The Physical Life of a Qubit:
From Nobel Prize to a Qiskit Gate

Qiskit Fall Fest 2025

Presenter: Tanvir Ahmed Masum

UMass Amherst

Two Hardware Talks!

- Superconducting Qubits
  - Engineered ‘Artificial Atoms’

On Next:

- Trapped Ions
  - Nature’s perfect atoms

Agenda:

- The Nobel Prize in 2025
  - The breakthrough that made our field possible
- The workhorse: The transmon qubit

- The hardware it takes to protect and control these ‘fragile qubits’
  - The dilution refrigerator: the big Chandelier!

- Quantum gate:
  - How to control the qubits to run an algorithm.

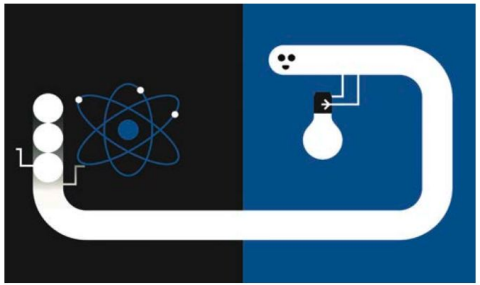
The 2025 Nobel Prize in Physics:

[1]

John Clarke

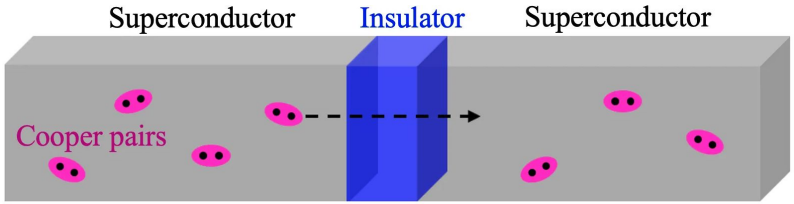
Michel H. Devoret

John M. Martinis



"for the discovery of **macroscopic quantum mechanical tunnelling** and **energy quantisation** in an electric circuit"

Josephson Junction:

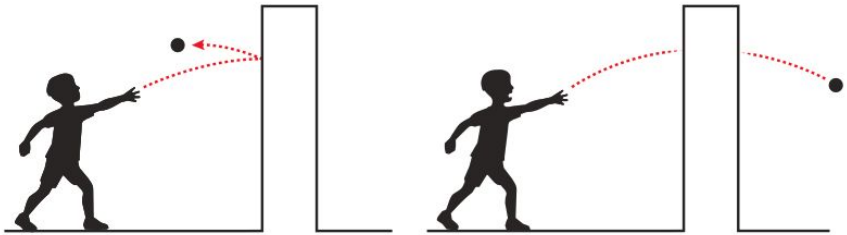


Two main discoveries:

- Macroscopic Quantum Tunnelling (MQT)
- Energy Quantization in a electrical circuit

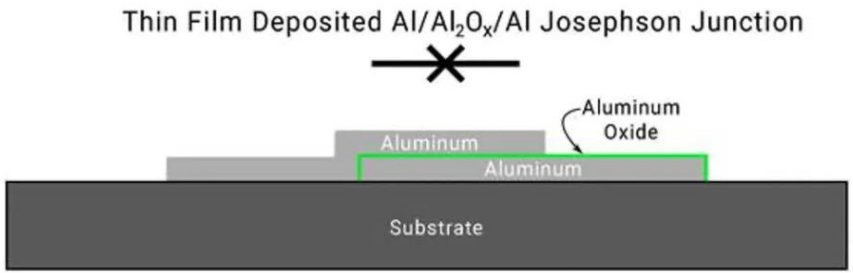
[1] Niklas Elmehed © Nobel Prize Outreach
[2] www.nobelprize.org

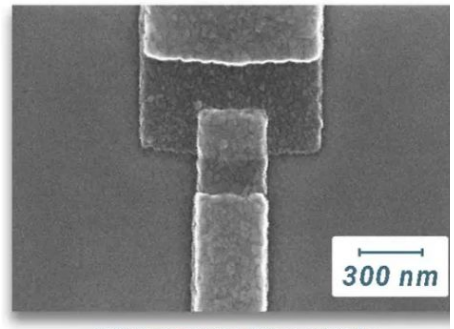
Discovery 1: Macroscopic Quantum Tunnelling (MQT)



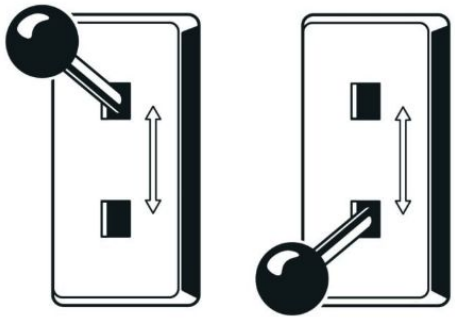
Classical picture Quantum picture

This was the proof. An entire, human-made object, with billions of particles, was obeying the laws of quantum mechanics as a single entity.



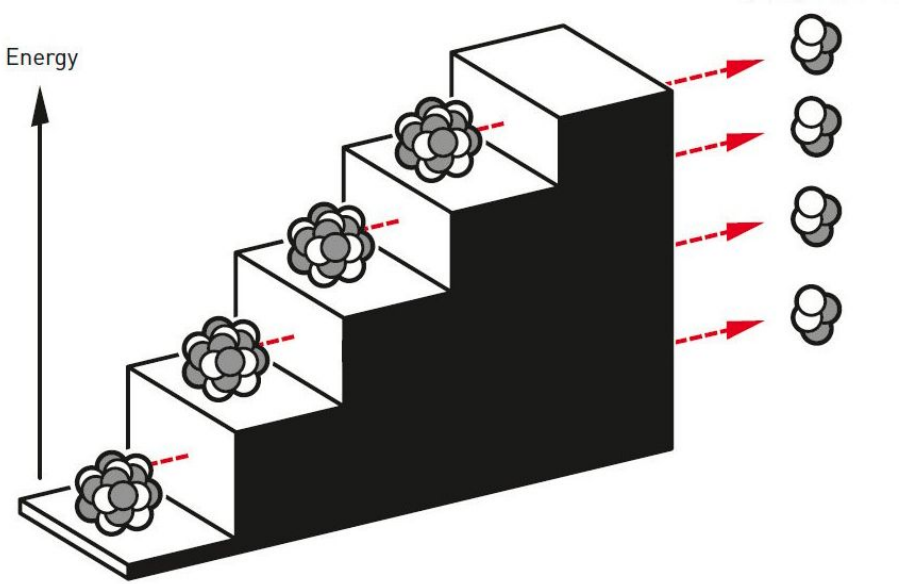


SEM image courtesy of the Institute for Quantum Computing (IQC) at the University of Waterloo



[2] www.nobelprize.org

Discovery#2 : Energy Quantization

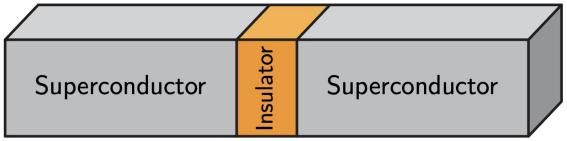


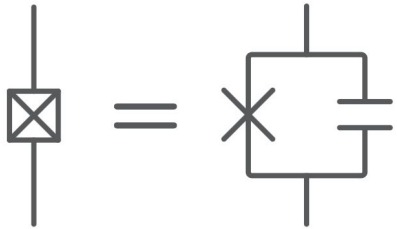
The circuit only absorbs or emits energy in ‘specific’ amounts.

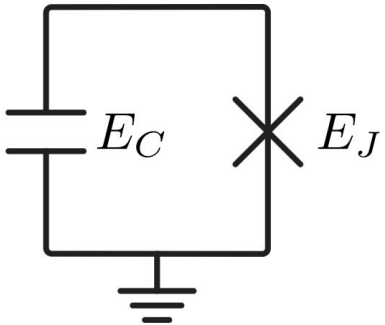
They proved this by introducing microwaves. (1-10 GHz)

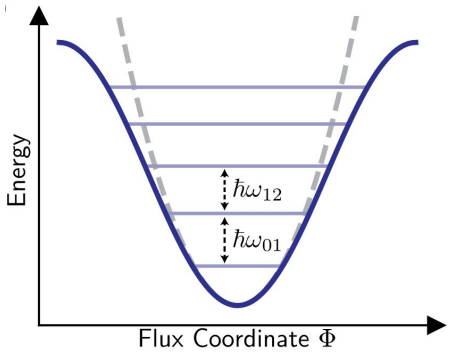
By changing frequency i.e. energy you can jump from one state to another.

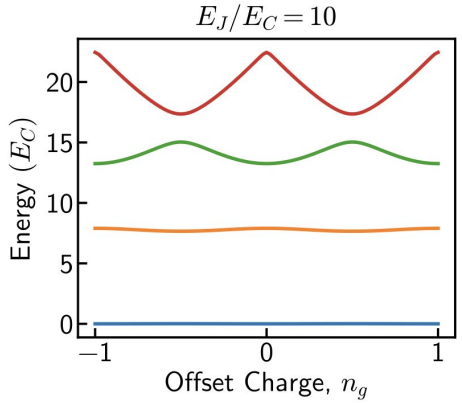
Current workhorse : The Transmon Qubit



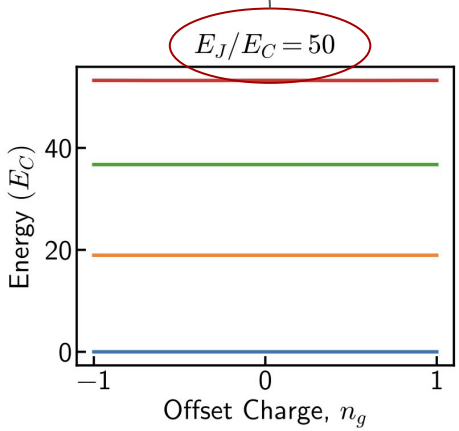








Transmon (2007)



Part 2: The Hardware and System Building

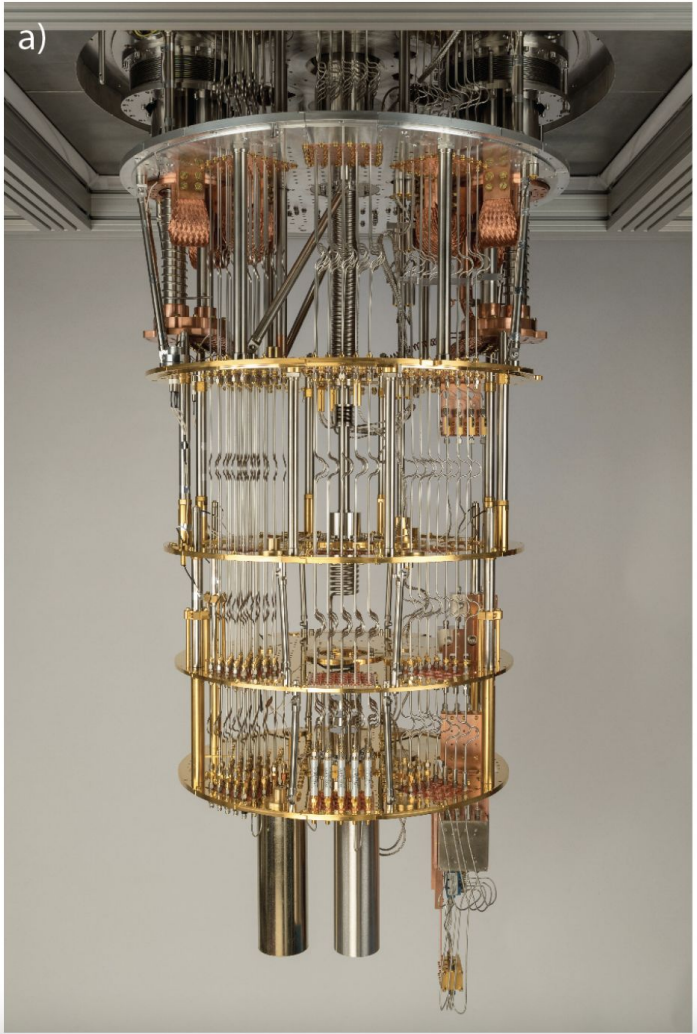
These qubits i.e.
'Artificial atoms' are :

- very fragile
- Smallest charge, flux, vibration or thermal noise can change the state or disrupt any quantum information

How to Protect quantum information?

(arguably) Build the quietest, coldest place in the Universe ~ 10-20 mk.

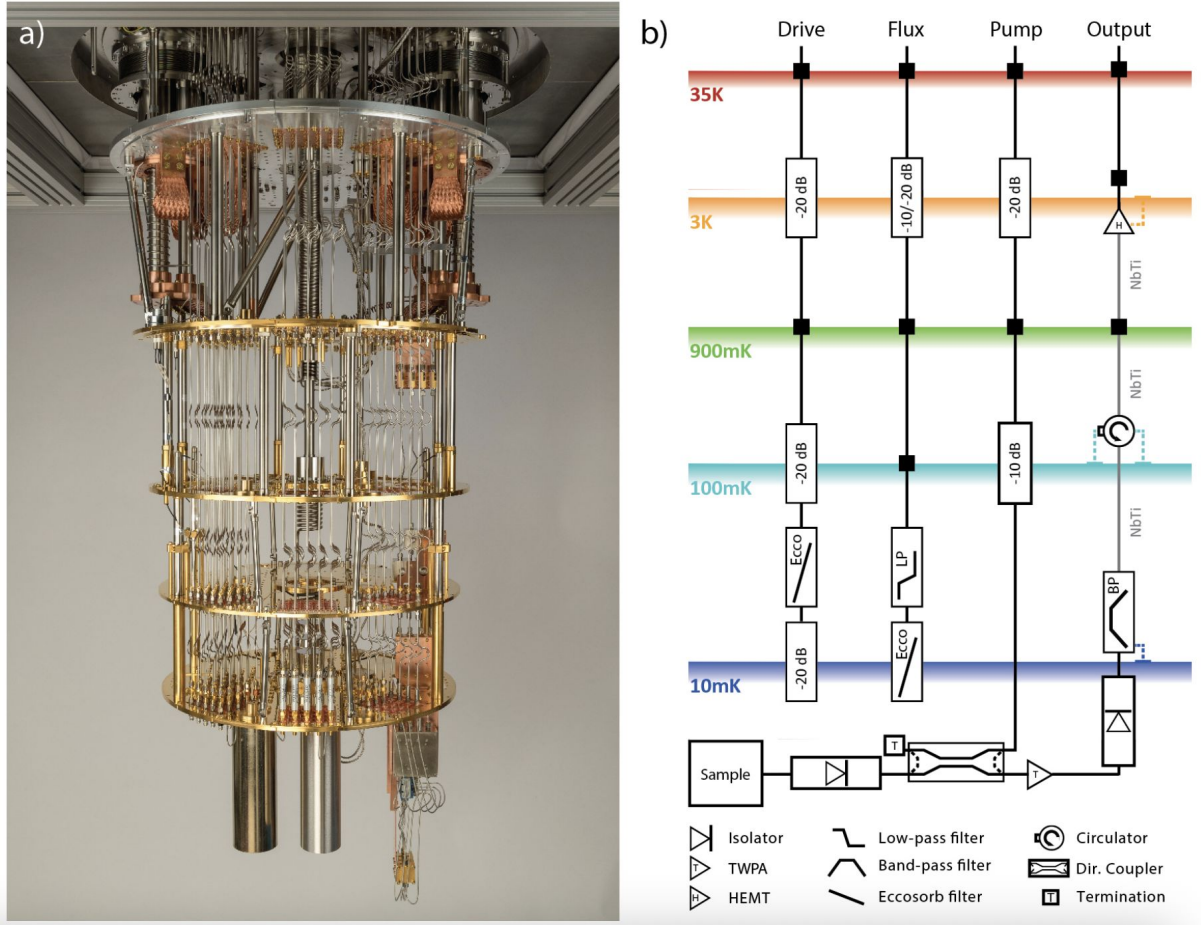
- A **Dilution Refrigerator**



Wiring and Microwave lines

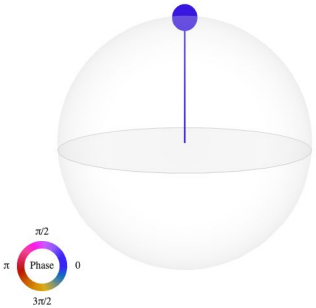
Concern 1:
Sending Signals IN
(Control)

Concern 2:
Getting Signals OUT
(Readout)

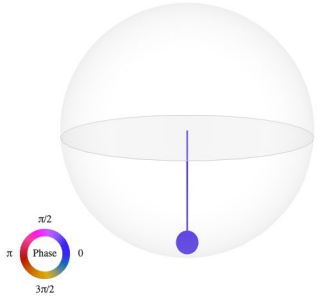


[3] S.Krinner et al. (2019)

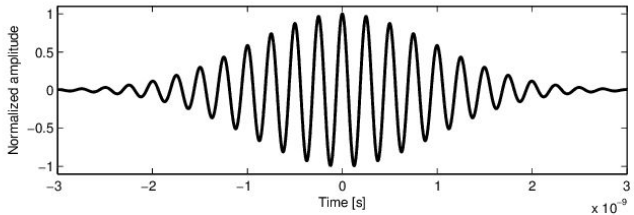
How to Perform a Gate

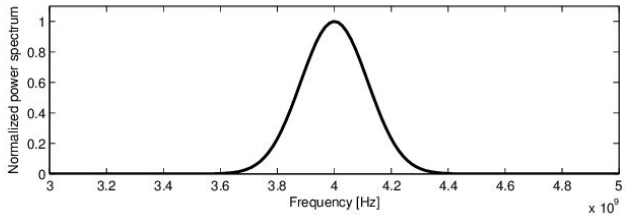


qc.x(0)



- Send precisely shaped microwave pulse (frequency, amplitude, duration)
- e.g. 4 GHz, 40ns (typical X gate speed)





All gates are just pulses

`X` Gate: A 20ns pulse
`H` Gate: A 10ns pulse with a different phase.
`CNOT`: A more complex sequence of pulses on two qubits.

"A quantum algorithm is just a complex symphony of microwave pulses."

Conclusion:

So, we went from...

1. A Nobel-Prize *proof* (the junction is quantum).
2. An *engineered solution* (the Transmon).
3. A complex *house* (the fridge and wiring).
4. ...all to deliver one simple microwave *pulse* that runs `qc.x(0)`.

This all was **Superconducting** approach. Now, **Debopriyo Biswas** will show how these complicated problems can be tackled in a totally different and powerful way : **Trapped Ions**

Thanks for your patience!
Any Questions?