Boxed-In Qubits (BIQs): A New Approach to Qubit Computing

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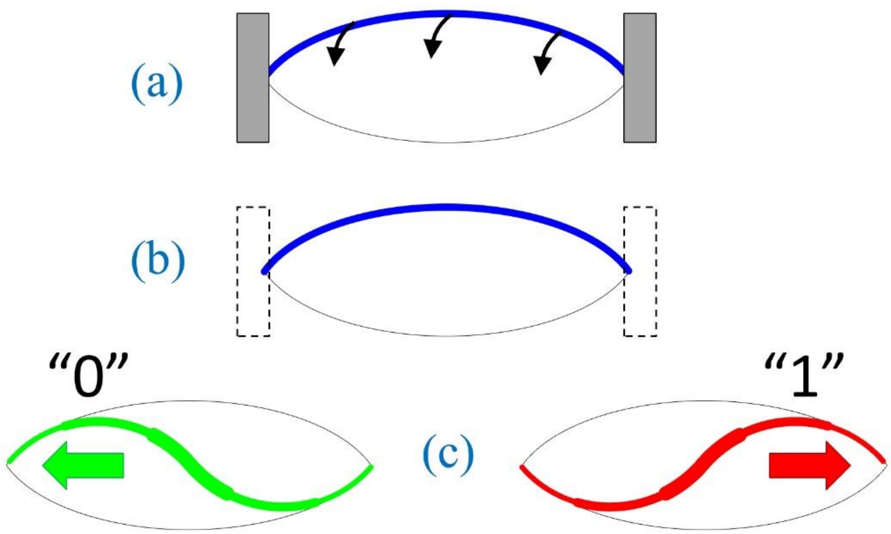

Figure 1. *Opening the ends of a traditional particle-in-a-box reveals it to be an unrecognized type of qubit.*

Abstract: In replying to an excellent quantum mechanics tutorial article by Matt Strassler [1], my analysis of some of the particulars of his description led me to realize that the well-known quantum problem known as the particle-in-a-box problem is an unrecognized type of qubit (Fig. 1). Since these "boxed-in qubits" (BIQs or biqs, pronounced "bicks") send their superposed states down independent spatial paths, it has surprisingly good potential for use in designing and building cheaper, easier-to-design qubit networks with less extreme environmental constraints. This article is mostly a capture of the comment [2], since the idea seems worth capturing and letting innovative folks know about it.

Hi Matt Strassler,

Now that I've made a fully supportive comment [3], it's time to get back to being me:

"Unlike familiar standing waves, [an electron standing wave] needs no walls."

You are a very sharp fellow, so you have to know that's not correct. The wave you showed is even *called* "particle in a box" because… you know… boxes have walls!

More specifically, and simplifying terribly about those other two pairs of walls, particles get into these kinds of lowest-energy (single lobe) states *only* when reflectively bound at each end. What you have shown is a variant of an electron p-orbital (not s, p) "cut and unwrapped," so the ends reside at opposite ends of the box instead of interacting with each other.

So, someone reading this might now say: "But electrons exist in free space without walls!" Sure they do: As *wave packets*, which are more akin to multi-frequency sharp laser pulses than simple sinusoidals. And even those wave packets spread and spread pretty quickly!

So fine, fine, fine. Terry, you silly fellow, take the box end off and… Voila! You have a simple sinusoidal wave representing an electron! No walls are needed! Point proved!

Except…

No, that's not what you get, not even close. What you get is a *very fast spreading wave function* that represents two superposed states: An electron moving to the left, whose wave component looks like a rapidly spreading cork-screw motion in the "rope," or an electron moving to the right with a similar but opposite helicity cork-screw motion. Both have well-defined velocities (momenta) due to the sharpness of the original confined-to-a-box states, and both move *away* from the box region faster than they spread in their length, thus quickly leaving the box region empty of any electron probability at all.

The electron escaped, but you don't know in which direction. Conveniently, this is what you would expect at the classical limit of removing both walls with a box bouncing between them.

The wave function, however, has two regions of location probability with a potentially huge gap between them. There's a word for that: Entanglement! You don't need spin to get entanglement. You only need a true, universal unknown bit of information, and in this case, the unknown is a true, single bit, literally a qubit:

Did the electron go left (call that "0") or right ("1")? Both have equal probability!

If the box worked well enough to produce a resonant standing wave, then the two states were truly and genuinely quantum entangled. When you collapse this superposition, you get *either* an electron moving left with a well-defined momentum or the same electron moving the right with equally well-defined momentum.

So again, do electrons travel in one direction in a fashion mostly like particles? Sure they do, though the "particle" part often gets grotesquely exaggerated in the minds of many beholders. Our brains work that way. What is going on is almost entirely waves until the wave function hits something and "clicks" into a captured electron. But more importantly, to get a particle-like electron moving in one direction only, you need a more complicated wave function than a simple, inherently two-way-ambiguous sinusoidal. It works best if you have fairly complicated wave packets, ideally ones that work a bit like solitons.

And since I do this sort of thing intentionally and frequently and have even helped more than one small company become a big company by doing it (I love it when that happens), has anyone built a quantum computer using the kind of super-simple qubits I just described? I've never seen them in the literature, yet they are one of the purest, simplest, and truest forms of qubit I can imagine. It seems like there's potential there.

I think "boxed in qubits," biqs, makes a decent name for momentum pair qubits.

Thank you, Matt Strassler, for tempting me down this analysis path! Until you claimed "no walls," I had always accepted, as you did, that the single sinusoidal is the best capture of a free electron. I never would have gone down this path without you tempting me!

You would do nothing more than confine particles in boxes and release the box ends simultaneously. You then get a qubit splitting off along two literal branches, which could interact with other similarly set-up qubits. The speed would not be tremendous, but I'm guessing these qubits would be much easier (and probably "warmer") to create than most cryogenic approaches to quantum computing.

Momentum-pair, particle-in-a-box qubits would be much easier to design since they convert into mechanical ball computers at the classical limit.

References

[1] M. Strassler, *A Wave that Stands on its Own*, Of Particular Significance (WordPress), Mar. 12 (2024). https://profmattstrassler.com/2024/03/12/a-wave-that-stands-on-its-own/

[2] T. Bollinger, *Particles in boxes are not free electrons*, WordPress, Mar. 15, 19:34 EDT (2024). https://profmattstrassler.com/2024/03/12/a-wave-that-stands-on-its-own/#comment-450647. A comment in M. Strassler, *A Wave that Stands on its Own*, Of Particular Significance, Mar. 12 (2024).

[3] T. Bollinger, *The electron-in-a-box jump rope analogy*, WordPress, Mar. 15, 18:36 EDT (2024). https://profmattstrassler.com/2024/03/12/a-wave-that-stands-on-its-own/#comment-450646. A comment in M. Strassler, *A Wave that Stands on its Own*, Of Particular Significance, Mar. 12 (2024).