# Quantum mechanics and the sanctity of linearity

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1. L-ity of SE is different from the approximate L-ity in other theories
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# L-ity of SE is different from the approximate L-ity in other theories

- hydrodynamics: obviously NL
- Maxwell ED: perfect L; QED: NL corrections, $\gamma - \gamma$ interaction
- ...

Why is L-ity of quantum theory different ('foundational')?

# Peaceful coexistence ...

of quantum mechanics and special relativity (Shimony)

Despite

- apparent action-at-a-distance in EPR situation
- quantum non-locality in Bell formulation

action-at-a-distance (AAD) & faster-then-light (FTL) communication remain impossible.

Reason: linear structure of quantum mechanics
Non-linear modifications open door to FTL communication! (Gisin)

$$i\hbar\frac{d\psi}{dt} = \hat{H}\psi + \hat{V}_\psi\psi$$

allows for FTL communication for whatever small (non-trivial) $\hat{V}_\Psi$.

# L-ity of SE follows from its standard statistical interpretation

- Suppose any **dynamics** $\mathcal{M}$, not necessarily linear:

$$\hat{\rho}^f = \mathcal{M}[\hat{\rho}^i]$$

- Consider statistical **mixing** of $\hat{\rho}_1, \hat{\rho}_2$ with weights $\lambda_1 + \lambda_2 = 1$:

$$\hat{\rho} = \lambda_1 \hat{\rho}_1 + \lambda_2 \hat{\rho}_2$$

In von Neumann standard theory

**mixing and dynamics are interchangeable:**

$$\mathcal{M}[\lambda_1 \hat{\rho}_1 + \lambda_2 \hat{\rho}_2] = \lambda_1 \mathcal{M}[\hat{\rho}_1] + \lambda_2 \mathcal{M}[\hat{\rho}_2]$$

Recognize the condition of $\mathcal{M}$'s linearity!

- Interchangeability excludes non-linear Schrödinger equations
- Without interchangeability statistical interpretation collapses

(D.: *A Short Course in Quantum Information Theory*, Springer, 2007, 2011)

# NLSE invalidates statistical interpretation, requests new one

?

i.e.: yet to be proposed

# NLSE exposes further fatal symptomes, like superluminality

- superluminality (Jánossy 1952, Kibble, Gisin, Polchinski, ...)
- action-at-a-distance (Bialynicki-Birula&Mycielski 1976, ...)
- non-standard (NL) observables (?, ..., D. 1986, ..., Weinberg)
- inapplicability for mixed states (?, ..., D. 2016)
- . . .

Above all: fall of statistical interpretation (Mielnik 1974, ..., D. 2007)

# Many NLSEs were proposed over 60-80 years

Approximate (mean-field) theories:

- Hartree-Fock
- semiclassical Einstein Eq. ($\hat{T}_{ik} \approx \langle \hat{T}_{ik} \rangle$)

$\Psi(x)$ is not wave-function:

- E.m. waves in medium, fibre, etc.
- Gross-Pitaevski equation

Foundational:

- Stop wave function expansion, Jánossy eq. 1952
- Same, scaled by G: Schrödinger-Newton Eq. (D. 1984, Penrose)
- Just why not NLSE, Weinberg eq. 1989

# Persistent NLSE: Schrödinger-Newton Equation

Single-body SNE for c.o.m. free motion of “large” mass $M$:

$$i\hbar\frac{d\psi}{dt}=\frac{\hat{p}^2}{2M}\psi+M\Phi_\psi(\hat{x})\psi, \qquad \Phi_\psi(\hat{x})=-GM\int\frac{|\psi(r)|^2}{|\hat{x}-r|}d^3r$$

May be foundational (D., Penrose)

- Stationary solution: single soliton $\bigcirc$ of $\emptyset\sim(\hbar^2/GM^3)$
- Schrödinger Cat state: two-soliton $\psi_\pm=\bigcirc_L\pm\bigcirc_R$

By mean-field $\Phi_\psi(\hat{x})$, parts in $\psi_\pm$ attract each other, like, e.g.:

$$\bigcirc\qquad\bigcirc\Longrightarrow\bigcirc\bigcirc\Longrightarrow\bigcirc\!\!\!\!\bigcirc\Longrightarrow\bigcirc\bigcirc\Longrightarrow\bigcirc\qquad\bigcirc$$

1-solitons $\bigcirc_L$ and $\bigcirc_R$ are static, 2-solitons $\psi_\pm=\bigcirc_L\pm\bigcirc_R$ evolve. Initial overlap is $1/\sqrt{2}$. NL-ity makes them orthogonal after time

$$\sim\frac{\hbar}{GM^2}d_{L-R}$$

# NL quantum mechanics are not necessarily evil if we are aware all of their fundamental anomalies that we must rather overcome than ignore

Weinberg became less tolerant (in *Dreams of a Final Theory*): This theoretical failure to find a plausible alternative to quantum mechanics, even more than the precise experimental verification of linearity, suggests to me that quantum mechanics is the way it is because any small change in quantum mechanics would lead to logical absurdities. If this is true, quantum mechanics may be a permanent part of physics. Indeed, quantum mechanics may survive not merely as an approximation to a deeper truth, in the way that Newton's theory of gravitation survives as an approximation to Einstein's general theory of relativity, but as a precisely valid feature of the final theory.