Hacking Heisenberg's uncertainty principle with quantum clones

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Summary: Performing simultaneous non-commuting measurements on a single quantum system is impossible because of the disturbances generated by the measurements. However, if one possesses two copies of the system, this problem can be overcome. We perform simultaneous non-commuting measurements and fully determine the state of the system using quantum clones.

1. Introduction

In classical physics, the position and the momentum of a particle can be fully determined. Indeed, one can first measure the position of a particle, then its momentum (or the other way around) to acquire full knowledge of the state of the particle. However, as all quantum physicists know, because of Heisenberg's uncertainty principle, it is not possible to simultaneously measure complementary observables with an arbitrary precision. In this case, if one precisely determines the position of the particle, then its momentum will be random, and thus only one aspect of the full quantum state of the particle will be known.

One possible way to get around this problem is to use weak measurements. In this situation, the state of the particle is weakly coupled to a pointer, which is measured. Since the coupling between the particle and the pointer is weak, the particle's state remains unchanged, thereby allowing subsequent measurements of complementary observables. It has been shown that a quantum system can be entirely determined using a series of two non-commuting weak measurements followed by a strong measurement [1].

A second possible way to solve the problem would be to make two identical copies of the particle. Then, one could measure its position on the first copy and its momentum on the second copy. But, the no-cloning theorem states it is impossible to make two perfect copies of a quantum state. Instead, it is possible to generate optimal (but imperfect) clones. Here, optimal means both clones are identical and as similar to the original state as theoretically possible. We simultaneously measure non-commuting observables on each optimal clone. This joint measurement (which can alternatively be described using weak values [2]) can be used to determine the state of the quantum system [3].

2. Experimental results

The optimal clones are generated by interfering on a 50:50 beam splitter two 808 nm photons produced by a type-II spontaneous parametric downconversion (SPDC) process. If the photons are indistinguishable, they will bunch due to Hong-Ou-Mandel interference. To jointly measure complementary observables on each clone, we need to coherently interfere the cases where the clones bunch and anti-bunch. This is done by implementing a square root swap transformation in a subsequent interferometer.

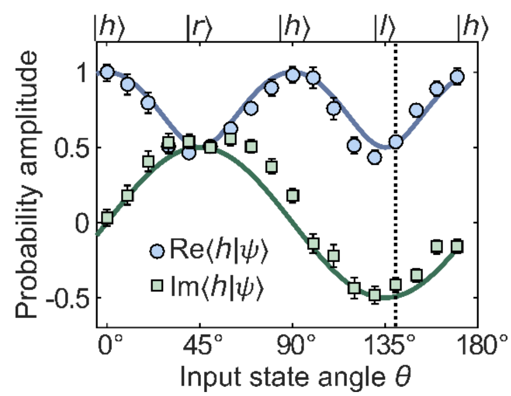

Fig 1. Real and imaginary part of projection of Ψ onto the horizontal polarization as a function of the input state

3. Conclusion

We have shown that using optimal quantum clones, it is possible to perform non-commuting measurements and determine the state of a quantum system.

4. References

[1] G.S. Thekkadath, L. Giner, Y. Chalich, M.J. Horton, J. Banker, and J.S. Lundeen Phys. Rev. Lett. **117**, 120401 (2016)

[2] H.F. Hofmann Phys. Rev. Lett. **109**, 020408 (2012)

[3] G.S. Thekkadath, R.Y. Saaltink, L. Giner, and J.S. Lundeen arXiv:1701.04095v2 [quant-ph] 27 Feb 2017