Observations of Josephson's Effects

John M. Rowell
Arizona State University
1961 to 1983 Bell Telephone Laboratories

"100 Years of Superconductivity"

edited by Horst Rogalla and Peter H. Kes. CRC Press 2012

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 - 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

February Physical Review Letter submitted

May - $I_c(H)$ pattern in Pb/I/Pb junctions

June - Shapiro reports AC Effect

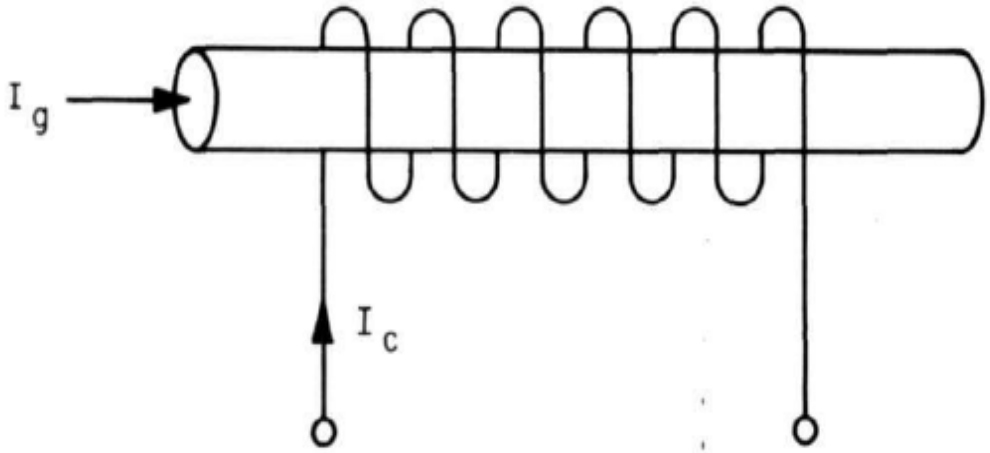
1964

January - First patent application filed

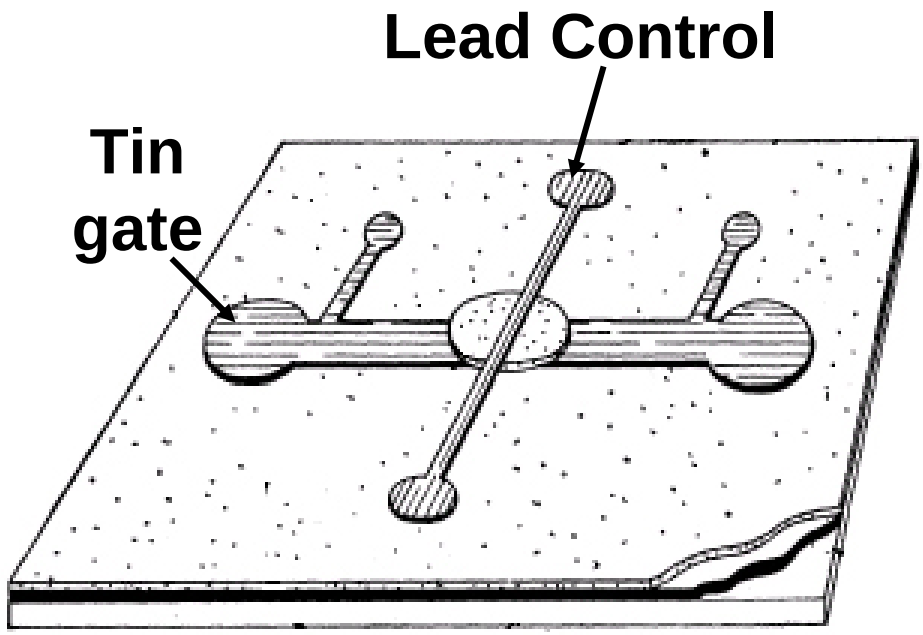
The Ford group reports double junction interference

February – Parks and Mochel, Anderson, weak links

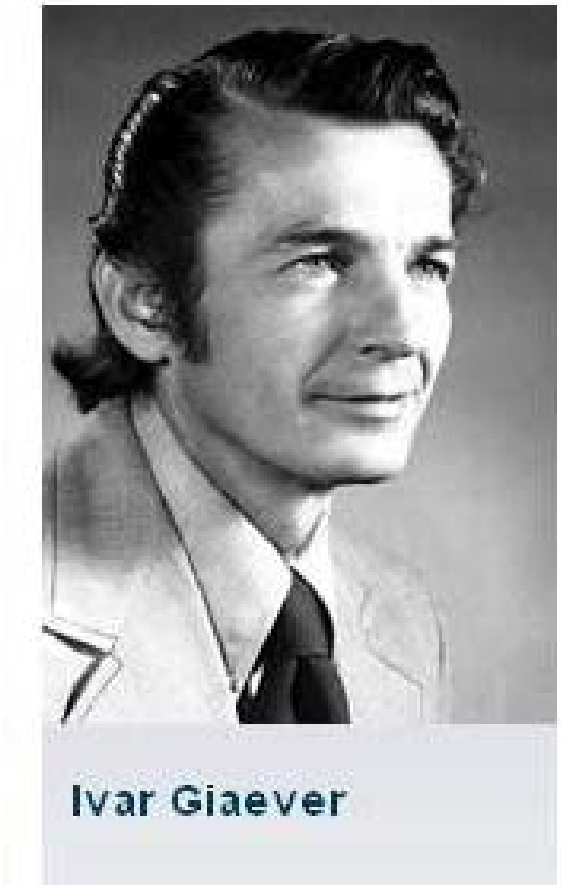
Cryotron



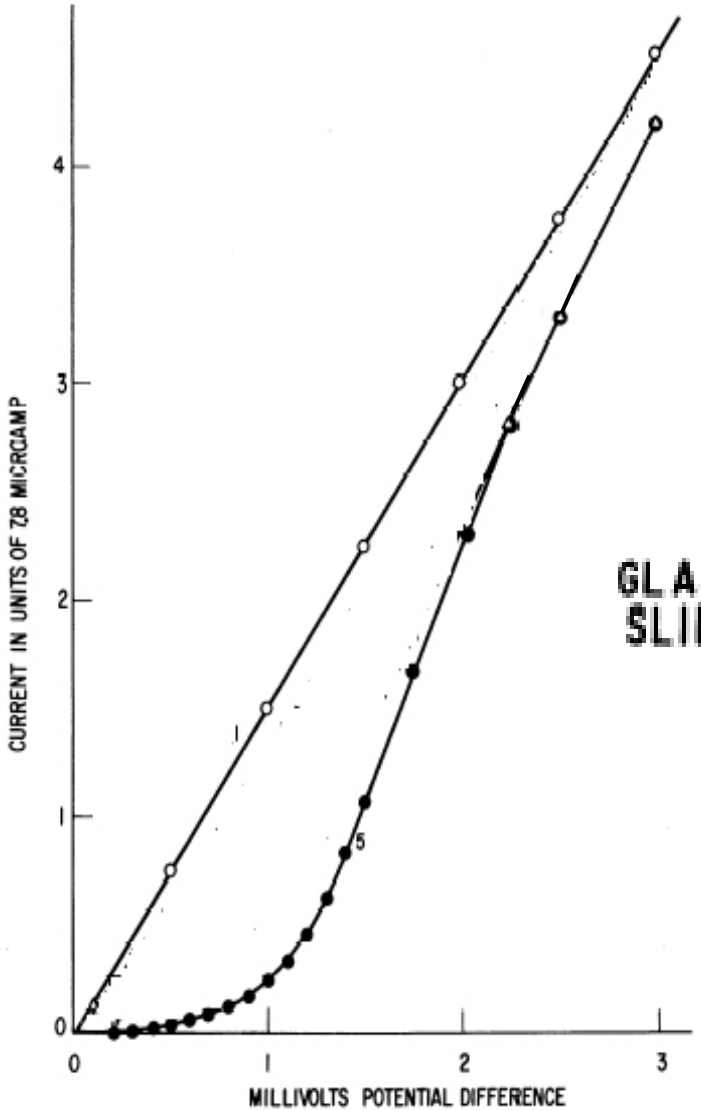
Dudley Buck, 1955

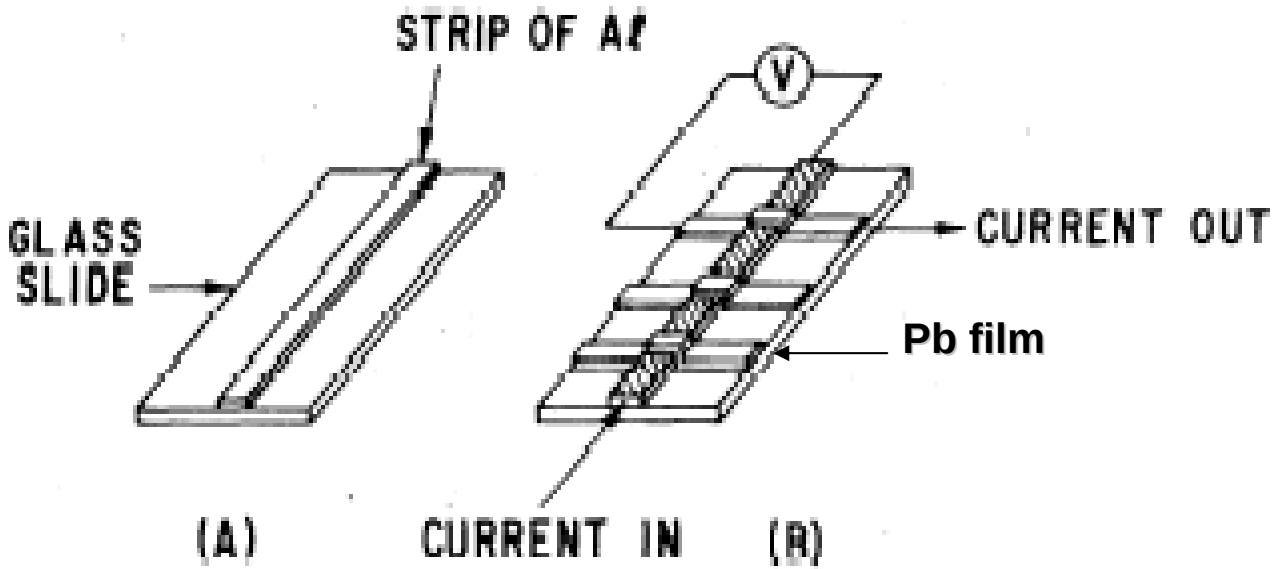


Slade, 1960



Studying for his Ph.D. while working at GE



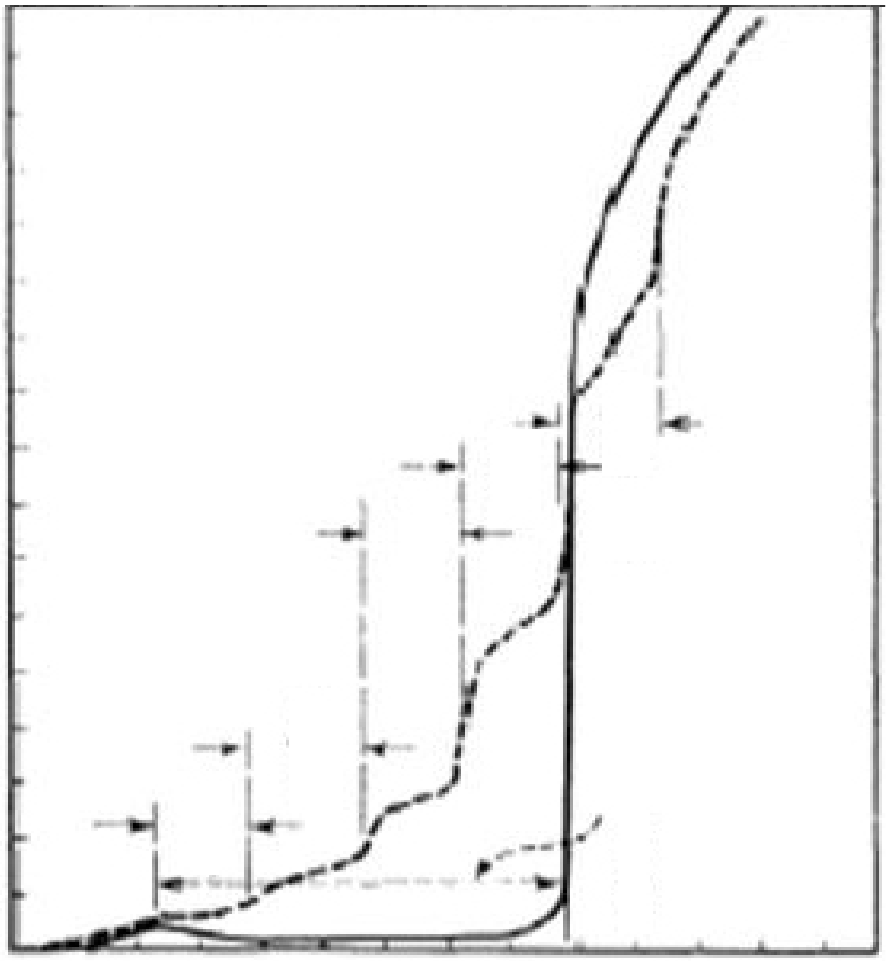


Current versus Voltage for an Al/ I /Pb junction

Giaever, General Electric, 1960.

“Suggest the M/B/S and S/B/S structures for quantum detection of microwave and submillimeter-wave radiation - - -.”

E. Burstein, D.N. Langenberg and B.N. Taylor, Univ. Pennsylvania, 1961.



Dayem and Martin, Bell Labs, 1962.

Research student, Cambridge University, aged 22 in 1962

"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.

Magnetic fields, and currents in the films destroy the time reversal symmetry and reduce |J1|. . . . .Cancellation of supercurrents would start to occur when the amount of flux between the films, including that in the penetration region, became of the order of a quantum of flux.

August 10, 1962. First mention of Josephson Experiment.

4

DATE August 10

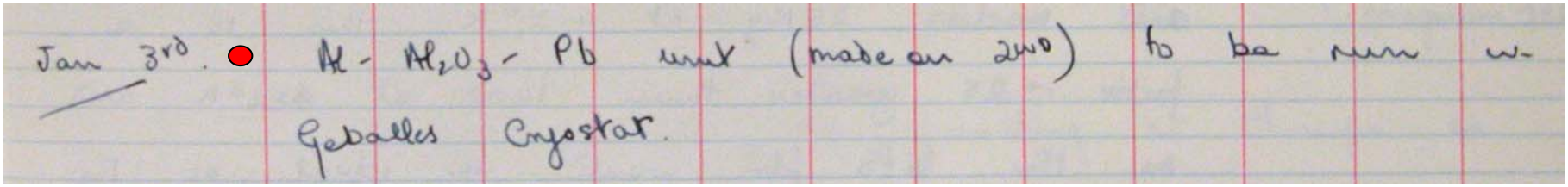
CASE No.

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 < .03g + should be 0.1K at Helium.

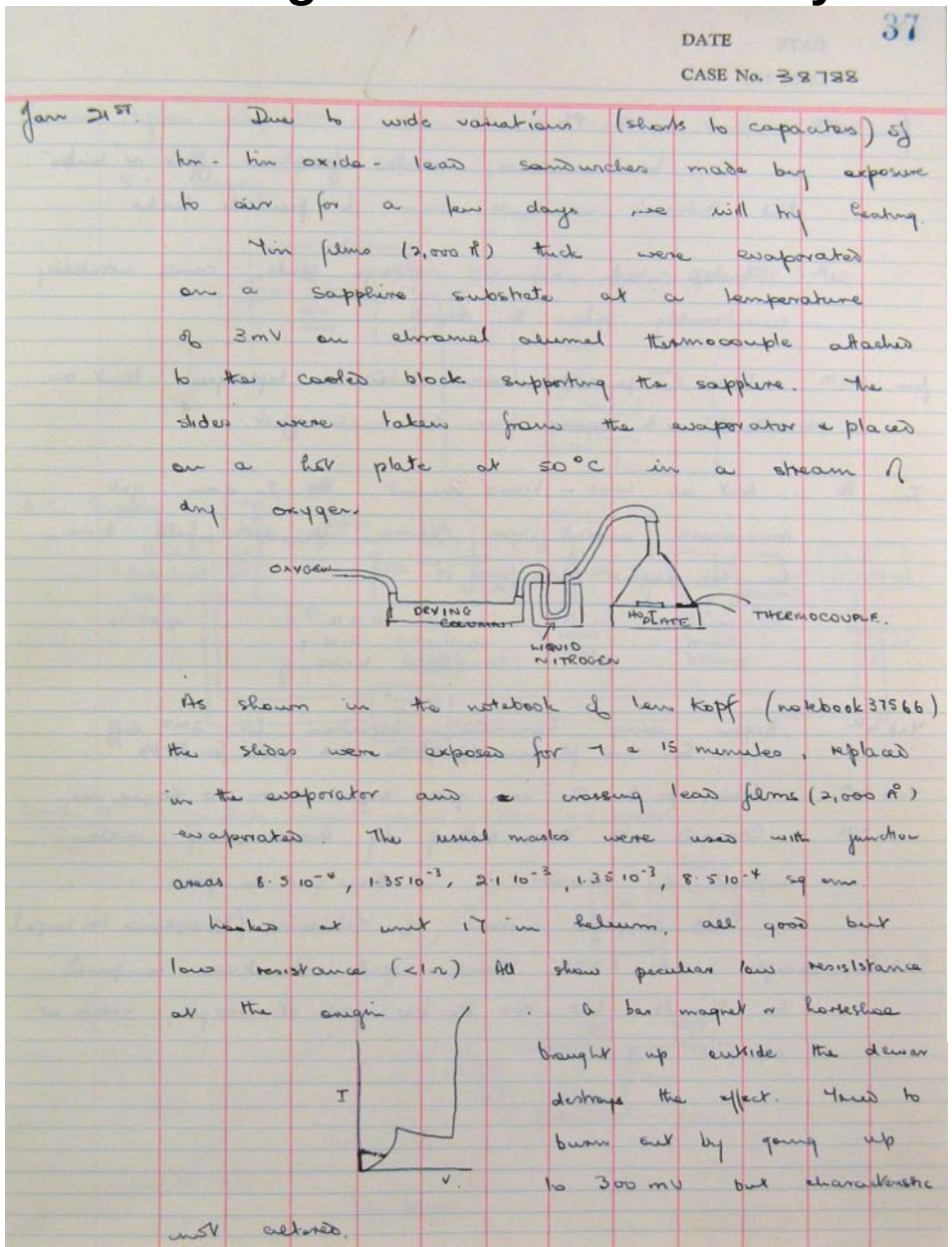
So R A Chegwiddon (x 4626, 1A107) suggests take 1/32" 30" wide μ metal + make a can (4-79 Mo Perm .014" is more difficult to work) by overlapping >1/4" & spot welding. Then he will anneal to make it go 8fr. Made can.

January 3, 1963.
First experiment on Al-Al_2O_3-Pb junction at 0.3K.



No supercurrent observed. Anderson proposes the importance of a coupling energy, hence junctions required with lower resistances.

January 21, 1963.
In a Sn-SnO_x-Pb junction, observation of a supercurrent and its magnetic field sensitivity.



DATE 37

CASE No. 38738

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.

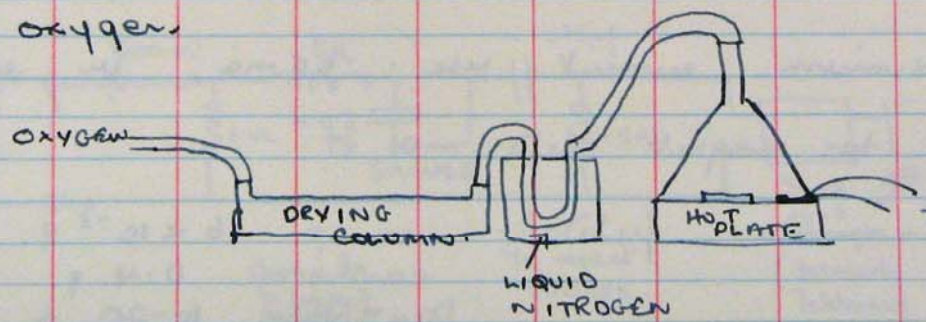
As shown in the notebook of Iwan Kopf (notebook 37566) the slides were exposed for 1 & 15 minutes, replaced in the evaporator and a crossing lead films (2,000 Å) evaporated. The usual masks were used with junction areas $8.5\,10^{-4}$, $1.35\,10^{-3}$, $2.1\,10^{-3}$, $1.35\,10^{-3}$, $8.5\,10^{-4}$ sq cm.

Leaks at unit 17 in Saturn, all good but low resistance (<1 Ω) 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 unstable.

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.

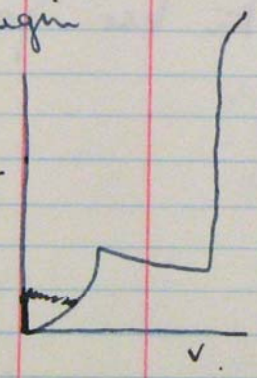


As shown in the notebook of Lew Kopf (notebook 37566)

NITROGEN

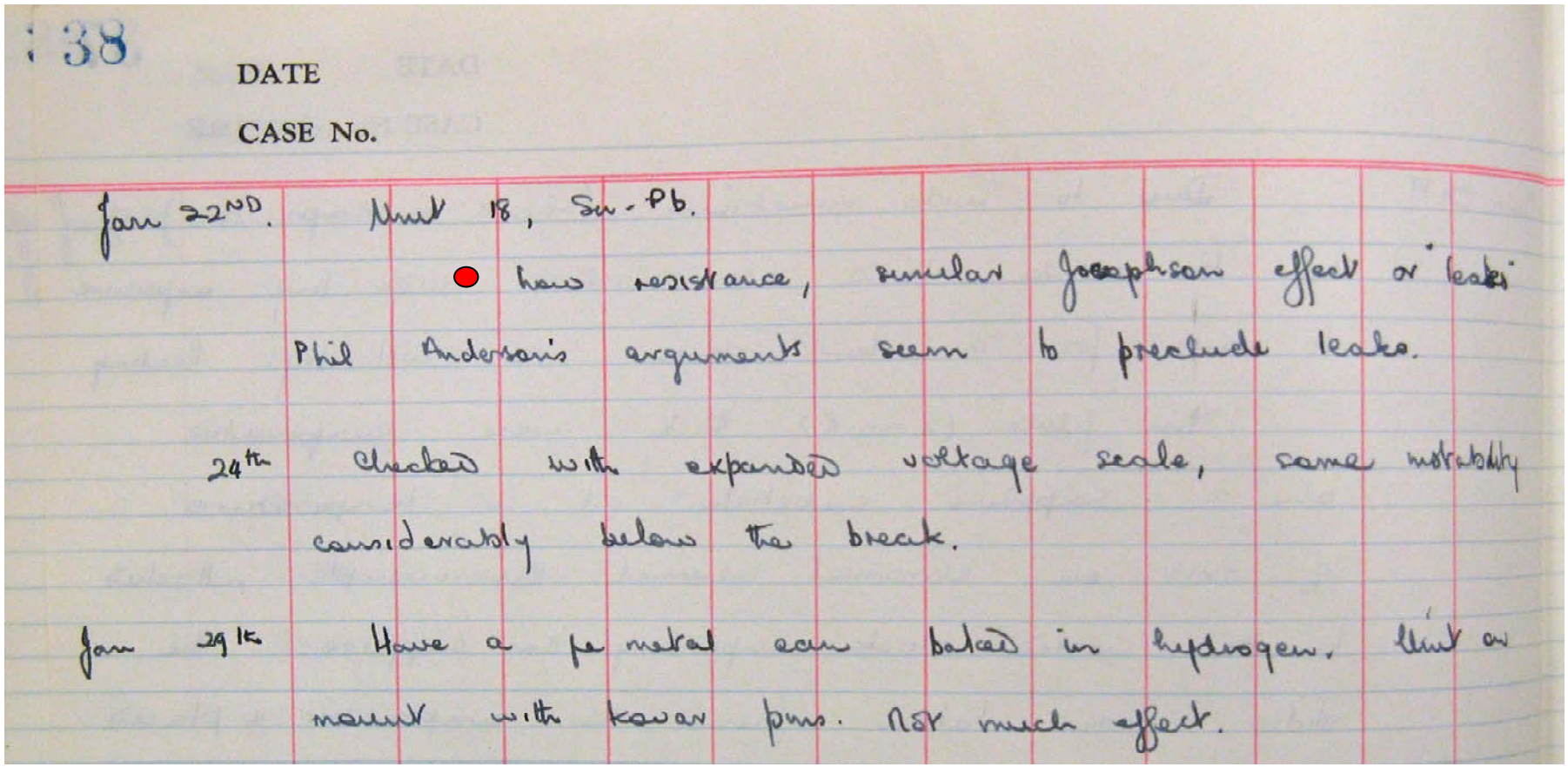
As shown in the notebook of Lew Kopf (notebook 37566) the slides were exposed for 7 & 15 minutes, replaced in the evaporator and ~~a~~ crossing lead films (2,000 Å) evaporated. The usual masks were used with junction areas $8.5\,10^{-4}$, $1.35\,10^{-3}$, $2.1\,10^{-3}$, $1.35\,10^{-3}$, $8.5\,10^{-4}$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

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



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

The next day, another junction showed similar Ic and H effects


38

DATE

CASE No.

Jan 22ND. Nmk 18, Sn-Pb.

● have resistance, similar Josephson effect or leaks

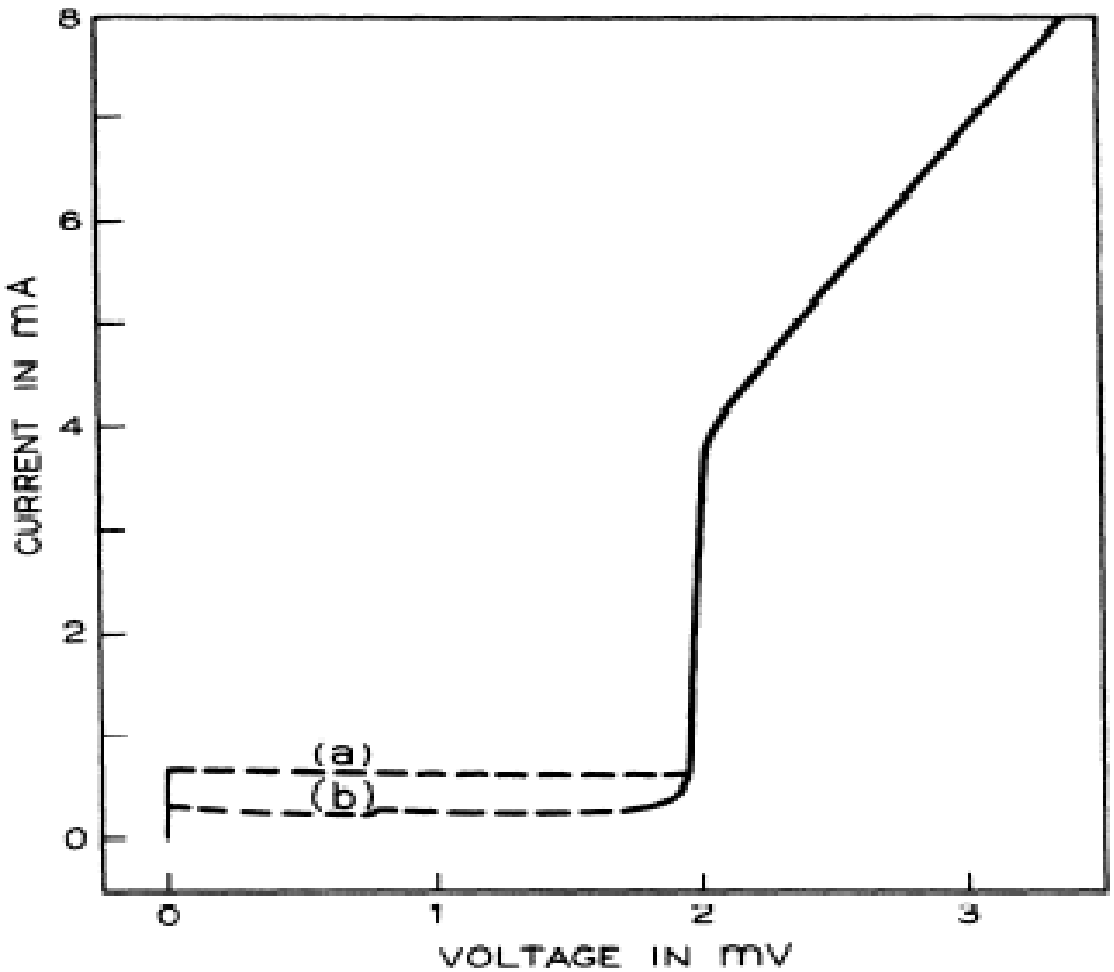
Phil Anderson's arguments seem to preclude leaks.

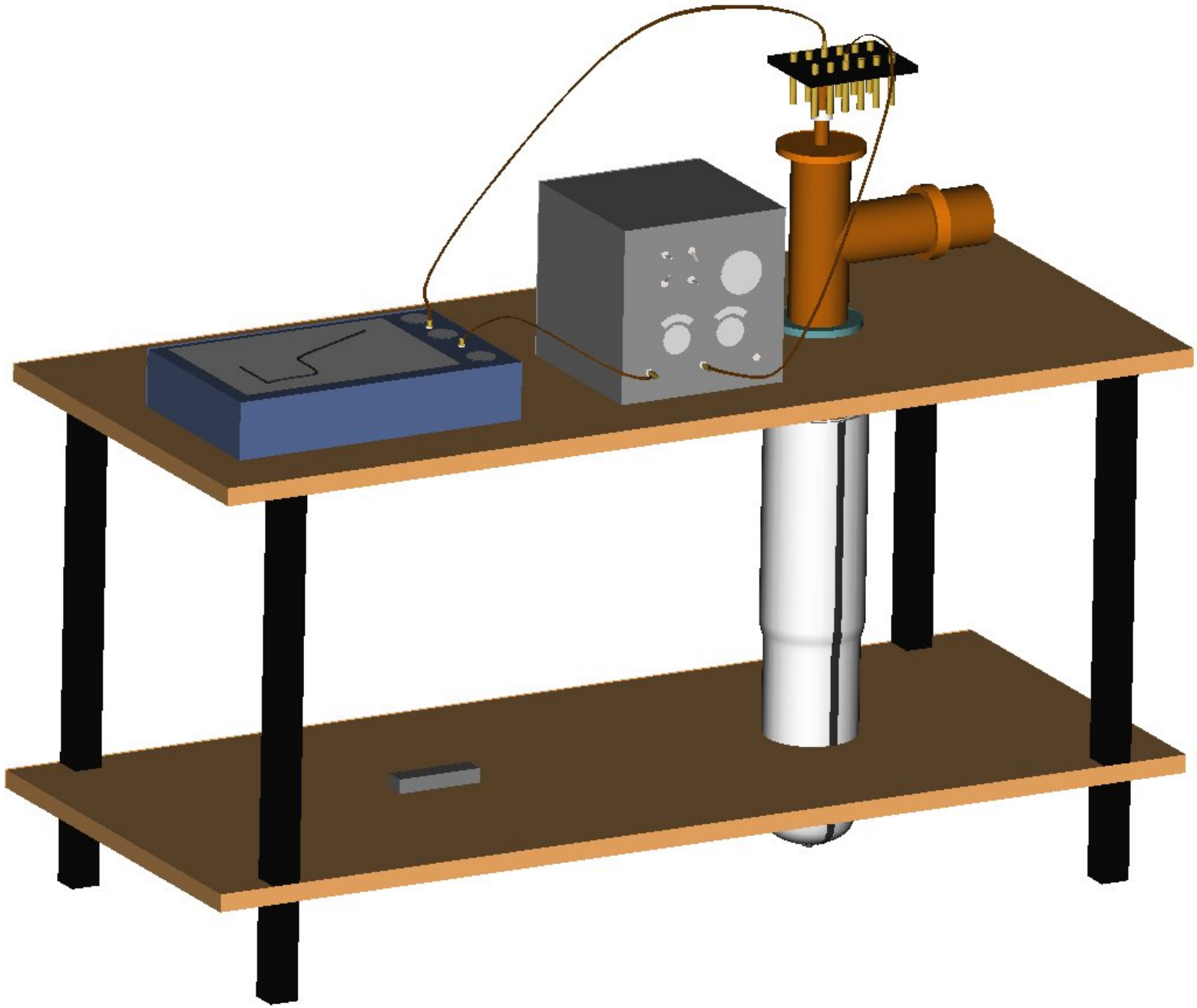
24th checked with expanded voltage scale, same noticably considerably below the break.

Jan 29th Have a pt metal coin baked in hydrogen. Mnk on mount with known 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.



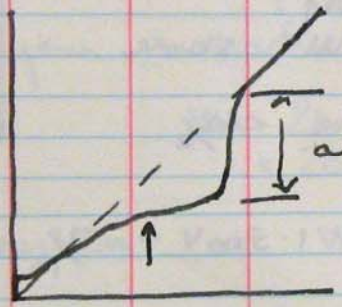



STATES OF A
ONE DIME

May 21, 1963. Change to Pb-PbO_x-Pb junctions.

May 21 made two Pb-Pb, 7mm & 15 mm at 1 to 1.1 mV.
Resistances all ~ ½ Ω room, somewhat higher nitrogen.
Heated 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 O voltage current as function of field - no ears.
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.

First notebook sketch of Fraunhofer $I_c(H)$ pattern

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

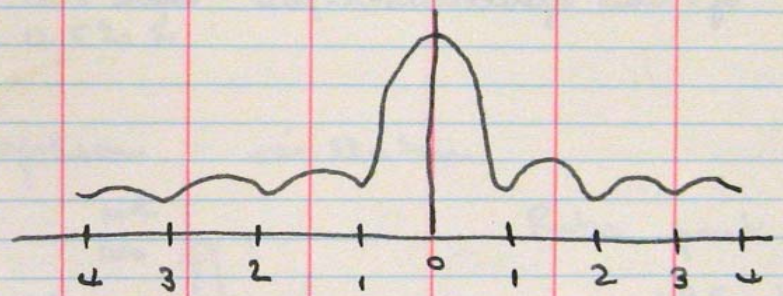
Oscillates with about 30 mV period = 1.2 gauss.

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

↑ width — 2x pen dist for lead films

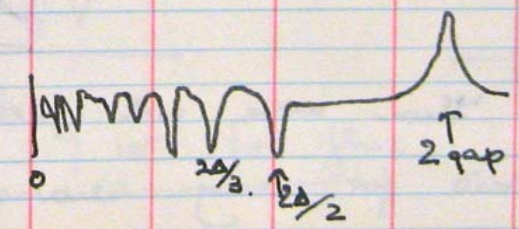
$= 2.2\ 10^{-7}$ = flux quantum.

Peculiarly see 4 dips and then some residual current



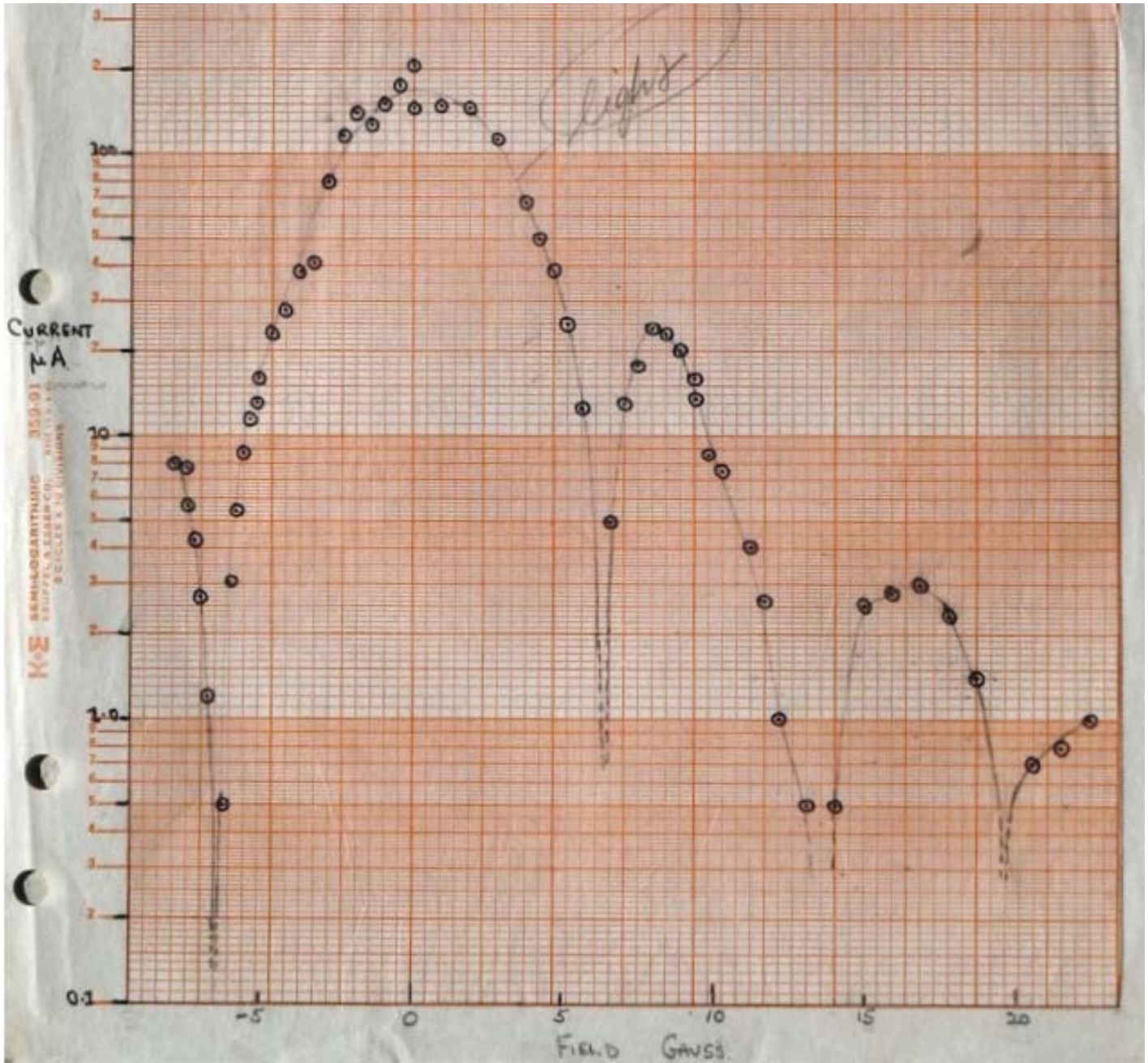
Earths field complicates near zero.

May 22. Differentiated one of above units

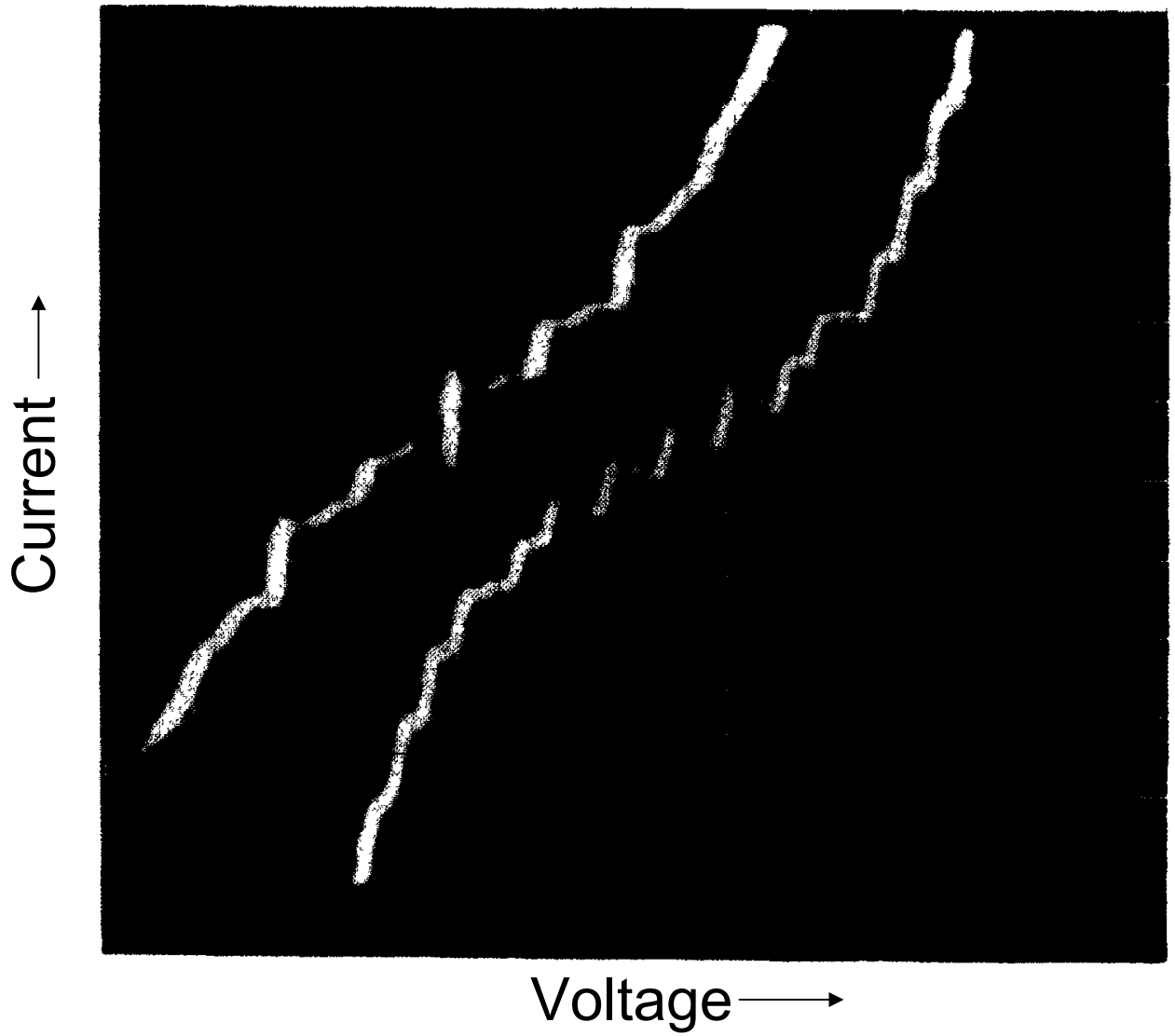


Find sub harmonics of gap down to $2\Delta/12$!

May 29, 1963. Log I_c versus H for Pb-PbO_x-Pb junction.



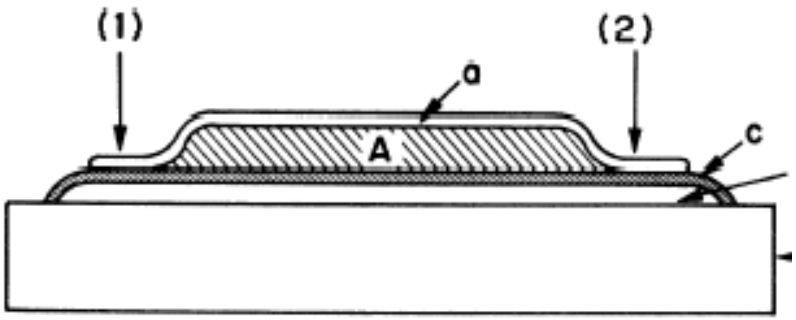
June, 1963.
Josephson's AC Effect - Microwave Steps in I-V.

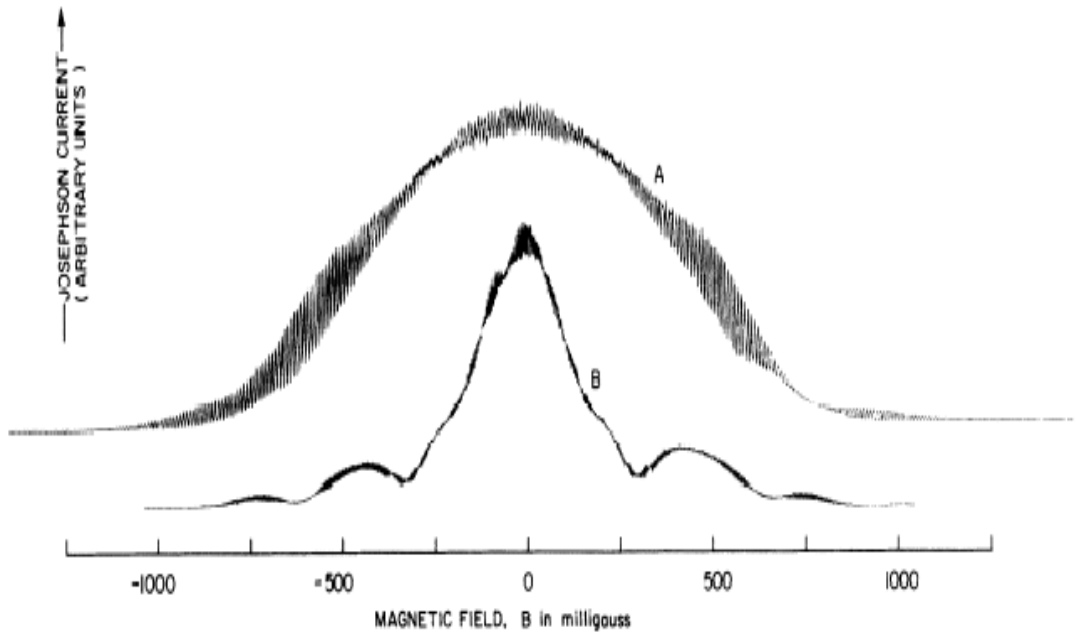


Shapiro, Arthur D. Little, 1963.

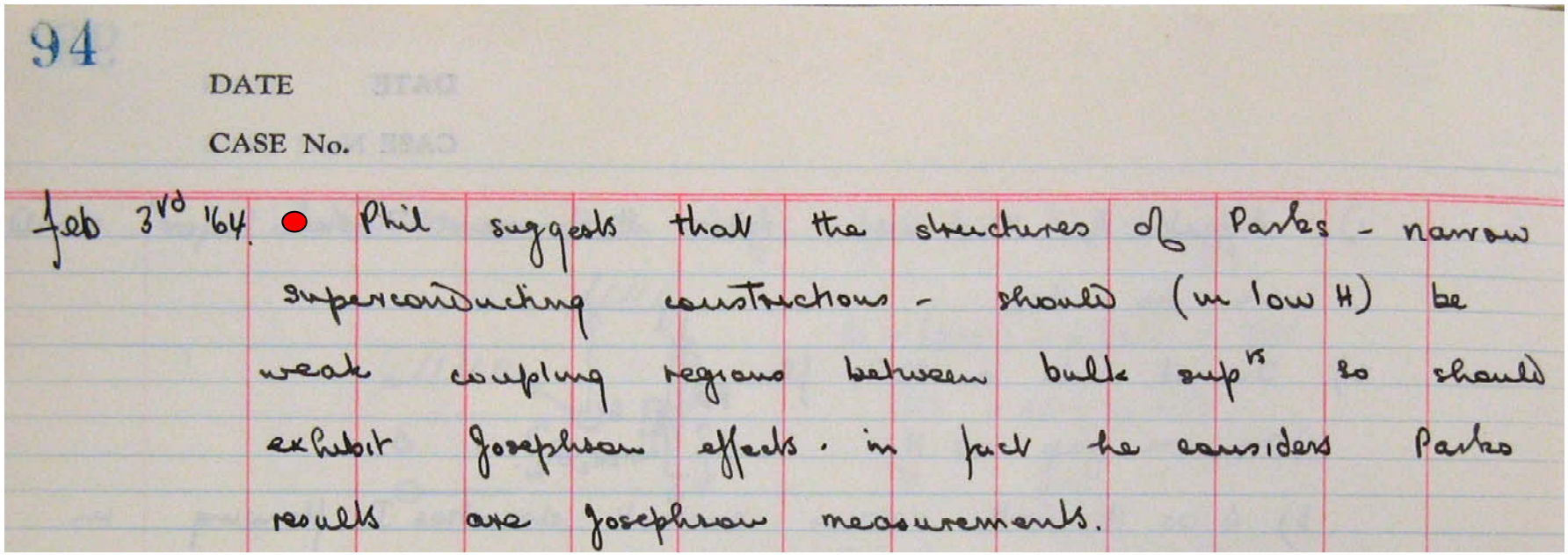
"This second period involves a quantum mechanical interference between the currents flowing through separate junctions in direct analogy with double-slit electron beam interference effects "

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





February 3, 1964. Extension of the Josephson Effects to Weak Links.



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.

94

DATE

CASE No.

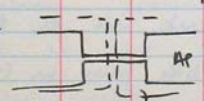
Feb 3rd '64. Phil suggests that the structures of Parks - narrow superconducting constrictions - should (in low H) be weak coupling regions between bulk supⁿ so should exhibit Josephson effects. In fact he considers Parks results are Josephson measurements.

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

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

Structure about 7 gauss which is too high.

Feb 7 made structure



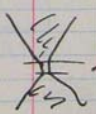
by scraping ~ 7.2 μ wide, masking with fibre, evaporating so make bridge 8 μ long (but contact may not be good between Al films) Supg ~ 2 mms. Structure about 1.4 g but not conclusive

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

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

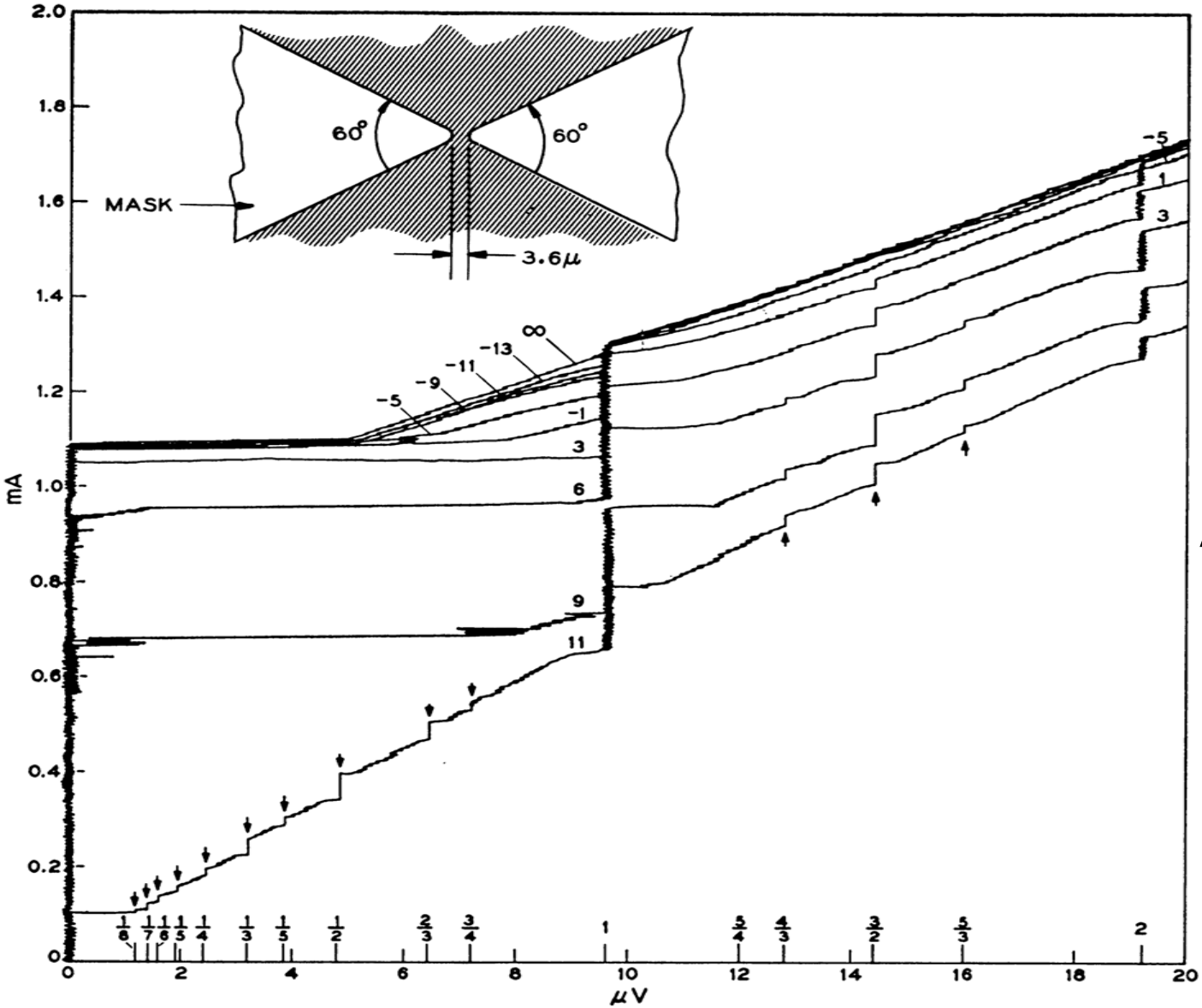
Feb 18 Al on fibre not supg.

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

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

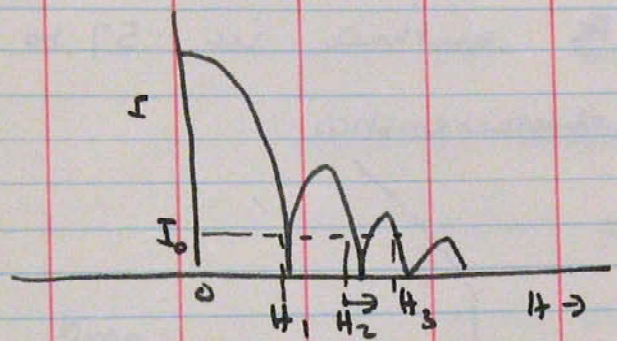
July 23 1963. First discussion of a patent.

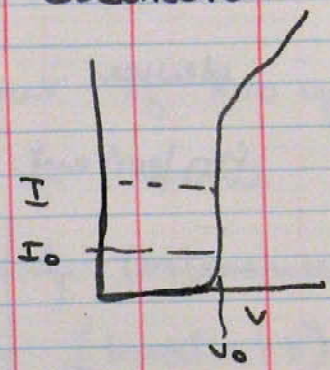
61

DATE

CASE No.

July 23rd. Have suggested use of Josephson oscillation



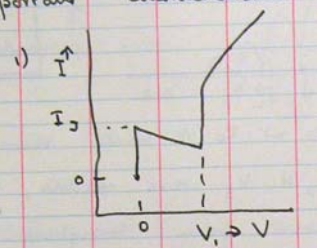


as a device – Held at I_0 it would show a voltage V_0 when fields H_1, H_2 H_3 were reached, zero voltage between. ● No interest from Torpedo.

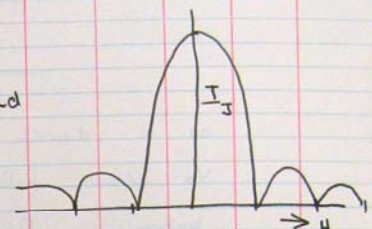
DATE

CASE No.

September 11th 1963. Wrote up a patentability survey on josephson devices. As outlined in 57 to 61, we have two important characteristics



and

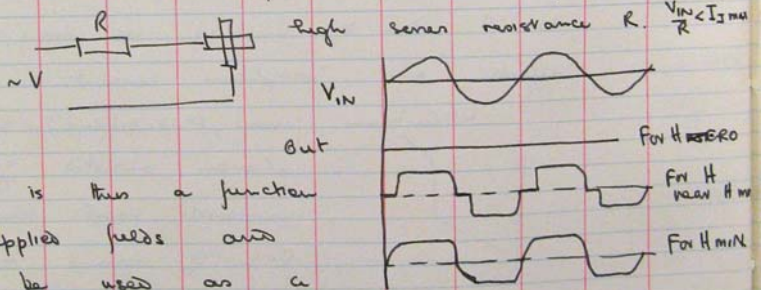


On the basis of these I suggested

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 → Hmin.

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



But V_{out} is then a function of applied fields and can be used as a logic device. The proposals will be inserted in the notebooks when typed up.

J. M. Rowell. Sept 11 '63

Witnessed Ralph A. Logan Sept 11, 1963

Oct. 25, 1966 J. M. ROWELL 3,281,609
CRYOGENIC SUPERCURRENT TUNNELING DEVICES
Filed Jan. 17, 1964 3 Sheets-Sheet 2

FIG. 4

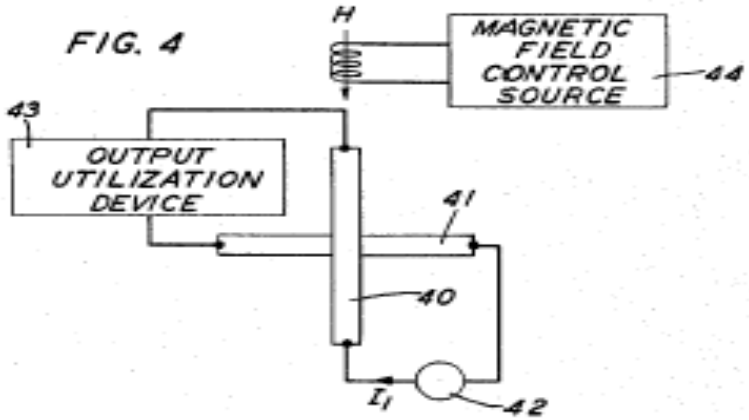


FIG. 5

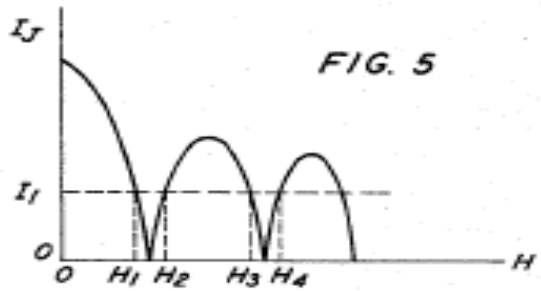
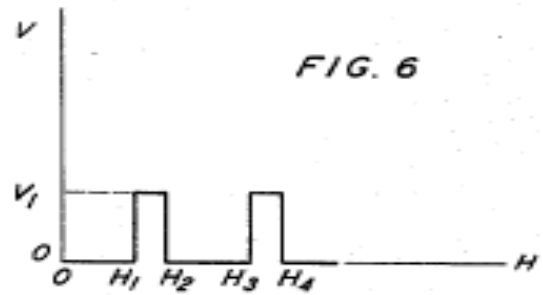


FIG. 6



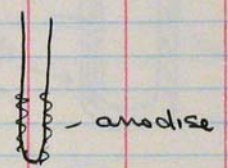
November 19, 1965. An attempt to make a SLUG.

18

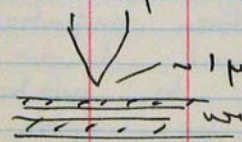
DATE

CASE No.

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

September 8, 1970.
First discussion of single flux quantum device.

56

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 ship. The only question regarding speed is whether the inductance of such a long structure becomes prohibitive.

J. M. Rowell 9/8/70.

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

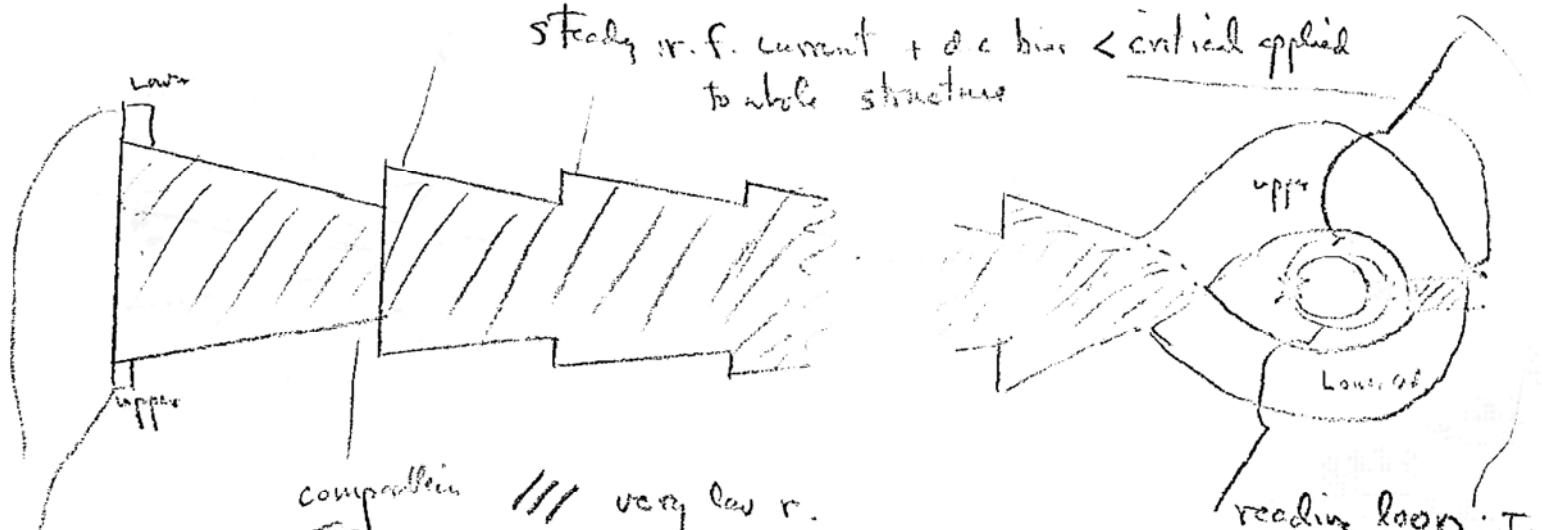
On this page is sketch a sketch by Phil Anderson of a long Josephson junction of such a shape that it will move flux as a storage register.

Josephson shift register

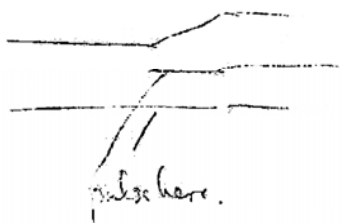
Peter Wolf

says Ali Dayem will do

if one of your guys will. P



Can fork by



gate here.

J. M. Rowell
Sept 20.

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 Wolf

says Ali Dayem will do

it one of your guys will. P

Summary

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

Conclusion

With many thanks to the colleagues at Bell Labs, Bellcore, Conductus and ASU, and to all of you, who have made 50 years of research in superconductivity such an enjoyable experience