Quantum Strangeness in Unexpected Places

Aash Clerk

- Can we make “large” objects act in strange quantum ways?
- Quantum computers? When can I buy one?

Schrodinger’s Homer?
Quantum Weirdness?

• Quantum mechanics
  • Theory describing the behaviour of very small stuff (atoms, electrons, etc.)
  • Incredibly well-tested; basis for various technologies (laser, transistor, etc.)
  • Tells us that small particles can behave in incredibly strange ways....
    • “the doughnut has a definite location and speed”
    • “the doughnut which just hit me followed some definite trajectory to get here”
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Two slit experiment: non-quantum

- First, keep only one slit open....
Two slit experiment: non-quantum

- Launch particles one by one; record where they land.
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• Repeat the experiment a zillion times…
Two slit experiment: non-quantum

- Same sort of result when only top slit open…

\[ X = 0 \]
Two slit experiment: non-quantum

• Now, open both slits. For non-quantum particles, boring...

Each particle hitting the screen either came from the upper or the lower slit....
Quantum version

• Now for quantum particles: same if one slit open
Quantum Version

- Both slits open? Craziness…

![Graphs showing wave patterns for different slit configurations.](image)
Quantum Version

• Two slit experiment, quantum particles:

Opening the second slit can **reduce** the number of particles that make it to a given point on the screen!
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Actual Experiment?

- Two slit experiment, quantum particles:
  - 200 electrons
  - 6,000 electrons
  - 40,000 electrons
  - 140,000 electrons
Two paths at once?

- Two slit experiment, quantum particles:

  Each particle “goes through both slits”; think of it as a wave....

![Diagram showing particle distribution with and without both slits open.](image)
Two paths at once?

- Two slit experiment, quantum particles:

  Each particle “goes through both slits”; think of it as a wave....
What about in between?

• Before the particle hits the screen, we can’t say where it is
• If we were forced, we would say it is in a “state of limbo”…
  ~ in two places at once…

\[ | \cdot \rangle + | \cdot \rangle \]

• What if you try to look at the particle right at the slits?
  • Kill the state of limbo!
    • 50% of the time its at the top slit, 50% at the bottom slit
  • Get the boring “classical” pattern
Back-action

• Why does looking mess up the pattern?

  • Quantum back-action: if you try to measure the position of the particle, you must mess up its speed and direction
Quantum Effects for “Big” Things?

• Can we get objects much bigger than an atom in these “states of limbo”?

• Problem: something is always “looking”, destroys the interesting state…

• Something I work on:
  • “Weirdness preservation”: how do you keep a state like this alive? (technical & more respectable term: preventing “decoherence”)

\[ |\cdot\rangle + |\cdot\rangle \]
Example: Small Chunk of Aluminum

- Acts as an electron box, where the box can have 0 or 2 extra electrons…

\[
\begin{align*}
10^8 \text{ electron pairs} & \quad + \quad 10^8 + 1 \text{ electron pairs}
\end{align*}
\]

(box is about 5000 nm long = 1/200 of a milimetre)
Example: Small Chunk of Aluminum

• Can see that you have a “state of limbo” by doing an interference experiment in time

1. Start in 0 state
2. Whack with microwaves
3. Wait a time $\Delta t$
4. Whack with microwaves
5. See if you are back in the 0 state
**Why do people pay $$$ for this?**

- This could (with a lot of work!) for the basis of a new kind of computer, a *quantum computer*
  - Classical computer: uses bits to store information; a bit can be either 0 or 1.
  - Quantum computer: uses quantum bits; these can be *both* 0 and 1 at the same time!

- In principle, can do things impossible for a normal computer…
Factoring Large Numbers

• It is hard to factor large numbers into product of prime numbers
  • Easy: $15 = 5 \times 3$
  • Hard: $519920419074760465703 = ?? \times ??$

• This is the basis of modern cryptography (i.e. how we have secure transactions on the internet)

• How would a classical computer try to get the factors?

  Guess. “Try every key”
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- How would a quantum computer get the factors?

Try all they keys at once! (quantum bits can represent different numbers at the same time!)
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• Compare for a 500-digit number:
  • Classical computer: would take $10^{12}$ years (1 2.5 GHz CPU)
  • Quantum computer: \sim minutes to hours

• A quantum computer could break known codes…
A long way to go…

• A quantum computer has successfully shown that $15 = 5 \times 3$ (used 7 qubits)

\[
\text{Experimental realization of Shor's quantum factoring algorithm using nuclear magnetic resonance}
\]

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• A company in BC claims to have solved a Sudoku(!) using 16 qubits; their result is very controversial…

Since 1999, they have received $38$ million in funding, half from the Canadian government…
Another system: small vibrating beam

• Can we see quantum behaviour in the beam?

• Measuring current tells you about position of beam… can do this as well as quantum mechanics allows!
  • Can detection motion with amplitude less than 0.001 nm!
Another system: small vibrating beam

• Can we see quantum behaviour in the beam?

• Have seen the quantum “back-action”: pairs of electrons kick the beam
  • Even stranger: these kicks can cool the beam
  • “Quantum mother-in-law effect”
    = making something cold by looking at it.
END
Quantum Weirdness vs. Weird uses of the word “Quantum”

“Our bodies ultimately are fields of information, intelligence and energy. Quantum healing involves a shift in the fields of energy information, so as to bring about a correction in an idea that has gone wrong.”

(Winner of the Ig Nobel prize in physics, 1998)