A new approach to quantum mechanics

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Standard formulation of QM:

- the state of a system at a given moment is described by one wave-function, evolving from the past to the future.
Time-Symmetric formulation of QM (TSQM)

- the state of a system at a given moment is described by two wavefunctions, one evolving from the past to the future, and one evolving from the future to the past

\[
\langle \Phi | \Psi \rangle
\]

The two-state vector

\[ P_\Phi = 1 \]

\[ P_\Psi = 1 \]
Boundary conditions: classical vs quantum

- Classical:
  \((X,P)_{\text{init}}\)

- Quantum:
  \(\langle \Phi_1 \mid \langle \Phi_2 \mid \langle \Phi_3 \mid \Psi \rangle \)
What can we say about the system at the intermediate time?
\[ P(c) = \frac{|\langle \Phi | U(t_2, t) | c \rangle|^2 |\langle c | U(t, t_1) | \Psi \rangle|^2}{\sum_{c'} |\langle \Phi | U(t_2, t) | c' \rangle|^2 |\langle c' | U(t, t_1) | \Psi \rangle|^2} \]
\[ P(c) = \frac{\left| \langle \Phi, t \mid c \rangle \langle c \mid \Psi, t \rangle \right|^2}{\sum_{c'} \left| \langle \Phi, t \mid c' \rangle \langle c' \mid \Psi, t \rangle \right|^2} \]
\[ \sigma_y = 1 \]
\[ \frac{\sigma_x + \sigma_y}{\sqrt{2}} = ? \]
\[ \sigma_x = 1 \]
STRONG MEASUREMENTS

\[ \langle \Phi | \ A | \Psi \rangle \]

EIGENVALUES
WEAK MEASUREMENTS

\[ \langle \Phi | A | \Psi \rangle \]

\[ A \]

\[ A_W \]
$A_w = \frac{\langle \Phi | A | \Psi \rangle}{\langle \Phi | \Psi \rangle}$
\[
\sigma_y = 1 \\
\left( \frac{\sigma_x + \sigma_y}{\sqrt{2}} \right)_w = \frac{1 + 1}{\sqrt{2}} = \sqrt{2}
\]
WEAK MEASUREMENTS WITHOUT POSTSELECTION

\[ \langle \Psi | A | \Psi \rangle \]
\[ \langle \Psi | A | \Psi \rangle = \sum_i P(\Phi_i | \Psi) \frac{\langle \Phi_i | A | \Psi \rangle}{\langle \Phi_i | \Psi \rangle} \]
Where is the ball?

\[ \langle \Phi \rangle = \frac{1}{\sqrt{3}} \langle A \rangle + \langle B \rangle - \langle C \rangle \]

\[ |\Psi\rangle = \frac{1}{\sqrt{3}} |A\rangle + |B\rangle + |C\rangle \]

Y. Aharonov and L. Vaidman

\[ \langle \Phi \rangle = \frac{1}{\sqrt{3}} \left( \langle A \rangle + \langle B \rangle - \langle C \rangle \right) \]

\[ |\Psi\rangle = \frac{1}{\sqrt{3}} |A\rangle + |B\rangle + |C\rangle \]

OPEN A (STRONG PA)

It is in A always!
THE THREE BOX PARADOX

\[ \langle \Phi \rangle = \frac{1}{\sqrt{3}} \left( \langle A \rangle + \langle B \rangle - \langle C \rangle \right) \]

\[ |\Psi\rangle = \frac{1}{\sqrt{3}} \left( |A\rangle + |B\rangle + |C\rangle \right) \]

OPEN B (STRONG \( P_B \))

It is in \( B \) always!
\[ P_A = 1 \implies P_A^w = 1 \]
\[ P_B = 1 \implies P_B^w = 1 \]
\[ P_A + P_B + P_C = 1 \implies P_A + P_B + P_C^w = 1 \]
\[ \implies P_C^w = -1 \]

This has been seen experimentally: Resch, Lundeen, Steinberg PLA 324, 125-131 APR 12 2004
Applications: metrology, algorithms

- new paradigm for amplifying signals with enhanced sensitivity (Aharonov Vaidman 1990, Tollaksen 2007)

Other experimental verifications:


For weak value resolution of Hardy’s paradox

Aharonov. Botero, Popescu, Reznik, Tollaksen, PLA, v301, 130 concerning Hardy’s paradox