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Nobel Preis inspired notes on

Physics 2025

Macroscopic quantum tunnelling and quantisation

Bassano Vacchini @ FG3

Press release

PRESS RELEASE

7 October 2025

The Nobel Prize in Physics 2025

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2025 to

John Clarke
University of California, Berkeley, USA

Michel H. Devoret
Yale University, New Haven, CT,
University of California, Santa Barbara and
Google Quantum AI, Santa Barbara, CA, USA

John M. Martinis
University of California, Santa Barbara
and Qolab, Los Angeles, CA, USA

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

that is ...

PRESSMEDDELANDE

7 oktober 2025

Nobelpriset i fysik 2025

Kungl. Vetenskapsakademien har beslutat utdela Nobelpriset i fysik 2025 till

John Clarke
University of California, Berkeley, USA

Michel H. Devoret
Yale University, New Haven, CT,
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Google Quantum AI, Santa Barbara, CA, USA

John M. Martinis
University of California, Santa Barbara
och Qolab, Los Angeles, CA, USA

"för upptäckten av makroskopisk kvantmekanisk tunnling och energikvantisering i en elektrisk krets"

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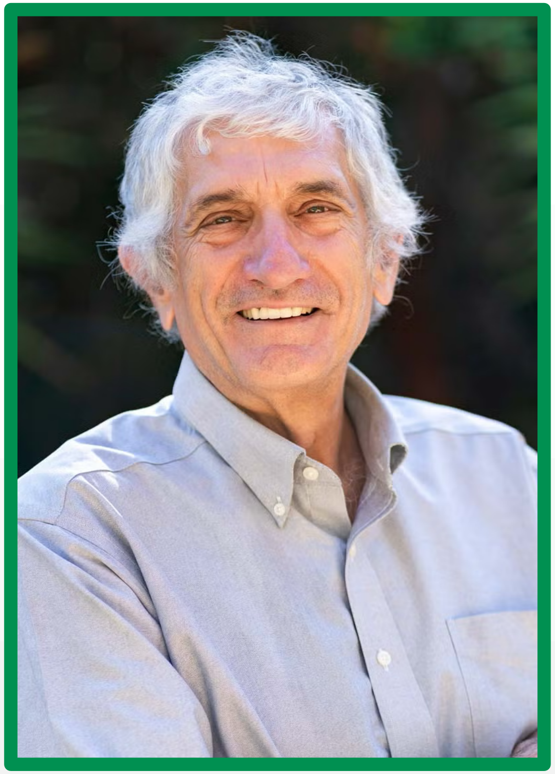
Awardees

John Clarke
Born 1942, Cambridge, UK

Michel H. Devoret
born 1953, Paris, France



John M. Martinis
born 1958
in Los Angeles, CA, USA

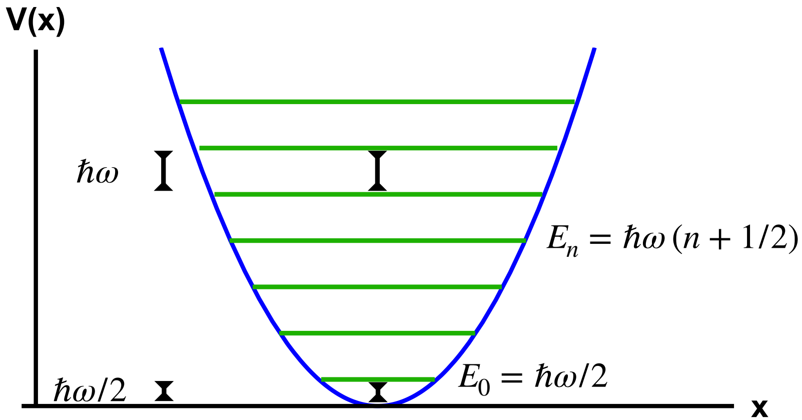
M. H. Devoret, J. M. Martinis, D. Esteve, J. M. Clarke, Phys. Rev. Lett. **53**, 1260 (1984)

J. M. Martinis, M. H. Devoret, J. Clarke, Phys. Rev. Lett. **55,** 1543 (1985)

M. H. Devoret, J. M. Martinis, J. Clarke, Phys. Rev. Lett. **55**, 1908 (1985)

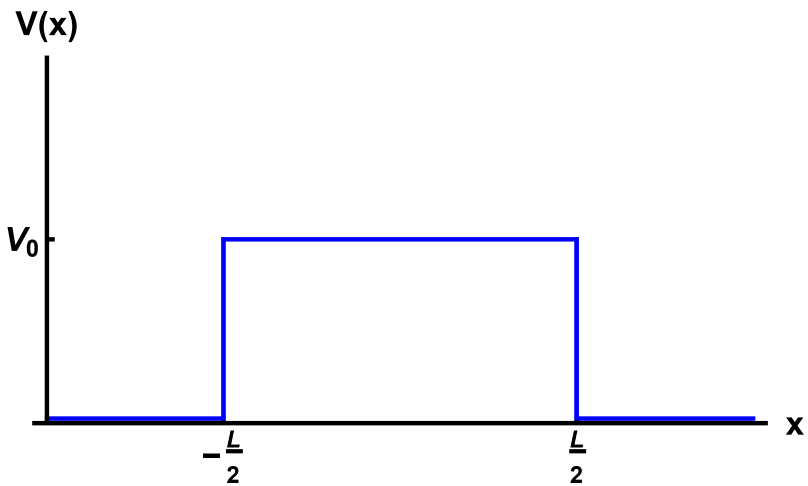
Scientific background

An early successful application of this theory was the explanation of alpha decay, where the alpha particle is confined in the nucleus by a potential barrier but has a finite probability to tunnel through this barrier. Tunnelling also explained why radioactive decay is a probabilistic process, where the half-life crucially depends on height and thickness of the potential barrier.[6]



$$E_n = \hbar\omega\left(n + \frac{1}{2}\right)$$

$$E_{n+1} - E_n = \hbar\omega$$

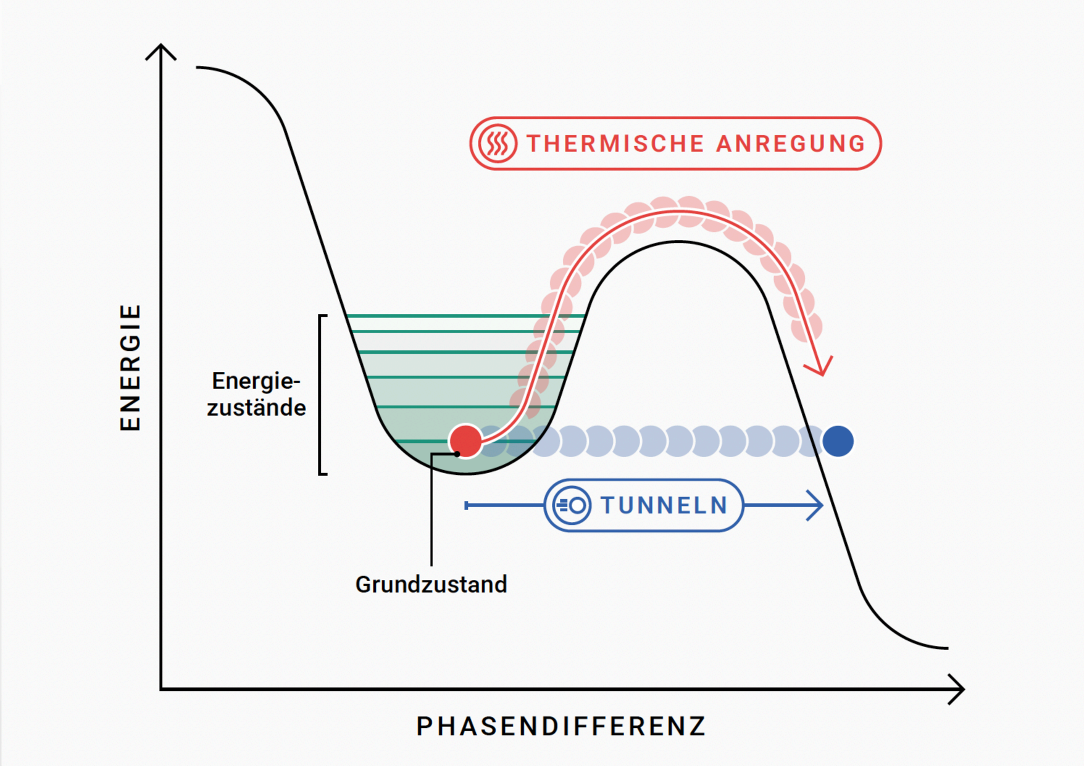


$$T(E) = \frac{1}{1 + \frac{1}{4}\frac{1}{\frac{E}{V_0}\left(1 - \frac{E}{V_0}\right)}\sinh^2(KL)}$$

[6] In this respect the the Swedish Nobel Committee highly recommends the ***Dispense del corso di Fisica Generale 3*** used by students at the Math Department of UNIMI

Scientific background

Closer to reality:
- relevant regime has to be identified
- the potential gets smoother
- thermal environment cannot be neglected



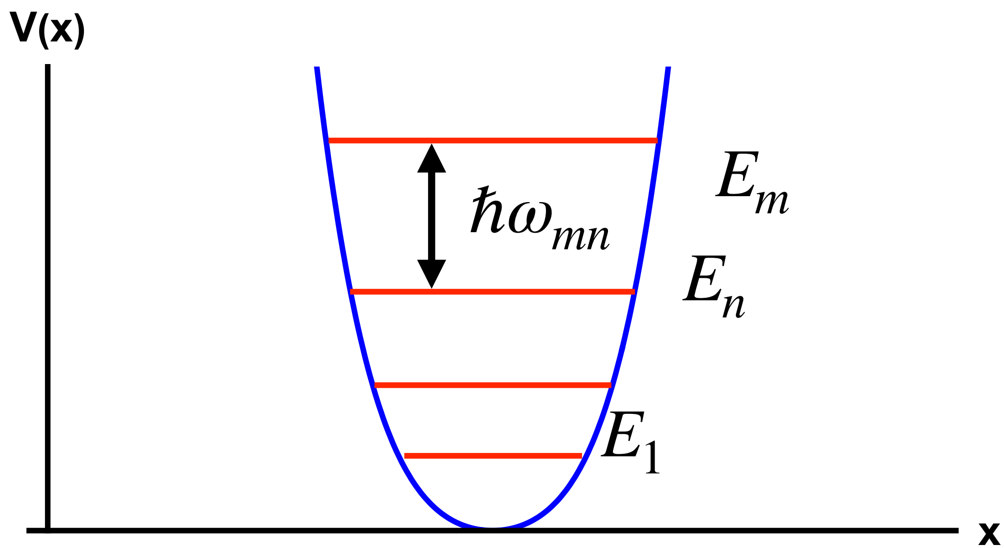
$$T(E) \approx \kappa e^{-2\sqrt{\frac{2m_e|E-V_0|}{\hbar^2}}L}$$

$$\frac{\hbar^2 K^2}{2m_e} = |E - V_0|$$

$$KL \gtrsim 1 \qquad L \gtrsim \frac{\Lambda}{2\pi}$$

Scientific background

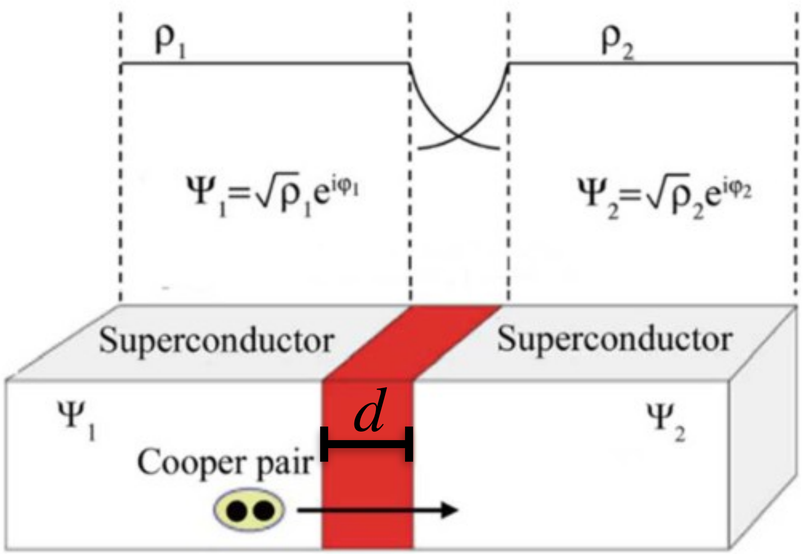
Closer to desire:
- the potential gets anharmonic
- levels can be individually addressed



$$\{E_1, E_2, \ldots, E_n, \ldots\}$$

The heart of the matter: macroscopicity

Josephson junctions



$$T \approx \mathrm{mK}$$
$$d \approx \mathrm{nm}$$

Superconducting flux quantum

$$\Phi_0 = \frac{h}{2e} \approx 10^{-15}\mathrm{Wb}$$

$$\delta(t) = \varphi_1(t) - \varphi_2(t)$$

$$I_J(t) = I_0 \sin\delta(t) \qquad \text{(1st Josephson eq)}$$

$$\dot{\delta}(t) = \frac{2\pi}{\Phi_0} V \qquad \text{(2nd Josephson eq)}$$

B. D. Josephson, Phys. Lett. **1**, 251 (1962); Adv. Phys. **14**, 419 (1965)

A. O. Caldeira and A. J. Leggett, Phys. Rev. Lett. **46**, 211 (1981)

$$V = L_J(t)\frac{dI_J(t)}{dt} \Rightarrow L_J(t) = \frac{1}{\cos\delta(t)}\frac{\Phi_0}{2\pi}\frac{1}{I_0}$$

nonlinear inductance

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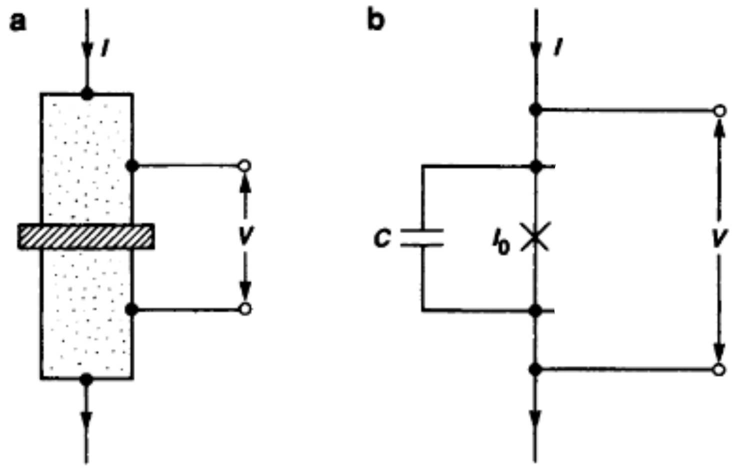
The heart of the matter: macroscopicity



$$I_J(t) = I_0 \sin\delta(t) \qquad \text{(1st Josephson eq)}$$

$$\dot{\delta}(t) = \frac{2\pi}{\Phi_0} V \qquad \text{(2nd Josephson eq)}$$

$$I(t) = C\frac{dV}{dt} + I_J(t) = C\frac{\Phi_0}{2\pi}\ddot{\delta}(t) + I_J(t)$$

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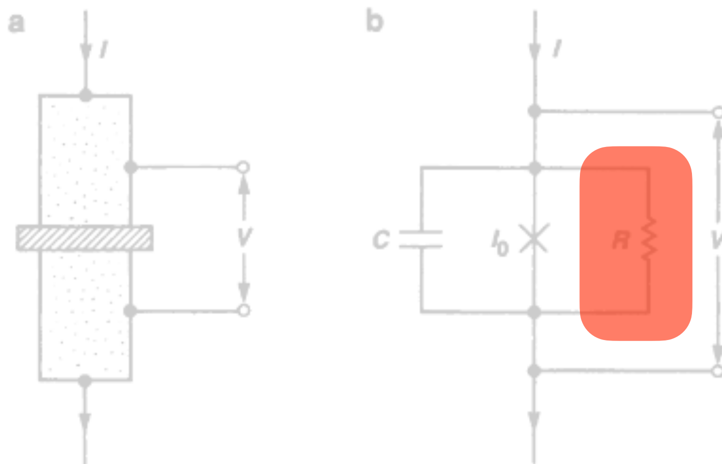
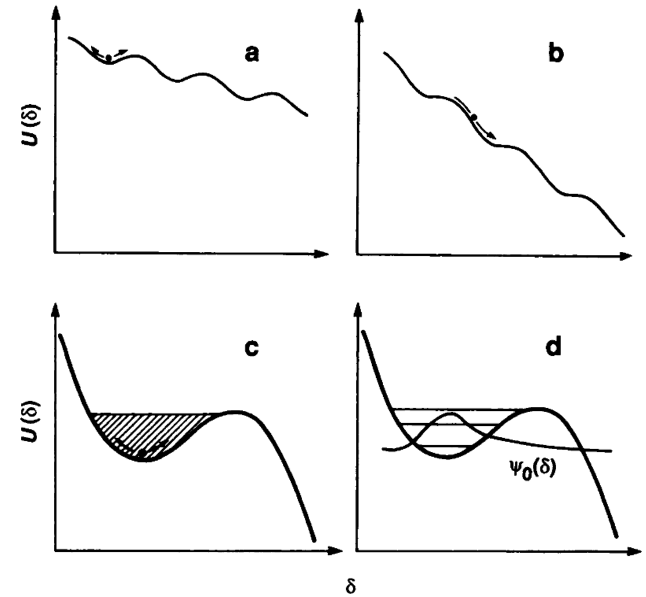
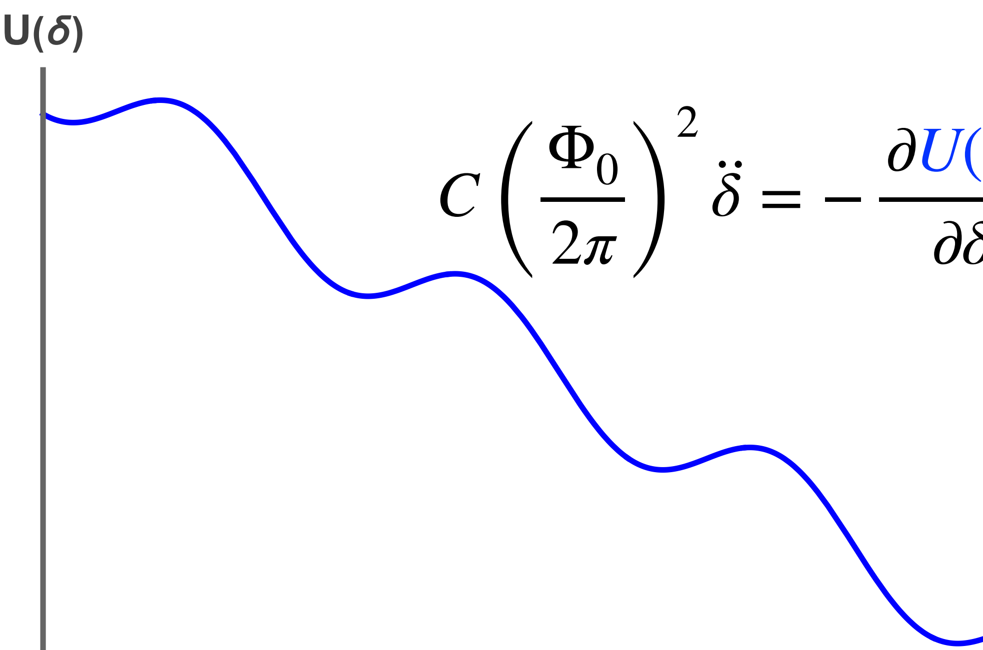
The heart of the matter: macroscopicity







$$C\left(\frac{\Phi_0}{2\pi}\right)^2\ddot{\delta} = -\frac{\partial U(\delta)}{\partial\delta} - \frac{1}{R}\left(\frac{\Phi_0}{2\pi}\right)^2\dot{\delta} + \frac{\Phi_0}{2\pi}I_{\mathrm{noise}}(t)$$

$$U(\delta) = -\frac{I_0\Phi_0}{2\pi}\left[\cos\delta + \frac{I}{I_0}\delta\right]$$

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Detailed achievements

VOLUME 53, NUMBER 13 PHYSICAL REVIEW LETTERS 24 SEPTEMBER 1984

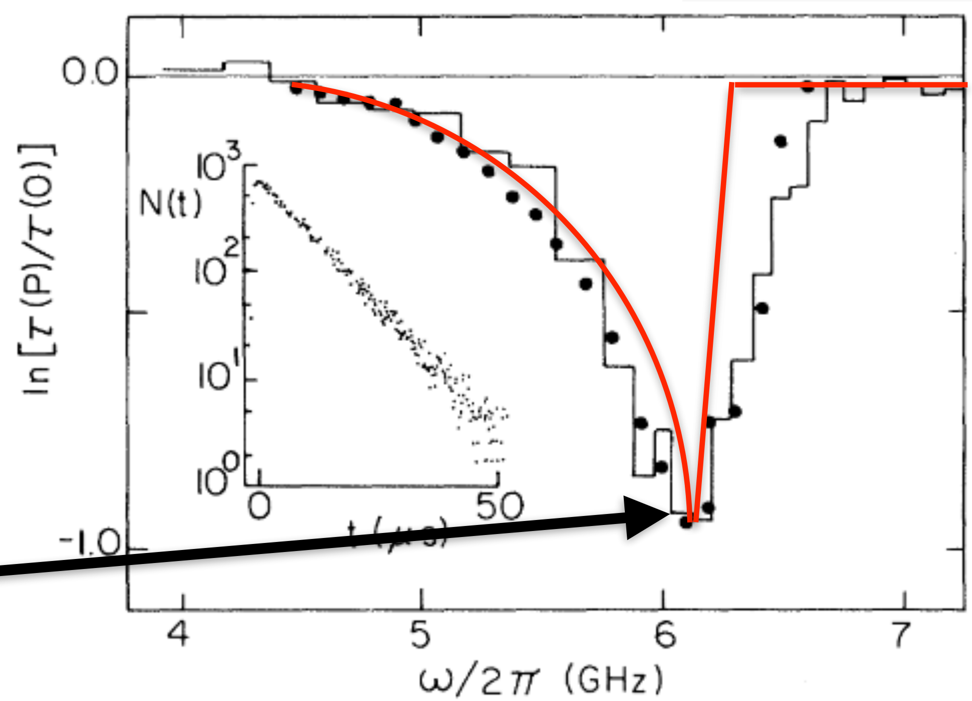
Resonant Activation from the Zero-Voltage State of a Current-Biased Josephson Junction

Michel H. Devoret,[a] John M. Martinis, Daniel Esteve,[a] 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 1984)

The lifetime τ of the zero-voltage state of a current-biased Josephson junction in the thermal limit has been measured in the presence of a weak microwave perturbation. When the microwave frequency is close to the plasma frequency of the junction, the junction is "resonantly activated" out of the zero-voltage state, with a corresponding reduction in τ. The results are well explained by numerical simulations.

$\tau(P)$ lifetime at ω_P of zero-voltage state in which system is trapped in wells of the washboard

$$\frac{\tau(P)}{\tau(0)} = \frac{1}{\mathrm{e}}$$



Detailed achievements: tunnelling

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

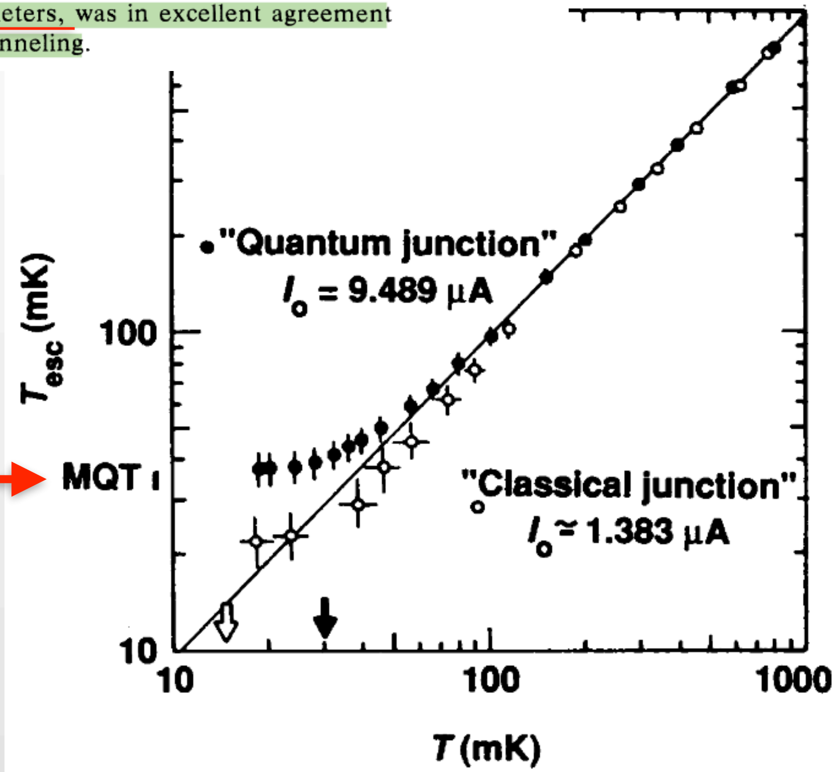
Michel H. Devoret,[a] John M. Martinis, and John Clarke
Department of Physics, University of California, Berkeley, California 94720, and Materials and Molecular Research Division, Lawrence Berkeley Laboratory, Berkeley, California 94720
(Received 26 July 1985)

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.

Microscopically derived escape rate at zero temperature

$$\Gamma_q(0) = \left[120\pi\left(\frac{7.2\Delta U}{\hbar\omega_p}\right)\right]^{1/2} \frac{\omega_p}{2\pi} \exp\left[-7.2\frac{\Delta U}{\hbar\omega_p}\left(1 + \frac{0.87}{Q}\right)\right]$$

A. O. Caldeira and A. J. Leggett, Ann. Phys. (N.Y.), **149**, 374 (1983)



Detailed achievements: quantization

VOLUME 55, NUMBER 15 PHYSICAL REVIEW LETTERS 7 OCTOBER 1985

Energy-Level Quantization in the Zero-Voltage State of a Current-Biased Josephson Junction

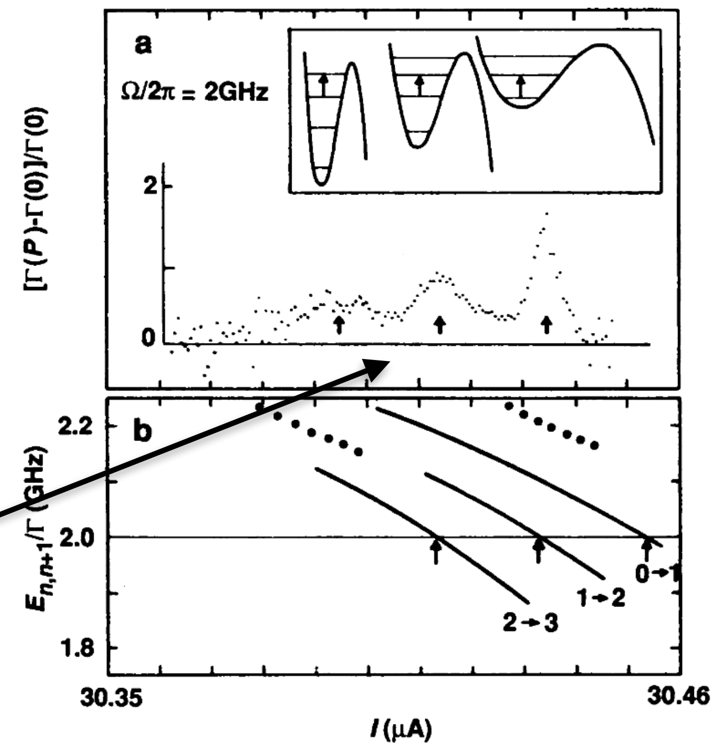
John M. Martinis, Michel H. Devoret,[a] and John Clarke
Department of Physics, University of California, Berkeley, California 94720, and Materials and Molecular Research Division, Lawrence Berkeley Laboratory, Berkeley, California 94720

(Received 14 June 1985)

We report the first observation of quantized energy levels for a macroscopic variable, namely the phase difference across a current-biased Josephson junction in its zero-voltage state. The position of these energy levels is in quantitative agreement with a quantum mechanical calculation based on parameters of the junction that are measured in the classical regime.

Peaks of escape rate in the dependence on the frequency ω_P

$$\frac{\Gamma(P)-\Gamma(0)}{\Gamma(0)}$$



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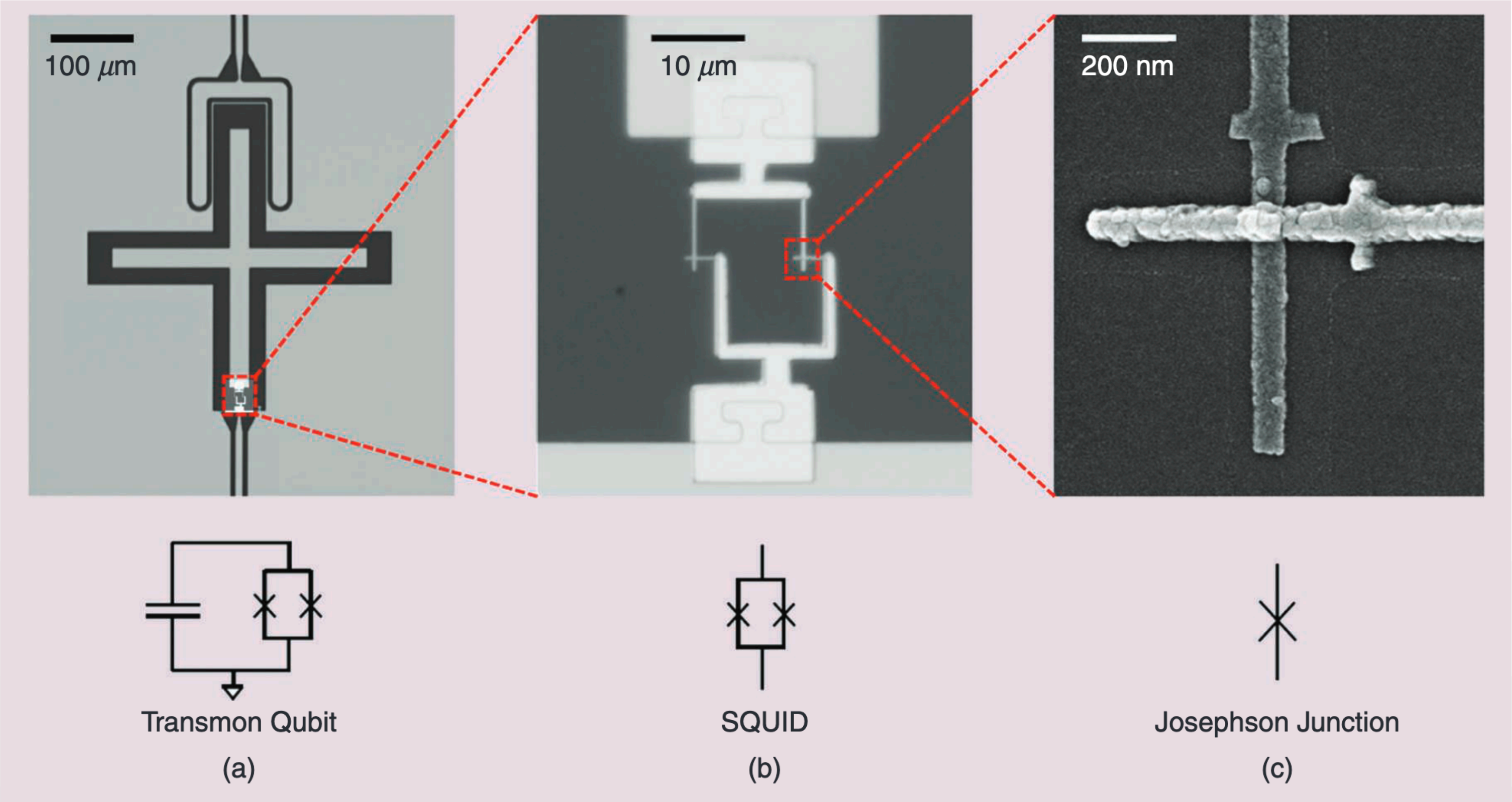
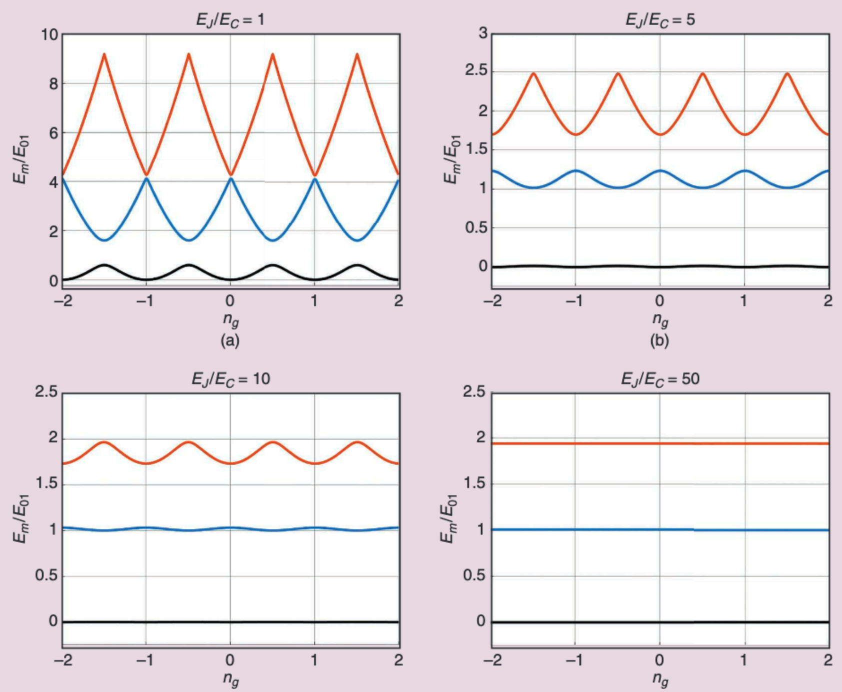
Further developments

From Josephson junctions to
SQUIDs (Superconducting QUantum Interference Device)
and
Transmon qubits (transmission line shunted plasma oscillation qubit)

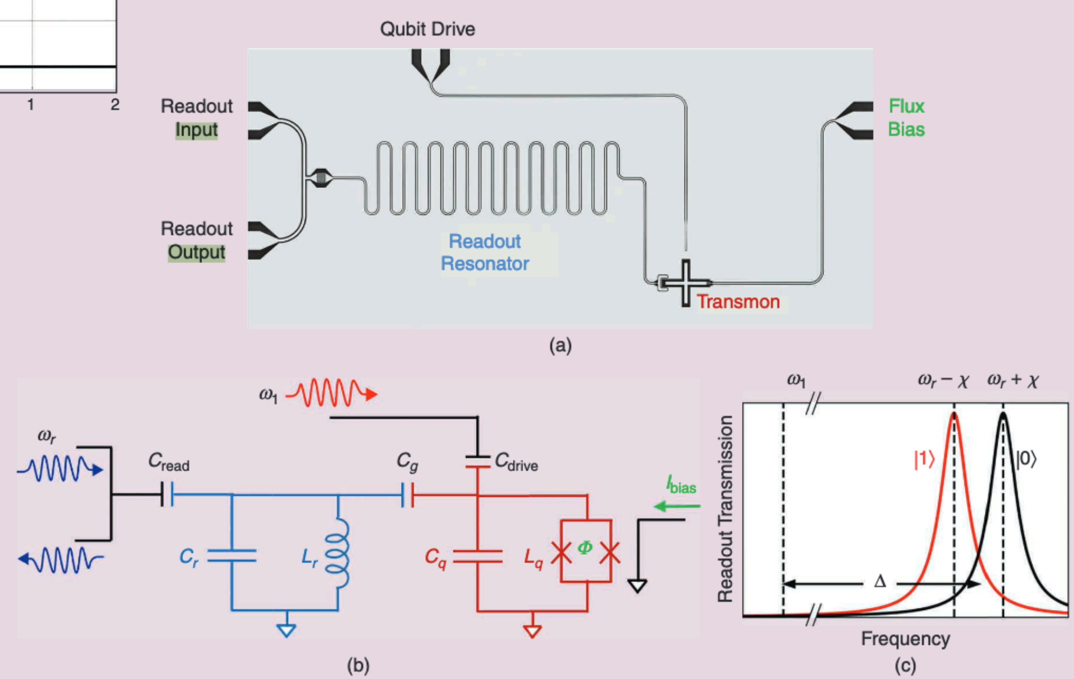


Superconducting qubits



Search for robust non-linear regime engineering devices with different Josephson (E_J) and capacitive (E_C) energy contributions

External connections for input, control and readout with microwave resonators



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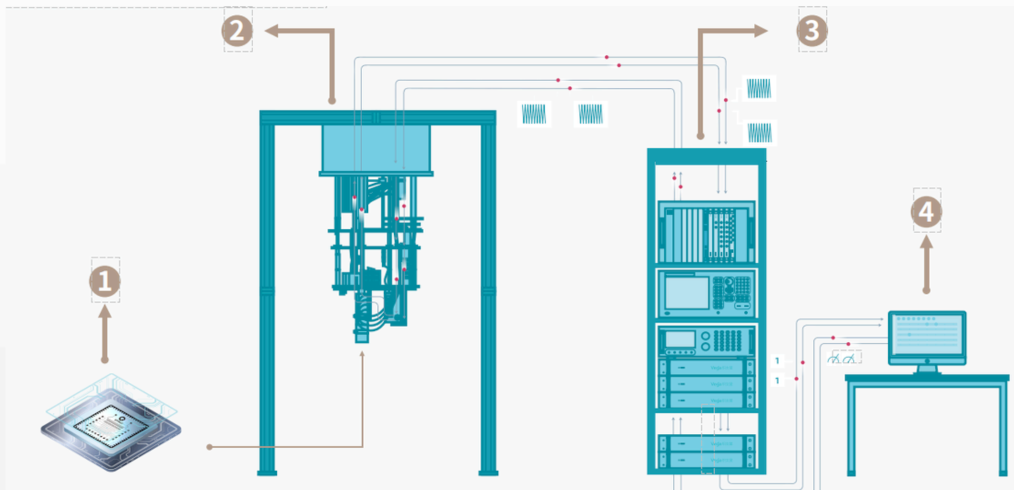
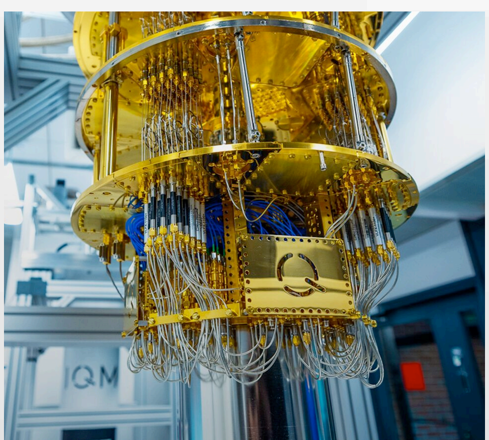
Quantum computing

1. Superconducting Quantum Processing Unit
2. Milli-Kelvin Cryogenic Systems (~10 mK)
3. Quantum Control & Measurement System
4. Quantum Operating System, Quantum Algorithm and Quantum Software





Sources

- The Nobel Prize in Physics 2025
- Press release
- Scientific motivation
- DPG announcement
- Physik Journal article