Observations of Brian Josephson's Effects

John M. Rowell

Arizona State University

1961 to 1983   Bell Telephone Laboratories

1960

July -	Giaever reports NIS tunneling in Al/I/Pb junctions
October -	Nicol, Shapiro and Smith report SIS junctions

1961

April -	Bell Labs

1962

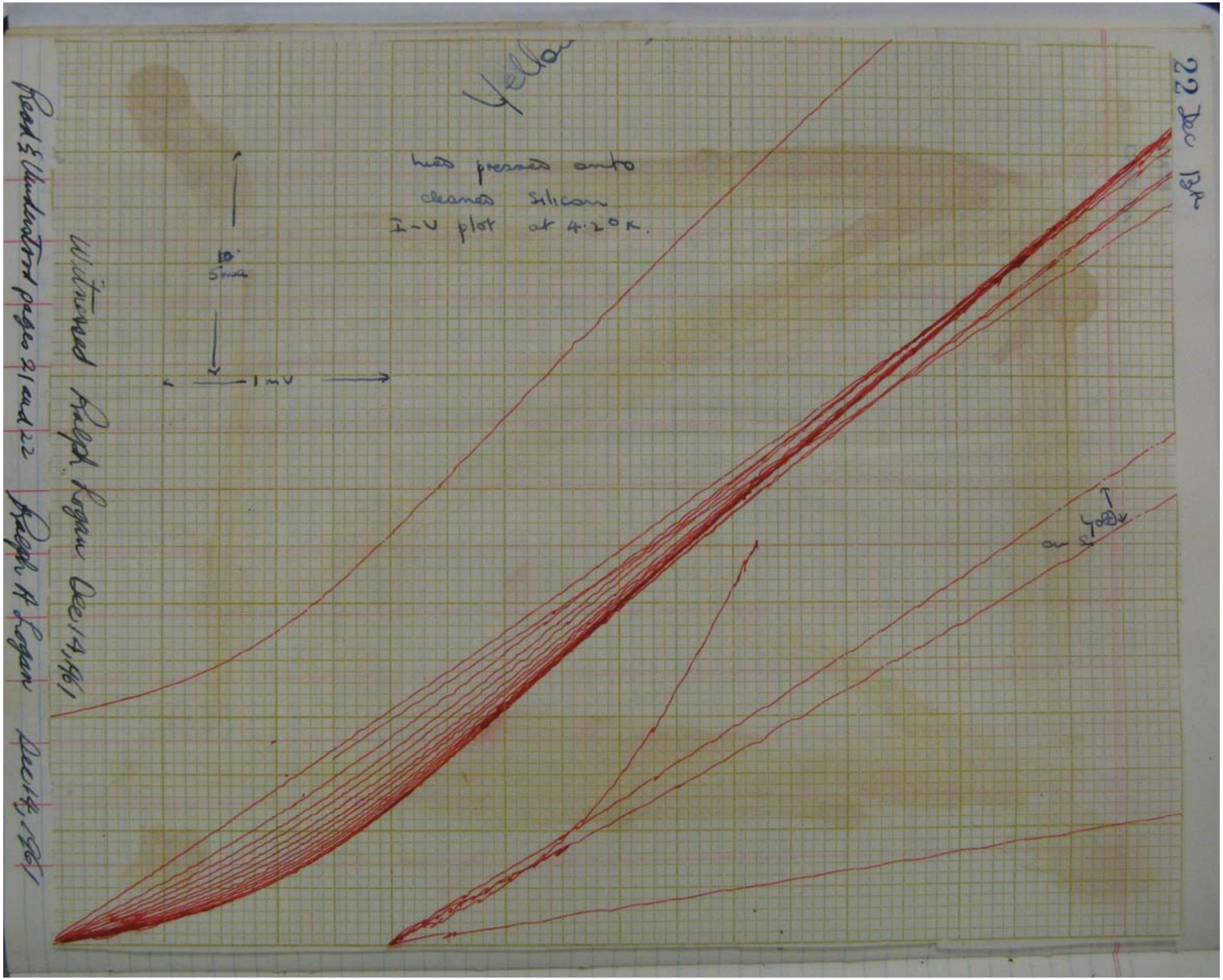
June -	Brian Josephson's letter submitted
August -	First notebook entry about his letter

1963

January -	Al/I/Pb junction at 0.3K
	Supercurrent in Sn/I/Pb junction
May -	I_c(H) pattern in Pb/I/Pb junctions
June -	Shapiro reports AC Effect

1964

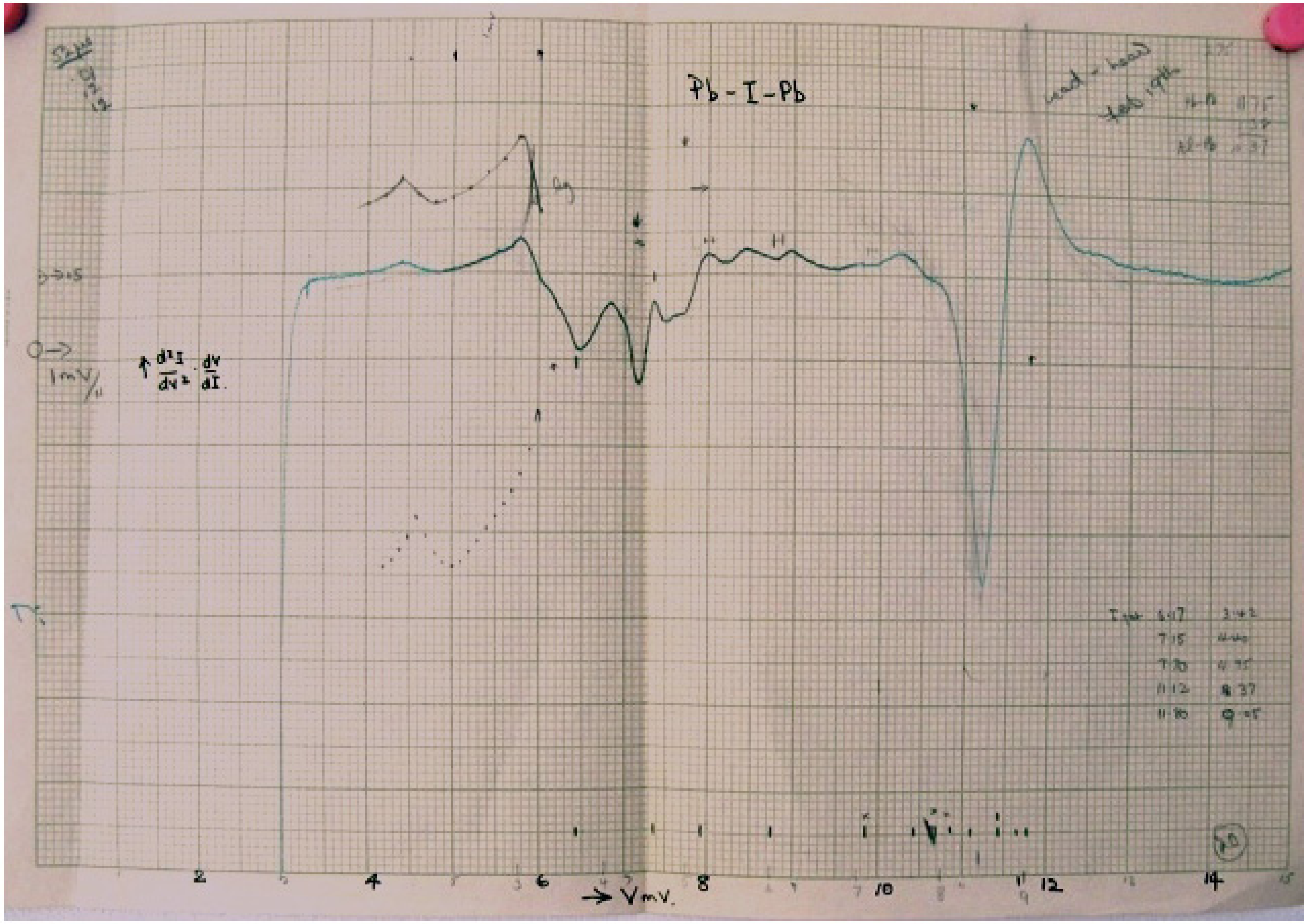
January -	The Ford group reports double junction interference
February –	Parks and Mochel, Anderson, weak links



Yellow
lead pressed onto
cleaned silicon
I-V plot at 4.2°K.
5ma
1 mV
22 Dec 13th
Witnessed Ralph Logan Dec 14, 1961
Read & Understood pages 21 and 22 Ralph A Logan Dec 14, 1961

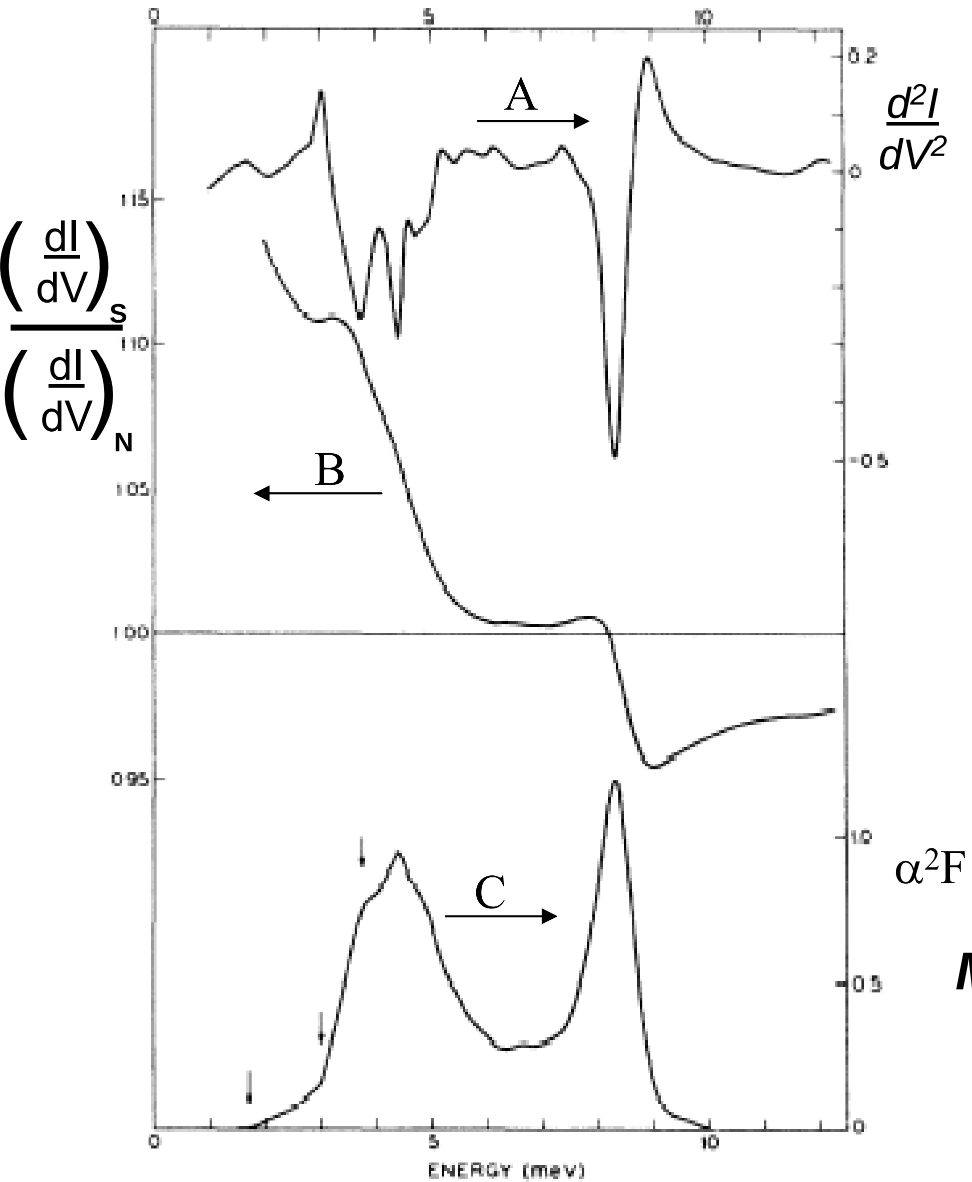
“ We have resolved the structure in detail and can assign much of it to specific Van Hove singularities expected from neutron measurements of the Pb phonon spectrum ”

Rowell, Anderson, and Thomas, Bell Labs, 1963.



d^2I/dV^2 vs V (measured from 2Δ) for a Pb-Pb junction at 1.3K.

The Pairing Mechanism



The tunneling experiment is unique in probing the dynamical structure of the superconducting state and has provided a confirmation of the correctness of the strong coupling theory."

McMillan, London Prize lecture, 1978.

McMillan and Rowell, Bell Labs, 1964.

“New effects are predicted, due to the possibility that electron pairs may tunnel through the barrier.

Our theory predicts that:

i) At zero voltage, a DC supercurrent up to a maximum value can occur

ii) At finite voltages there is an AC supercurrent of frequency ${}^{2eV}/_{\hbar}$”

B.D. Josephson, Cambridge, 1962.

4

DATE August 10

CASE No.

Josephson Experiment.

Need to produce superconductor - superconductor tunnelling in an H = 0 space (H < ·1'g actually) tested a μ metal can with Joe Dillons meter, apparently < ·03 g + should be 0.1K at helium.

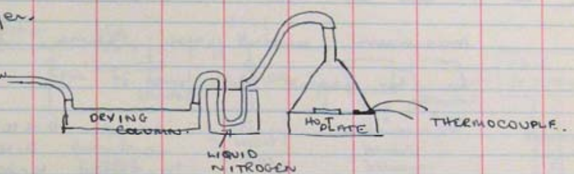
So R A Chegwiddon (x 4626, 1A107) suggests take 1/32" 30" wide μ metal + make a can (4-79 Mo Perm ·014" is more difficult to work) by overlapping > 1/4" + spot welding. Then he will anneal to make it go s.c. Made can.

Jan 2nd. For a Sn - SnO$_x$ - In unit at 1.6°K we see a small amount of structure / a dip below $\frac{dI}{dV}$ = No but fine phonon structure almost in noise.
Suggested to Don that alternative method of diff^n should be used as by Daniels at Princeton.

Jan 3rd. Al - Al$_2$O$_3$ - Pb unit (made on 2nd) to be run w- Geballes Cryostat.

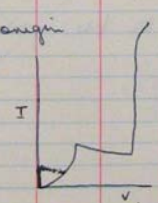
Jan 21st. Due to wide variations (shorts to capacitors) of tin - tin oxide - lead sandwiches made by exposure to air for a few days we will try heating.

Tin films (2,000 Å) thick were evaporated on a sapphire substrate at a temperature of 3mV on chromel alumel thermocouple attached to the cooled block supporting the sapphire. The slides were taken from the evaporator & placed on a hot plate at 50°C in a stream of dry oxygen.



As shown in the notebook of Len Kopf (notebook 37566) the slides were exposed for 7 & 15 minutes, replaced in the evaporator and crossing lead films (2,000 Å) evaporated. The usual masks were used with junction areas $8.5\ 10^{-4}$, $1.35\ 10^{-3}$, $2.1\ 10^{-3}$, $1.35\ 10^{-3}$, $8.5\ 10^{-4}$ sq mm.

Tested at unit 17 in helium, all good but low resistance (<1Ω) All show peculiar low resistance at the origin



. A bar magnet or horseshoe brought up outside the dewar destroys the effect. Tried to burn out by going up to 300 mV but characteristic not altered.

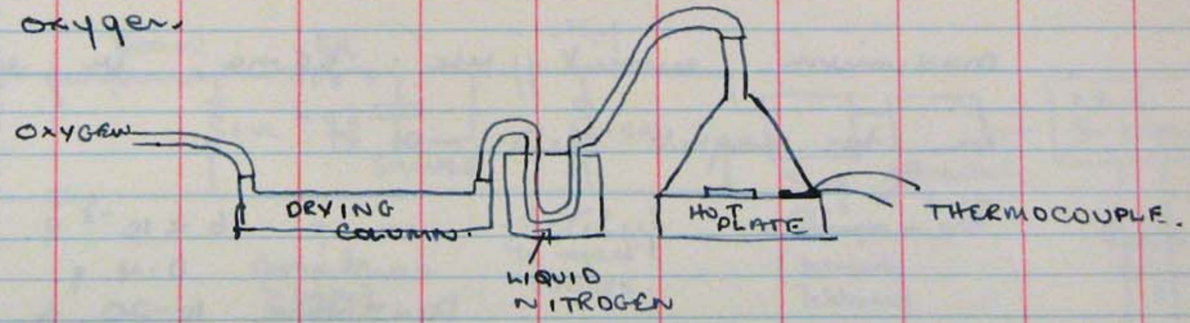
DATE

CASE No. 38788

Jan 21st

Due to wide variations (shorts to capacitors) of tin - tin oxide - lead sandwiches made by exposure to air for a few days we will try heating.

Tin films (2,000 Å) thick were evaporated on a sapphire substrate at a temperature of 3mV on chromel alumel thermocouple attached to the cooled block supporting the sapphire. The slides were taken from the evaporator & placed on a hot plate at 50°C in a stream of dry oxygen.

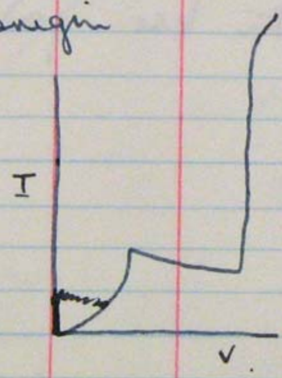


As shown in the notebook of Len Kopf (notebook 37566)

NITROGEN

As shown in the notebook of Len Kopf (notebook 37566) the slides were exposed for 7 a 15 minutes, replaced in the evaporator and crossing lead films (2,000 Å) evaporated. The usual masks were used with junction areas $8 \cdot 5\ 10^{-4}$, $1 \cdot 35\ 10^{-3}$, $2 \cdot 1\ 10^{-3}$, $1 \cdot 35\ 10^{-3}$, $8 \cdot 5\ 10^{-4}$ sq mm.

Looked at unit 17 in helium, all good but low resistance ($<1\Omega$) All show peculiar low resistance at the origin



. A bar magnet or horseshoe brought up outside the dewar destroys the effect. Tried to burn out by going up to 300 mV but characteristic not altered.

38

DATE

CASE No.

Jan 22ND. Unit 18, Sn-Pb.

● Low resistance, similar Josephson effect or "leaks"

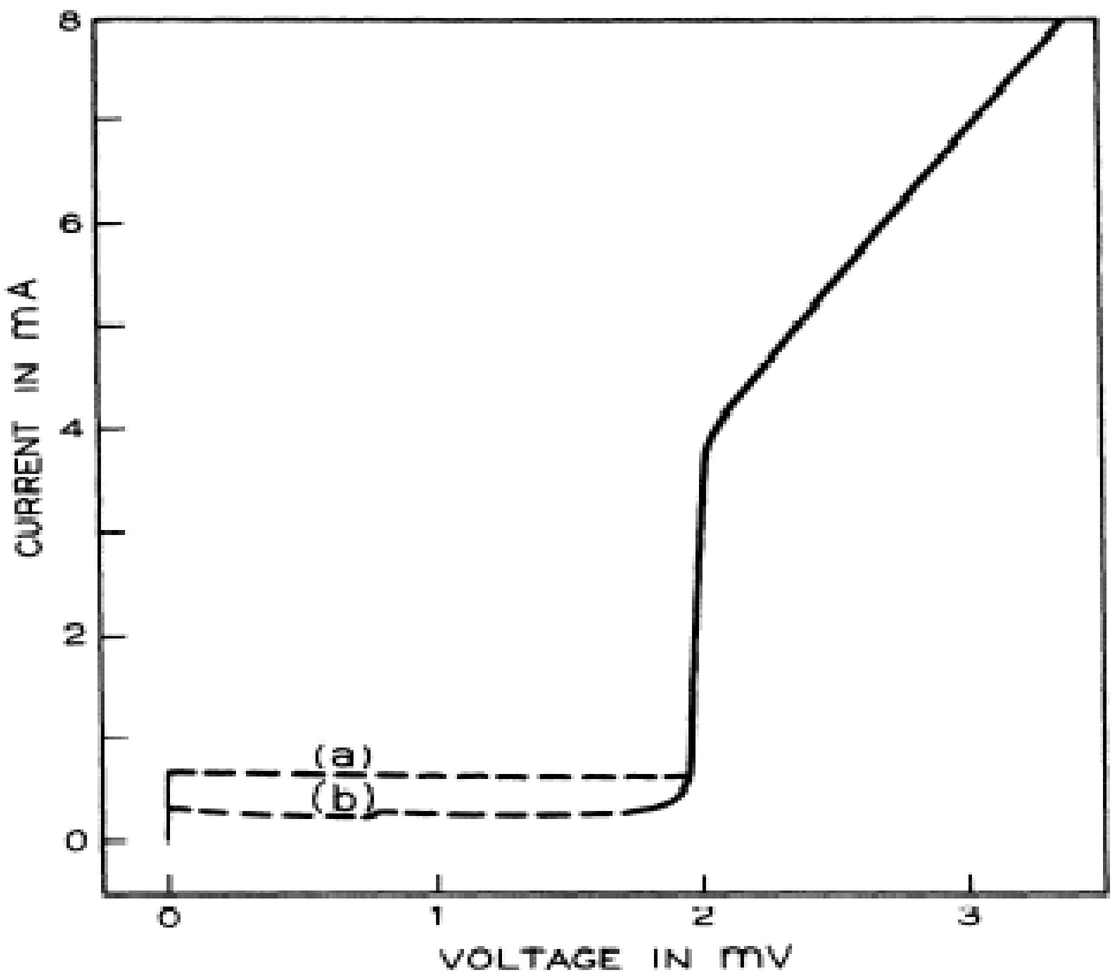
Phil Anderson's arguments seem to preclude leaks.

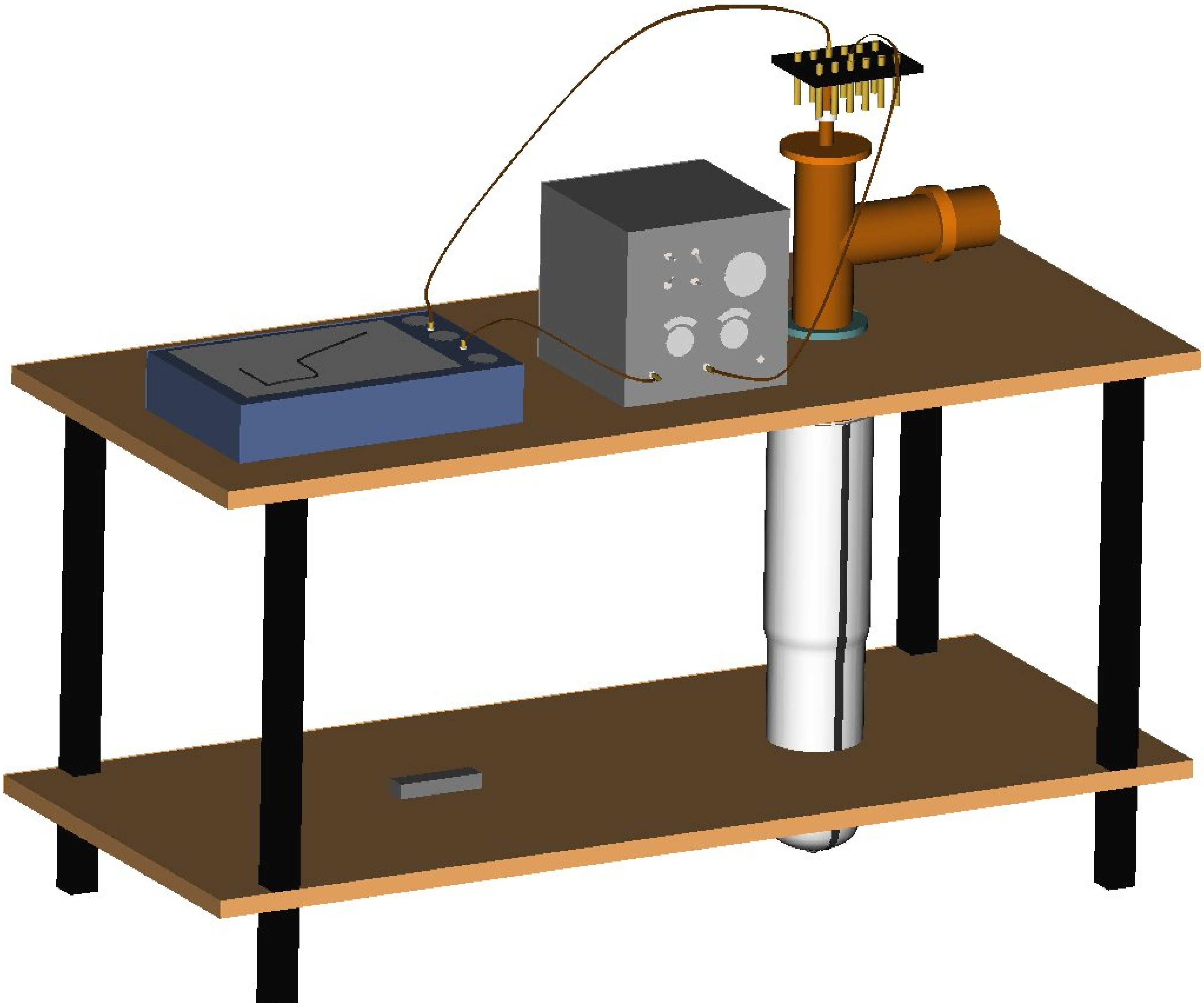
24th Checked with expanded voltage scale, same instability considerably below the break.

Jan 29th Have a μ metal can baked in hydrogen. Unit on mount with kovar pins. Not much effect.

"We have observed an anomalous dc tunneling current at or near zero voltage in very thin tin oxide barriers between superconducting Sn and Pb, which we cannot ascribe to superconducting leakage paths across the barrier - - -"

Anderson and Rowell, Bell Labs, 1963.






STATES OF
ONE DIME

DATE

CASE No.

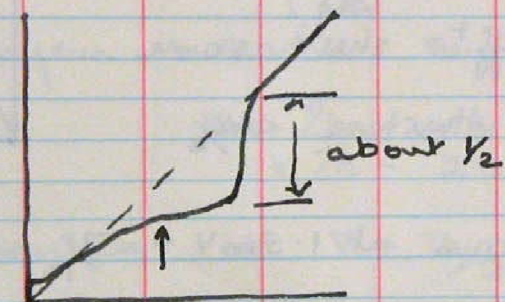
May 21 made two Pb-Pb, 7mm & 15 mm at 1 to 1.1 mV.

Resistances all ~ $1/2\,\Omega$ room, somewhat higher nitrogen.

Isolated at 15 mm at helium.

1) Has peculiar "excess current" within the gap.

All 5 jns similar.



Structure

is apparently at $\frac{2\Delta}{2}$, $\frac{2\Delta}{3}$, $\frac{2\Delta}{4}$ etc.

2) measured 0 voltage current as function of field - no can.

Oscillates with about 30 mV period = 1.2 gauss.

Flux = $1.2 \times 2.4\ 10^{-2} \times 780 \times 10^{-8}$

↑ width 2x pen dist for lead films

= $2.2\ 10^{-7}$ = flux quantum.

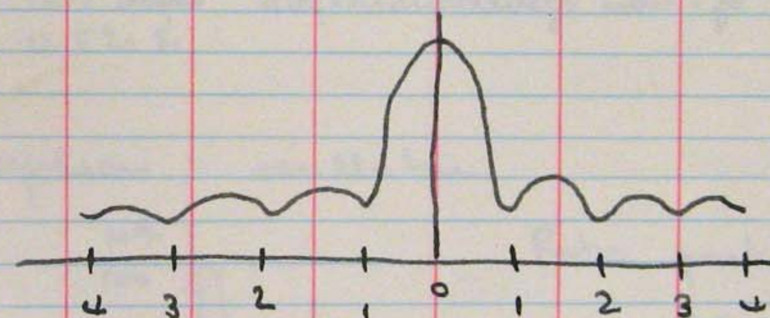
2) Measured 0 voltage current as function of field - no can.

Oscillates with about 30 mV period = 1.2 gauss.

Flux = $1.2 \times \underset{\uparrow \text{ width}}{2.4\ 10^{-2}} \times 780 \times 10^{-8}$ 2× pen dist for lead films

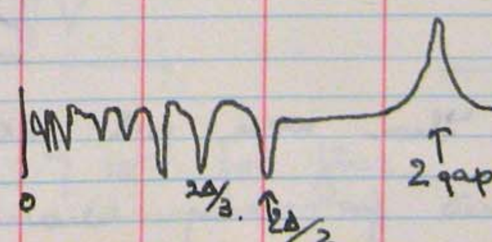
= $2.2\ 10^{-7}$ = flux quantum.

Peculiarly see 4 dips and then some residual current



Earths field complicates near zero.

May 22. Differentiated one of above units



Find sub harmonics of gap down to 2Δ/12 !

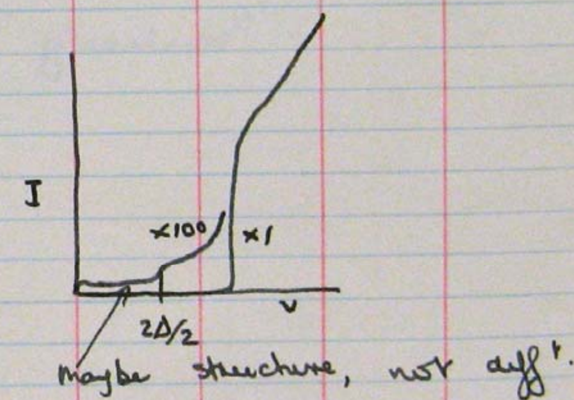
looked at 7 min at 1.0 mv

1) good Josephson currents go up to over 1/2 2Δ current.

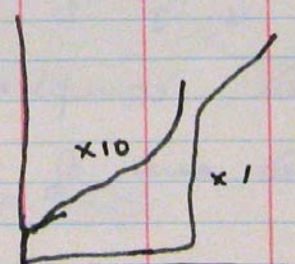
2) with field (can in use now) I_J reduces with H and gets very small around 24 - 30 ma. Any oscillations are difficult to see because of noisy. breaks from 0v once above 30 ma.

junctions 9 to 9.5 mls wide.

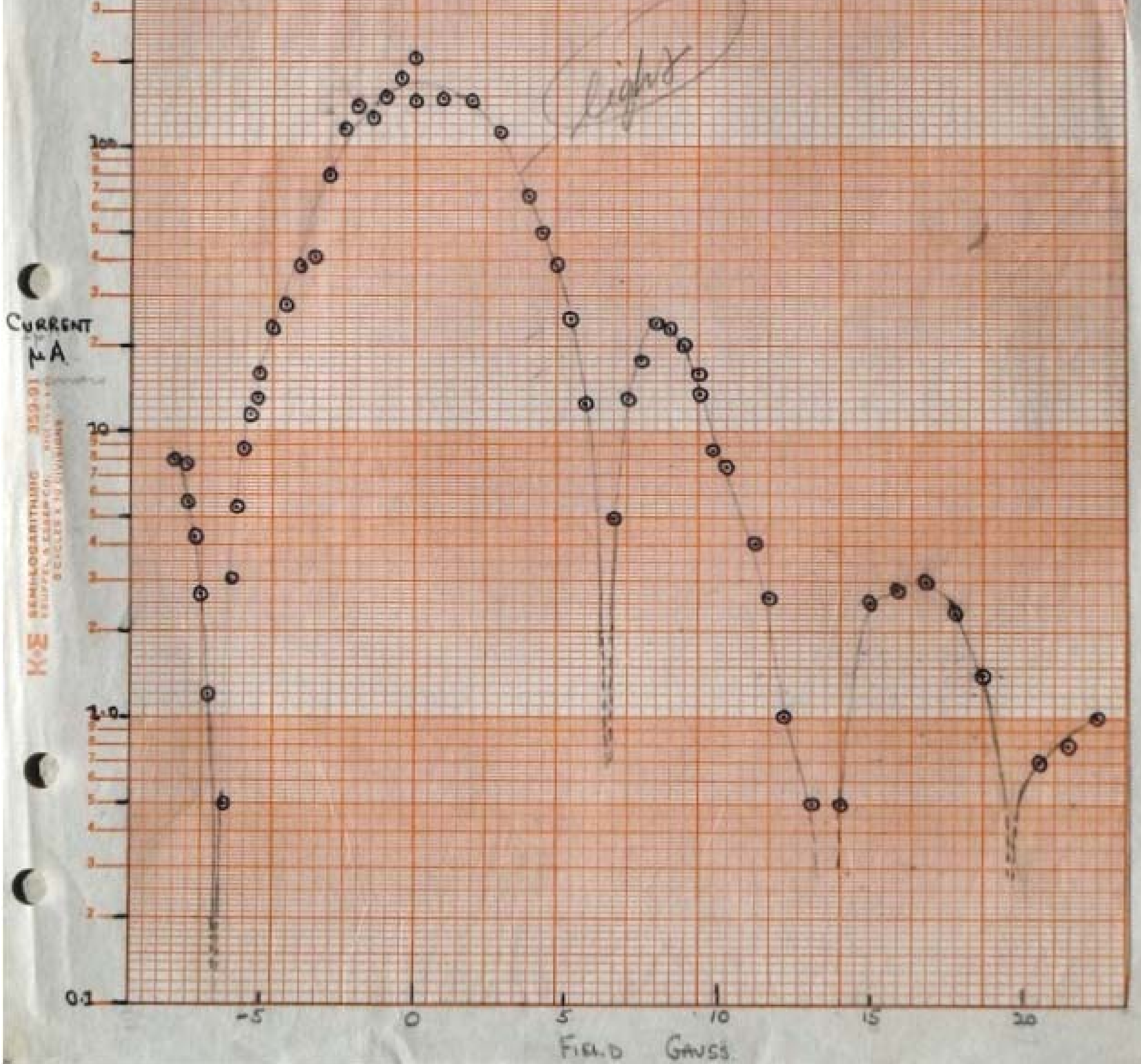
3) of 3 junctions two have



and one has

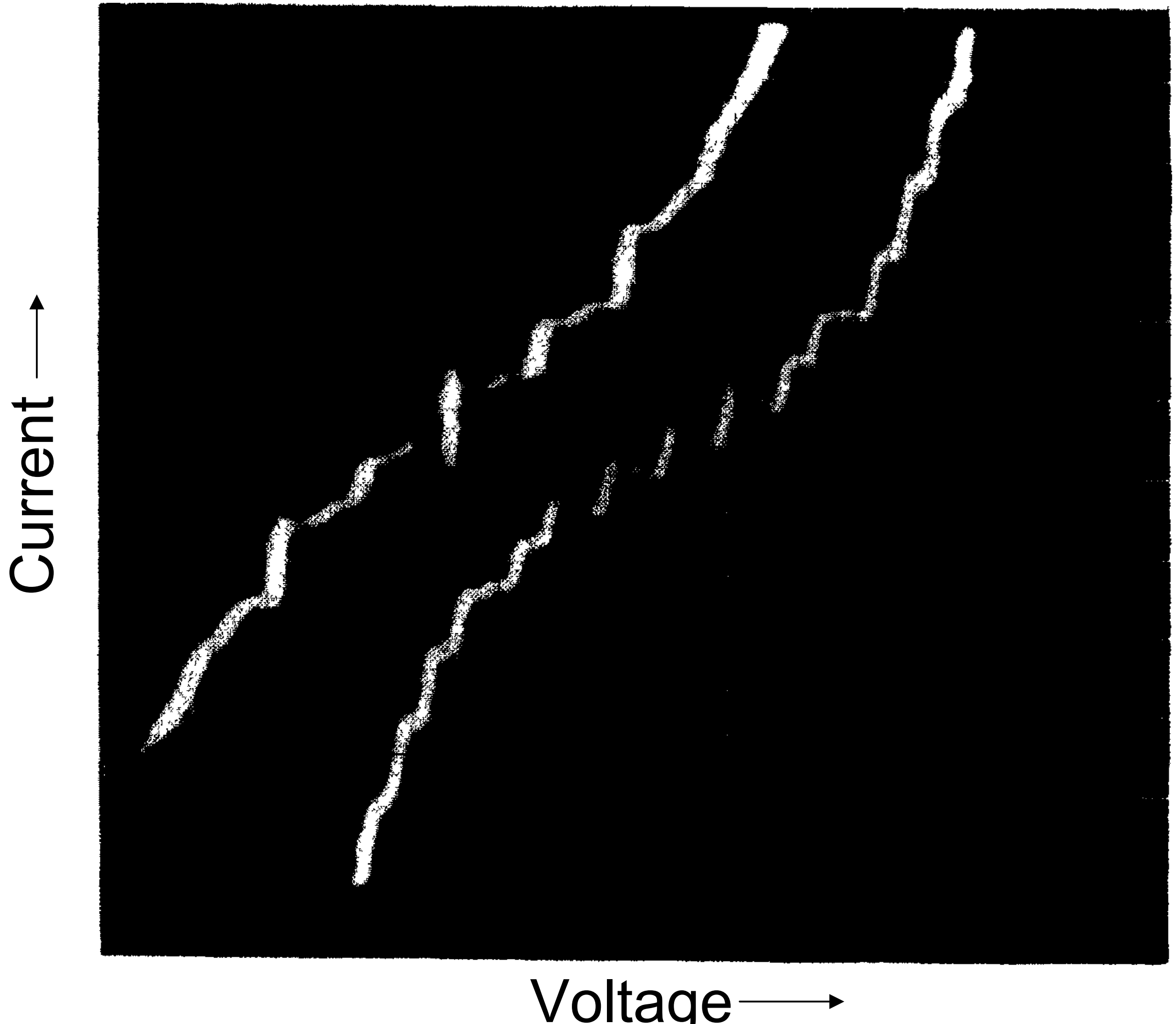


These were with 200 ma in magnet - should have looked for any changes in characteristic with H.



CURRENT
μA
light
FIELD GAUSS
-5
0
5
10
15
20
100
10
1.0
0.1

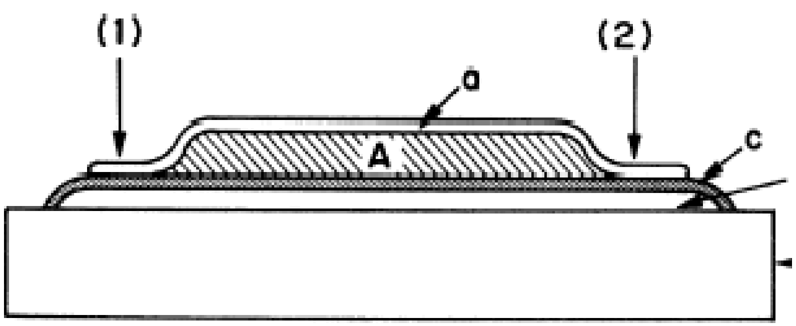
"Microwave steps" in I-V of Josephson junction

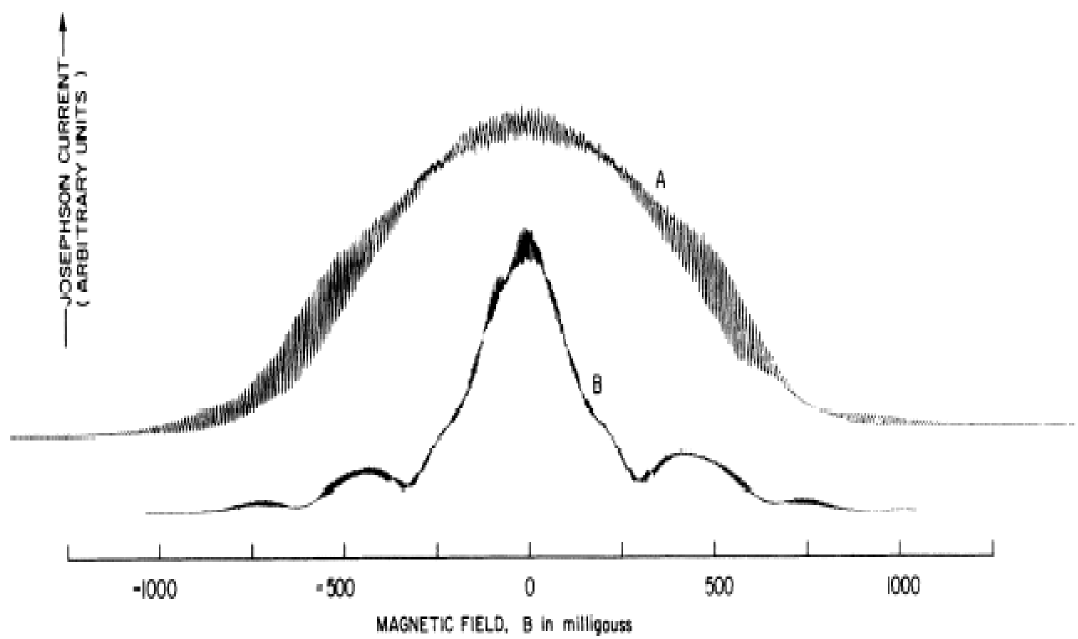


Shapiro, Arthur D. Little, 1963.

“This second period involves a quantum mechanical interference between the currents flowing through separate junctions in direct analogy with double-slit electron beam interference effects ”

Jaklevic, Lambe, Silver, and Mercereau, Ford Lab,1964.





94

DATE

CASE No.

Feb 3rd '64. Phil suggests that the structures of Parks - narrow superconducting constrictions - should (in low H) be weak coupling regions between bulk sup^rs so should exhibit Josephson effects. in fact he considers Parks results are Josephson measurements.

DATE

CASE No.

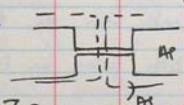
Feb 3rd '64. Phil suggests that the structures of Parks - narrow superconducting constrictions - should (in low H) be weak coupling regions between bulk sup^rs so should exhibit Josephson effects. in fact he considers Parks results are Josephson measurements.

Try to repeat Parks expts. 7031 glue fibres drawn out down to ~ 3 μ. Spiders web ~ 1½ μ. Using aluminum have troubles with continuity on fibres.

Feb 6th Al on glue fibre ~ 8 μ. Went supg o.k.

Structure about 7 gauss which is too high.

Feb 7 Made structure



by scraping ~ 7.2 μ wide, masking with fibre, evaporating so make bridge 8 μ long (but contact may not be good between Al films) Supg ~ 2 mms. Structure about 1.4 g but not conclusive

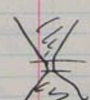
Feb 11. Al through 1.3 mil mask gives $\rho_{4.2}$ for Al films = 9 10^{-5} Ω cm.

Feb 11. Al on fibre ~ 3 μ didn't go supg to ½ mm.

Feb 18 Al on fibre not supg.

Feb Change to Sn on glue fibre - much better coeff. of resistance, $\frac{R_{290}}{R_{4.2}} > 10$.

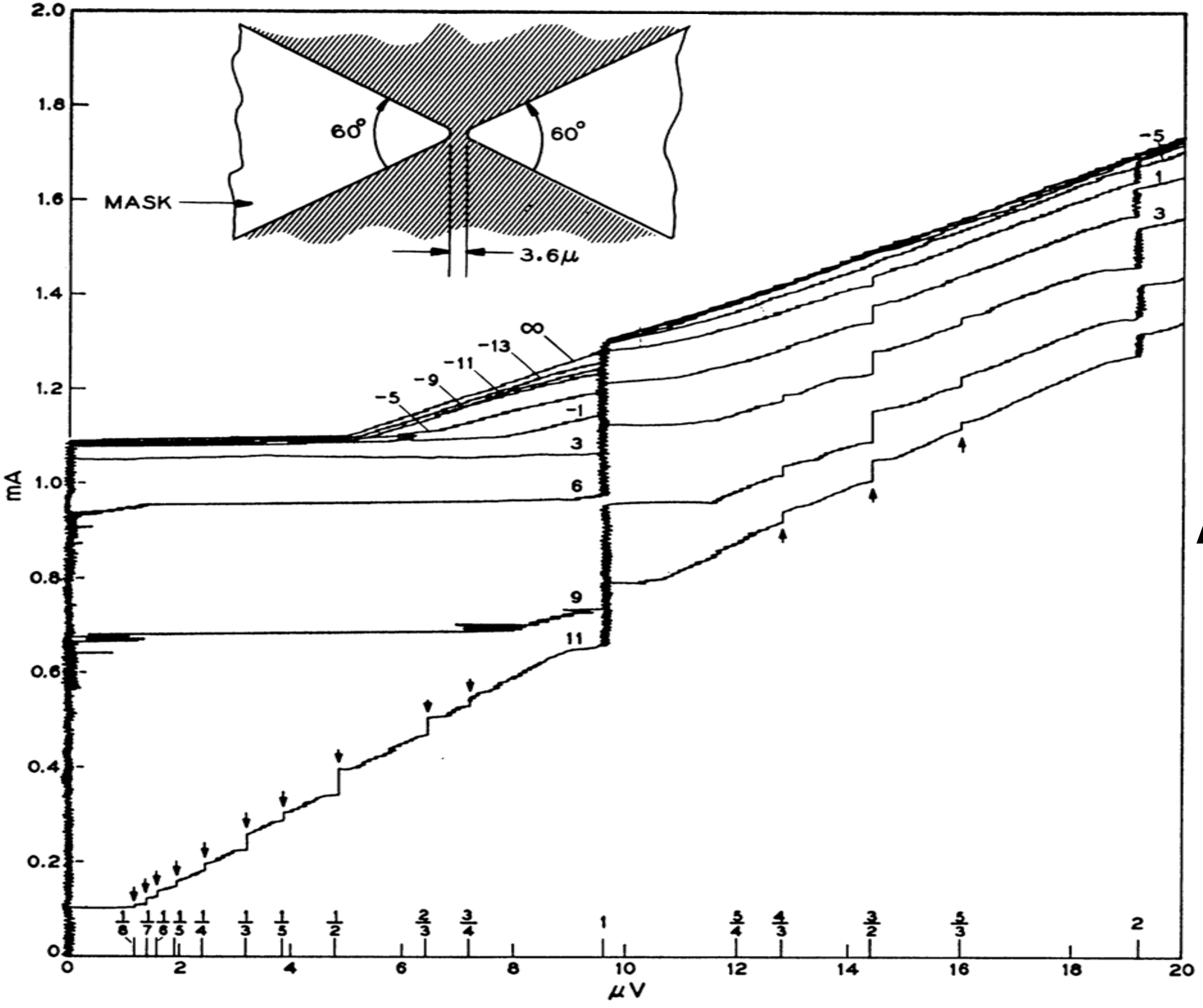
Feb 14. Ali made Al bridge



~ 5 μ square

Looked over temp range, no effects except V α I^2 behaviour near transition in 0 H.

Josephson Effect in Weak Links

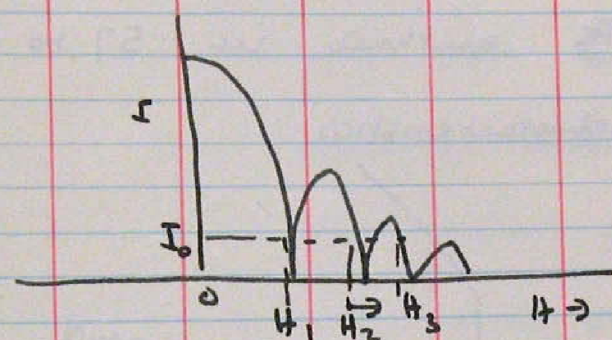


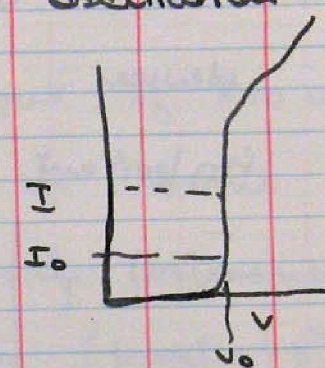
Anderson & Dayem, Bell Labs, 1964

DATE

CASE No.

July 23rd. Have suggested use of Josephson oscillation





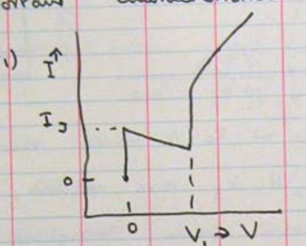
as a device – Held at I_0 it would show a voltage V_0 when fields H_1, H_2 H_3 were reached, zero voltage between. • No interest from Forsglien.

DATE

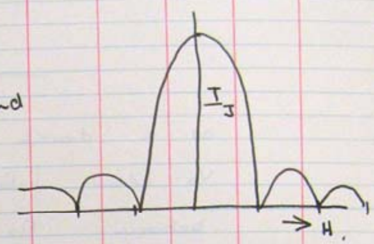
CASE No.

September 11th '63. Wrote up a patentability survey on Josephson devices. As outlined in 57 to 61, we have two important characteristics

1)



and

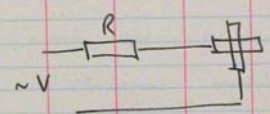


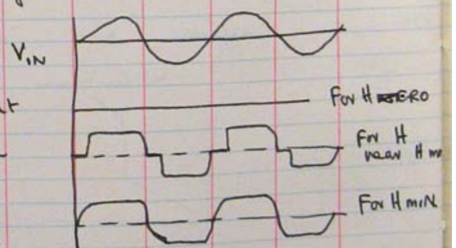
On the basis of these I suggested

1) The I-V characteristic alone can be used as switch - V_1 appearing when I exceeds I_J.

2) A small coil wrapped around the junction gives H_1 - V_1 appears when $H \to H_{min}$.

3) The unit is fed with alternating V through high series resistance R. $\frac{V_{IN}}{R} < I_{J\,max}$





V_{out} is thus a function of applied fields and can be used as a logic device. These proposals will be inserted in the notebook when typed up.

J. M. Rowell. Sept 11 '63

Witnessed Ralph A. Logan Sept 11, 1963

DATE September 8 1970

CASE No. 38788.

Before P.W. Anderson left for Japan (Sept 1, '70), we talked of possible memory storage devices utilising superconductors. He (and T.A. Fulton) believe the structure of Page 54 is too slow to be of interest as currents are essentially being created in normal material. Phil suggests as an alternative a Josephson structure which is depicted on the opposite page (57). It is essentially a long Josephson junction shaped such that a fluxoid will prefer certain locations in the strip. The only question regarding speed is whether the inductance of such a long structure becomes prohibitive.

J. M. Rowell 9/8/70.

Read + understood 11/12/70
J.K. Galt

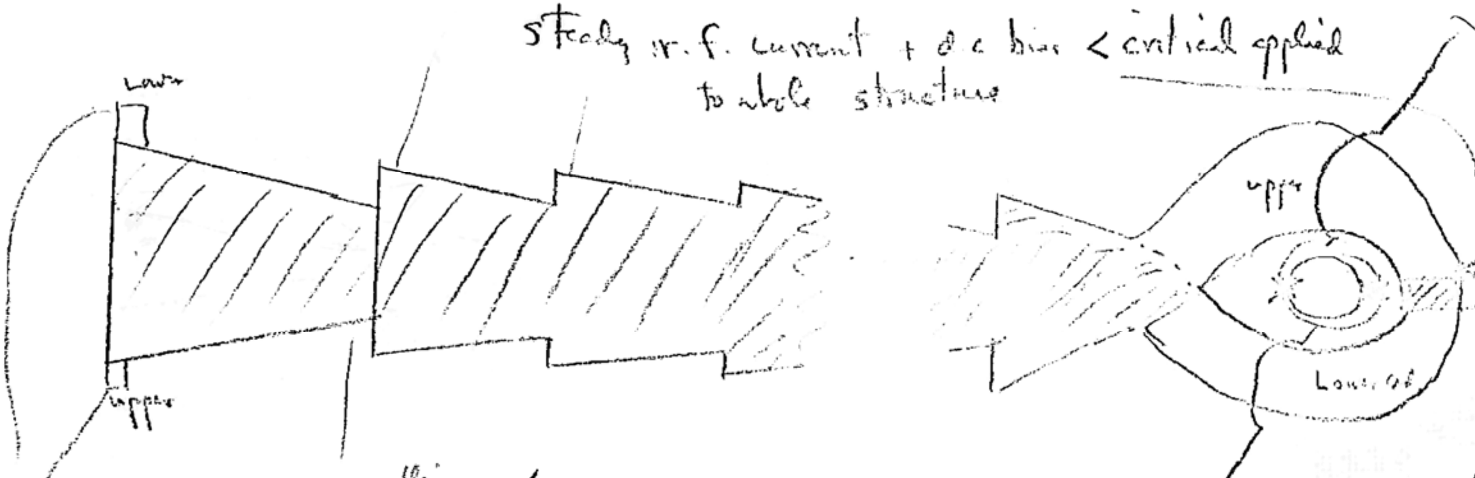
On this page is sketch a sketch by Phil Anderson of a long Josephson junction of such a shape that it will move flux as a storage register. Josephson shift register

Peter Wolff

says Ali Dayem will do

if one of you guys will. P

Steady r.f. current + d.c. bias < critical applied to whole structure



pulse in
... actually pulse
(w/ > 1 fluxon)

compatible I_c
width to λ_J
sections a bit larger than λ_J.

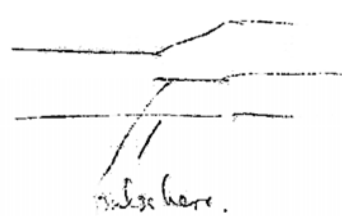
/// very low r.

// low resistance tunnel junction

X high " " "

reading loops: I_c dep. on vortex or not.

Can fork by



J.M. Rowell
Sept 8 '70.

p.c. 9

On this page is sketch a sketch by Phil Anderson
of a long Josephson junction of such a shape that
it will move flux as a storage register.
Josephson shift regist

Peter Wolff

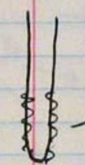
Says Ali Dayem will do
if one of you guys will. P

DATE

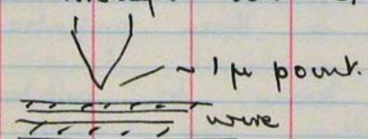
CASE No.

Nov 19th '65 Today will try to make galvanometer of the type described by Clarke (preprint from Cambridge)

Lewinstein has taken some 20 mil Ta wire which is etched and anodised to blue colour after bending into a loop



Will try to make two holes in oxide - by discharge from a capacitor through an etched Ta needle or



by scratching. Then dip in solder to see if we can make superconducting shorts through the holes and hence the double interference device.

J. M. Rowell. Nov 19th '65

Jan 5th '66

Summary

Brian Josephson's Effects, predicted in his Physics Letter submitted on June 8 1962, were observed within 12 months.

The DC Effect in January 1963 at Bell Labs

The AC Effect in June 1963 at Arthur D. Little, Inc.

Applications have followed over the past 50 years