Proposal for a Quantum Delayed-Choice Experiment

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Phys. Rev. Lett. **107**, 230406 – Published 2 December 2011

2017-05-02 Journal Club

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- Research interest
  - Gravity and entropy
  - Relativistic aspects of quantum information
  - holographic principles
  - black hole physics and quantum gravity

- Favorite papers

  - D. R. Terno, Localization of relativistic particles and uncertainty relations, Physical Review A **89**, 042111 (2014)

  - A. Brodutch and D. R. Terno, Entanglement, discord and the power of quantum computing, Physical Review A **83**, 010301(R) (2011)

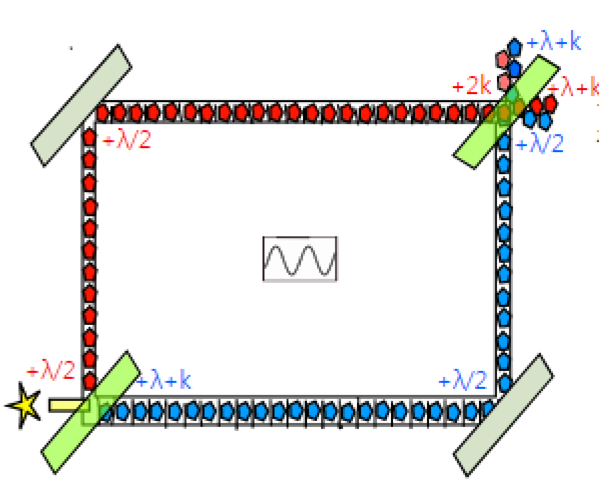
Introduction

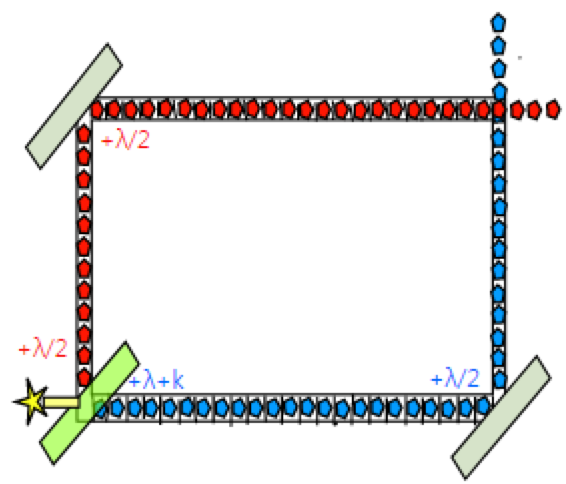
- Definition of Particle & Wave

  Wave : able to make interference pattern

  Particle : unable to make interference pattern

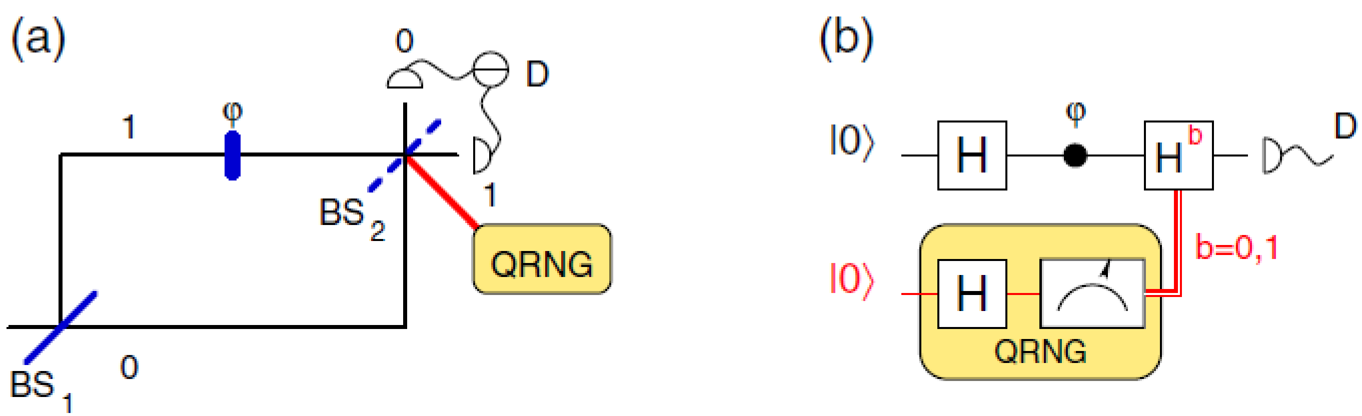
- Wheeler's Delayed Choice Experiment





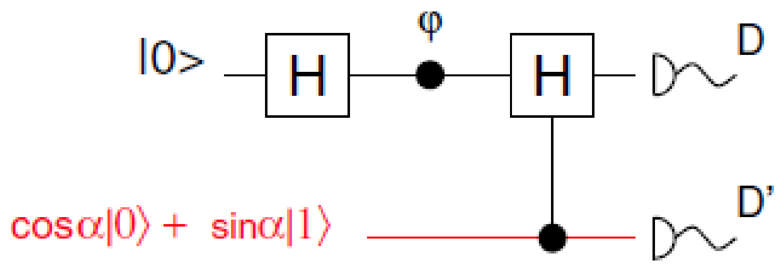
Quantum equivalent schematic

- Hadamard gate H play the role of beam splitter.
- Top black line in (b) represents the photon and bottom red line represents the ancilla.
- Quantum Random Number Generator is prepared in the superposition state $|+> = \frac{1}{\sqrt{2}}(|0> + |1>)$
- The measurement |0> and |1> controls BS2 is inserted or removed



Quantum superposed ancilla

- Preparing the ancilla in the state
$$|+\rangle = \cos\alpha\,|0_A\rangle + \sin\alpha\,|1_A\rangle$$
- The final state becomes
$$|final\rangle = \cos\alpha\,|particle\rangle|0_A\rangle + \sin\alpha|wave\rangle|1_A\rangle$$
- The photon detector D now measures
$$I_0(\varphi,\alpha) = I_p(\varphi)\cos^2\alpha + I_w(\varphi)\sin^2\alpha$$
- Continuously morphing as α changes



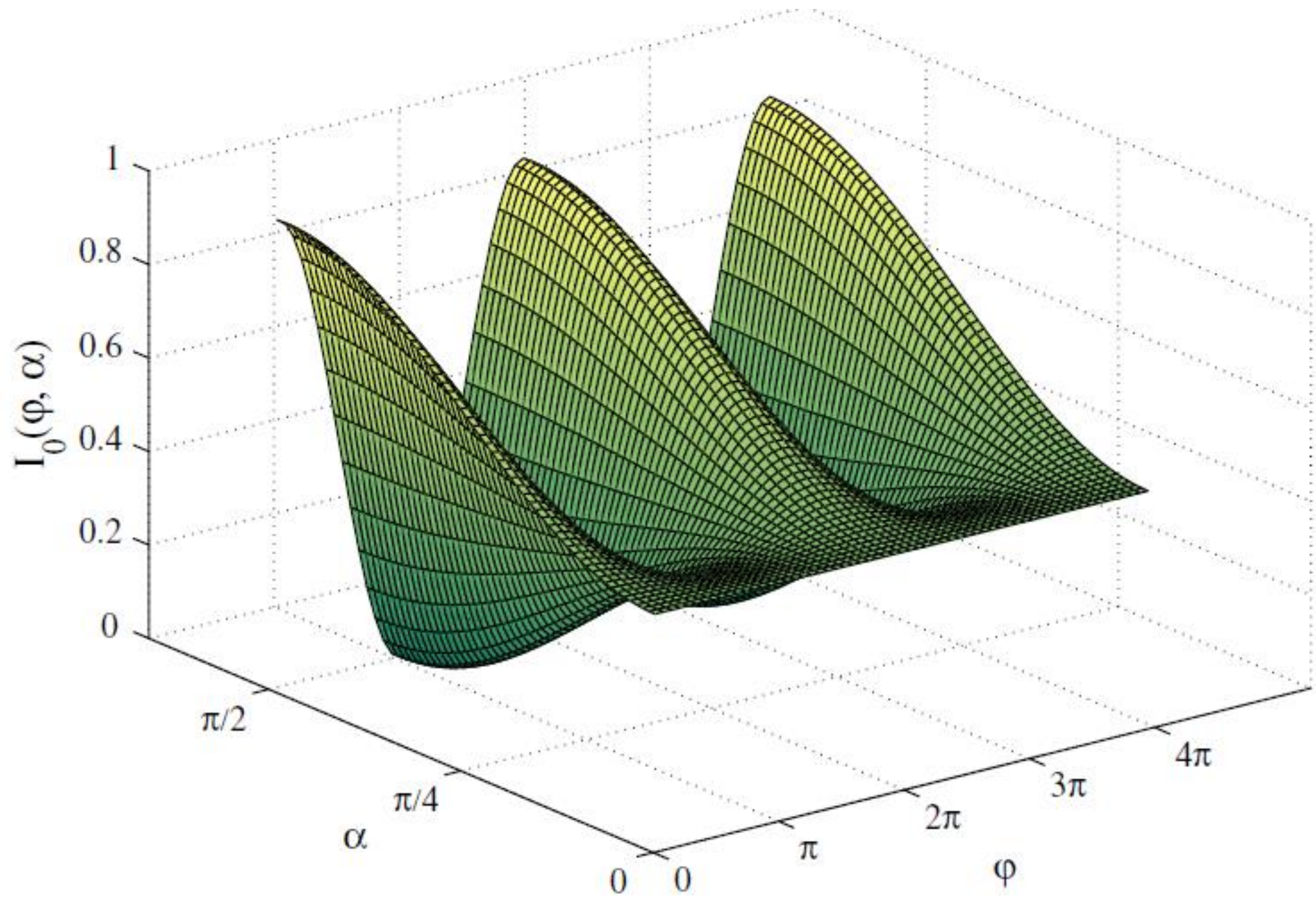


FIG. 2 (color online). Morphing behavior ($\alpha = 0$) and wave ($\alpha = \pi/2$).

HV model

a = photon, b = ancilla, λ = hidden variable

p(a,b)=$\left(\frac{1}{2}\cos^2\alpha,\ \sin^2\alpha\cos^2\frac{\varphi}{2},\ \frac{1}{2}\cos^2\alpha,\ \sin^2\alpha\sin^2\frac{\varphi}{2}\right)$

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p(a,b)=$\sum_\lambda p(a,b,\lambda) = \sum_\lambda p(a|b,\lambda)p(b|\ \lambda)$p(λ)

p(a|b=0, λ=p) = $\left(\frac{1}{2}, \frac{1}{2}\right)$

p(a|b=1, λ=w) = $\left(\cos^2\frac{\varphi}{2}, \sin^2\frac{\varphi}{2}\right)$

p(a|b=0, λ=w) = (x,1-x)

p(a|b=1, λ=p) = (y,1-y)

p(λ)=(f,1-f)

(emits particle with probability f)

p(b| λ=p) = (z,1-z)

p(b| λ=w) = (v,1-v)

v(1-f)(x-$\frac{1}{2}$)=0 f(1-z)(y-$\cos^2\frac{\varphi}{2}$)=0 zf+v(1-f)-$\cos^2\alpha$ = 0

HV model

v(1-f)(x-$\frac{1}{2}$)=0 f(1-z)(y-$\cos^2\frac{\varphi}{2}$)=0 zf+v(1-f)-$\cos^2\alpha$ = 0

- v = 0, f = 0 -> $\cos^2\alpha$ = 0
- f = 1, z = 1 -> $\cos^2\alpha$ = 1
- x = $\frac{1}{2}$ -> p(a|b = 0, λ = w) = ($\frac{1}{2}$, $\frac{1}{2}$)
- y =$\cos^2\frac{\varphi}{2}$ -> p(a|b = 1, λ = p) = ($\cos^2\frac{\varphi}{2}$, $\sin^2\frac{\varphi}{2}$)
- v = 0, z = 1, f = $\cos^2\alpha$ -> p(λ) = ($\cos^2\alpha$, $\sin^2\alpha$)

- The hidden variable λ and the ancilla b are perfectly correlated
  $p(b|\lambda) = \delta_{\lambda_p}\delta_{b0} + \delta_{\lambda_w}\delta_{b1}$

- Paradox : The hidden variable which can determine the value of the ancilla p(λ) is identical to p(b) which is set by a experimenter

Summary

- Morphing behavior between particle and wave

- Particle and wave merely reflect how we look at the photon

- The choice particle vs wave can be made after the photon has been already detected, by correlating the photon data with the measured value of the ancilla