

# Josephson junctions



two Josephson effects

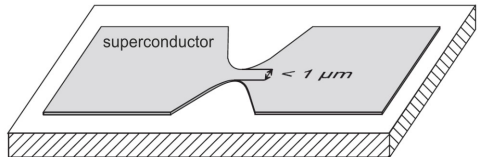
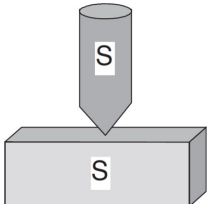
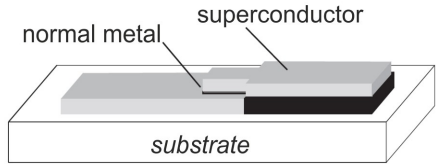
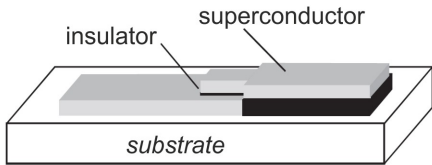


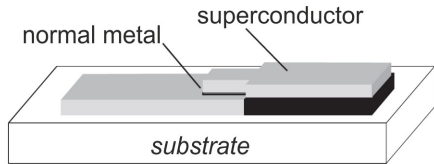
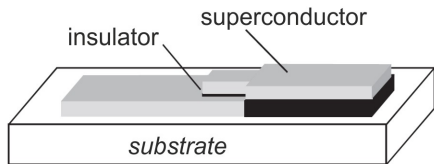
voltage standard



Brian Josephson



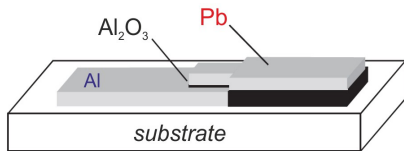
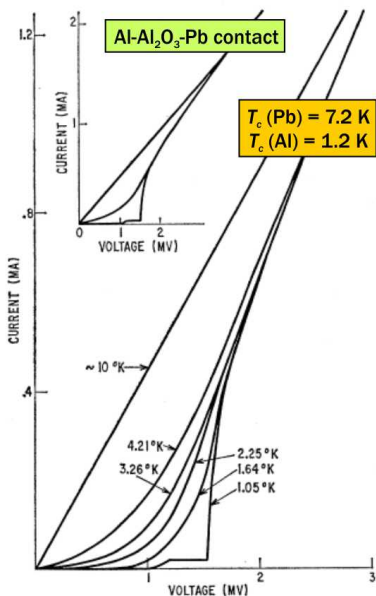




Example:

Al / Al<sub>2</sub>O<sub>3</sub> / Al

# First tunneling experiments



Ivar Giæver:

Finite voltage is required  
to induce supercurrent

*nothing special here...*



Personality

*Brian Josephson*



Brian Josephson  
born 1940

"Who is this chap Josephson? He seems to be going through the theory like a knife through butter"

David Shoenberg

"A disconcerting experience for a lecturer, I can assure you, because everything had to be right or Josephson would come up and explain it to me after class"

Philip Anderson



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POSSIBLE NEW EFFECTS IN SUPERCONDUCTIVE TUNNELLING \*

B. D. JOSEPHSON  
Cavendish Laboratory, Cambridge, England

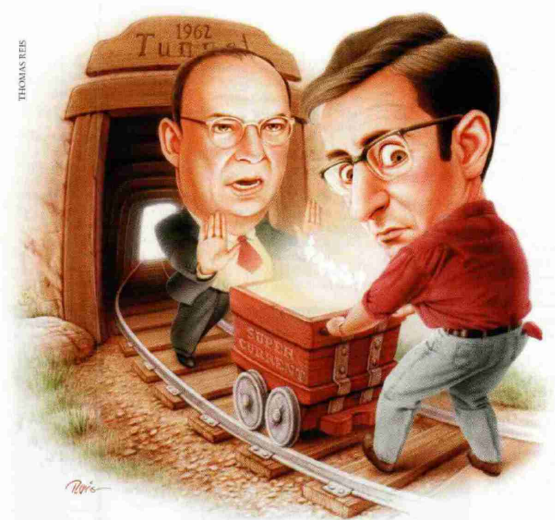
PHYSICS LETTERS

Received 8 June 1962

Volume 1, number 7

from Felix Bloch recalled the perplexity with which Josephson's theory was received: "[C. N.] Yang told me that he could not understand it, and asked whether I could. In all honesty I had to confess that I could not either, but we made a deal that whoever of us first understood the effect would explain it to the other."<sup>78</sup>

Felix Bloch about Josephson's theory



**1962, Josephson:**  
supercurrent depending on  $\Delta\varphi$

**1962, Bardeen:**  
no supercurrent whatsoever

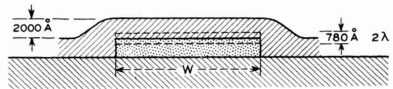
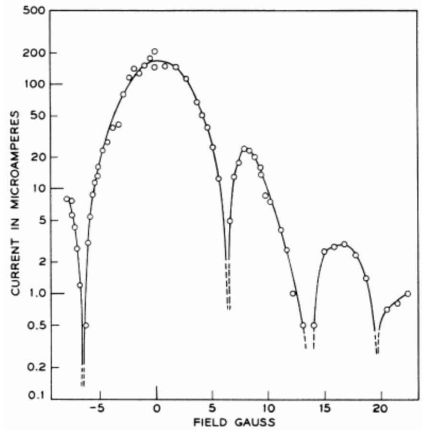
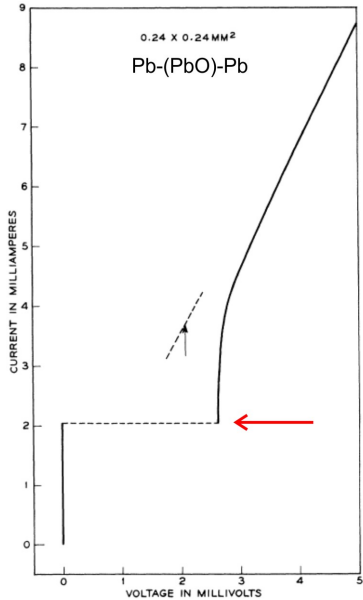
Note added in proof: In a recent note, Josephson<sup>7</sup> uses a somewhat similar formulation to discuss the possibility of superfluid flow across the tunneling region, in which no quasi-particles are created. However, as pointed out by the author (reference 3), pairing does not extend into the barrier, so that there can be no such superfluid flow.

Phys. Rev. Lett. 9, 149 (1962)

**1963, Rowell and Anderson:**  
supercurrent observed!



# Experimental confirmation





Brian Josephson  
born 1940

1973 Nobel prize in physics

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Felix Bloch about Josephson's theory



Brian Josephson  
born 1940

1973 Nobel prize in physics  
later notorious for "promoting  
unorthodox causes" (telepathy,  
water memory, cold fusion)

"Who is this chap Josephson? He seems to be going through the theory like a knife through butter"

David Shoenberg

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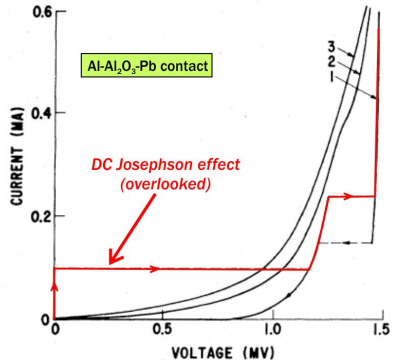
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Felix Bloch about Josephson's theory

# Tunneling experiments reconsidered



Ivar Giaever  
born 1929



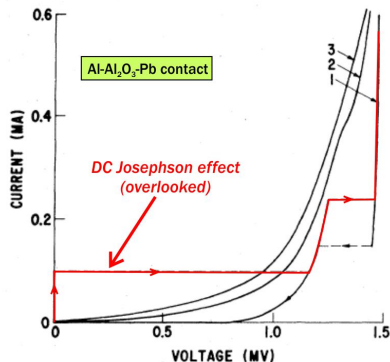
suppress the dc current. In our first paper Megerle and I published a curve, which is shown in Fig. 13, demonstrating such a supercurrent and also that it depended strongly on a magnetic field. However, I had a ready-made explanation for this supercurrent—it came from a metallic short or bridge. I was puzzled at the time because of the sensitivity to the magnetic field which is unexpected for a small bridge, but no one knew how a 20Å long and 20Å wide bridge would behave anyway. If I have learned anything as a scientist it is that one should not make things complicated when a simple explanation will do.

# Tunneling experiments reconsidered



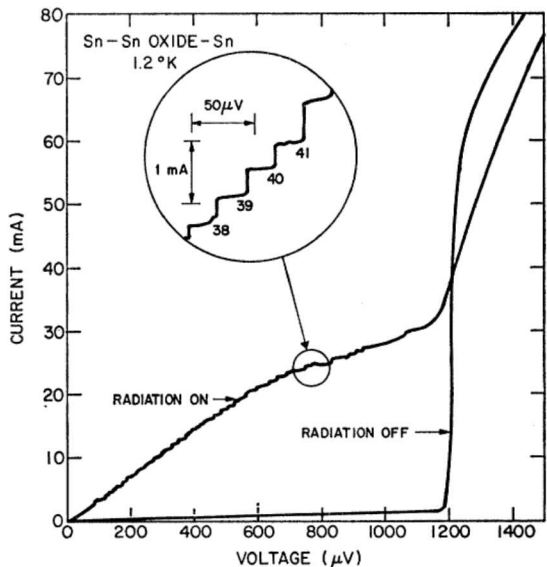
Ivar Giaever  
born 1929

1973 Nobel prize in physics  
(nonetheless)



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# Shapiro steps: Determination of $e/h$



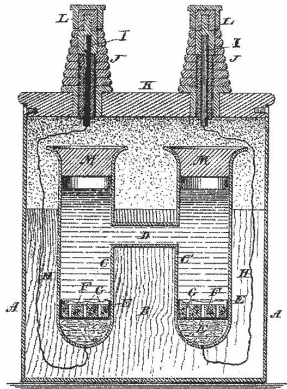
Microwave radiation  
in the GHz range  
yields steps  
in the  $I - V$  curve

The  $e/h$  constant  
can be measured to  
 $2 \times 10^{-6}$  accuracy

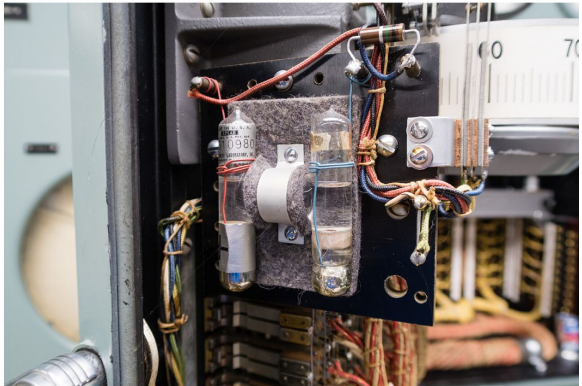


# Material / Technology

*voltage standard*



Cd-Hg battery

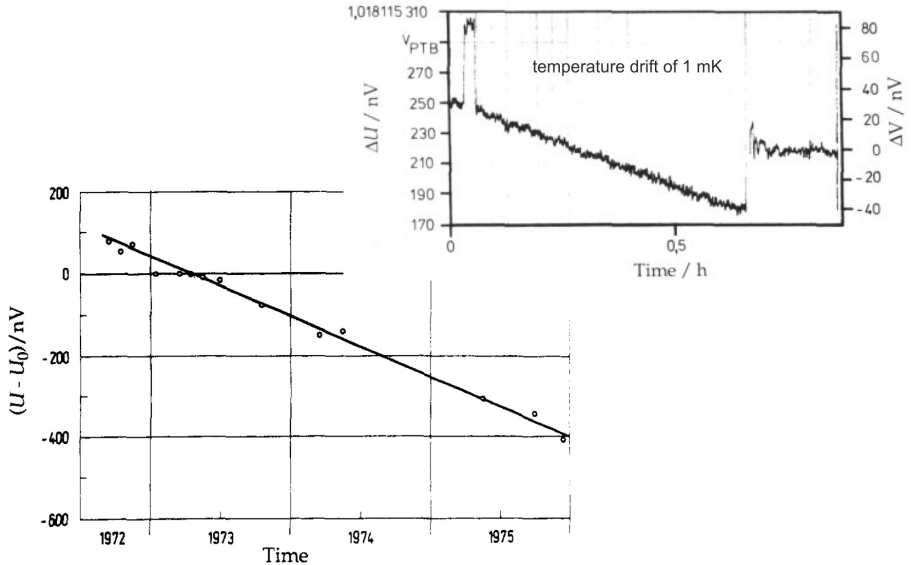


Invented: 1893

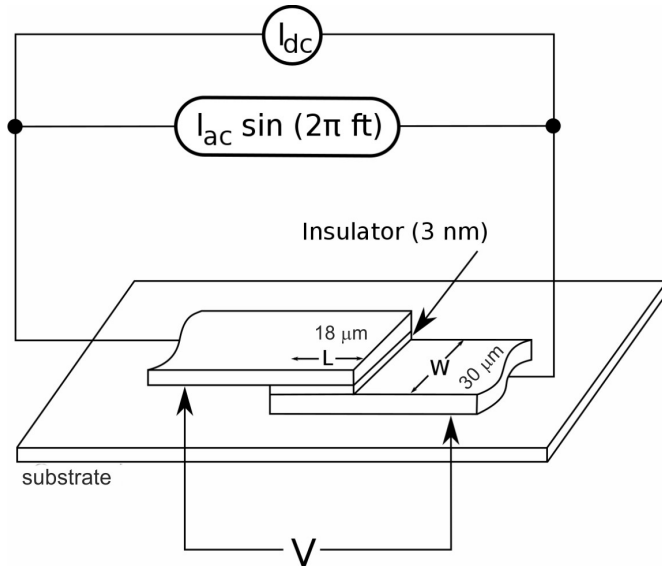
Used as standard: 1911–1990

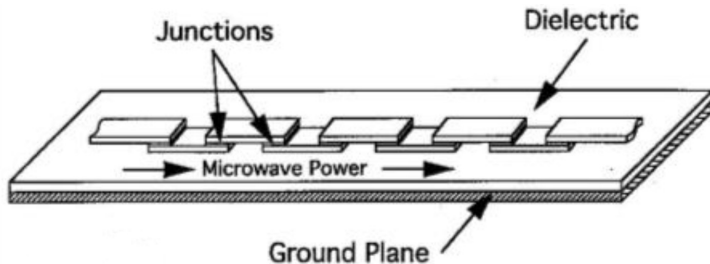


# Weston cell: not that stable



# JVS: Josephson voltage standard





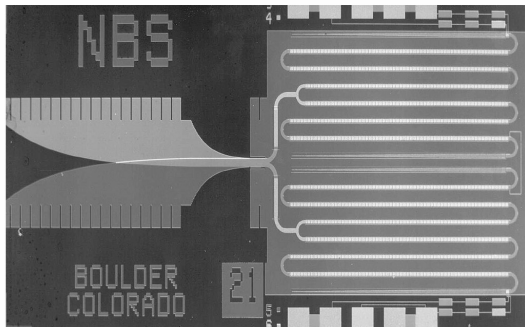
Nb / Al<sub>2</sub>O<sub>3</sub> / Nb

$T = 4 \text{ K}$

$\nu = 75 \text{ GHz}$

10 Volt

from 20 000 junctions



# Latest voltage standard



Image credit: NIST

- **30.05 (today):** seminar, solutions of problem sheet 3
- **6.06: lecture online** (use Zoom link on the web page)
- **10.06:** exam questions and problem sheet 4
- **13.06, 20.06, 27.06:** regular in-presence lectures
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SUMMER BREAK!