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Nobel Prize in Physics 2025
RAL presentation

Dr Jonathan Burnett

Deputy Director of Research – National Quantum Computing Centre

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

National Quantum Computing Centre

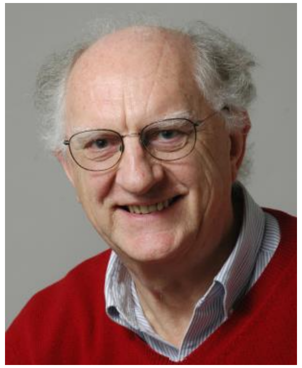
Engineering and Physical Sciences Research Council

Science and Technology Facilities Council

NOT GOVERNMENT POLICY

Nobel prize in Physics 2025

“For the discovery of macroscopic quantum mechanical tunnelling and energy quantisation in an electric circuit”



John Clarke (born 1942)
Professor Emeritus at UC Berkeley

Michel H. Devoret (born 1953)
Professor Emeritus at Yale
Professor at UC Santa Barbara
Chief Scientist at Google AI

John M. Martinis (born 1958)
Professor Emeritus at UC Santa Barbara
Team-lead Google AI
Co-Founder & CTO at QoLab

+Many awards and honours between them

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Nobel prize in Physics 2025

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

Headline paper(s) –

- Devoret, Martinis & Clarke PRL 55 (1985)
- Martinis, Devoret & Clarke, PRL 55 (1985)

Accompanying papers

- Devoret, Martinis, Esteve & Clarke, PRL 53 (1984)
- Martinis, Devoret & Clarke, PRB 35 (1987)
- Devoret, Esteve, Martinis, Cleland & Clarke, PRB 36 (1987)
- Clarke, Cleland, Devoret, Esteve & Martinis, Science 239 (1988)

VOLUME 55, NUMBER 18 PHYSICAL REVIEW LETTERS 28 OCTOBER 1985

Measurements of Macroscopic Quantum Tunneling out of the Zero-Voltage State of a Current-Biased Josephson Junction

Michel H. Devoret,[a] John M. Martinis, and John Clarke
Department of Physics, University of California, Berkeley, California 94720, and Materials and Molecular Research Division, Lawrence Berkeley Laboratory, Berkeley, California 94720
(Received 26 July 1985)

The escape rate of an underdamped ($Q \approx 30$), current-biased Josephson junction from the zero-voltage state has been measured. The relevant parameters of the junction were determined *in situ* in the thermal regime from the dependence of the escape rate on bias current and from resonant activation in the presence of microwaves. At low temperatures, the escape rate became independent of temperature with a value that, with no adjustable parameters, was in excellent agreement with the zero-temperature prediction for macroscopic quantum tunneling.

PACS numbers: 74.50.+r, 03.65.−w, 05.30.−d, 05.40.+j

The observation of macroscopic quantum tunneling is regarded as a test of whether quantum mechanics is valid for macroscopic variables, a fundamental question[1] that has only recently been addressed experimentally. The necessary conditions for the observation of macroscopic quantum tunneling can be realized in the current-biased Josephson tunnel junction, where the phase difference between the two superconductors is the macroscopic variable, and the tunneling occurs from the zero-voltage state to the nonzero-voltage state. Previous experiments on a current-biased Josephson junction[2–4] or on a superconducting ring interrupted by a Josephson junction[5–7] have yielded results that have been interpreted as being consistent with the theoretical predictions for macroscopic quantum tunneling. In this Letter, we present results of

In the zero-voltage state, the plasma frequency $\omega_p/2\pi$ of small oscillations of the particle at the bottom of the well is $\omega_p = (2\pi I_0/C\Phi_0)^{1/2}[(1-(I/I_0)^2]^{1/4}$, while the damping factor is $Q = \omega_p RC$.

In the thermal regime ($k_B T >> \hbar\omega_p$), the escape of the particle from the well occurs via thermal activation at a rate[10]

$$\Gamma_t = a_t(\omega_p/2\pi)\exp(-\Delta U/k_B T), \quad (1)$$

where $a_t = 4/[(1+Qk_BT/1.8\Delta U)^{1/2}+1]^2$ is of the order of unity in our experiment, k_B is Boltzmann's constant, and T is the temperature. In the quantum regime ($k_B T << \hbar\omega_p$), to lowest order in $1/Q$ the escape is predicted to occur via macroscopic quantum tunneling at a rate[11]

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Outline

Background physics

- Quantum tunnelling
- When might we expect quantum behaviour
- Superconductivity
- Josephson effect

Walk through the experiment

- Experimental setup
- Results – tunnelling
- Results – quantisation

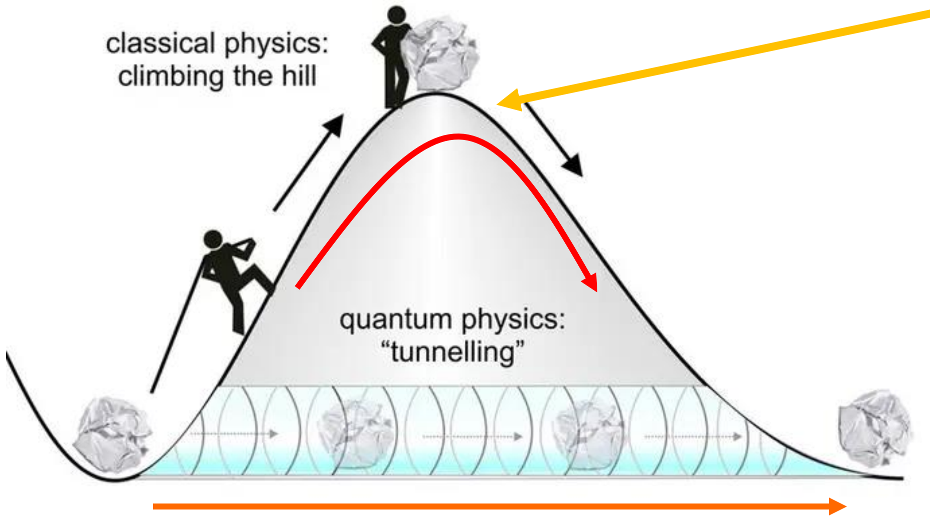
So what followed

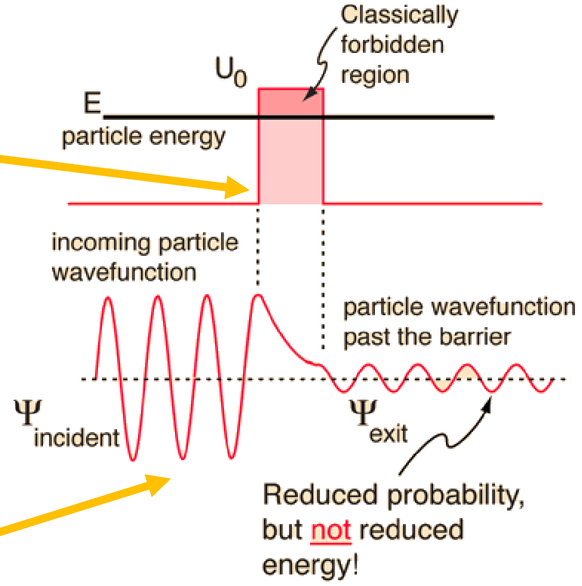
Quantum Computing in the UK

Quantum tunnelling

Concept of classical mechanics –
have to climb over energy barrier (hill)

- Forbidden from being inside





Concept of a quantum particle
– able to tunnel through the energy barrier (hill)

- Probability of quantum particle existing on far side (tunnelled)

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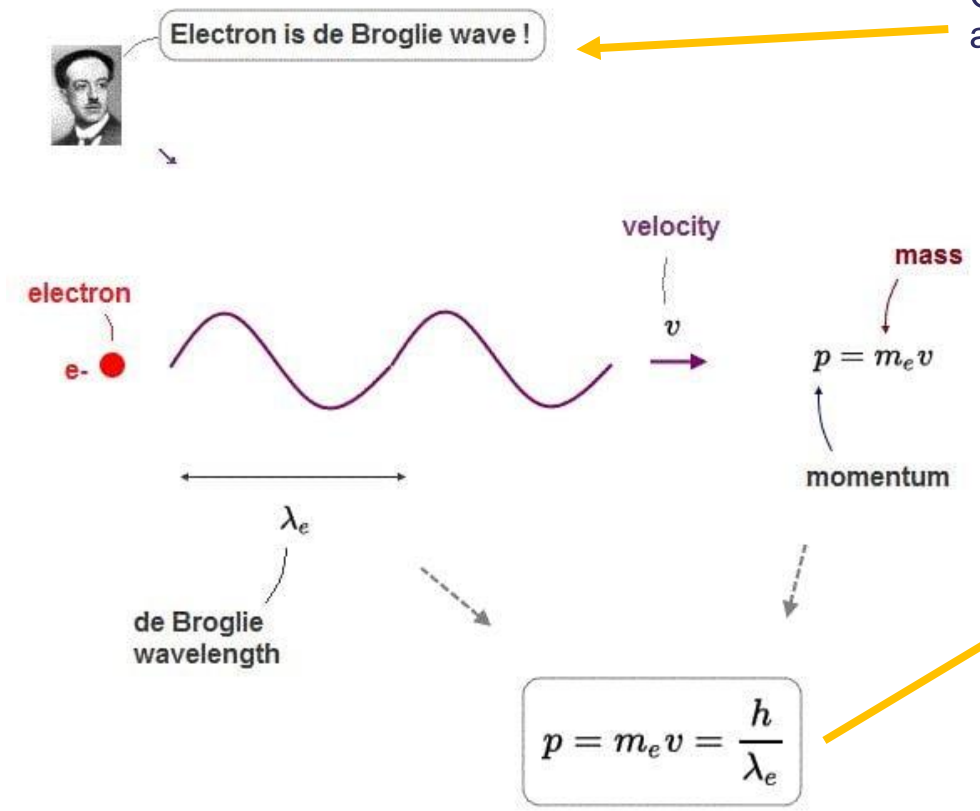
Source (left) – https://www.mpg.de/549767/electrons-caught-in-the-act-of-tunnelling
Source (right) – http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/barr.html

When does something behave in a quantum way?

Quantum mechanical property of wave-particle duality, an electron behaves both as a ***particle*** and as a ***wave***



$$\lambda = \frac{h}{\rho}$$

Lets compare an electron to a cannon-ball

Electron (mass $9\text{x}10^{-31}$ kg, velocity $2\text{x}10^{6}$ ms^{-1})

Wavelength $3\text{x}10^{-10}$ m -> An atomic length-scale
-> **quantum behaviour expected**

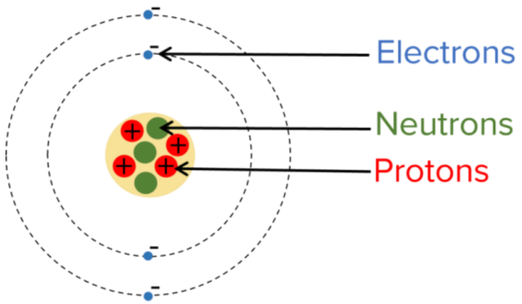
Cannon-ball (mass 10 kg, velocity $3\text{x}10^{2}$ ms^{-1})

Wavelength $2\text{x}10^{-36}$ m -> unphysically small
-> **no quantum behaviour expected**

Source (left) – https://interestingengineering.com/science/what-is-an-electron-its-discovery-nature-and-everything-else

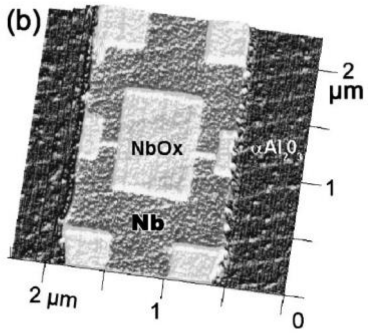
Micro- and Macro- systems

Microscopic system e.g. an atom (or electron, or photon)



Can quantify properties
- Mass, charge, nuclear spin etc.

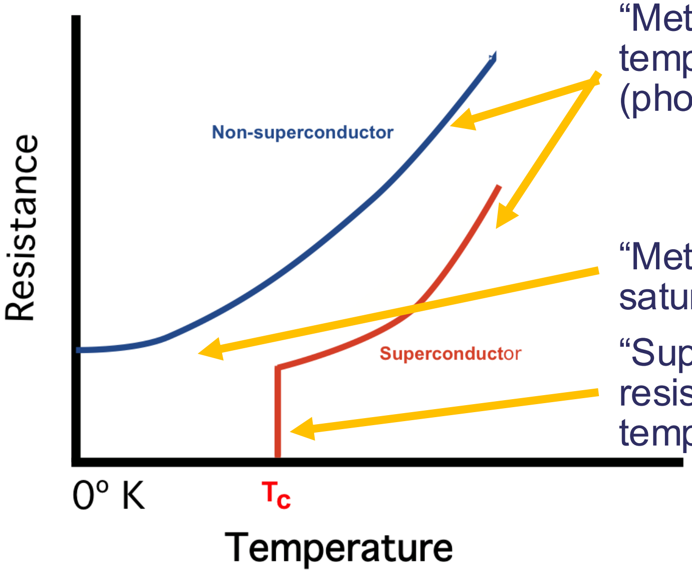
Macroscopic system e.g. Niobium circuit



Hard to quantify "size"
- How many atoms?
- What about imperfections?
Order-of magnitude estimates of properties

Source (left) – https://mmerevise.co.uk/gcse-physics-revision/atomic-structure/
Source (right) – V. Bouchiat et. al., Applied Physics Letters, 79 (2001)

Superconductivity



"Metallic" behaviour, reducing temperature reduces lattice vibrations (phonons) and reduces resistance

"Metallic" behaviour, resistance saturates due to impurities / defects

"Superconductor" behaviour, resistance drops to zero at a critical temperature Tc

Superconductivity discovered in 1911 – K Onnes
Theory descriptions – phenomelogical Ginzberg-Landau 1950s
Microscopic model Bardeen, Cooper and Schrieffer 1957

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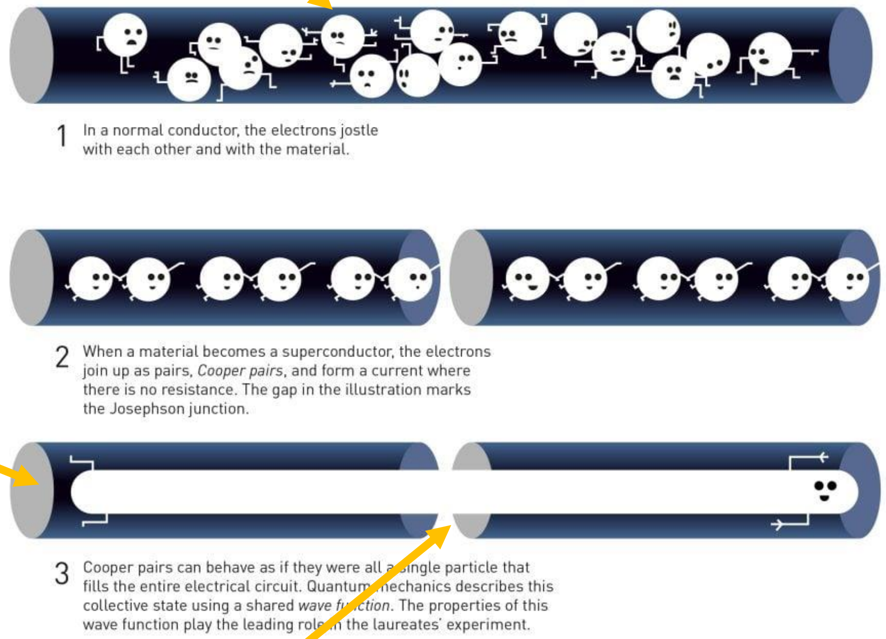
Source (left) – http://www.el.9.mri-q.com/superconductivity.html

Superconductivity

Electron collisions is what gives resistance

Electrons combine into Cooper Pairs which do not collide -> zero resistance

Cooper Pairs described by a collective quantum state (wavefunction phase φ_1)



Theory motivation for experiment

It is not clear that this wavefunction (collection from many many electrons) is a quantum mechanical variable! - A.J. Leggett (1983)

“Gap” represents a tunnel barrier called a Josephson junction, the wavefunction can tunnel through.

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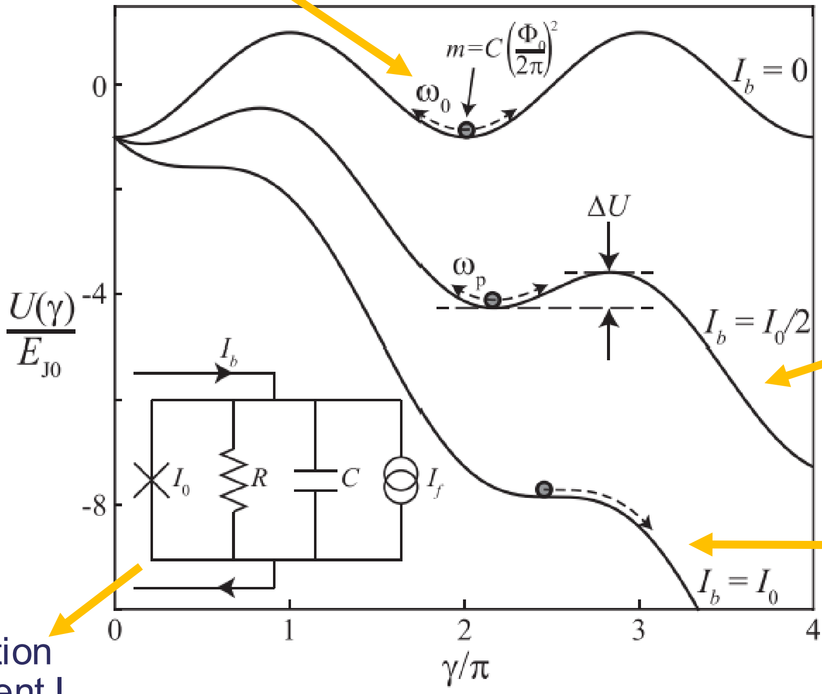
Source (left) – http://www.el.9.mri-q.com/superconductivity.html
Source (right) – Nobel Prize in Physics 2025 - Popular information - NobelPrize.org

Josephson junction circuit

Josephson junction circuit acts as a ***particle in a well***



Josephson-junction biased with current I_b

When Bias current I_b is 0, potential is a sinusoid

When Bias current $0 < I_b < I_0$, potential is a tilted sinusoid

When Bias current $I_b = I_0$, potential is effectively a slide

Height of the potential ΔU scales with I_b

Oscillation frequency ω_p also scales with I_b

Source (left) – S. Carabello et. al., Journal of Applied Physics, 120 (2016)

Josephson junction circuit

Look at the transport characteristics (I-V)

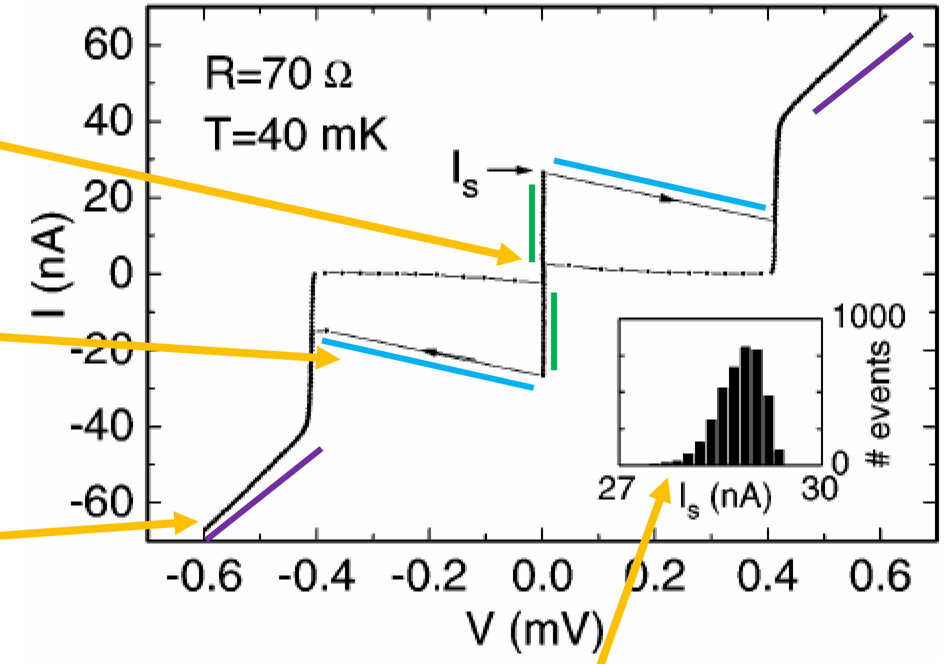
Start at zero current & ramp current

Observe a superconducting current (zero voltage state) is sustained up to a characteristic current I_S

At the switching I_S current the junction switches to a switches to a voltage state where it has resistance

Junction acts a threshold detector

When large bias current is applied, the Josephson junction behaves like a normal conductor e.g. V=IR



Through repeat and reset cycles, can look at the distribution of the switching current I_S

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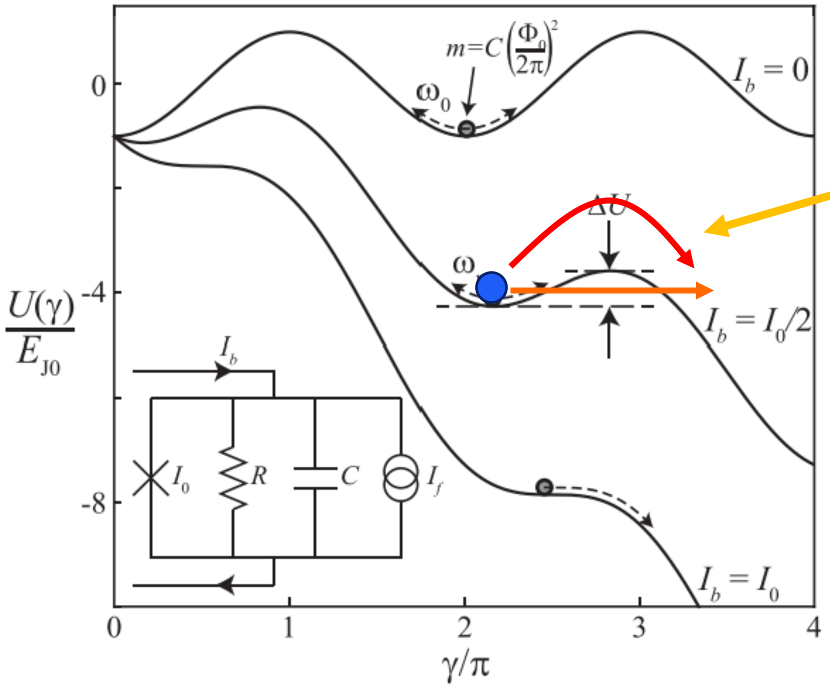
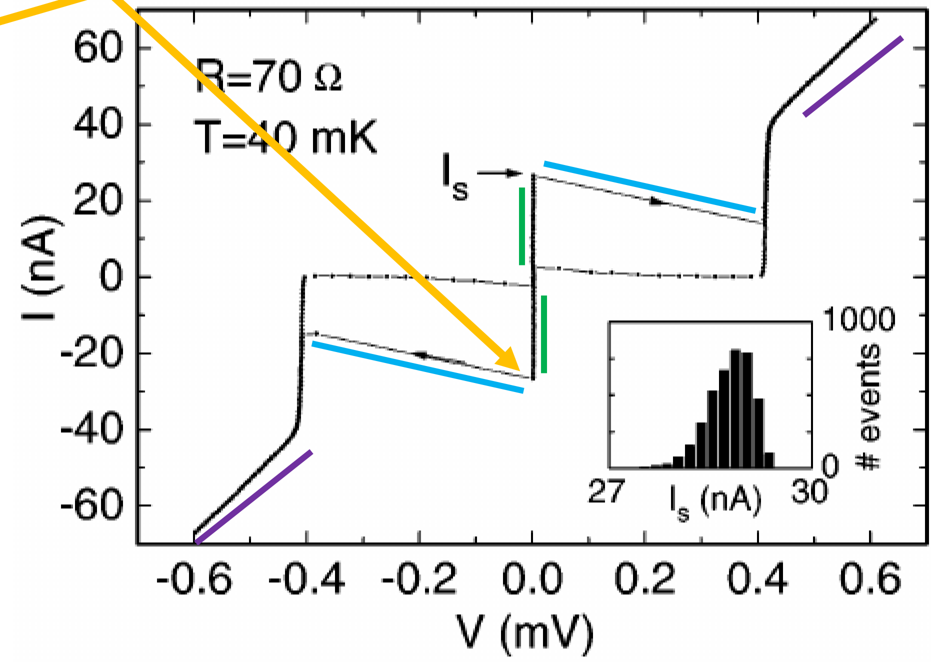
Source (right) – D. Vion et. al., Physical Review Letters, 77 (1996)

Josephson junction circuit

Junction acts a threshold detector with a switching event happening at I_S where it switches to a voltage state



Switching to a voltage state occurs when particle is **escaping** the potential well, but we do not know if this was classical or quantum tunnelling.



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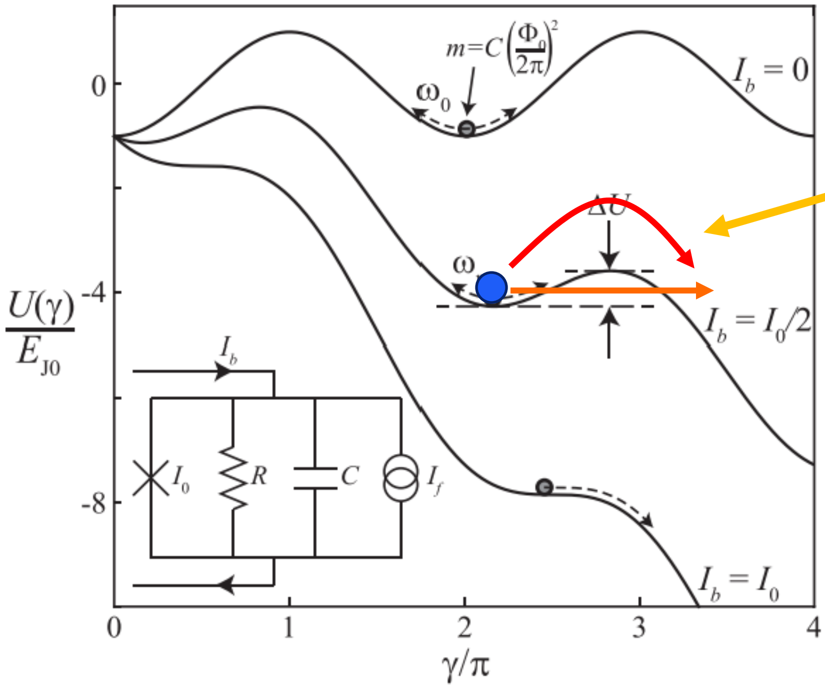
Source (left) – S. Carabello et. al., Journal of Applied Physics, 120 (2016)
Source (right) – D. Vion et. al., Physical Review Letters, 77 (1996)

Experiment 1

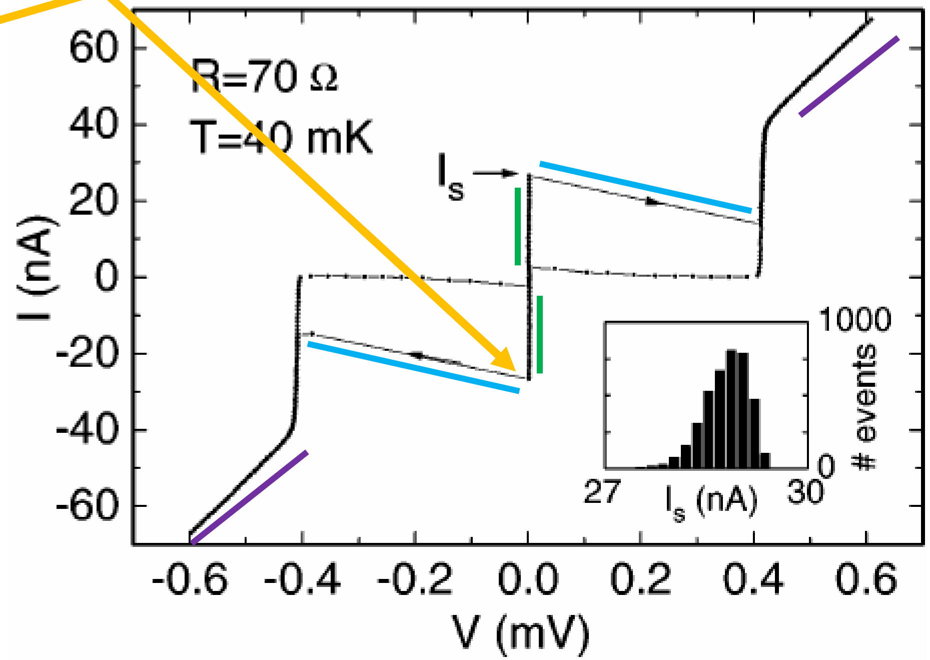
Create a system with a current ramp, use the voltage state as a threshold detector, vary temperature and look for non-classical behaviour (i.e. quantum tunnelling)

Experimental design

Junction acts a threshold detector with a switching event happening at I_S where it switches to a voltage state



Switching to a voltage state occurs when particle is **escaping** the potential well, but we do not know if this was classical or quantum tunnelling.



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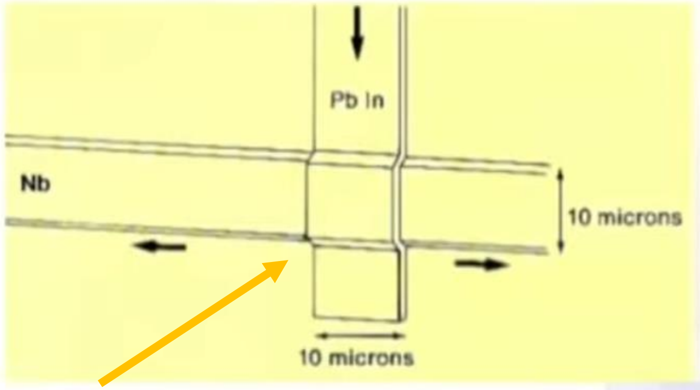
Source (left) – S. Carabello et. al., Journal of Applied Physics, 120 (2016)
Source (right) – D. Vion et. al., Physical Review Letters, 77 (1996)

Experiment 1

Create a system with a current ramp, use the voltage state as a threshold detector, vary temperature and look for non-classical behaviour (i.e. quantum tunnelling)

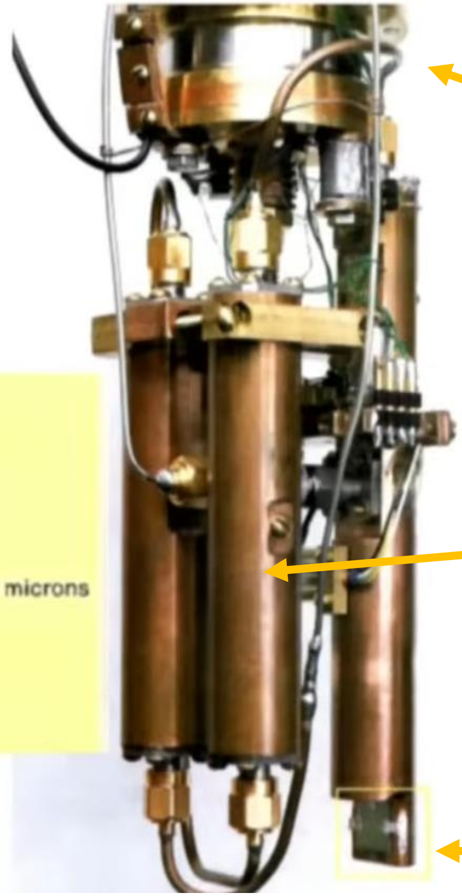
Experimental design

EXPERIMENTAL SETUP
OF THE 1985 BERKELEY
EXPERIMENT



Nb-NbOx-PbSn Josephson junction

(Superconductor-Insulator-Superconductor)



Dilution fridge to reach 20mK

(-273.13 Celsius)

Cu-Filters

(explained later)

Sample mount

(Josephson device sits here)

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Source (right) – Nobel lecture presentations

Experiment 1

Create a system with a current ramp, use the voltage state as a threshold detector, vary temperature and look for non-classical behaviour (i.e. quantum tunnelling)

Experimental design

Ramp-generator and A/D for measurement

Lots of filtering + screened-room

Screened room for removing AM-radio, FM-radio, RADAR

Filters for removing current noise from room-temperature components

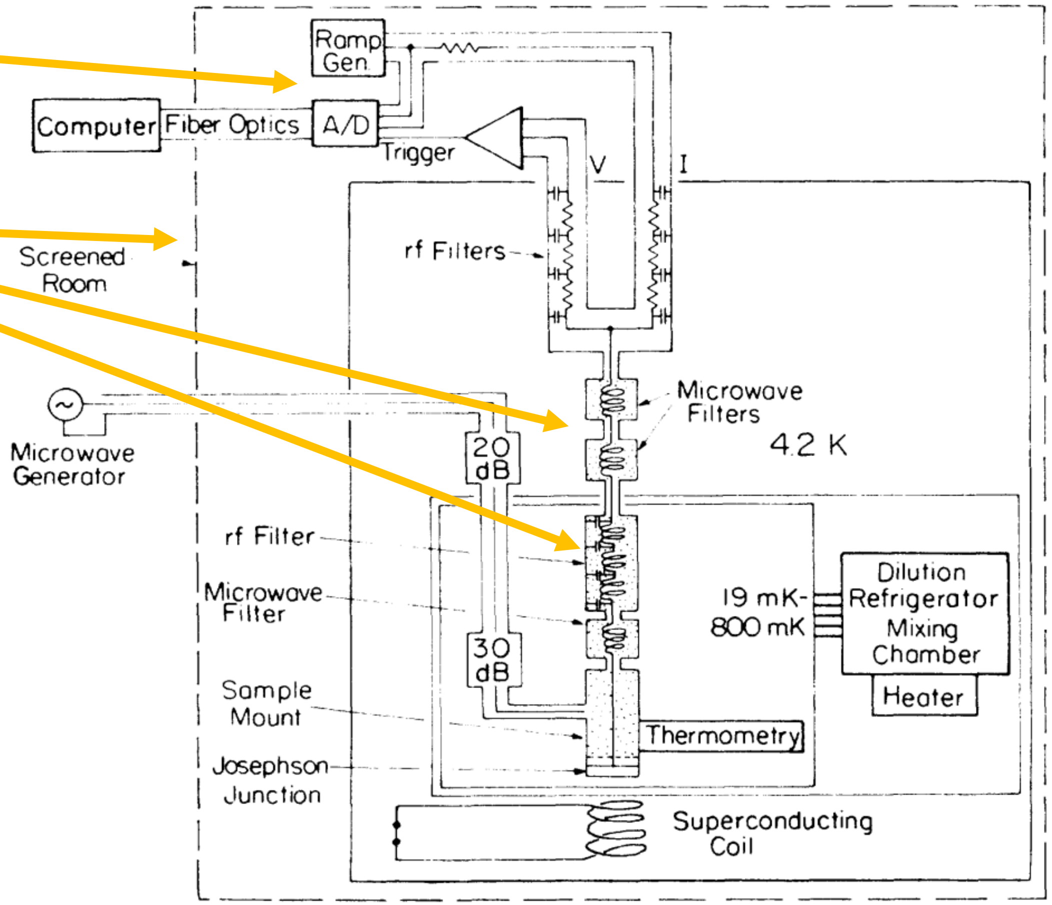


FIG. 3. Schematic drawing of apparatus.

Source (right) – Martinis, Devoret & Clarke, Physical Review B 35 (1987

Experiment 1

Create a system with a current ramp, use the voltage state as a threshold detector, vary temperature and look for non-classical behaviour (i.e. quantum tunnelling)

Experimental design

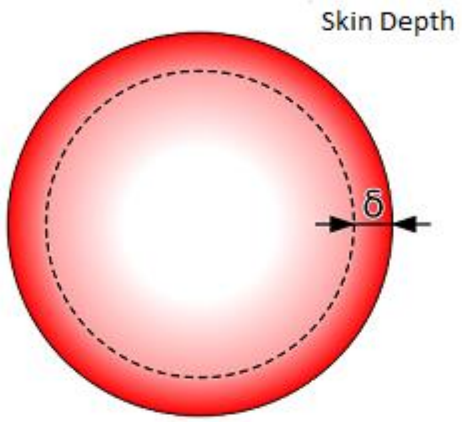
- Sample mount for the Josephson junction device
- Dilution fridge for cooling to 20mK
- Ramp-generator and A/D for measurement
- Lots of filtering + screened-room
  - Screened room for removing AM-radio, FM-radio, RADAR
  - Filters for removing current noise from room-temperature components

$$I_{RMS} = \sqrt{\frac{4\, k_B\, T\, BW}{R}}$$

$$I_b = I_{RMS} + I_{RampGen}$$

Without filtering,
➔ 2μA !

With filtering
➔ 0.0001μA = 0.1 nA!



$$\partial = \sqrt{\frac{\rho}{\pi f \mu_0 \mu_R}}$$

AC current concentrates at surface in skin depth.

Cu powder leads to large surface area -> large loss (filtering) at high frequencies

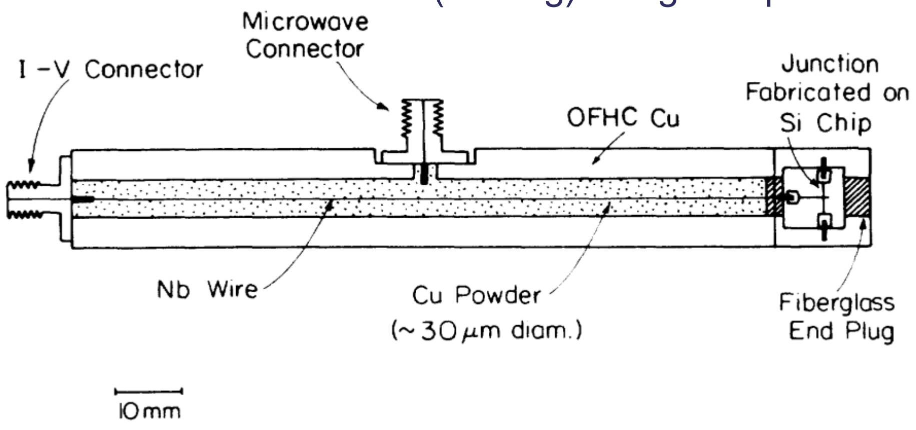


FIG. 4. Scale drawing of filter on which junction was mounted.

Source (right) – Martinis, Devoret & Clarke, Physical Review B 35 (1987)

Experiment 1

Create a system with a current ramp, use the voltage state as a threshold detector, vary temperature and look for non-classical behaviour (i.e. quantum tunnelling)

Experimental design

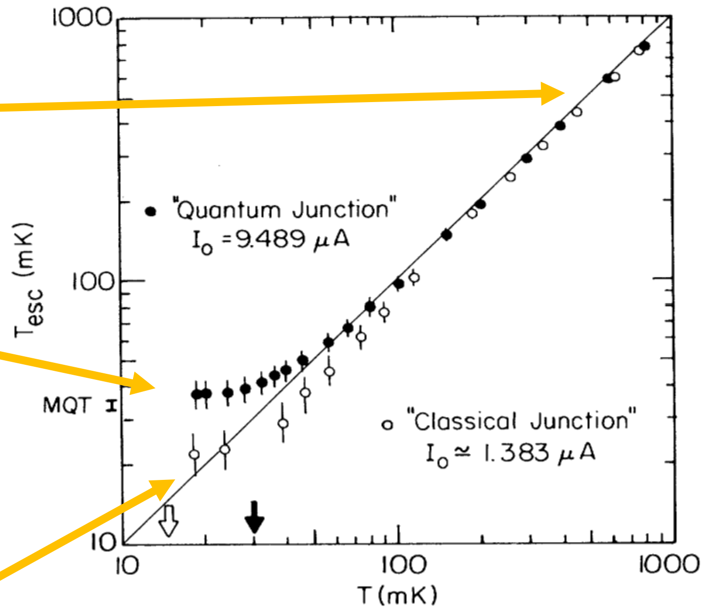
Measuring the escape events by measuring switching current switching events while varying temperature (x-axis)

High temperature, find switching events proportional to temperature

- Switching is classical (thermally assisted)

Low temperature, find switching events saturate at non-zero

- Evidence for quantum tunnelling



Had to demonstrate the saturation was not due to electrical noise!

Applying magnetic field suppresses superconductivity -> Suppress the critical current

Suppress the transition to quantum behaviour to lower threshold and no longer observe the evidence for quantum tunnelling

- Self calibration that the plateau was not due to noise!

Evidence for Macroscopic quantum tunnelling!

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Source (right) – Martinis, Devoret & Clarke, Physical Review B 35 (1987)

Experimental design

Experiment 2

With quantum behaviour shown, now drive with RF and look for resonant enhancements which would be evidence for **quantised energy levels**

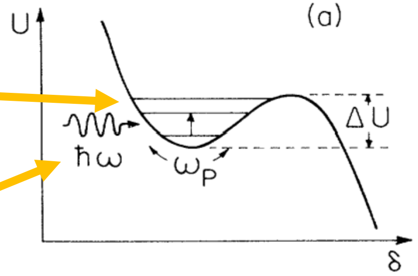
If the phase is a quantum system, would expect quantised energy levels.

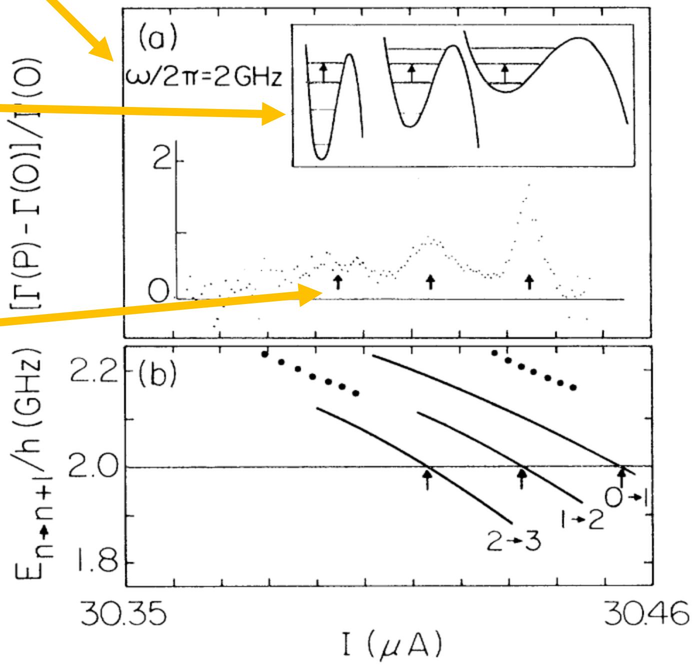
Apply microwave radiation at 2 GHz

When sweeping I_b we change the shape of the potential well,
-> which changes energy levels

When energy levels swept through the 2 GHz radiation, we then see peaks in the escape rate
-> resonant enhancement

Evidence for quantised energy levels!





Source (right) – Martinis, Devoret & Clarke, Physical Review B 35 (1987)

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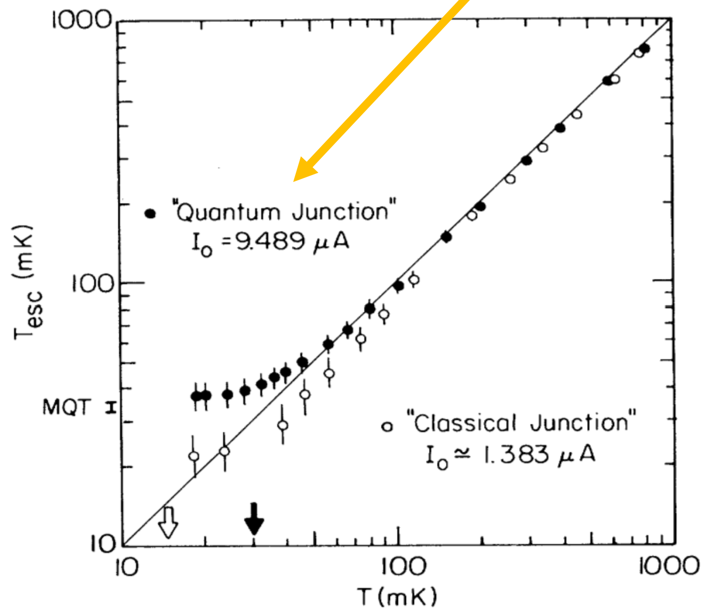
Nobel prize in Physics 2025

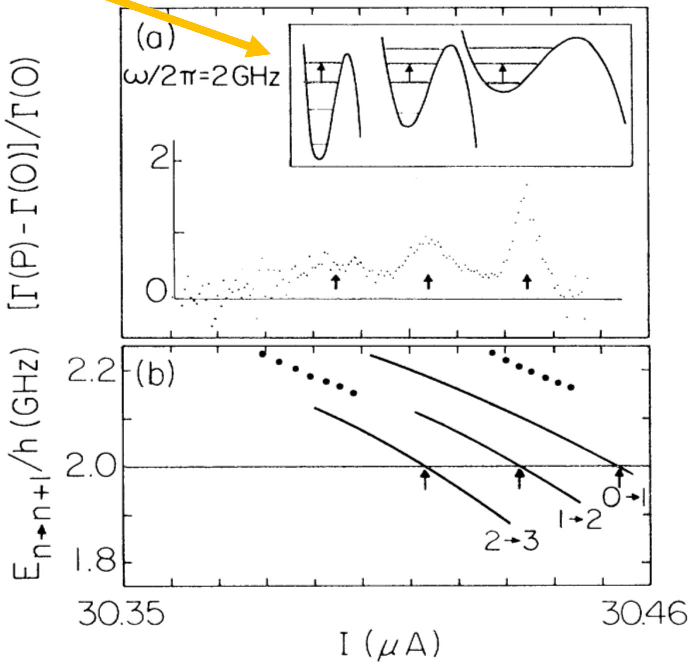
"For the discovery of macroscopic quantum mechanical tunnelling and energy quantisation in an electric circuit"

Discovery of macroscopic quantum tunnelling in an electronic circuit

Discovery of energy quantisation in an electric circuit

An electric circuit acting as an ***artificial atom***





Source (both) – Martinis, Devoret & Clarke, Physical Review B 35 (1987)

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An electric circuit acting as an ***artificial atom***

… so quantum computing?

So what followed: I

VOLUME 58, NUMBER 9 PHYSICAL REVIEW LETTERS 2 MARCH 1987

Superconductivity at 93 K in a New Mixed-Phase Y-Ba-Cu-O Compound System at Ambient Pressure

M. K. Wu, J. R. Ashburn, and C. J. Torng
Department of Physics, University of Alabama, Huntsville, Alabama 35899

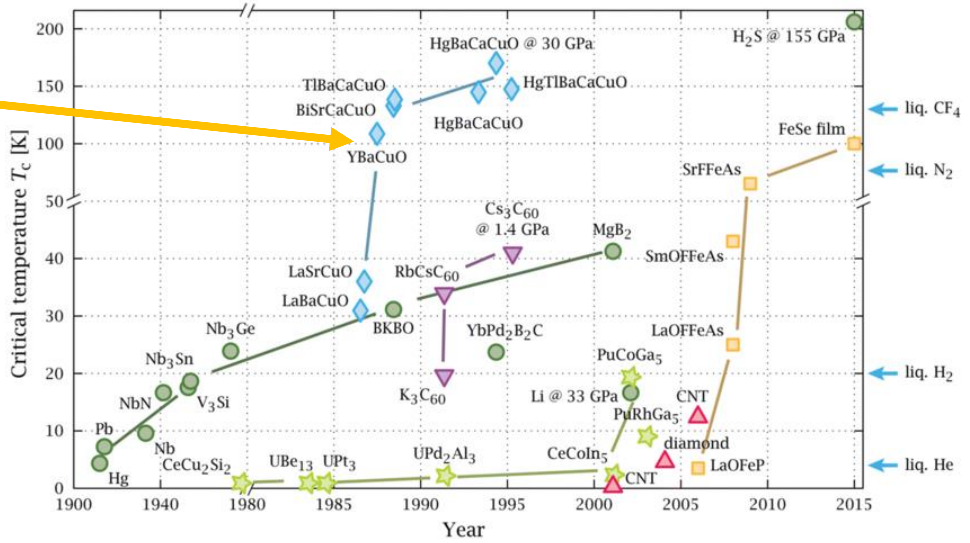
and

P. H. Hor, R. L. Meng, L. Gao, Z. J. Huang, Y. Q. Wang, and C. W. Chu[(a)]
Department of Physics and Space Vacuum Epitaxy Center, University of Houston, Houston, Texas 77004
(Received 6 February 1987; Revised manuscript received 18 February 1987)

A stable and reproducible superconductivity transition between 80 and 93 K has been unambiguously observed both resistively and magnetically in a new Y-Ba-Cu-O compound system at ambient pressure. An estimated upper critical field $H_{c2}(0)$ between 80 and 180 T was obtained.

PACS numbers: 74.70.Ya

The search for high-temperature superconductivity and novel superconducting mechanisms is one of the most challenging tasks of condensed-matter physicists and material scientists. To obtain a superconducting state reaching beyond the technological and psychologi- sharper transition. A transition width[10] of 2 K and an onset[11] T_c of 48.6 K were obtained at ambient pressure. Pressure[8,12] was found to enhance the T_c of the La-Ba-Cu-O system at a rate of greater than 10^{-3} K bar^{-1} and to raise the onset T_c to 57 K, with a "zero-resis-



Other results relating to high-Tc superconductors dominated funding and research in condensed matter

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Source (right) – Little, Journal of Superconductivity & Magnetism, 33 (2020)

So what followed: II

VOLUME 75, NUMBER 25 PHYSICAL REVIEW LETTERS 18 DECEMBER 1995

Demonstration of a Fundamental Quantum Logic Gate

C. Monroe, D. M. Meekhof, B. E. King, W. M. Itano, and D. J. Wineland
National Institute of Standards and Technology, Boulder, Colorado 80303
(Received 14 July 1995)

We demonstrate the operation of a two-bit "controlled-NOT" quantum logic gate, which, in conjunction with simple single-bit operations, forms a universal quantum logic gate for quantum computation. The two quantum bits are stored in the internal and external degrees of freedom of a single trapped atom, which is first laser cooled to the zero-point energy. Decoherence effects are identified for the operation, and the possibility of extending the system to more qubits appears promising.

PACS numbers: 89.80.+h, 03.65.–w, 32.80.Pj

We report the first demonstration of a fundamental quantum logic gate that operates on prepared quantum states. Following the scheme proposed by Cirac and ... computers and CN gates involving a dipole-dipole interaction between quantum dots or atomic nuclei [6,7,11,12] may suffer from decoherence efforts. The light shifts on

1995 – Trapped-ion qubit demonstrated

PRL 100, 113003 (2008) PHYSICAL REVIEW LETTERS week ending 21 MARCH 2008

Rabi Oscillations between Ground and Rydberg States with Dipole-Dipole Atomic Interactions

T. A. Johnson, E. Urban, T. Henage, L. Isenhower, D. D. Yavuz, T. G. Walker, and M. Saffman
Department of Physics, University of Wisconsin, 1150 University Avenue, Madison, Wisconsin 53706, USA
(Received 2 November 2007; published 19 March 2008)

We demonstrate Rabi oscillations of small numbers of ^{87}Rb atoms between ground and Rydberg states with $n \le 43$. Coherent population oscillations are observed for single atoms, while the presence of two or more atoms decoheres the oscillations. We show that these observations are consistent with van der Waals interactions of Rydberg atoms.

DOI: 10.1103/PhysRevLett.100.113003 PACS numbers: 32.80.Rm, 03.67.–a

Atoms in highly excited Rydberg states with principal quantum number $n \gg 1$ have very large transition dipole ... The experiment starts by loading a far-off-resonance optical trap (FORT) from a ^{87}Rb vapor cell magneto-

2003 – Photonics qubit demonstrated

PHYSICAL REVIEW A 68, 032316 (2003)

Experimental controlled-NOT logic gate for single photons in the coincidence basis

T. B. Pittman, M. J. Fitch, B. C Jacobs, and J. D. Franson
Applied Physics Laboratory, Johns Hopkins University, Laurel, Maryland 20723, USA
(Received 2 April 2003; published 26 September 2003)

We report a proof-of-principle demonstration of a probabilistic controlled-NOT gate for single photons. Single-photon control and target qubits were mixed with a single ancilla photon in a device constructed using only linear optical elements. The successful operation of the controlled-NOT gate relied on post-selected three-photon interference effects, which required the detection of the photons in the output modes.

DOI: 10.1103/PhysRevA.68.032316 PACS number(s): 03.67.Lx, 42.50.Dv, 42.65.Lm

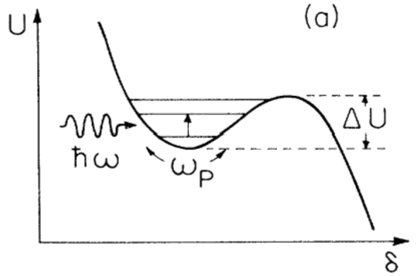
There has been considerable interest in a linear optics approach to quantum computing [1,2], in which probabilistic two-qubit logic operations are implemented using linear op- ... shown in Fig. 1(a). Here the logical value of each of the qubits is represented by the polarization state of a single photon, where a horizontal polarization state $|H\rangle$ represents a

2008 – Neutral atoms qubit demonstrated

"Natural" qubits

An electric circuit acting as an ***artificial atom***

… so quantum computing?



Qubit is building block of quantum computer

Isolate and manipulate the occupation of two energy levels
➔Qubit

letters to nature

Coherent control of macroscopic quantum states in a single-Cooper-pair box

Y. Nakamura*, Yu. A. Pashkin† & J. S. Tsai*
* *NEC Fundamental Research Laboratories, Tsukuba, Ibaraki 305-8051, Japan*
† *CREST, Japan Science and Technology Corporation (JST), Kawaguchi, Saitama 332-0012, Japan*

A nanometre-scale superconducting electrode connected to a reservoir via a Josephson junction constitutes an artificial two-level electronic system: a single-Cooper-pair box. The two levels consist of charge states (differing by 2*e*, where *e* is the electronic charge) that are coupled by tunnelling of Cooper pairs through the junction. Although the two-level system is macroscopic,

1999 – superconducting qubit demonstrated

RESEARCH ARTICLES

Coherent Manipulation of Coupled Electron Spins in Semiconductor Quantum Dots

J. R. Petta,[1] A. C. Johnson,[1] J. M. Taylor,[1] E. A. Laird,[1] A. Yacoby,[2] M. D. Lukin,[1] C. M. Marcus,[1] M. P. Hanson,[3] A. C. Gossard[3]

We demonstrated coherent control of a quantum two-level system based on two-electron spin states in a double quantum dot, allowing state preparation, coherent manipulation, and projective readout. These techniques are based on rapid electrical control of the exchange interaction. Separating and later recombining a singlet spin state provided a measurement of the spin dephasing time, T_2^*, of ~10 nanoseconds, limited by hyperfine interactions with the gallium arsenide host nuclei. Rabi oscillations of two-electron spin states were demonstrated, and spin-echo pulse sequences were used to suppress hyperfine-induced dephasing. Using these quantum control techniques, a coherence time for two-electron spin states exceeding 1 microsecond was observed.

2006 – semiconducting qubit demonstrated

"Engineered" qubits

2025 Nobel prize recognizes that an electrical circuit can behave as an artificial atom

➔ Foundational to "engineered" qubits being possible

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UK-NQTP
(Quantum Mission 1)

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

Department for Science, Innovation & Technology

Policy paper
National Quantum Strategy Missions
Updated 22 November 2023

Key components

- 10-year goal with key milestone at 2035
- UK-based system with compute capabilities that should enable application

Not specified

- Modality – Hardware agnostic
- Fidelities – agnostic to specifics of error-mitigation, specifics of error-correction
- Qubit count – agnostic to specifics of error-correction

Quantum computing specifically part of IS-8 in UK Industrial Strategy 2025

By **2035**, achieving quantum advantage at scale through reaching **10^{12}(a trillion) quantum operations**, enabling **applications** such as optimising the production of clean hydrogen.

By 2032, demonstrating large-scale error correction capabilities with **10^9 (a billion) quantum operations**, with including accelerated drug discovery. applications

By 2028, extending beyond the NISQ-era with **10^6 (million) quantum operations**, which will enable the exploration of applications associated with the simulation of chemical processes, helping to improve catalyst design for example.

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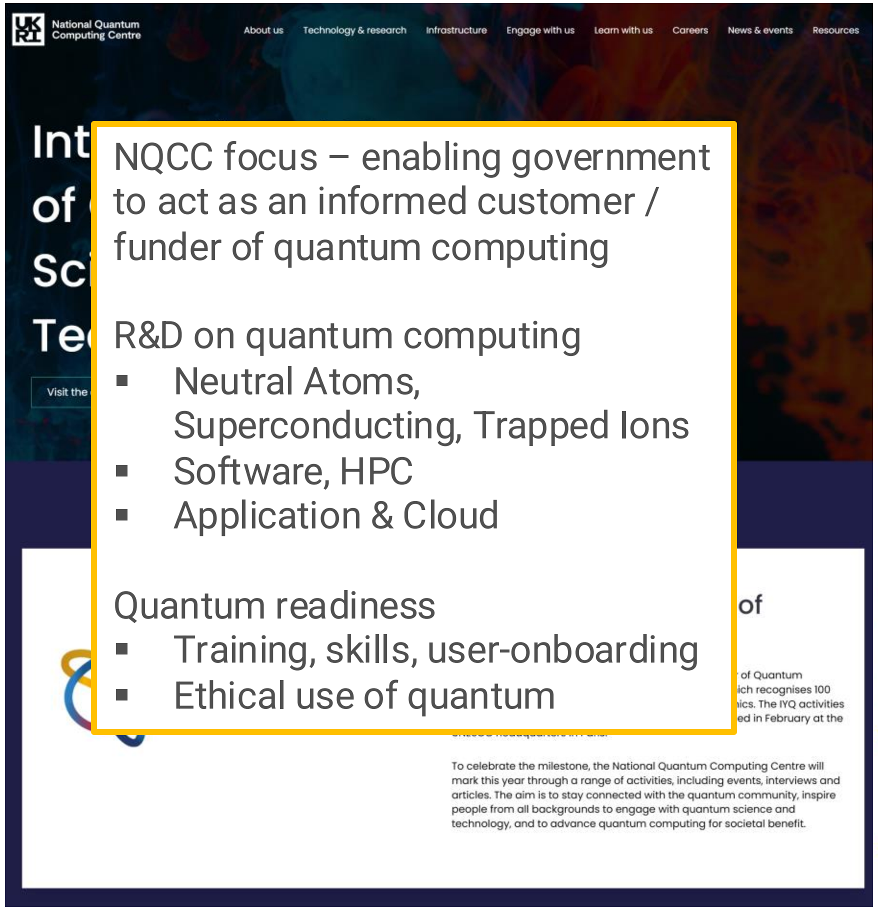
UKRI Quantum Computing



NQCC focus – enabling government to act as an informed customer / funder of quantum computing

R&D on quantum computing
- Neutral Atoms, Superconducting, Trapped Ions
- Software, HPC
- Application & Cloud

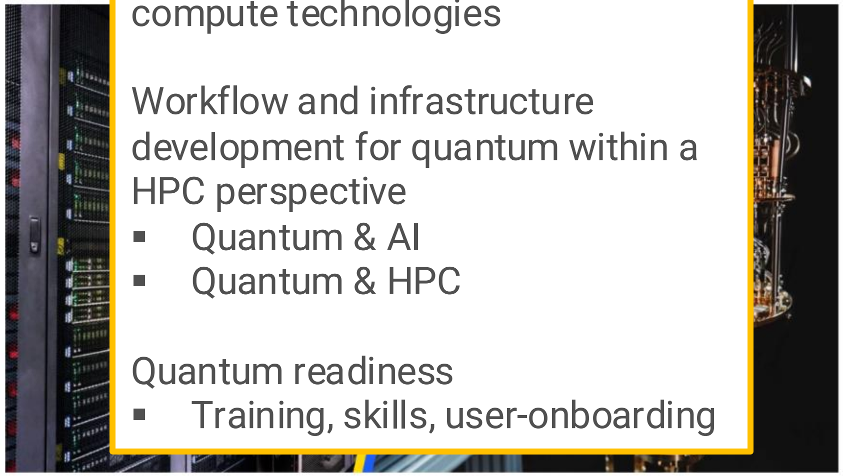
Quantum readiness
- Training, skills, user-onboarding
- Ethical use of quantum

Integrating Cat-Qubit Quantum Computers into Standard HPC Workflow and Job Sched

Hartree focus – Business transformation & integration of new compute technologies

Workflow and infrastructure development for quantum within a HPC perspective
- Quantum & AI
- Quantum & HPC

Quantum readiness
- Training, skills, user-onboarding



Alice & Bob, a global leader in the race for fault-tolerant quantum computing, today announced the software integration of their future QPUs with high performance computing (HPC) environments via SLURM, the world's most widely used workload management system, present in 60% of the world's top supercomputers.

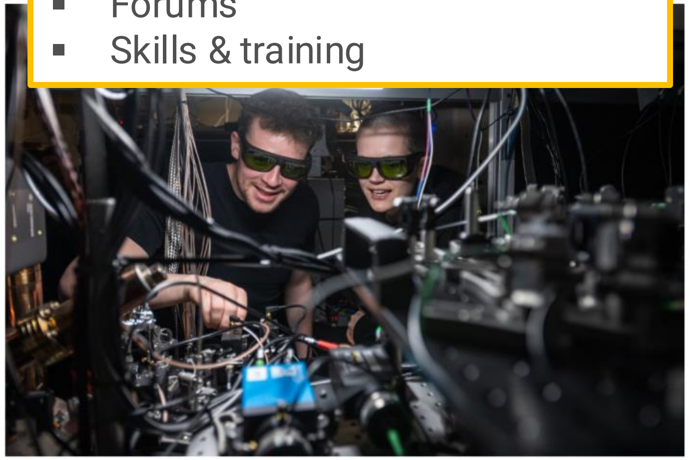
Developed in collaboration with the Science and Technology Facilities Council's (STFC) Hartree Centre through the Hartree National Centre for Digital Innovation (HNCDI), this integration makes Alice & Bob's technology compatible with existing HPC workflows, marking the first time cat-qubit technology is adapted for seamless scheduling and execution within standard HPC resource management frameworks.

QCI3: Hub for Quantum Computing via Integrated and Interconnected Implementations

Led by: Professor Dominic O'Brien, University of Oxford

QCi3 focus – Academic research hub – network of universities – underpinning science and applied research

- Working groups
- Forums
- Skills & training



Trapped Ions laboratory at the University of Oxford

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Science and Technology Facilities Council
Hartree Centre

QCi3 HUB

Summary

When does something behave quantum -> question of whether an electrical circuit (something macroscopic) could behave as a quantum object

Evidence found in electrical circuit demonstrating non-classical escape events i.e. **macroscopic quantum tunnelling**

Evidence found in electrical circuit demonstrating resonant enhancement of escape events i.e. **quantised energy levels**

Collectively – this means the electrical circuit acts an **artificial atom**

* Not all Quantum Computers based on macroscopic devices
– see instead AMO family (photonics, neutral atoms, Trapped Ions)

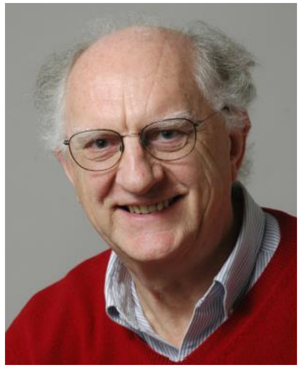
Quantum computing is part of IS-8 UK Industrial Strategy of 2025

- National Quantum Technologies Program: Quantum Mission 1 = 10^12 quantum operations by 2035 + quantum as a part of the digital sector
- UKRI activities in quantum computing -> NQCC, Hartree Centre, QCi3 hub (+ many more)

* Not all Quantum Technologies are
Quantum Computing!

Nobel prize in Physics 2025

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



John Clarke (born 1942)
Professor Emeritus at UC Berkeley

Michel H. Devoret (born 1953)
Professor Emeritus at Yale
Professor at UC Santa Barbara
Chief Scientist at Google AI

John M. Martinis (born 1958)
Professor Emeritus at UC Santa Barbara
Team-lead Google AI
Co-Founder & CTO at QoLab

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Measurements of Macroscopic Quantum Tunneling out of the Zero-Voltage State of a Current-Biased Josephson Junction

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(Received 26 July 1985)

The escape rate of an underdamped ($Q \approx 30$), current-biased Josephson junction from the zero-voltage state has been measured. The relevant parameters of the junction were determined *in situ* in the thermal regime from the dependence of the escape rate on bias current and from resonant activation in the presence of microwaves. At low temperatures, the escape rate became independent of temperature with a value that, with no adjustable parameters, was in excellent agreement with the zero-temperature prediction for macroscopic quantum tunneling.

PACS numbers: 74.50.+r, 03.65.−w, 05.30.−d, 05.40.+j

The observation of macroscopic quantum tunneling is regarded as a test of whether quantum mechanics is valid for macroscopic variables, a fundamental question[1] that has only recently been addressed experimentally. The necessary conditions for the observation of macroscopic quantum tunneling can be realized in the current-biased Josephson tunnel junction, where the phase difference between the two superconductors is the macroscopic variable, and the tunneling occurs from the zero-voltage state to the nonzero-voltage state. Previous experiments on a current-biased Josephson junction[2–4] or on a superconducting ring interrupted by a Josephson junction[5–7] have yielded results that have been interpreted as being consistent with the theoretical predictions for macroscopic quantum tunneling. In this Letter, we present results of

In the zero-voltage state, the plasma frequency $\omega_p/2\pi$ of small oscillations of the particle at the bottom of the well is $\omega_p = (2\pi I_0/C\Phi_0)^{1/2}[(1-(I/I_0)^2]^{1/4}$, while the damping factor is $Q = \omega_p RC$.

In the thermal regime ($k_B T >> \hbar\omega_p$), the escape of the particle from the well occurs via thermal activation at a rate[10]

$$\Gamma_t = a_t(\omega_p/2\pi)\exp(-\Delta U/k_B T), \quad (1)$$

where $a_t = 4/[(1+Qk_B T/1.8\Delta U)^{1/2}+1]^2$ is of the order of unity in our experiment, k_B is Boltzmann's constant, and T is the temperature. In the quantum regime ($k_B T << \hbar\omega_p$), to lowest order in $1/Q$ the escape is predicted to occur via macroscopic quantum tunneling at a rate[11]

Thanks for listening!

National Quantum Computing Centre