SUPERCONDUCTIVITY WS 15-16

Monday 10:00-11:30

SR Exp. physics II

Prof. Paul H.M. van Loosdrecht

pvl@ph2.uni-koeln.de

www.loosdrecht.net

Superconductivity
Main properties

- Macroscopic quantum phenomenon

- Vanishing resistance → Kamerlingh Onnes
- Perfect diamagnet → Meissner-Ochsenfeld effect
  - Type I and type II superconductors
- 2nd order phase transition → Thermodynamics (Heat cap.)
- Electronically gapped state → Tunneling spectroscopy, optics
- Isotope effect: Role of phonons? → Isotope experiments
- Unit of charge ‘responsible particle’ is 2e → Flux quantization

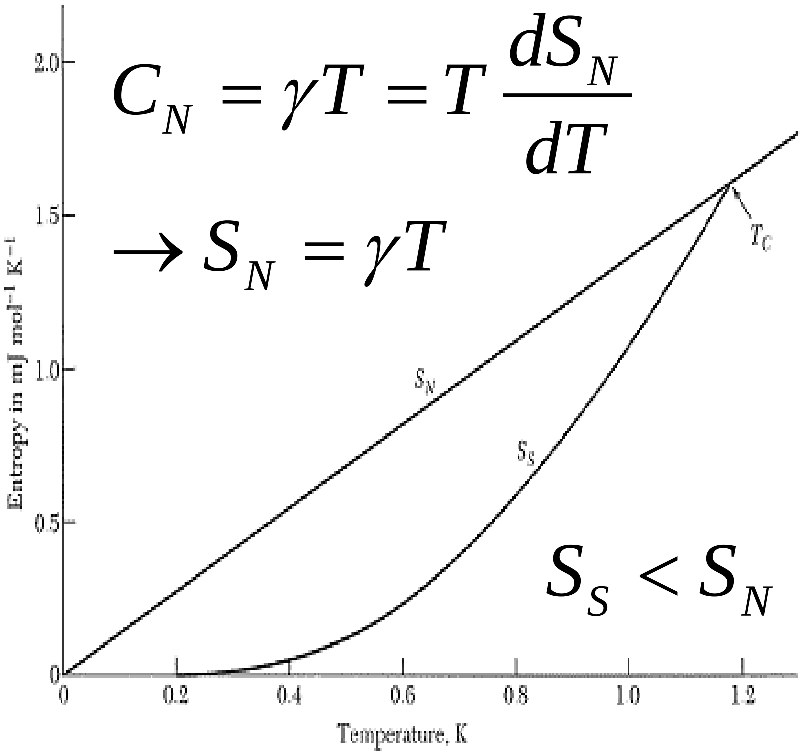
Second order phase transition

Aluminum

$$C_N = \gamma T = T\frac{dS_N}{dT}$$

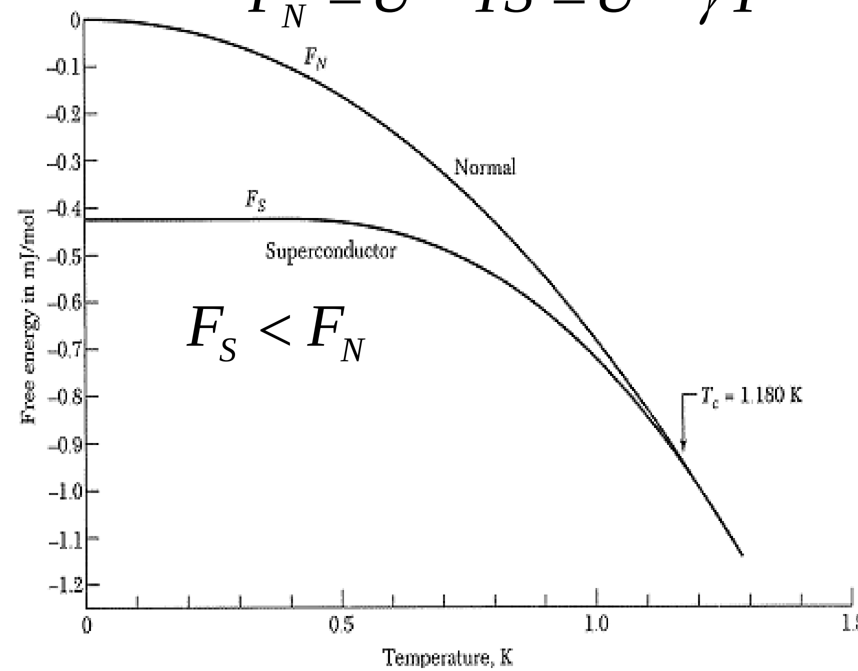
$$\rightarrow S_N = \gamma T$$

$$S_S < S_N$$



$$F_N = U - TS = U - \gamma T^2$$

$$F_S < F_N$$



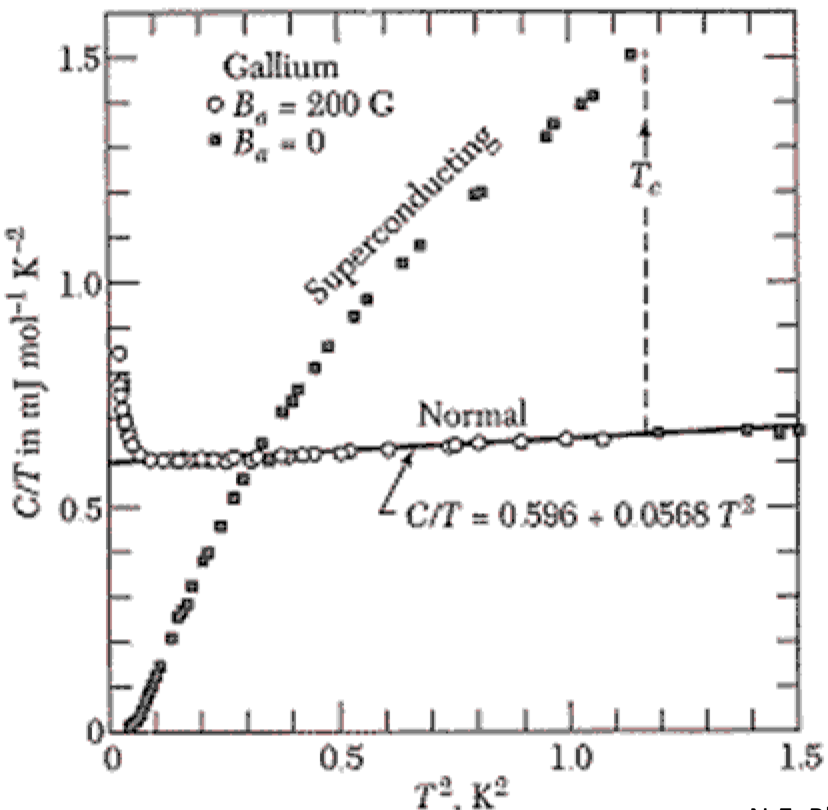
Since less entropy: SC state more ordered !!

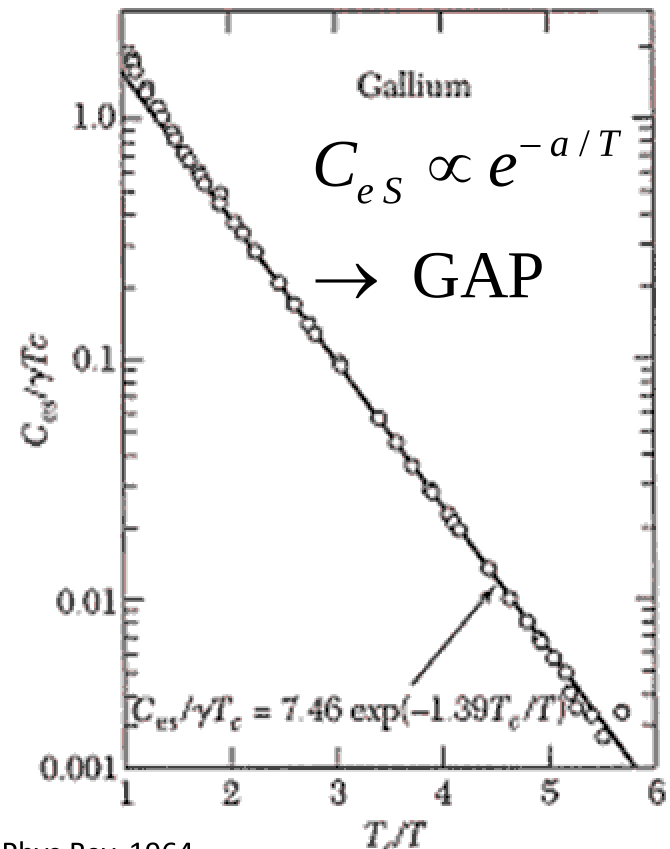
What orders ???

$\Delta S \sim 10^{-4}\, k_B$ per atom

$\rightarrow$ only 10^{-4} e's participate in transition.

Heat capacity





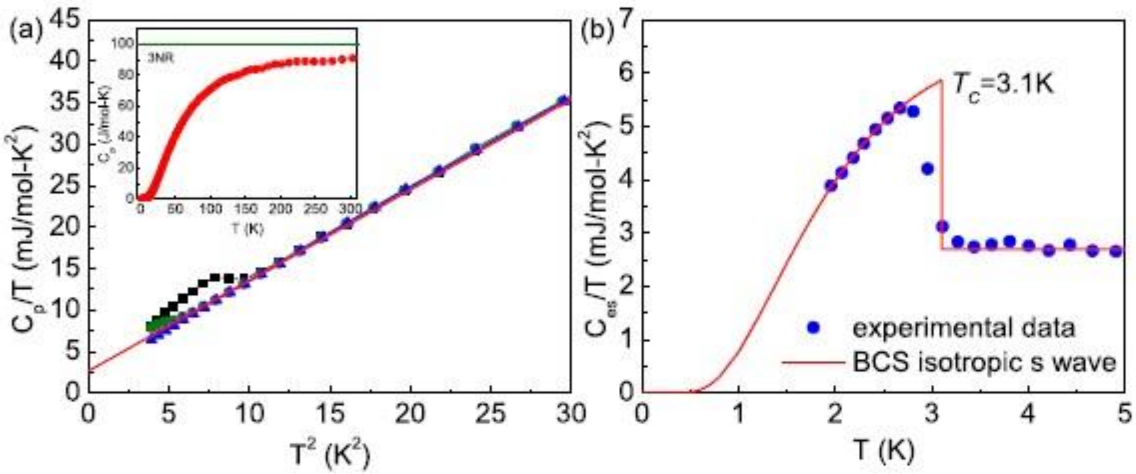
N.E. Phillips, Phys.Rev. 1964

For H=0 Entropy continuous at T_c
Jump in specific heat

➔ Second order phase transition

Low temperature:
Activated behaviour ➔ Excitation gap

Type II specific heat



(a) Low-temperature specific-heat behavior of $Ni_{0.05}ZrTe_3$ plotted as C_p/T *vs.* T at H = 0, 1 and 50 kOe. The solid line is a fit described in the text. Inset: temperature dependence of $C_p(T)$ from 1.95 K to 300 K at H = 0 kOe. (b) Temperature dependence of the electronic specific heat plotted as C_{es}/T *vs.* T at H = 0 kOe. The solid line shows fitted result of C_{es}/T assuming an isotropic *s*-wave BCS gap. [Lei et al., EPL 2011]

Superconducting gap

Tunneling (Giaever et al., 1961)

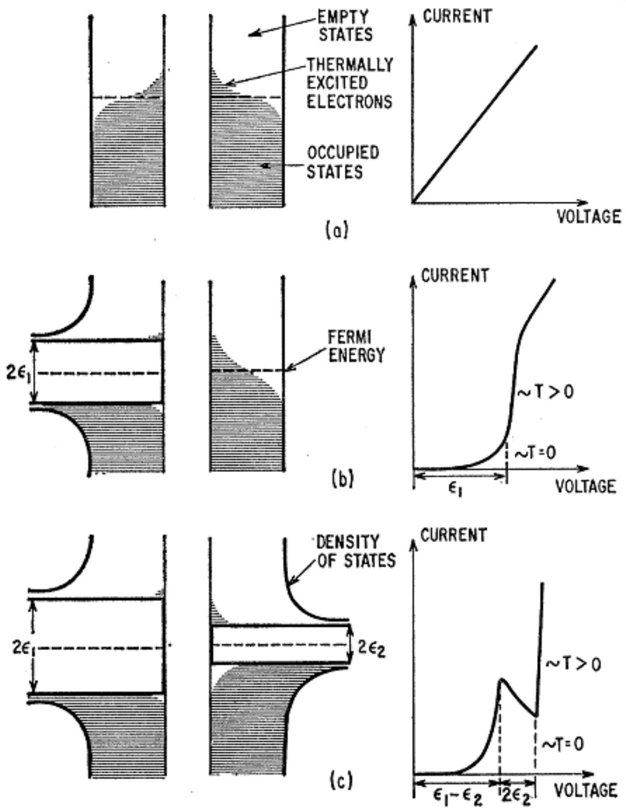


FIG. 4. Energy diagram displaying the density of states and the current-voltage characteristics for the three cases. (a) Both metals in the normal state. (b) One metal in the normal state and one in the superconducting state. (c) Both metals in the superconducting state.

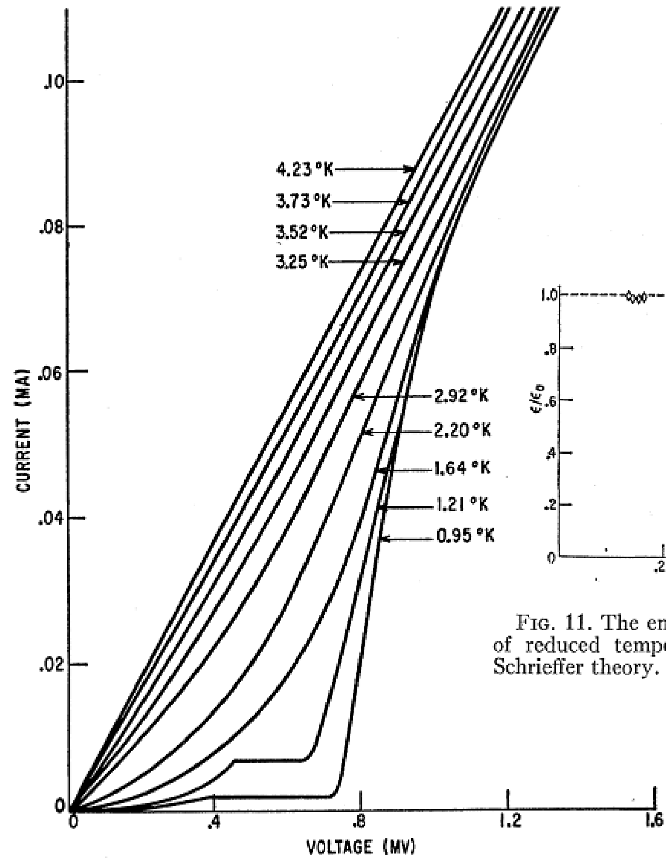


FIG. 6. Current-voltage characteristics of an Al-Al_2O_3-Sn sandwich at various temperatures.

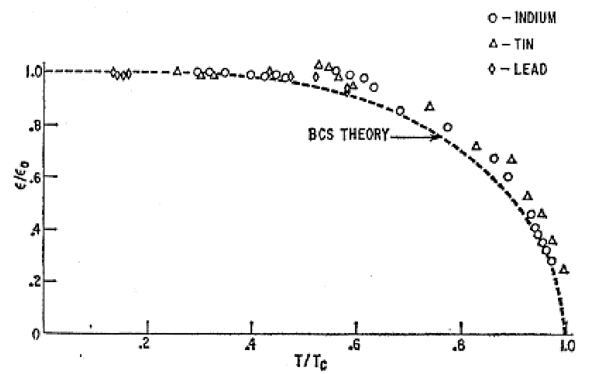


FIG. 11. The energy gap of Pb, Sn, and In films as a function of reduced temperature, compared with the Bardeen-Cooper-Schrieffer theory.

Superconducting gap

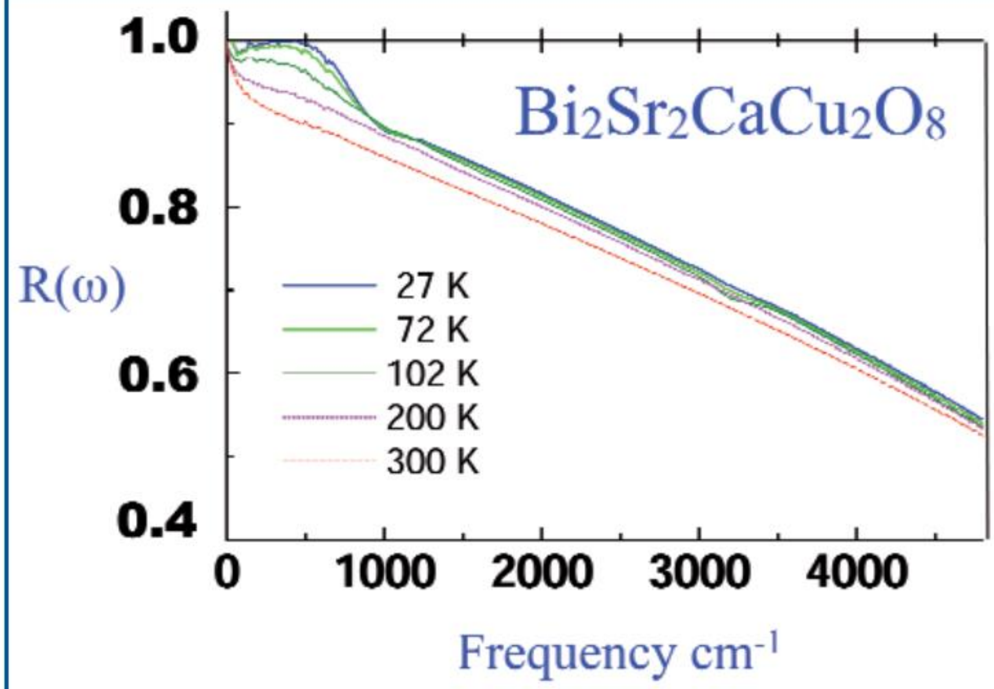


Fig. 2 (color online):The reflectance of a high temperature superconductor with $T_c = 91$ K at various temperatures from Hwang *et al* [13] Note the sharp onset of absorption at 27 K in the superconducting state, above a frequency of 500 cm^{-1}. In this clean limit superconductor the onset marks the energy where the incoming photon can break a Cooper pair and generate a bosonic excitation.

Optics (Hwang et al., 2007)

Isotope effect

Table I. Experimental and Calculated Infrared Absorption Bands for $^{12}C_{60}$ and $^{13}C_{60}$

	frequency (cm^{-1})			
$^{12}C_{60}$ (exptl)	1429	1183	576	527
$^{13}C_{60}$ (calcd[a])	1373	1137	553	506
$^{13}C_{60}$ (exptl)	1375	1138	554	506

[a] Calculated from the $^{12}C_{60}$ experimental data using $\nu(^{13}C_{60}) = \nu(^{12}C_{60})[M(^{12}C)/M(^{13}C)]^{1/2}$. IR spectra were recorded on C_{60} thin films using a Nicolet-5PC FT-IR.

J. Am. Chem. Soc. **1992**, *114*, 3141–3142

Synthesis of Pure $^{13}C_{60}$ and Determination of the Isotope Effect for Fullerene Superconductors

Chia-Chun Chen and Charles M. Lieber*

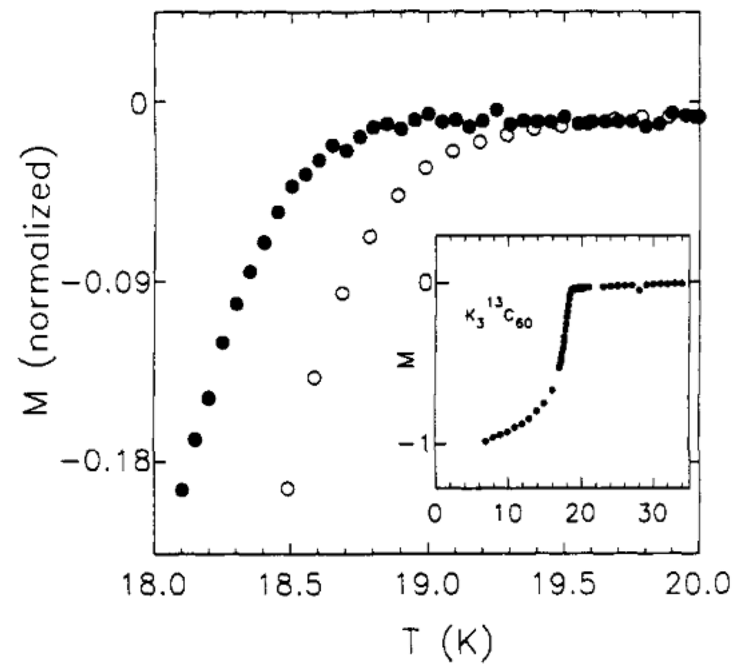


Figure 2. High-resolution temperature-dependent magnetization measurements obtained on $K_3{}^{13}C_{60}$ (●) and $K_3{}^{12}C_{60}$ (○) samples highlighting the depression in T_c for the isotopically substituted material. The samples were initially cooled in zero field to 5 K, and then the curves were recorded on warming in a field of 20 Oe. The curves were normalized to the value of the magnetization at 5 K. The inset shows a full magnetization curve for a $K_3{}^{13}C_{60}$ sample.

Flux quantization

VOLUME 7, NUMBER 2 PHYSICAL REVIEW LETTERS JULY 15, 1961

EXPERIMENTAL EVIDENCE FOR QUANTIZED FLUX IN SUPERCONDUCTING CYLINDERS*

Bascom S. Deaver, Jr., and William M. Fairbank
Department of Physics, Stanford University, Stanford, California
(Received June 16, 1961)

We have observed experimentally quantized values of magnetic flux trapped in hollow superconducting cylinders. That such an effect might occur was originally suggested by London[1] and Onsager,[2] the predicted unit being hc/e. The quantized unit we find experimentally is not hc/e, but $hc/2e$ within experimental error.[3]

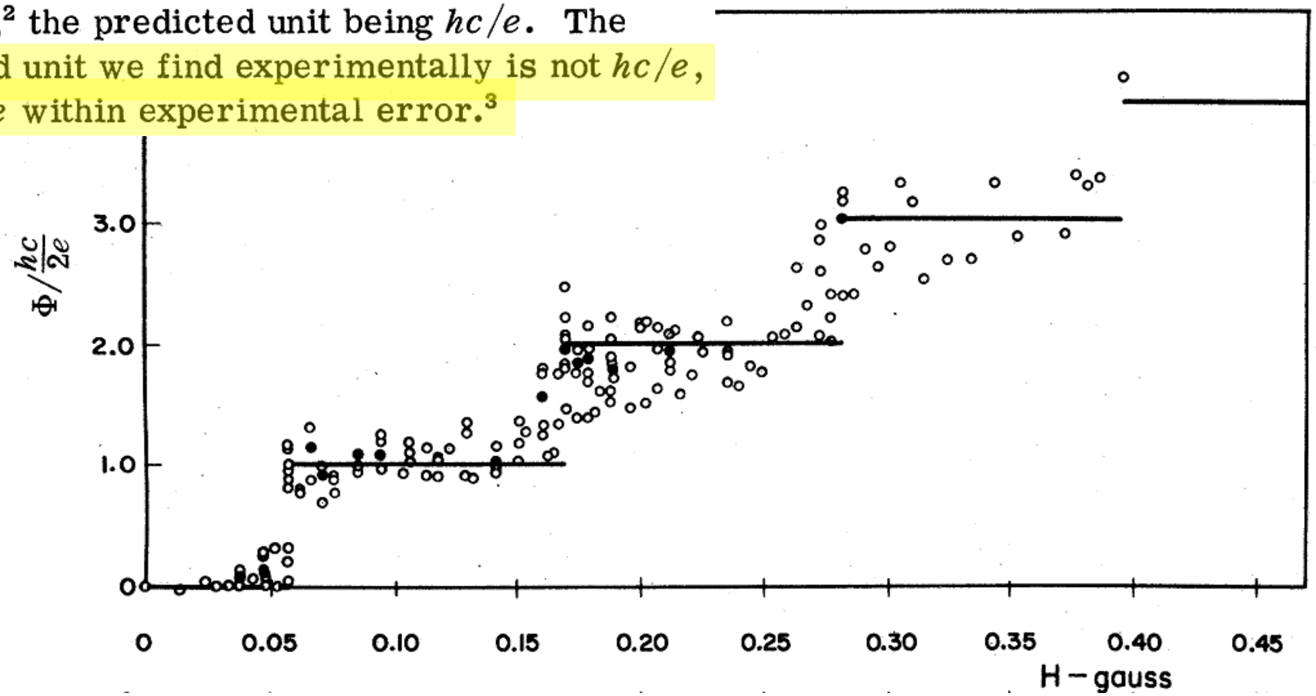


FIG. 1. (Upper) Trapped flux in cylinder No. 1 as a function of magnetic field in which the cylinder was cooled below the superconducting transition temperature. The open circles are individual data points. The solid circles represent the average value of all data points at a particular value of applied field including all the points plotted and additional data which could not be plotted due to severe overlapping of points. Approximately two hundred data points are represented. The lines are drawn at multiples of $hc/2e$. (Lower)