Kaleen Shrestha
16 September 2018

Interaction-Free Determination and Its Fundamental Role in Quantum Computing

To see an object requires interacting with it. For the macroscopic world, this can be done without disturbing the object significantly. However, in the subatomic level this interaction can completely change the state of the subatomic particle. Can we detect an object without actually interacting with it? Let us explore…

As described in **[1]**, suppose there is a company that creates tiny grains of photosensitive materials. The process to create these is quite difficult; so there are grains that work, as well as ones that do not work. The grains are extremely sensitive such that a grain that works, if struck by a photon, is immediately blackened and hence damaged. The company has an obvious problem: how to certify "live" grains? We know that "dud" grains (grains that do not work, not grains that were once working) are 100% transparent -- photons will travel straight through, and that live grains are 100% absorptive. To solve this problem, Avshalom Elitzur and Lev Vaidman suggested an interaction-free detection scheme using a Mach-Zehnder interferometer (*Figure 1a*).

First, having the light source in high-intensity mode, we tune the interferometer's optical arms such that D_1 never detects light and D_2 does. Then we dial the intensity down on the light source until a single photon is emitted at a consistent rate (taking note of the photon-detection rate). Since the interferometer is tuned, D_1 still never receives a photon and D_2 does **[2]**.

Now, a grain is placed in the middle of arm *a* (Figure 1b).

If it is a dud, D_1 is dark and D_2 is light because duds are 100% transparent, and it is as if nothing has changed at all with the original setting of the interferometer.

Now let us look at the live-grain case. A photon travels to B_1. It has a 50% chance of being transmitted and continuing on arm *a* and a 50% chance of reflecting off and traveling down arm *b*.

If it is transmitted, it will be absorbed completely by the live grain, blackening the grain and leaving both D_1 and D_2 dark. In this case we will know that the grain has been damaged, because the constant rate of detection would be disturbed.

However, if the photon instead goes down arm *b*, and bounces off the two mirrors to B_2, the photon will have a 50% chance of going to D_1 and a 50% chance of going to D_2.

If it goes to D_2, that grain could be either a dud or an undamaged live grain, but it is undetermined at this stage.

However, if D_1 detects a photon, it must mean that the grain is live and usable! In this case we will have certified a live grain without damaging it!

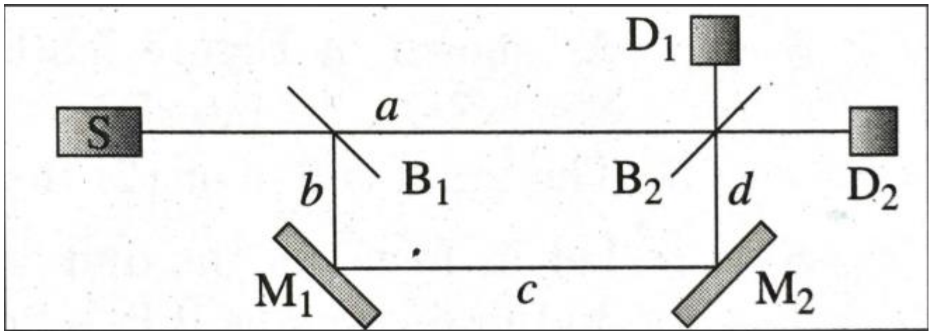
This is the basis of the interaction-free measurement scheme invented by the physicists Elitzur and Vaidman **[1]**.

This principle may be used in quantum computing for making very many simultaneous computations efficiently, without ever making any computation directly.

Figure 1a

S is the light source, B_1 and B_2 are beam splitters, M_1 and M_2 are mirrors, and D_1 and D_2 are photon detectors

Source: ***[1]***



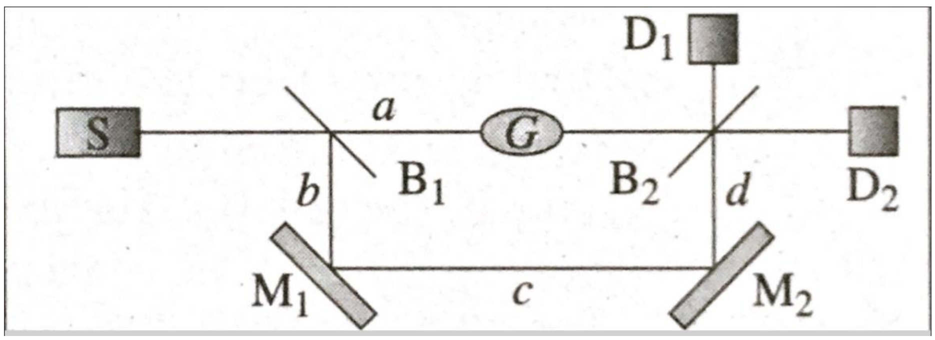


Figure 1b

A photosensitive grain (G) is placed on arm a

Source: ***[1]***

References

[1] Reinhold Blümel, *Foundations of Quantum Mechanics: From Photons to Quantum Computers*, Laxmi Publications Pvt. Ltd. 2011, Section 5.3, pp. 154-159, Print.

[2] Lee Spector, *Automatic Quantum Computer Programming: A Genetic Programming Approach*, Kluwer Academic Publishers 2004, Section 1.2, pp. 4-10, Web.