant because our knowledge does not Change. Not associated with any time.

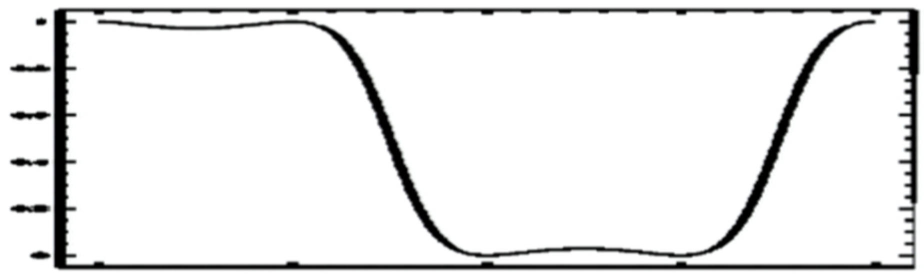
Single state no sufficient.

Spin 1/2 system

Sx=1/2 at 9AM   Sy=1/2 at 11 AM
What are the probabilities for spin cos(θ)Sx +sin(θ) at 10AM?

Easily calculated in quantum mechanics

$$P(S_\theta = 1/2) = \frac{cos(\frac{\theta}{2})^2(1 + sin(\theta))}{1 + cos(\theta)sin(\theta)}$$



No wavefunction or density matrix can give these results.
Conditions in quantum mechanics more general than Classical physics OR wave functions.

"Decoherence functional"

$$D(\{a_i\},\{b_j\}) = trace(\rho|[P_{a_1}..P_{a_r}P_{b_1}P_{a_{r+1}}...P_{b_2}...]|^2)$$

$$P(\{a_i\}) = \frac{D(\{a_i\},\{b_j\})}{\sum_{\{\hat{a}_i\}} D(\{\hat{a}_i\},\{b_j\})}$$

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Particles and Fields

Cannot have relativistic particle theories. --
Problem of coupling (only rel invar interaction is
Point interaction)

All theories of physics now are field theories
(or, very incompletely, string theories)

Physicists keep talking about particles, because in
Interactions with apparatuses, discrete energy tansfers

Fields obey causal equations of motion.
Change at A produces changes in the field in future of
A.

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Particles

$$\Box\Phi + m^2\Phi = 0$$

Modes

$$\Box\phi_i + m^2\phi_i = 0$$

$$< \phi_i, \phi_j >= \frac{i}{2}\int \left[\phi_i^\dagger \partial_\mu \phi_j - \partial_\mu \phi_i^\dagger \phi_j\right] dS_\mu = \delta_{ij}$$

$$a_i =< \phi_i, \Phi >$$ Annihilation operator

The probability of detecting the particle is proportional to the Square of the **mode** amplitude-- as if it were a wave function.

Quantum fields behave like quantum mechanics in certain Situations. Even though the observables are very different

Eg, X for particle(attribute is position) but Field strength for The quantum field.

Locality

Quantum mechanics is often called non-local
Codswollop

Bell's theorem

No realistic local theory can mimic quantum mechanics

Everybody 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.

$A(u,v,a,b\ \lambda)$,-- outcome of measurment.

Constraint:

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

Experimental determined outcome

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

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

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

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

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

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

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

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

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

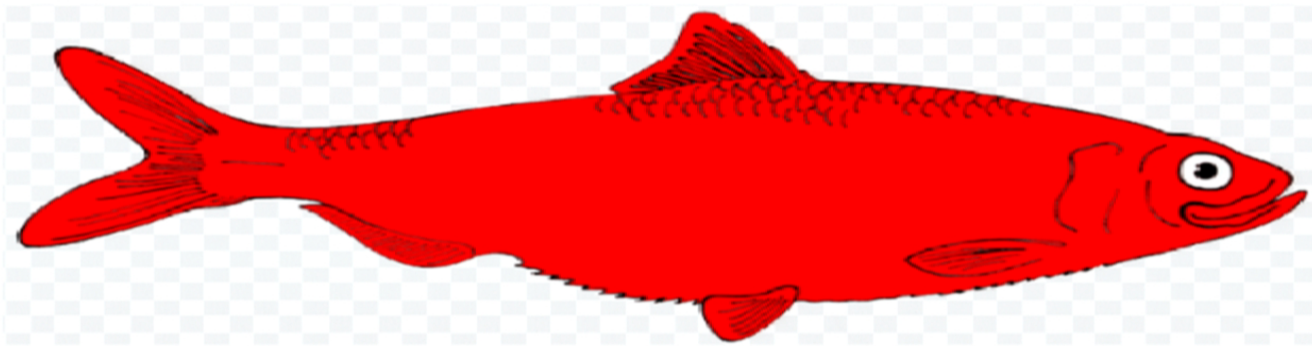
$$2sin(\frac{\psi}{2})(sin((\frac{\psi}{2}) - \int \mathcal{F}(\vec{u})|\vec{e}\cdot\vec{u}|d^2u) \geq 0$$

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

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

No crypto-deterministic theory can 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.



Quantum Mechanics is fine as it is.

Are there problems?

Yes-- once gravity comes into play.

* 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?

Timeless Quantum Gravity
If we believe in constraints of Gravity, (parts of the Einstein Equations which are not second order in time), then the only Dynamic variables are constants of the motion.

Has been used by Marlof to argue that black hole evap. is unitary, but it is using an aspect of Quantum GR we know to be wrong. We know that we are interested in change, not Stasis.

How can we preserve Einstein equations while allowing time dependence?