Chapter 1 Zero resistance

Introduction **Experimental Methods** **Summary**

Introduction

Through measurement to knowledge.

H. Kamerlingh Onnes

1908年，成功制备液氦[沸点4.2 K];

1911年，发现超导现象;

1913年，获得诺贝尔物理学奖.

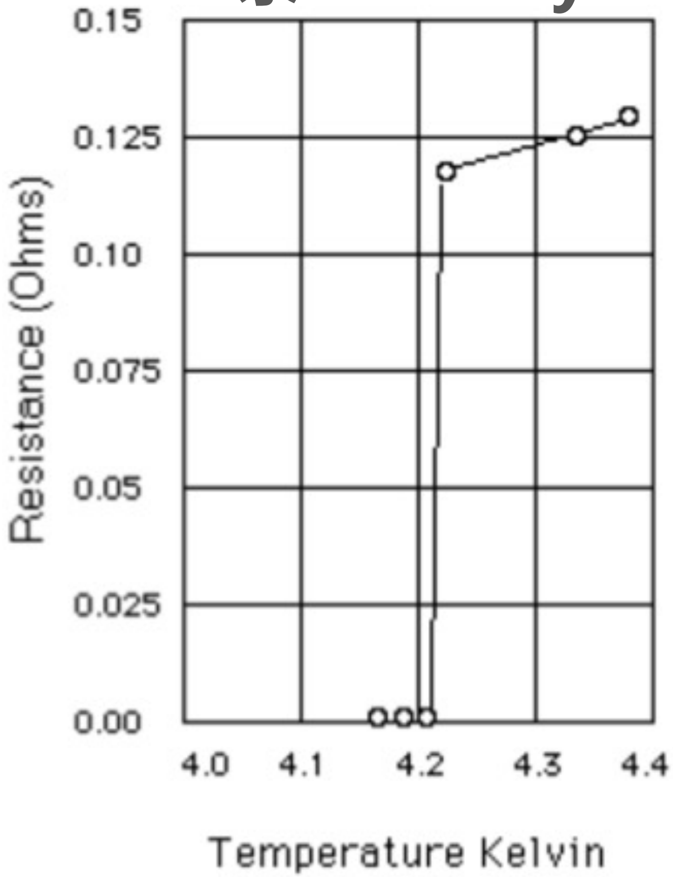
热力学温度

T(K)=T(° C)+273.15

4.2 K=-268.95 ° C

很cool的现象

汞 Mercury



H. K. Onnes, Commun. Phys. Lab.12,120 (1911).

Discovery of superconductivity

Introduction

1853
Onnes was born in Groningen, Netherlands

1870
University of Groningen
University of Heidelberg
Robert Bunsen
Gustav Kirchhoff

1873
$$\left(P+\frac{an^2}{V^2}\right)(V-nb)=nRT$$
Johannes Diderik van der Waals

1877
Louis P. Cailletet, French physicist
Raoul P. Pictet, Swiss scientist
Liquid Oxygen and Nitrogen
90 K **77 K**

1882
Leiden University
Kamerlingh Onnes Laboratory
Training of Instrument Makers

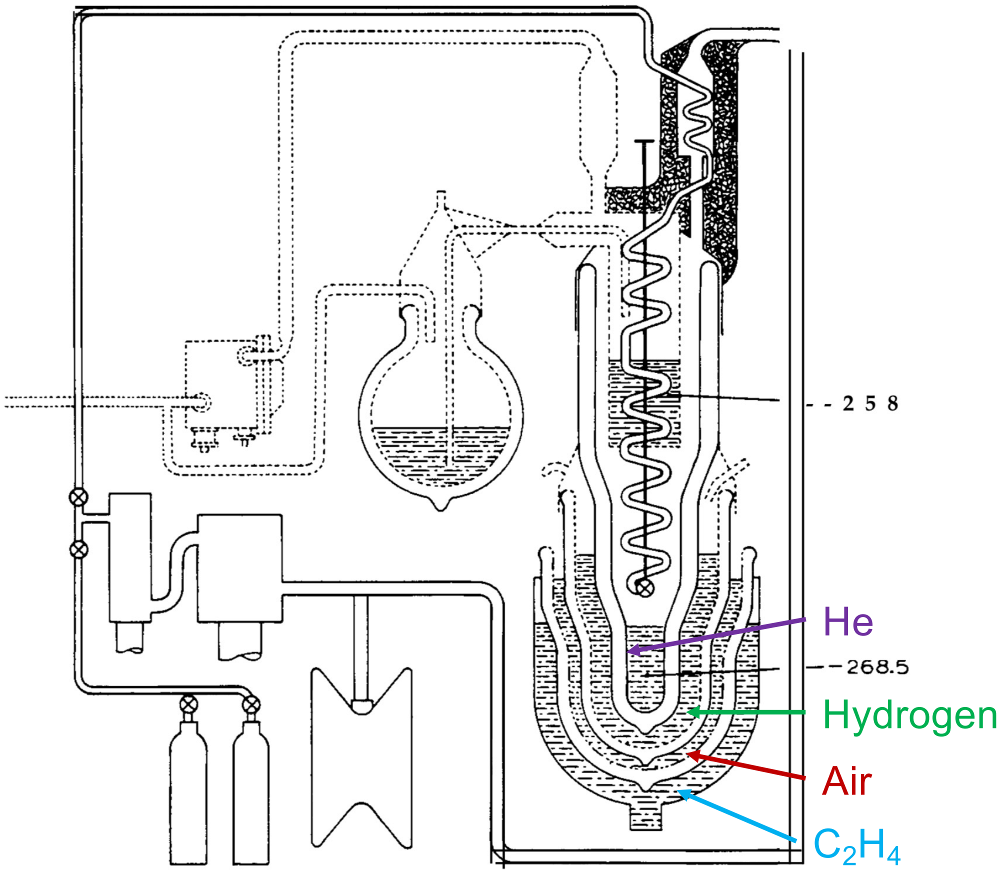
1898
James Dewar, Scottish physicist
Liquid Hydrogen
20 K

1908
4.2 K
Onnes
Liquid Helium

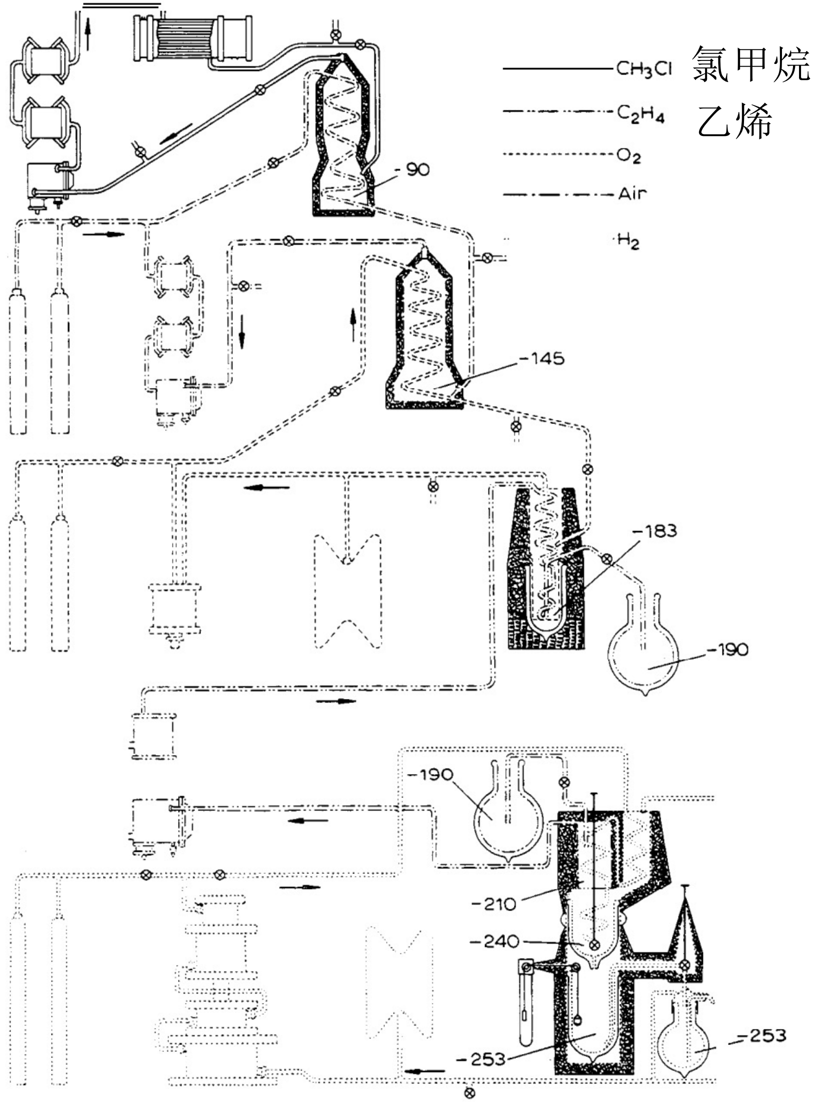
At constant Volume, the pressure becomes zero at T=-273.15 ° C

Discovery of superconductivity

Introduction

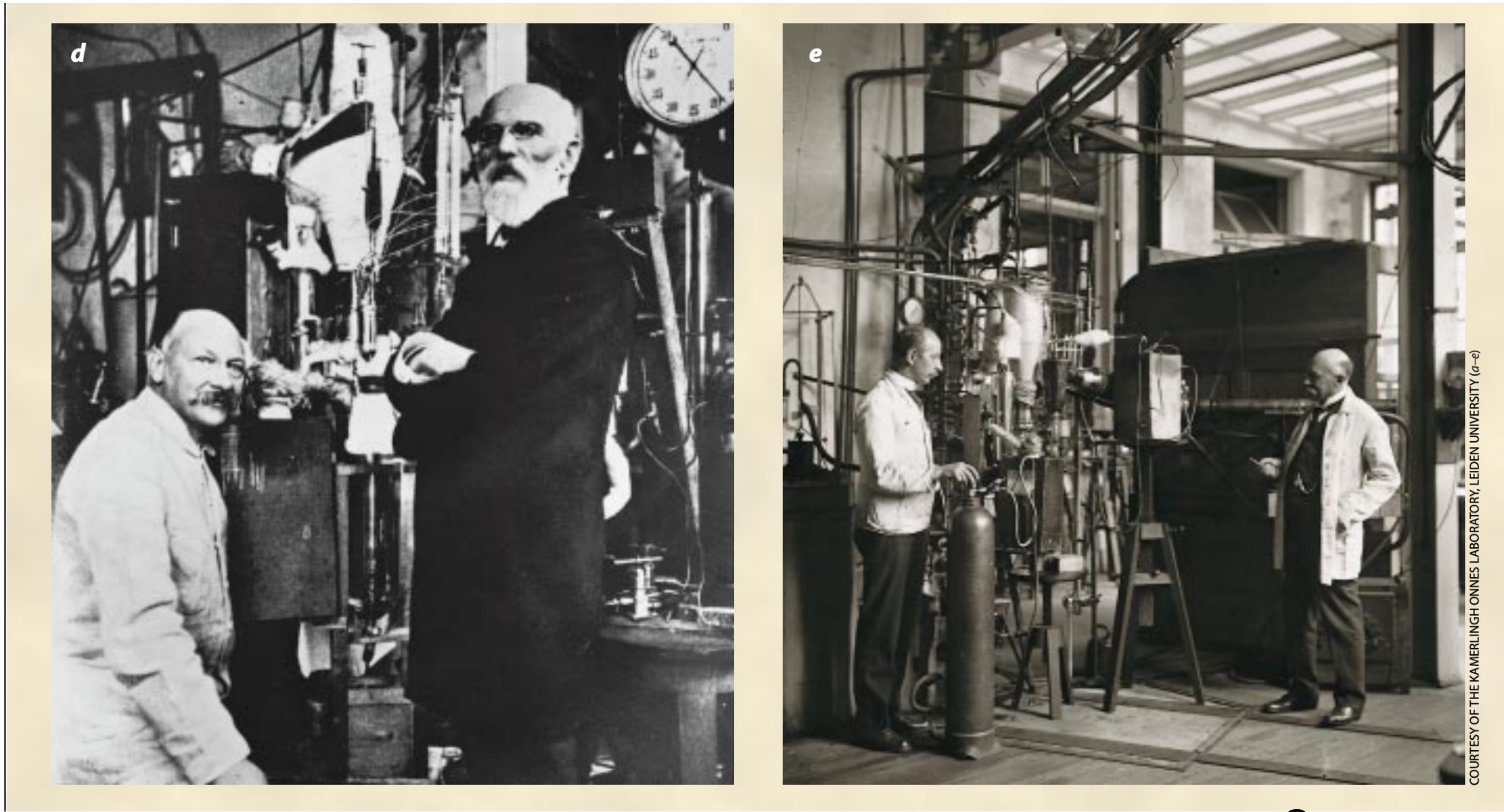


Onnes Nobel Lecture, December 11, 1913



Discovery of superconductivity

Introduction

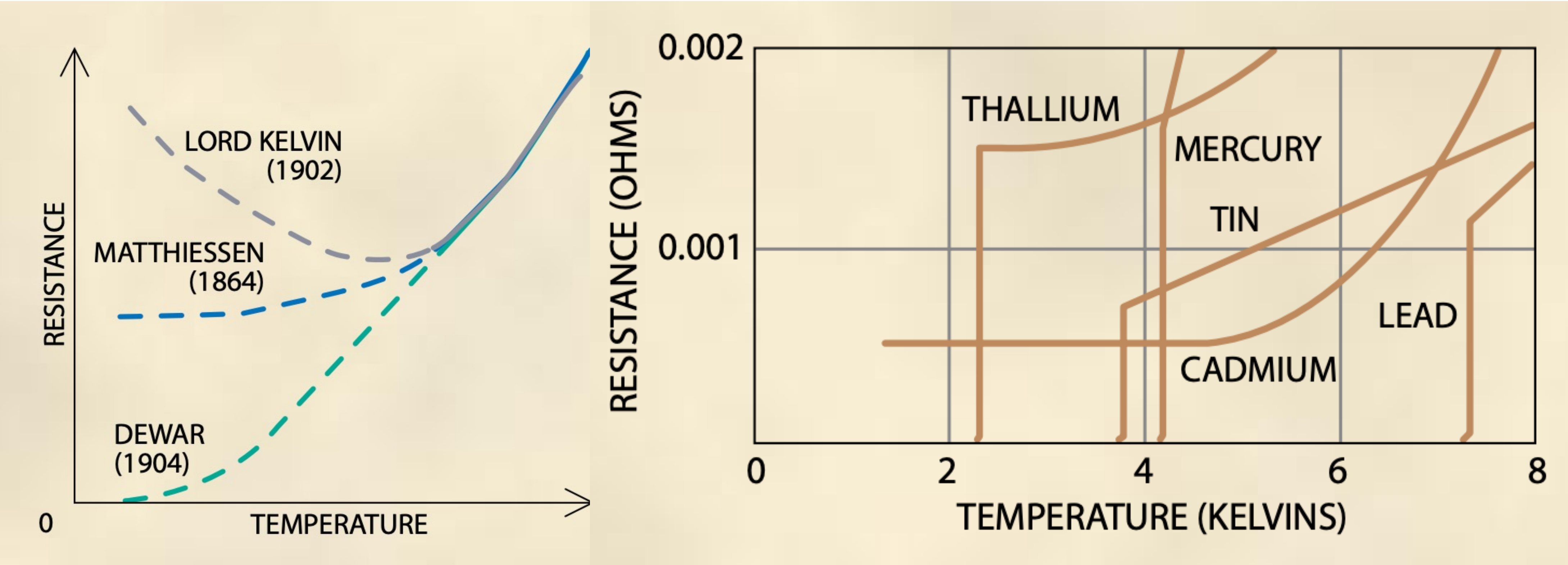


Onnes 1911 **van der Waals** **Gerrit Flim** **Onnes**

Rudolf de Bruyn Ouboter Scientific American 1997

Discovery of superconductivity

Introduction



Rudolf de Bruyn Ouboter Scientific American 1997

Discovery of superconductivity

Introduction

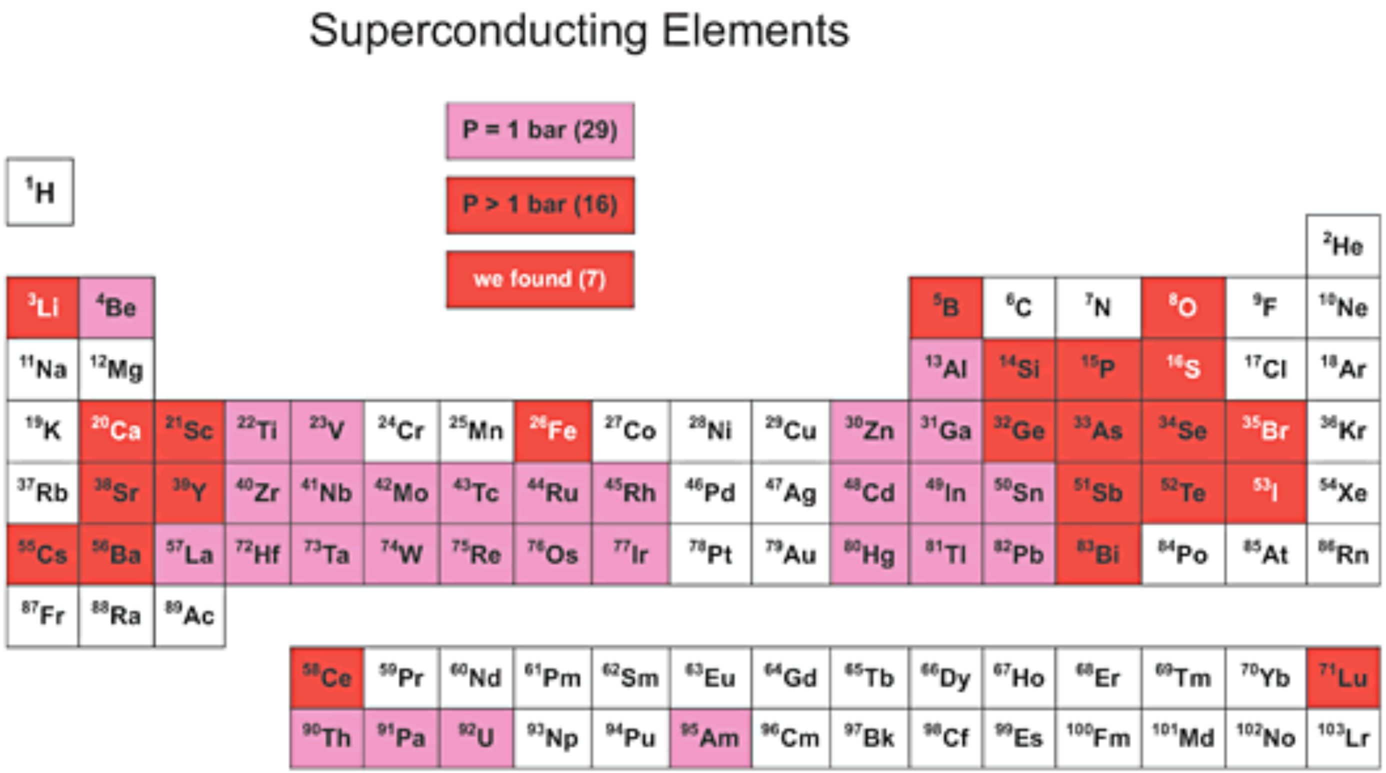


Figure 1. Superconducting elements in the periodic table. The elements paint in pink are superconductor under normal condition (P = 0 bar); 29 elements. The ones in red are superconductors under pressure (P > 1 bar); 23 elements, in which author group has found 7 elements.

Superconducting Elements

Introduction

Blue boy story?

An apprentice from the instrument-maker's school Kamerlingh Onnes had founded. (The appellation refers to the blue uniforms the boys wore.) As the story goes, the blue boy's sleepy inattention that afternoon had let the helium boil, thus raising the mercury above its 4.2-K transition temperature and signaling the new state—by its reversion to normal conductivity—with a dramatic swing of the galvanometer.

Introduction

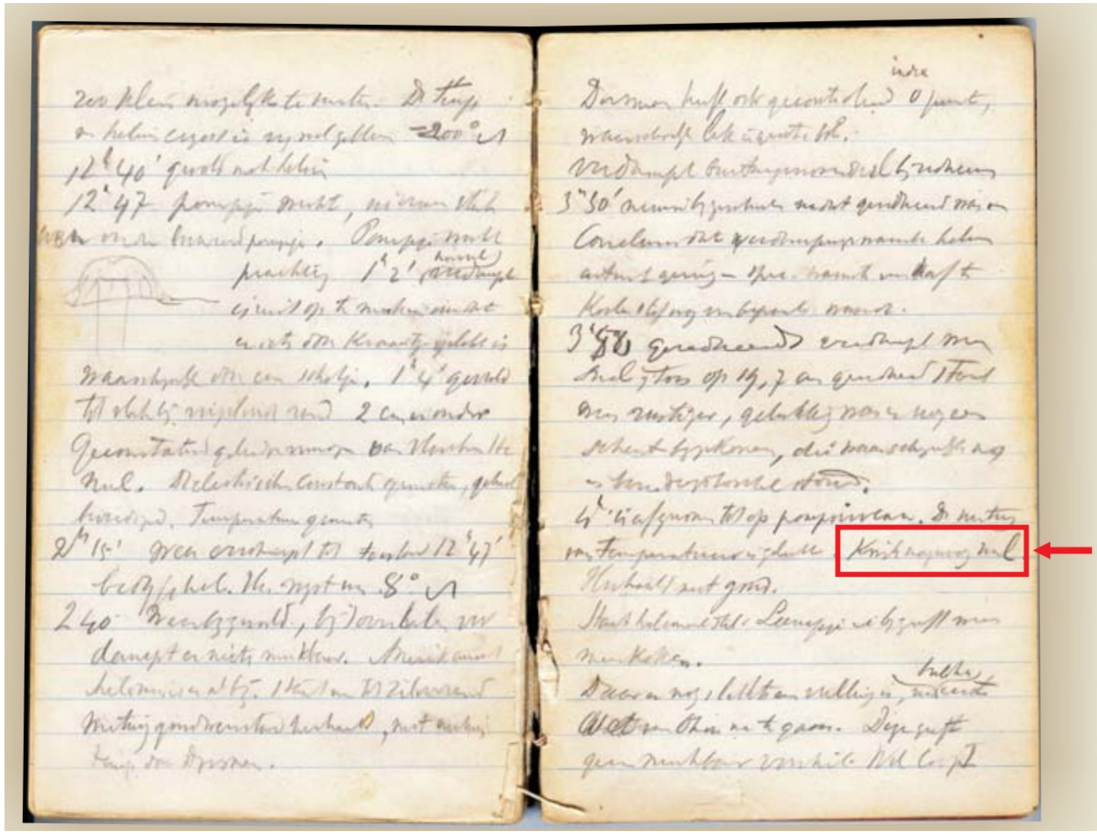
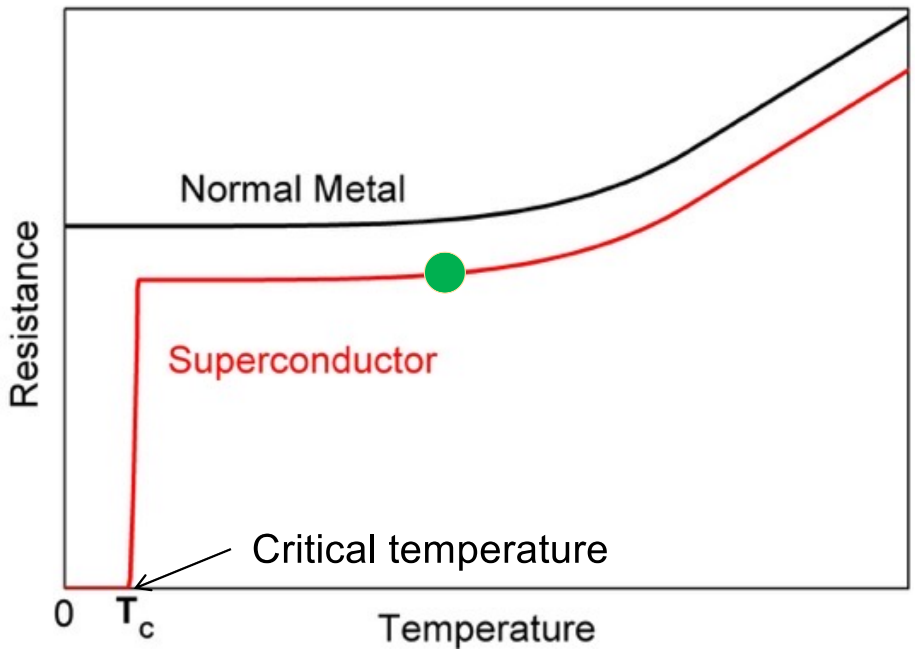


Figure 2. A terse entry for 8 April 1911 in Heike Kamerlingh Onnes's notebook 56 records the first observation of superconductivity. The highlighted Dutch sentence *Kwik nagenoeg nul* means "Mercury['s resistance] practically zero [at 3 K]." The very next sentence, *Herhaald met goud.* means "repeated with gold." (Courtesy of the Boerhaave Museum.)

Dirk van Delft and Peter Kes, 2010 Physics Today

Discovery of superconductivity

Introduction



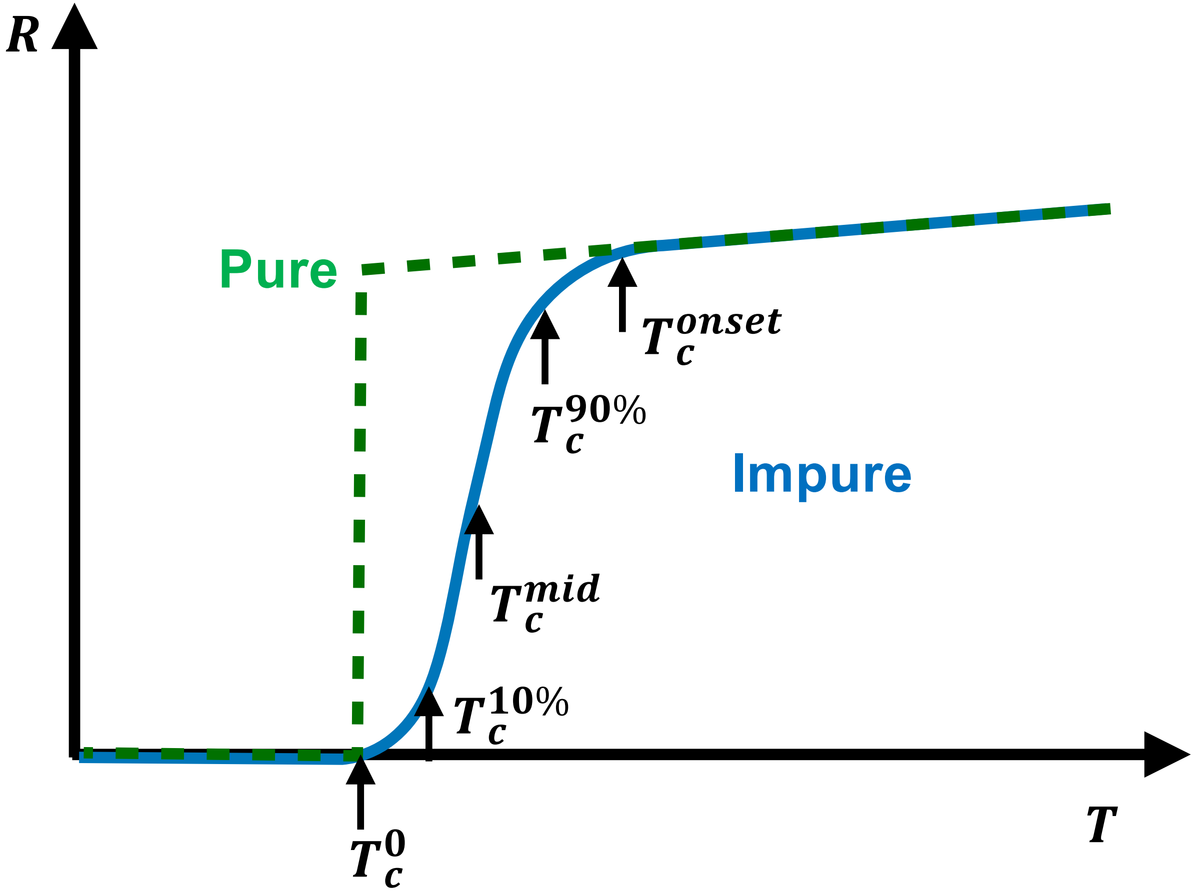
Normal Metal

Superconductor

T_c:**critical temperature,临界温度**

Zero Resistance and critical temperature

Introduction



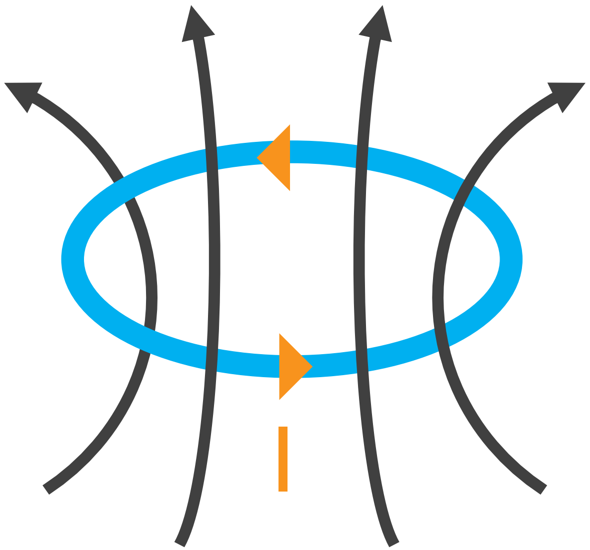
How to define Tc?

%10、%50、 %90 R_n

$$\Delta T_c = T_c^{90\%} - T_c^{10\%}$$

Zero Resistance and critical temperature

Introduction



$\rho < 10^{-26} \Omega\, m$

$\rho_{cu} \sim 10^{-8} \Omega\, m\ at\ 300\ K$

$I(t) = I(0) e^{-t/\tau}$

$\tau = L/R$

L:电感(Inductance)　　R:电阻

$\tau \sim 10^5$ years

or even up to $10^{10^{10}}$ years

Persistent current

Zero Resistance

Introduction

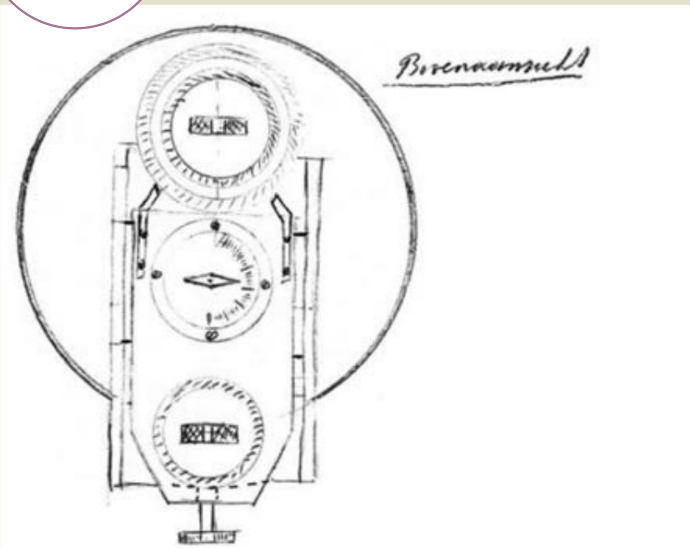


Figure 5. Gerrit Flim's drawing of the setup for a persistent-current experiment in May 1914. In this top view (*bovenaanzicht*), one sees a compass needle pointing north between a superconducting lead coil (west) immersed in liquid helium in a double-walled dewar and a normally conducting copper coil (east) of equal size immersed in liquid air in a single-walled vessel. The copper coil, whose connection to a current source and galvanometer is not shown, calibrates and monitors the persistent current in the superconducting coil. When both currents are equal, the compass points due north. (Courtesy of the Boerhaave Museum.)

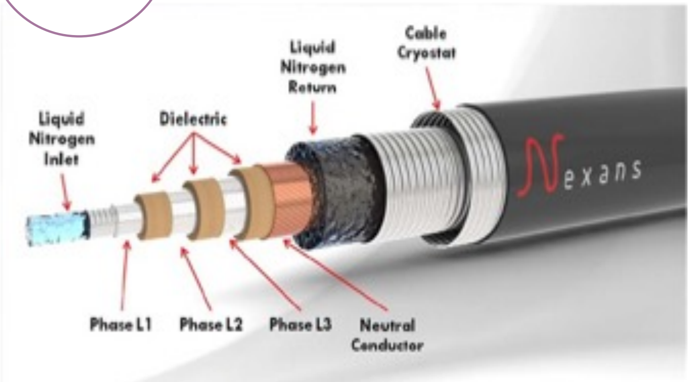
Dear Hendrik Lorentz,

I attended a fascinating experiment at the laboratory.... Unsettling, to see the effect of this "permanent" current on a magnetic needle. It is almost palpable, the way the ring of electrons goes round and round and round in the wire, slowly and virtually without friction.

--Paul Ehrenfest

Dirk van Delft and Peter Kes, 2010 Physics Today

Introduction

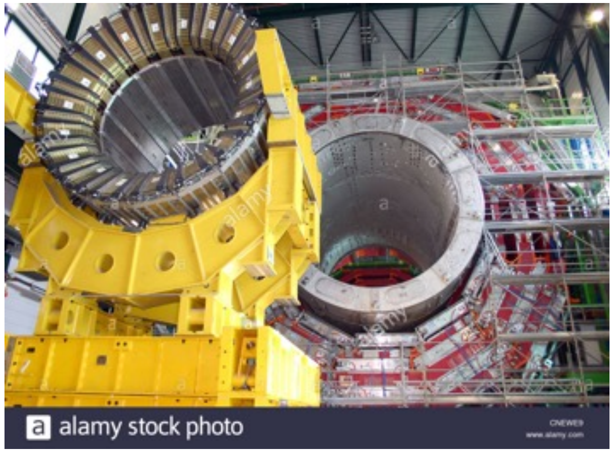


Superconducting cables

核磁共振成像仪 MRI

大型强子对撞机

~10 000 个超导磁体
>27 吨

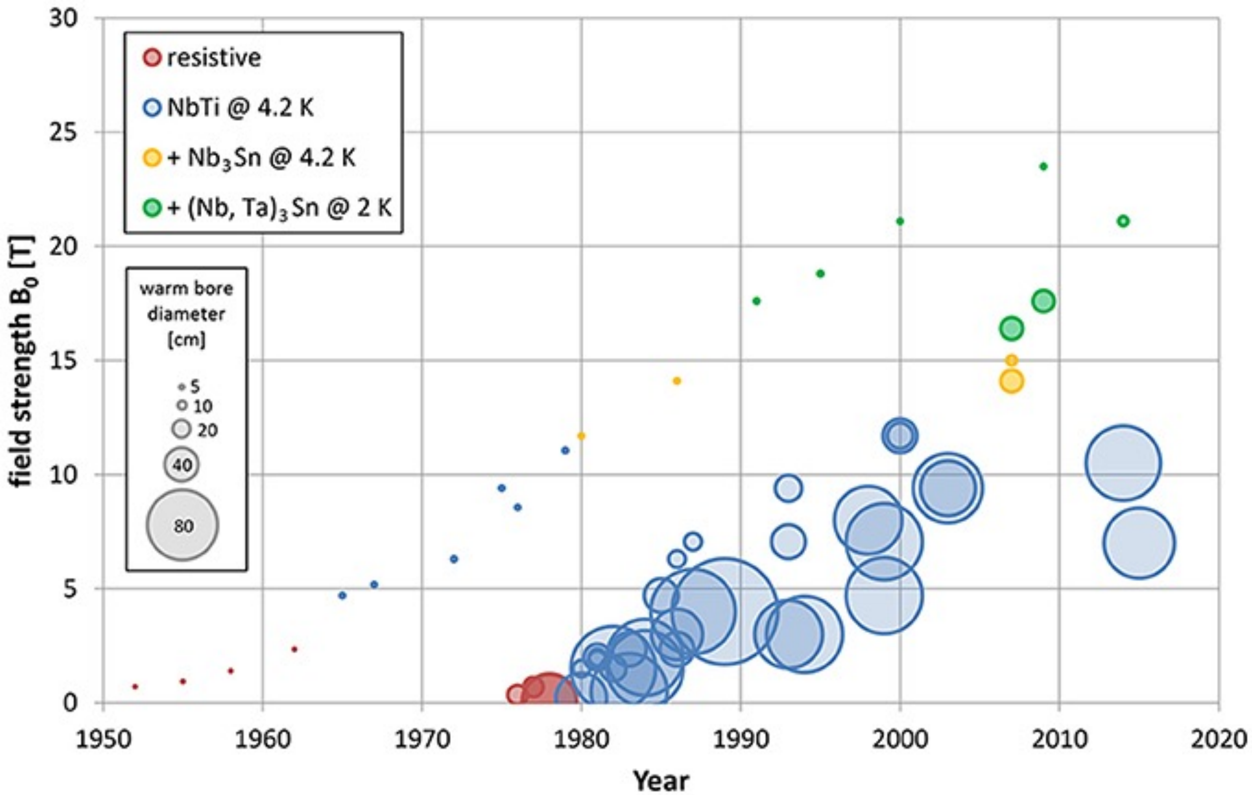


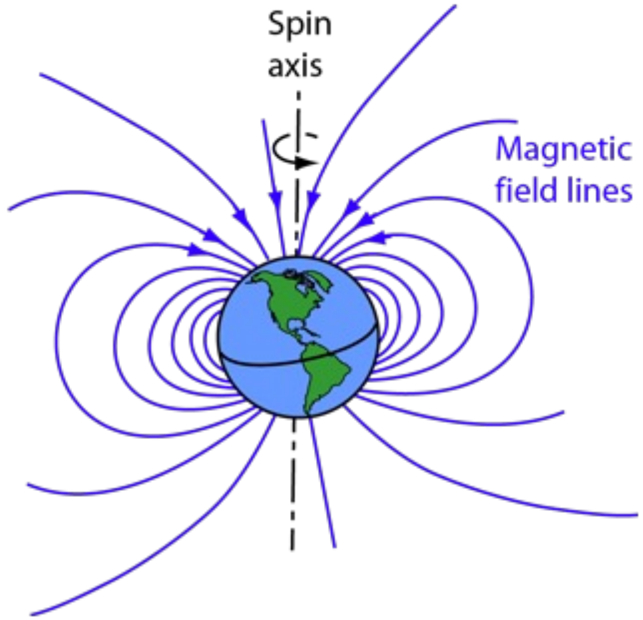
Superconducting Magnet

Applications-zero resistance

Introduction

Superconducting Magnet

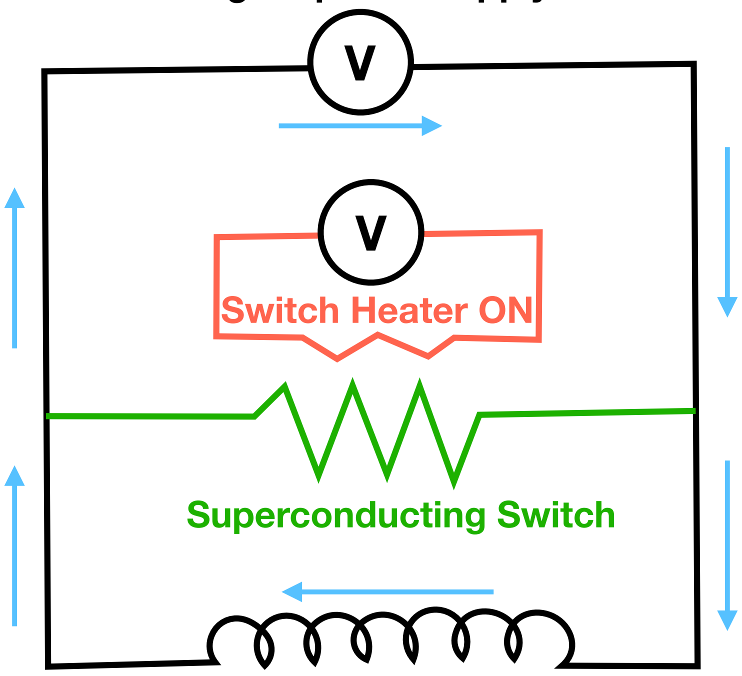


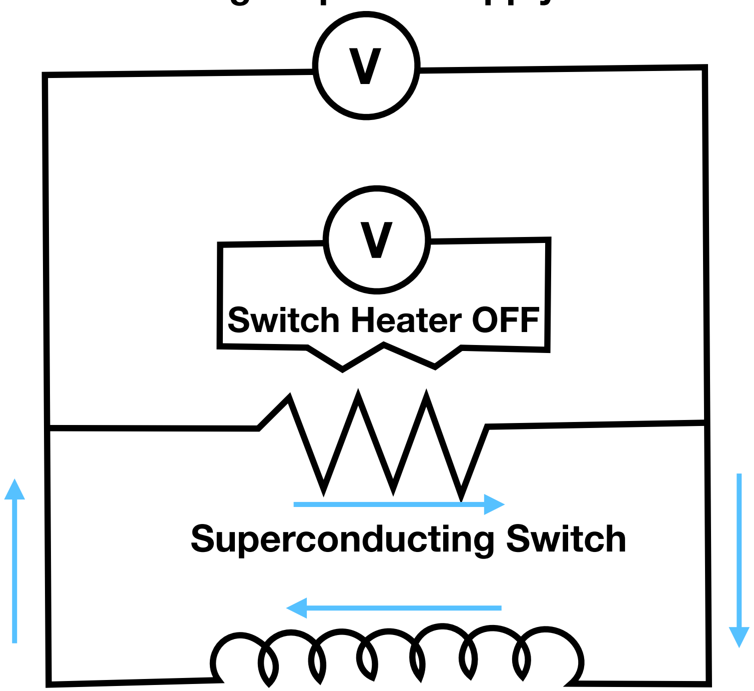


$25 - 65\ \mu T$

Applications-zero resistance

Introduction



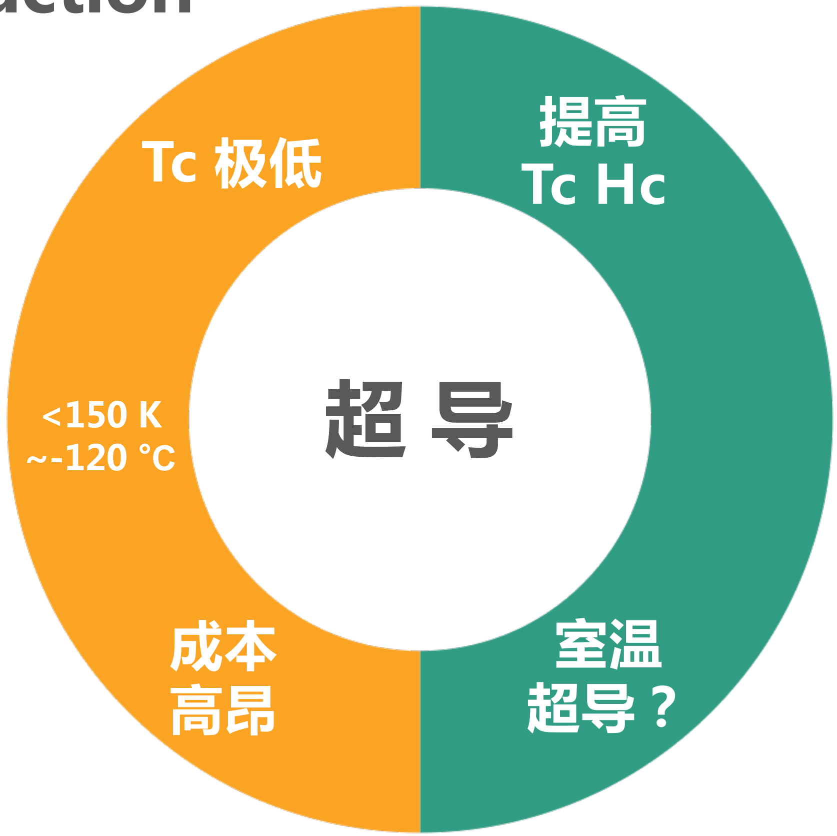


How to drive a Superconducting Magnet into persistent mode?

Applications-zero resistance

Introduction

太cool而
不可及

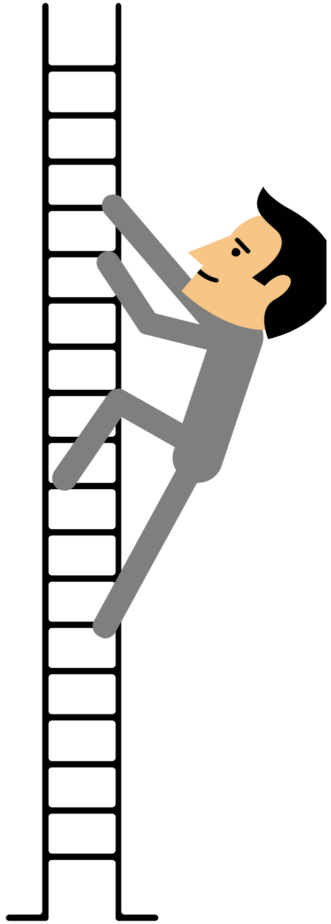


局 限

目 标

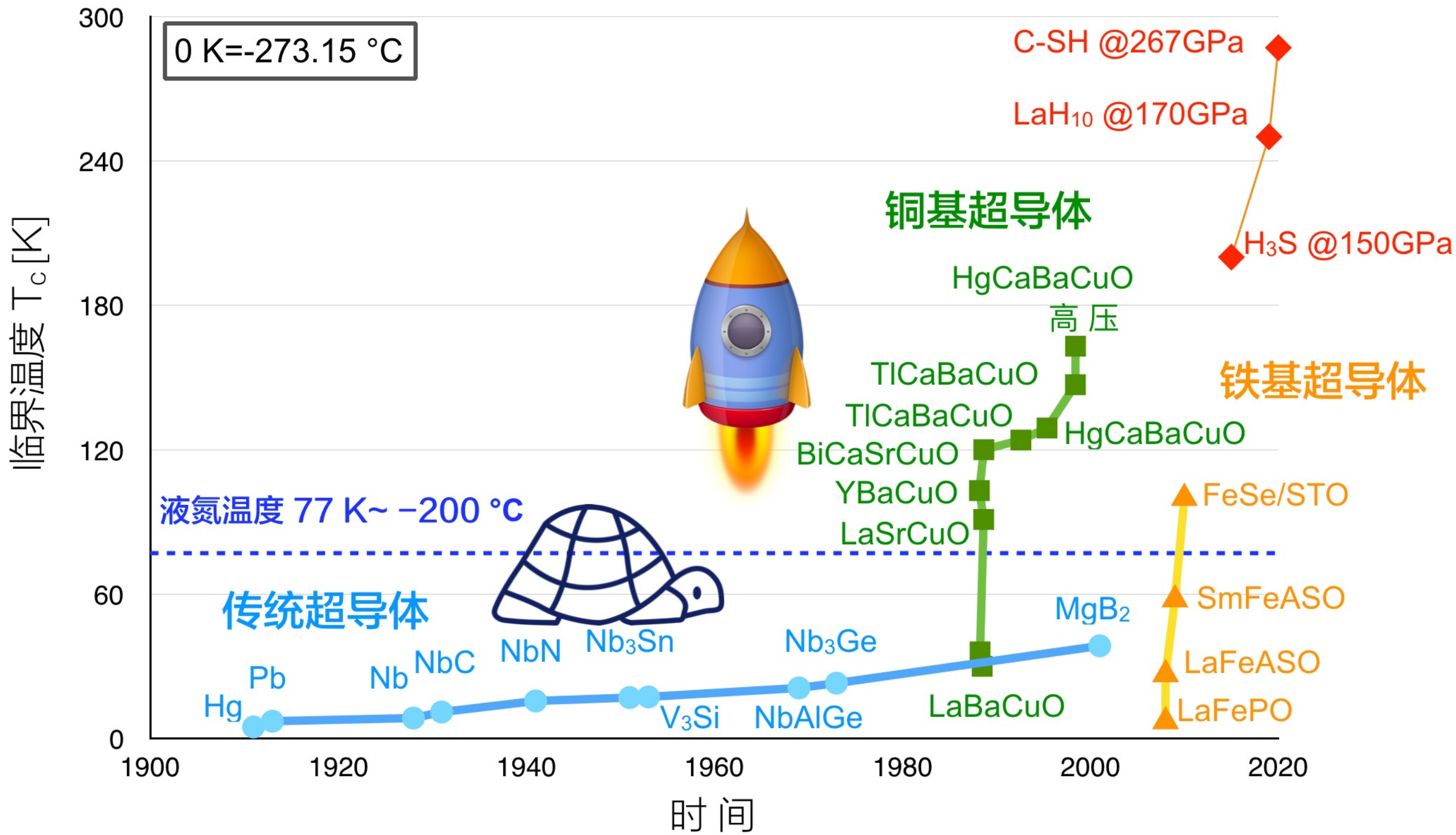
妈妈再也不用担心
我手机没电了！

Always 100%！



Limitations

Introduction



100 years in superconductivity

Introduction

Rules of B. Matthias for discovering new superconductors

1. high symmetry is best
2. peaks in density of states are good
3. stay away from <u>oxygen</u>
4. stay away from <u>magnetism</u>
5. stay away from <u>insulators</u>
6. stay away from <u>theorists</u>

这脸打的 pia pia 响

From Steve Girvin’s lecture (Boulder Summer School 2000) courtesy of Matthew Fisher

Interpretation of experimental data on odd numbers

- **1, 3, 5, 7 are all prime numbers.**
- **All odd numbers are prime numbers.**
- **9 is not a prime number! Error or unique**
- **11 13 are prime numbers.**
- **15 is not a prime number.**
- **infinitely many odd numbers, but not prime numbers .**

Introduction

Discovery of superconductivity H. Kamerlingh Onnes(1911) in Hg
1913 Nobel prize

Perfect diamagnetism: Meissner and Ochsenfeld(1933)

London equation: F. and H. London(1933)

Ginzburg-Landau theory: 1950s
2003 Nobel prize (with Abrikosov)

Isotope effect: H. Frohlich(1950)

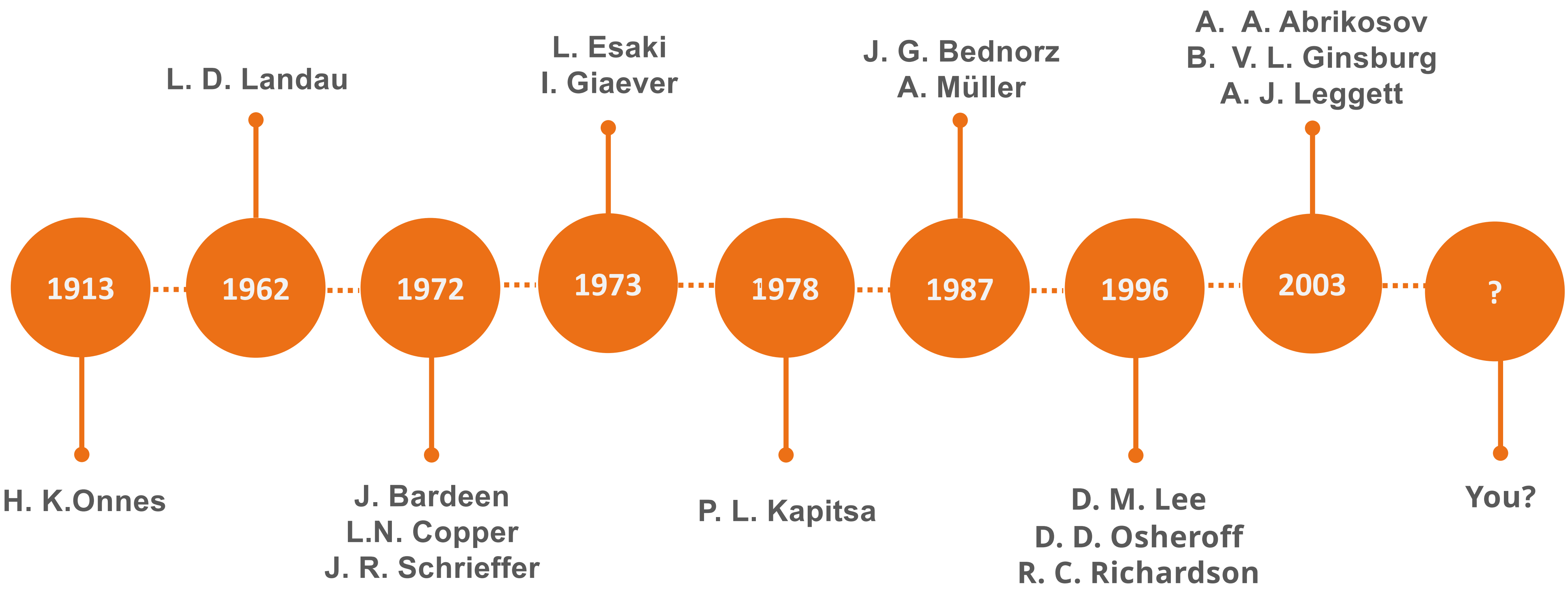
BCS theory: J. Bardeen, L. Cooper and J.R. Schrieffer(1957) 1972 Nobel prize

Tunneling: Josephson (1957) 1973 Nobel prize

Hi-Tc superconductivity: J. G. Bednorz and K. A. Muller(1986) in Ba-La-Cu-O system. 1987 Nobel prize

100 years in superconductivity

Introduction



100 years in superconductivity

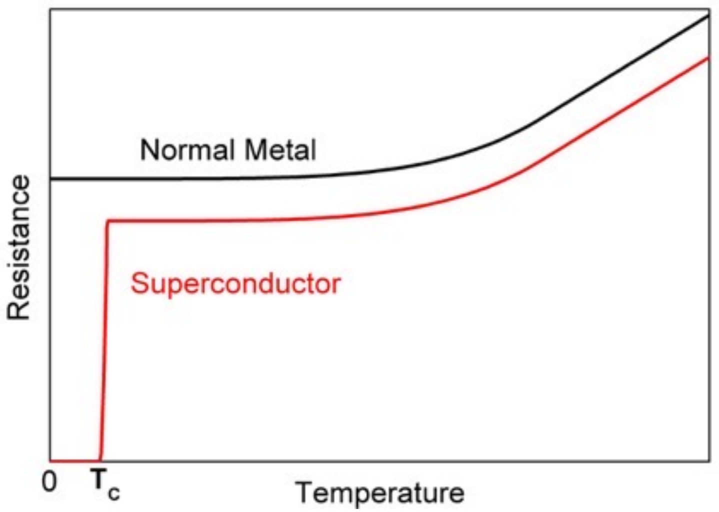
Chapter 1 Zero resistance

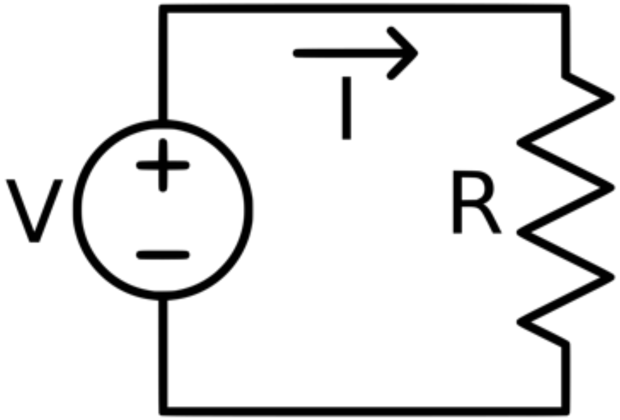
Introduction

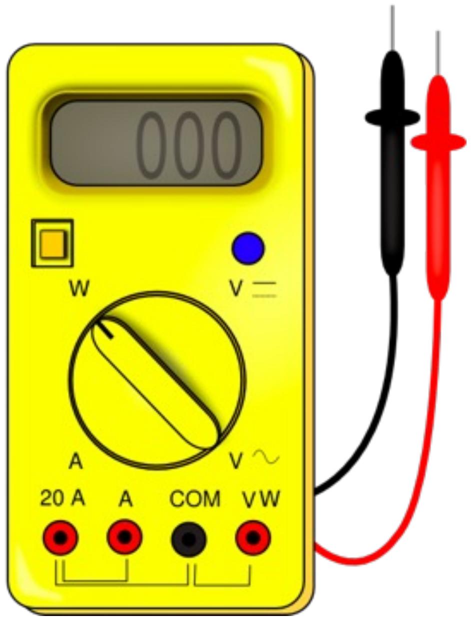
Experimental Methods

Summary

Experimental Methods







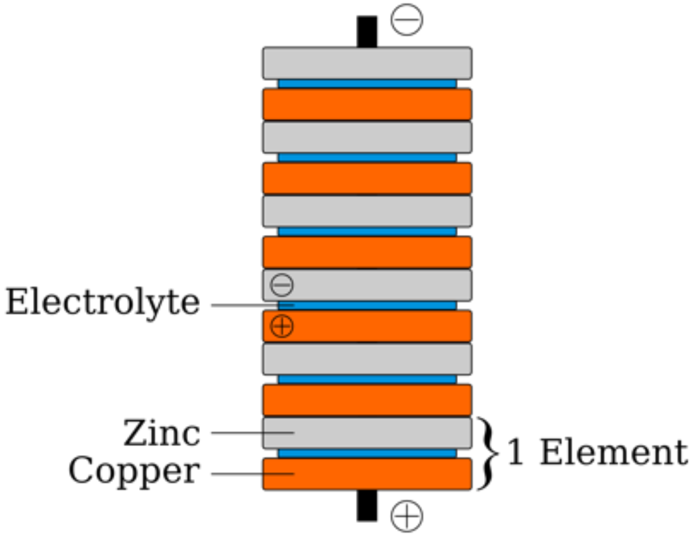
$$R = \frac{V}{I}$$

X

Electrical Transport

Experimental Methods

Alessandro Giuseppe Antonio Anastasio Volta
Italian physicist and chemist
1745 –1827



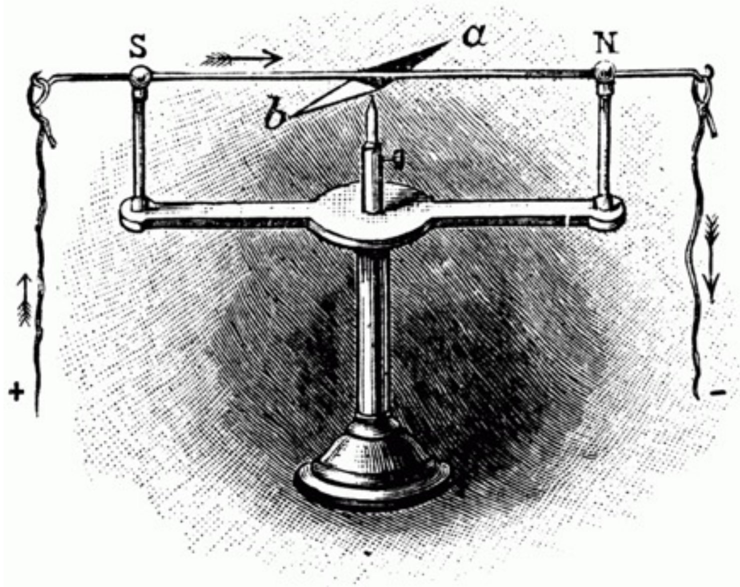
Volta explains the principle of the *"electric column"* to Napoleon in 1801

- Invented electric battery in 1799.
- Volt unit adopted internationally in 1881.

Experimental Methods

André-Marie Ampère
French physicist and mathematician
1775 –1836

Father of electrodynamics.

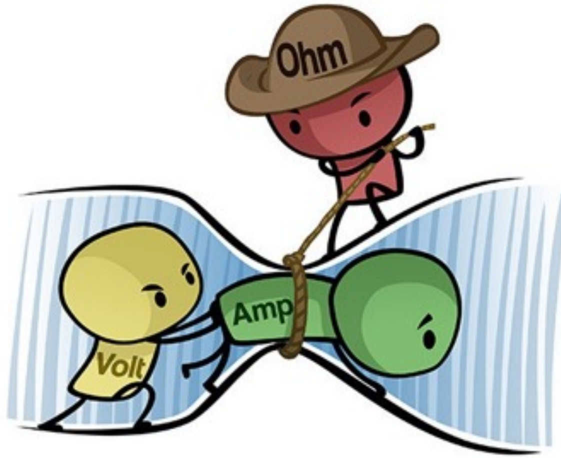


- Months after 1819 Hans Christian Ørsted's discovery of magnetic action of electrical current
- 1820 Law of electromagnetism (Ampère's law) magnetic force between two electric currents.
- First measurement technique for electricity Needle galvanometer .

Experimental Methods

Georg Simon Ohm
German physicist and mathematician
1789 –1854

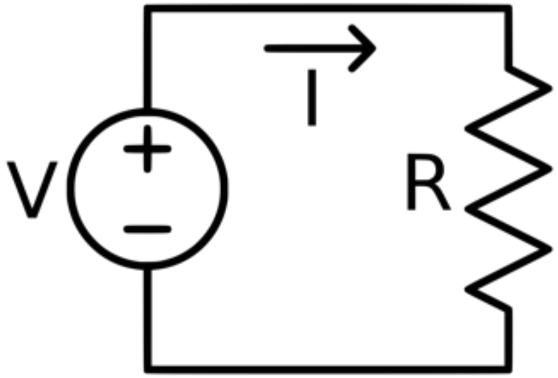
Ohm's law 1827

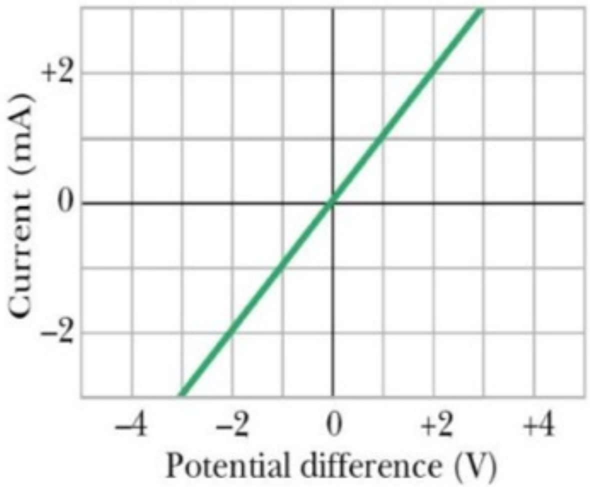


$$I = \frac{V}{R}$$

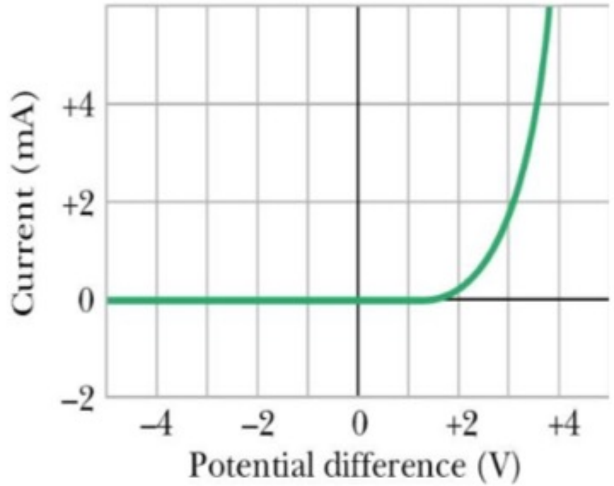
Electrical Transport

Experimental Methods





(b)



(c)

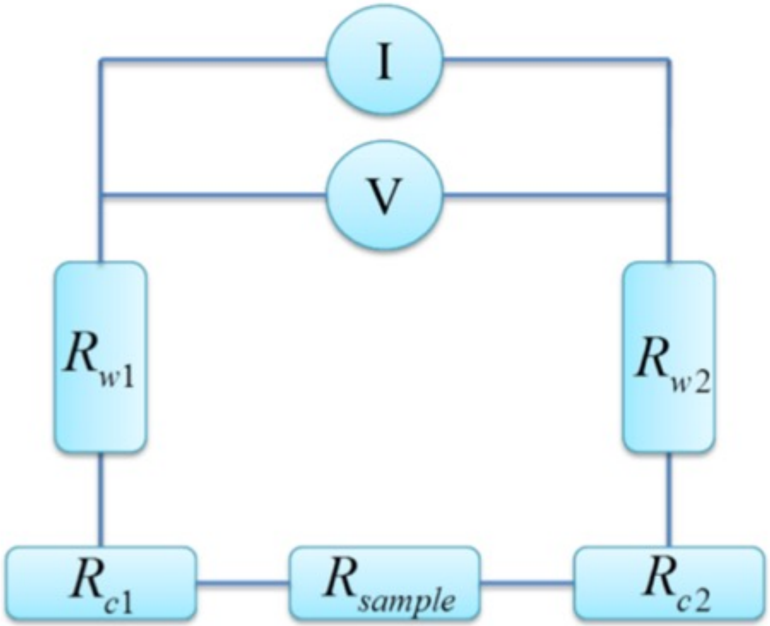
那不是小菜一碟

- Ohm’s law is valid ONLY when I-V curve is linear!
- Whole circuit is linear and no offsets!
- Wire resistance is negligible!

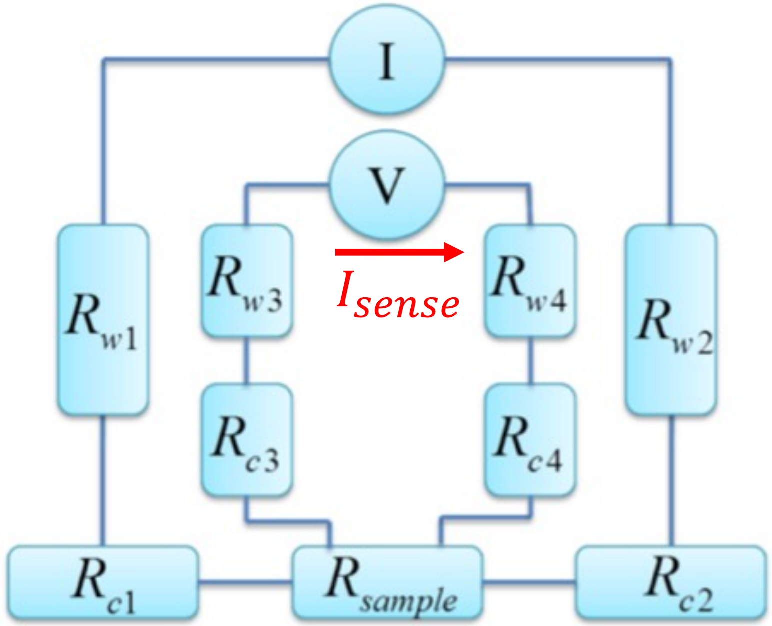
May be far from true!

Electrical Transport

Experimental Methods



2-Probe Method



4-Probe Method

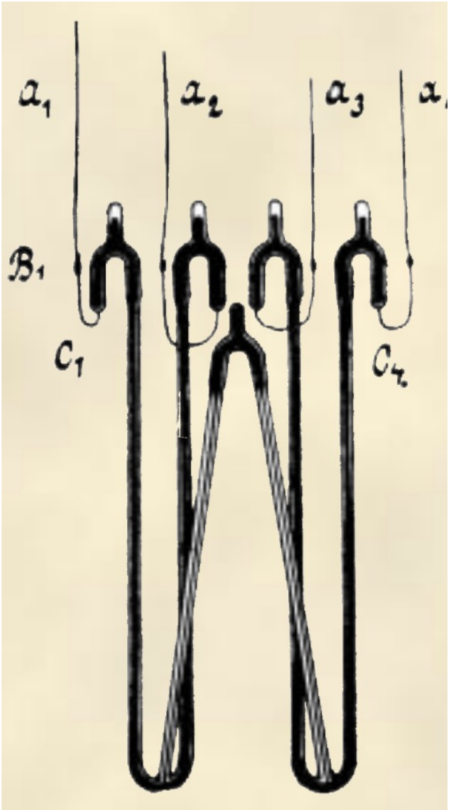
$$R_{Measured} = R_{w1} + R_{w2} + R_{c1} + R_{c2}$$

$R_V \gg R_{sample}$ I_{sense} is very small

4-Probe Method(Kelvin Method)

Electrical Transport

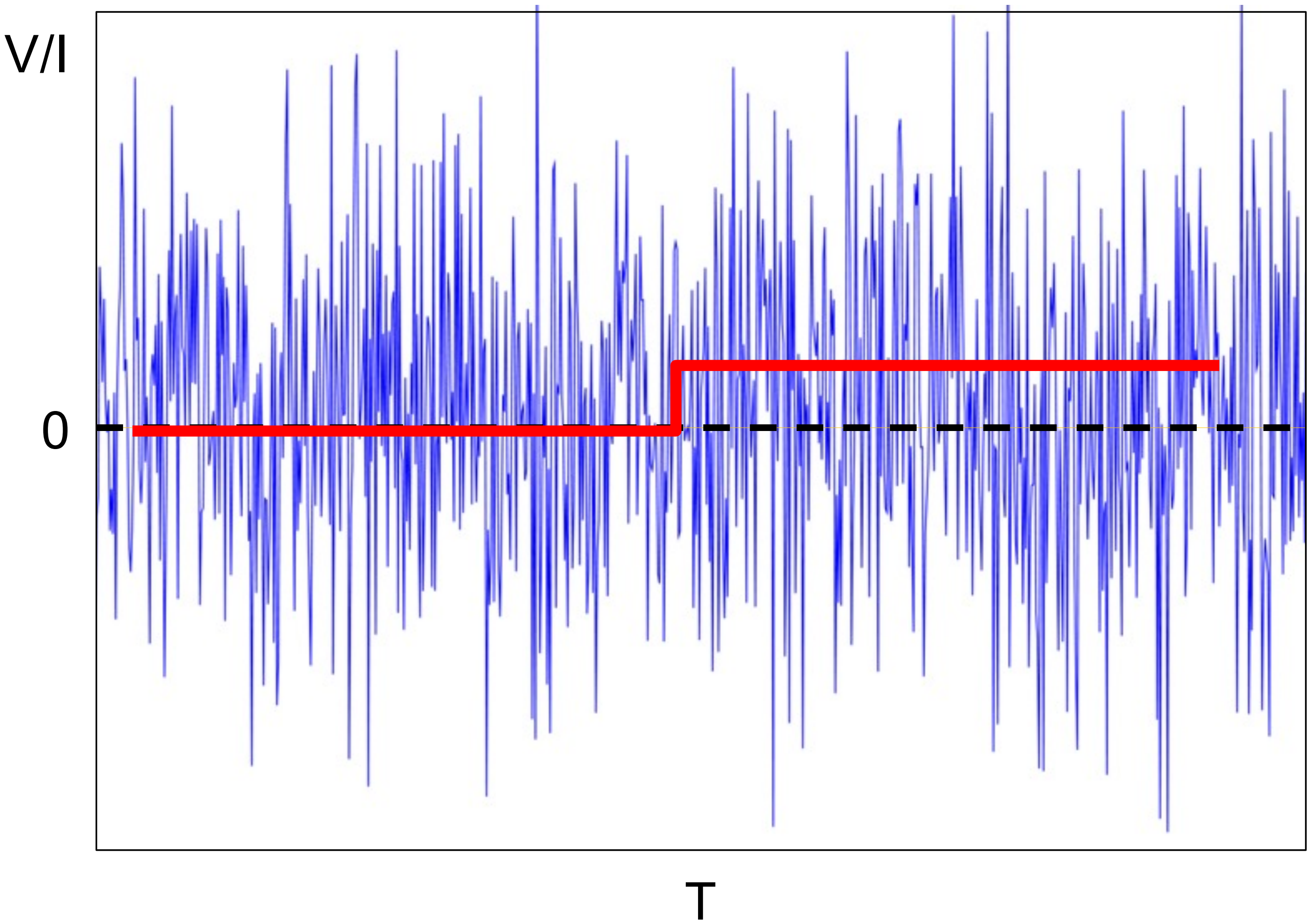
Experimental Methods



Rudolf de Bruyn Ouboter Scientific American 1997

4-Probe Method(Kelvin Method)

Experimental Methods



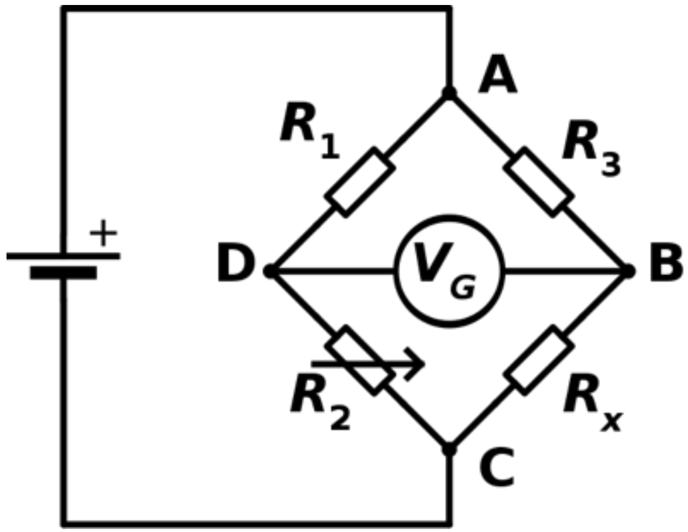
Total signal

Sample signal

Electrical Transport

Experimental Methods

Samuel Hunter Christie   Sir Charles Wheatstone

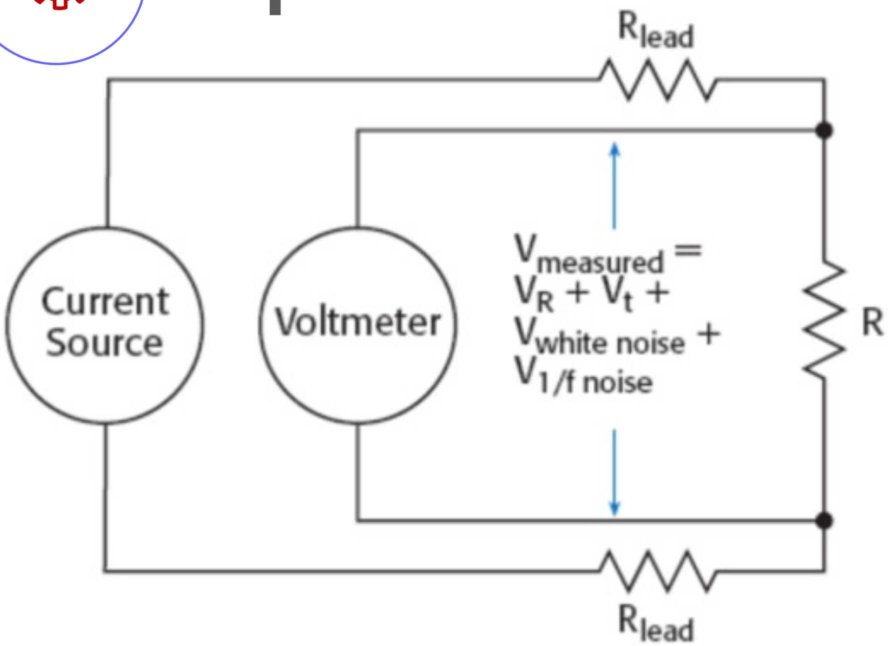


$$V_G = 0 \qquad \frac{R_2}{R_1} = \frac{R_x}{R_3}$$

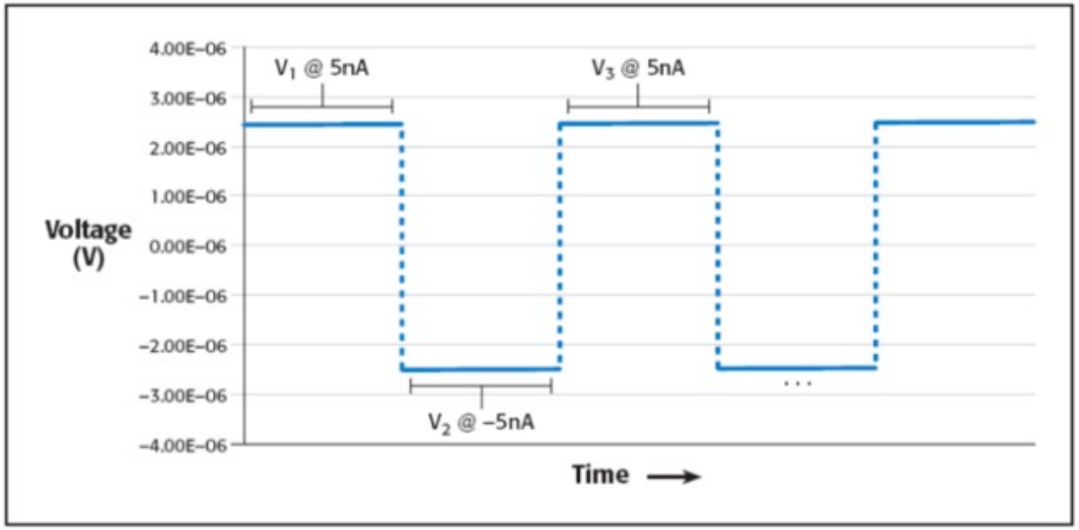
Wheatstone bridge for small resistance

$$R_x = R_3 \frac{R_2}{R_1}$$

Experimental Methods



Delta Mode



Wires generate spurious DC Voltages

- Thermoelectric(thermal gradients) 1/f noise
- Galvanic (oxidation) 1/f noise
- RF interference and rectification in contacts

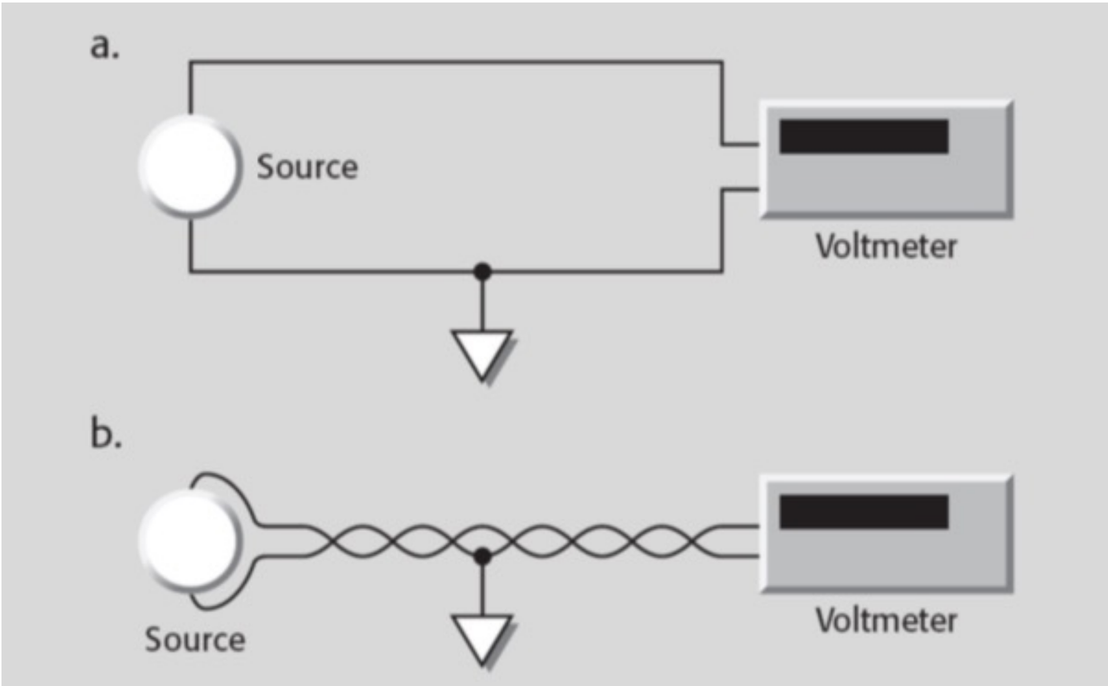
$$V_M = IR + V_{offset}$$

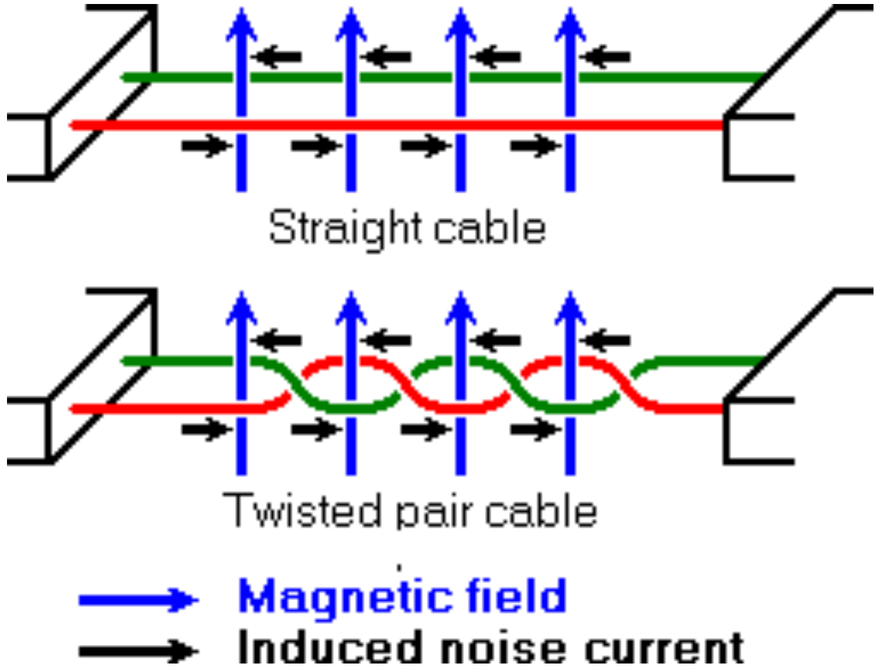
Noise sources

$$V_{M+} = IR + V_{offset} \qquad V_{M-} = -IR + V_{offset}$$

$$V_M = \frac{V_{M+} - V_{M-}}{2} = IR$$

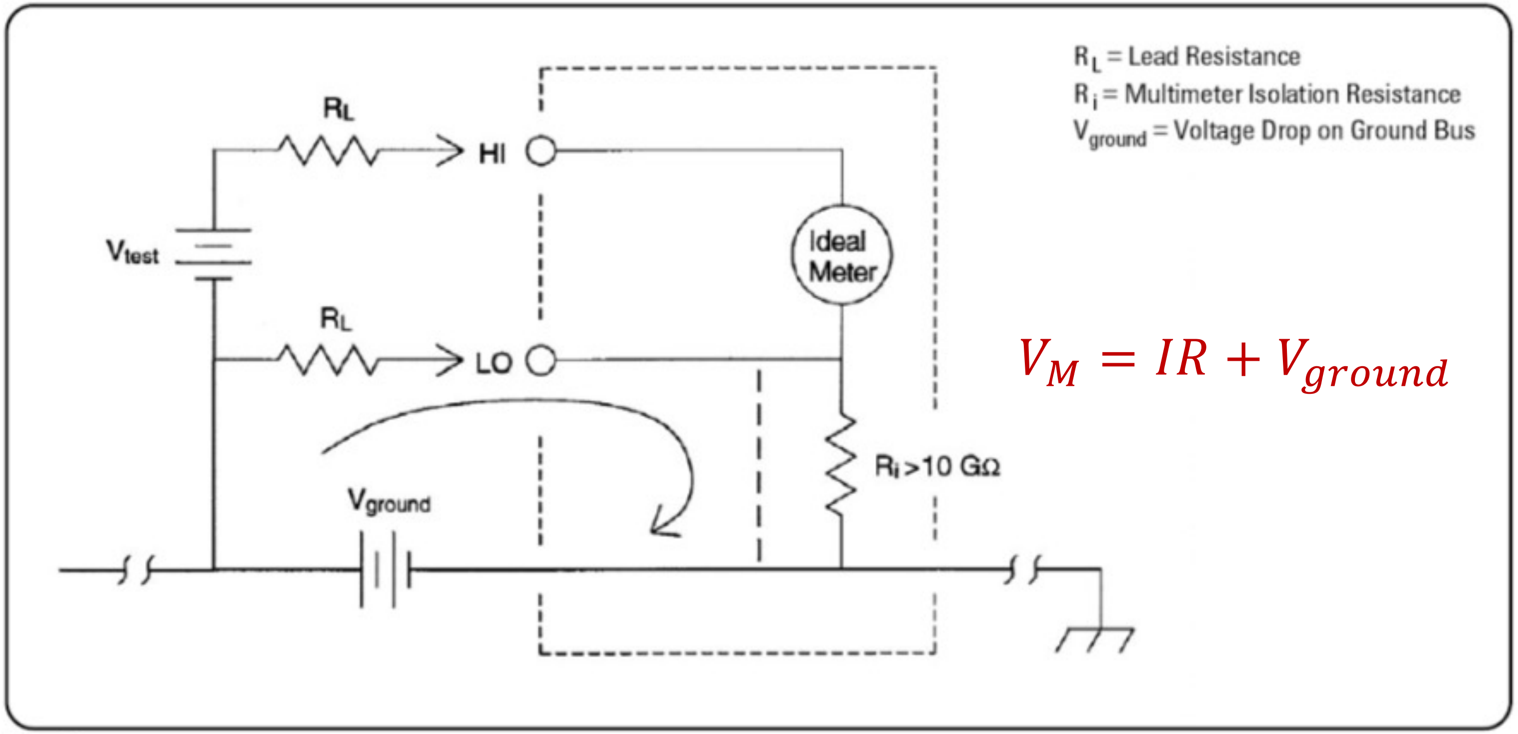
Experimental Methods





Minimizing interference from magnetic fields

Experimental Methods

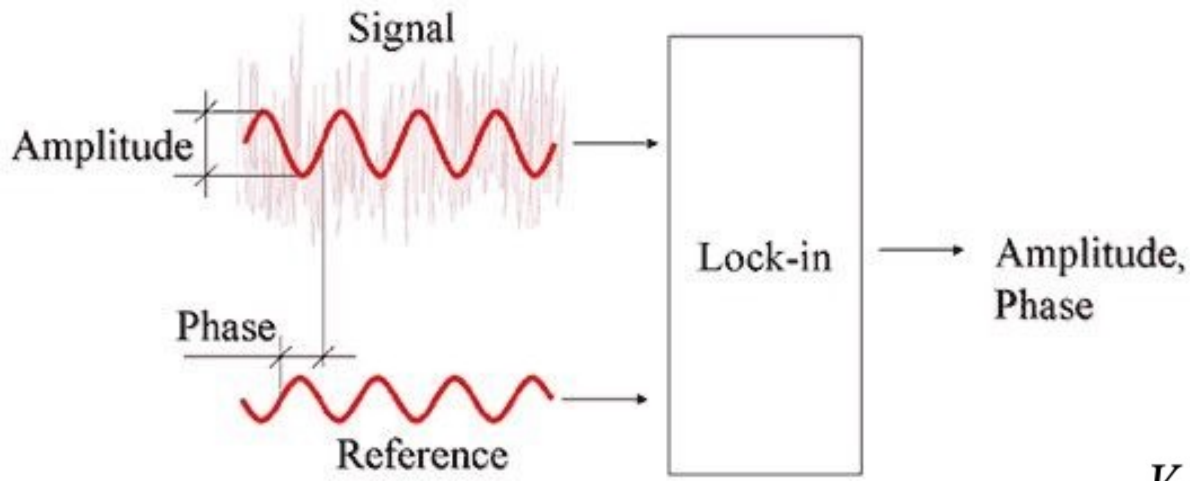


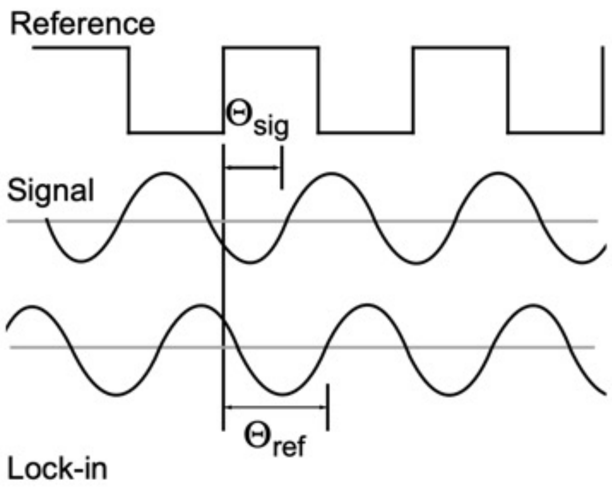
$$V_M = IR + V_{ground}$$

Devices grounded in different points acquire potential difference which contributes to the measured signal.

Ground Loop

Experimental Methods





$$V_{MI} = V_I V_R \sin(\omega_R t + \theta_I)\sin(\omega_R t + \theta_R)\,,$$

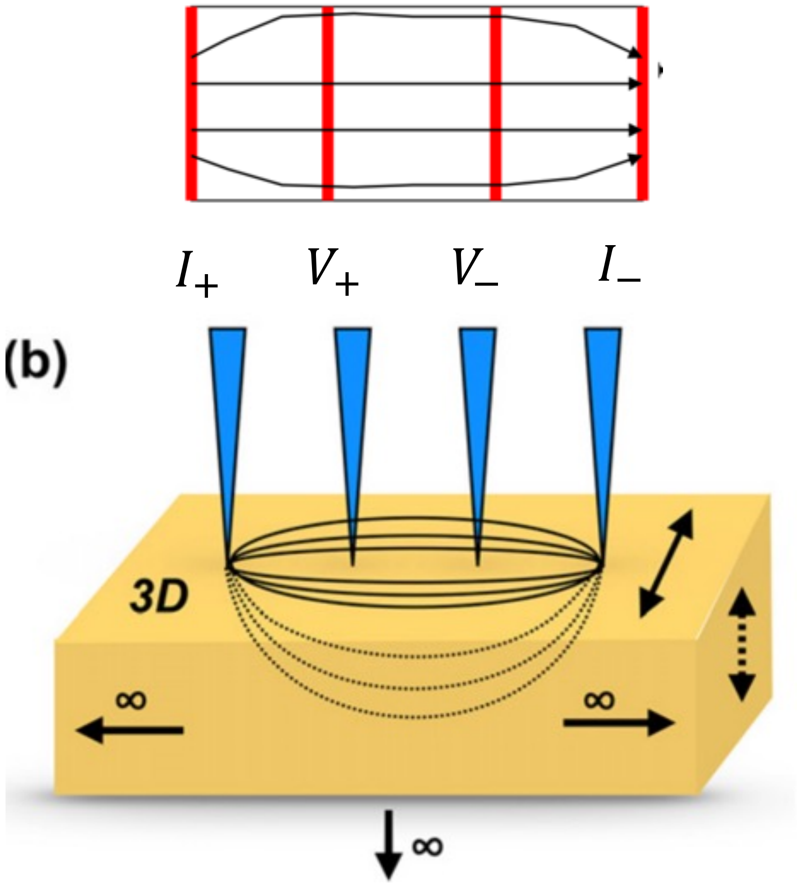
$$V_{MI} = \tfrac{1}{2} V_I V_R \cos(\theta_R - \theta_I) + \tfrac{1}{2} V_I V_R \sin(2\omega_R t + \theta_R + \theta_I)\,.$$

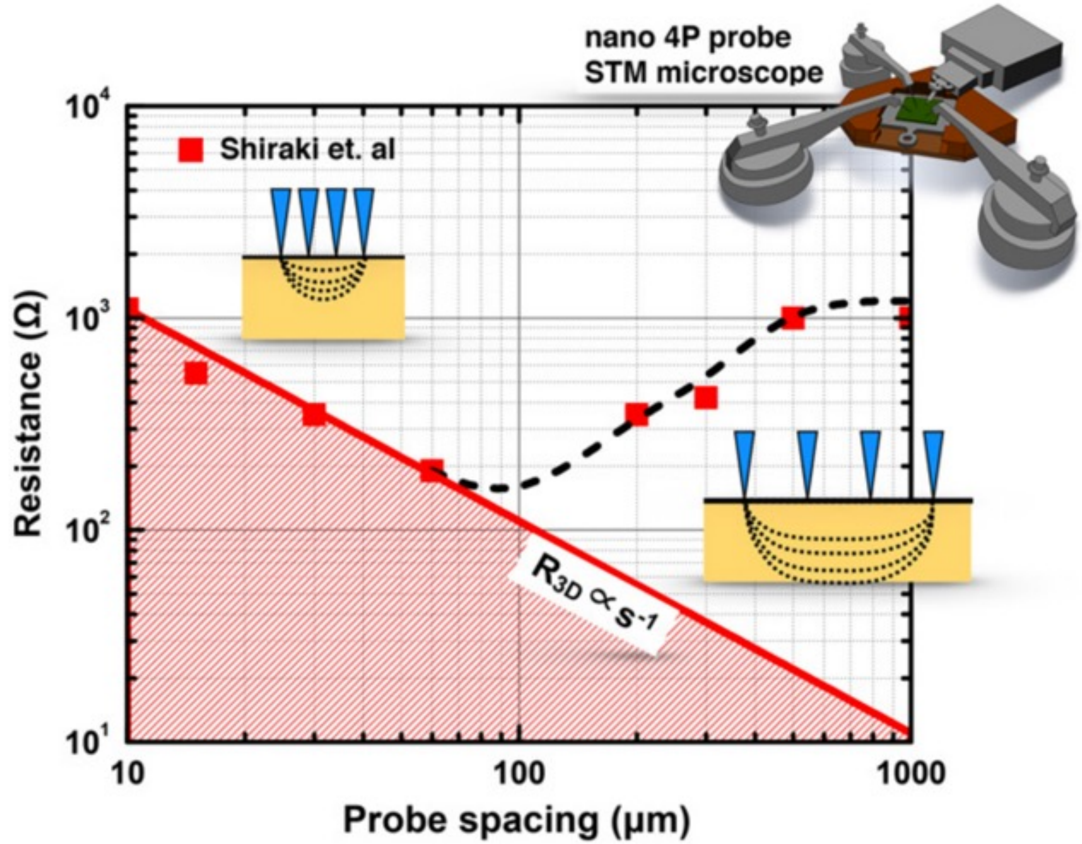
Low pass filter

$$V_{MI+FILT} = \tfrac{1}{2} V_I V_R \cos(\theta_R - \theta_I)$$

Lockin method for low resistances

Experimental Methods



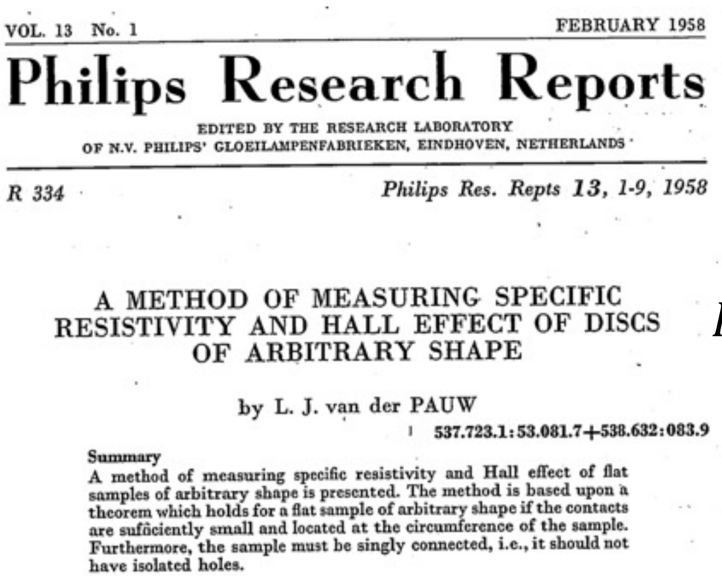


Sample shape

- "Ohmic contacts"
- Long and thin Bar

Electrical Transport

Experimental Methods



VOL. 13 No. 1 FEBRUARY 1958

Philips Research Reports

EDITED BY THE RESEARCH LABORATORY
OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, NETHERLANDS

R 334 *Philips Res. Repts* **13**, *1-9, 1958*

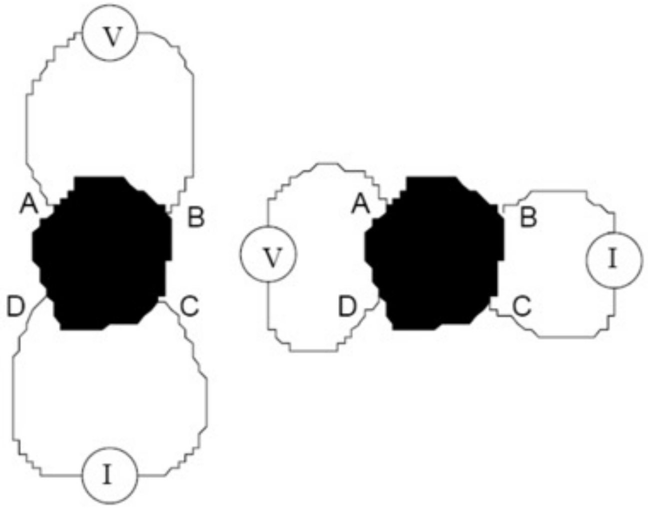
A METHOD OF MEASURING SPECIFIC RESISTIVITY AND HALL EFFECT OF DISCS OF ARBITRARY SHAPE

by L. J. van der PAUW

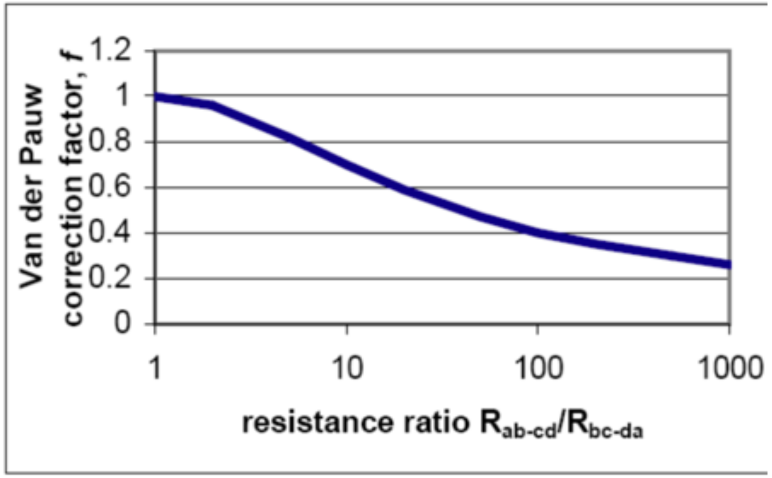
537.723.1:53.081.7+538.632:083.9

Summary
A method of measuring specific resistivity and Hall effect of flat samples of arbitrary shape is presented. The method is based upon a theorem which holds for a flat sample of arbitrary shape if the contacts are sufficiently small and located at the circumference of the sample. Furthermore, the sample must be singly connected, i.e., it should not have isolated holes.

$$R_{sheet} = f\,\frac{\pi}{ln2}\,\frac{R_{AB-CD} + R_{AD-BC}}{2}$$



Assumptions
1. Homogeneous sample.
2. Isotropic sample.
3. Two-dimensional, thickness is unimportant.
4. Sample boundary sharply defined.



van der Pauw Method

Experimental Methods

JOURNAL OF APPLIED PHYSICS VOLUME 42, NUMBER 7 JUNE 1971

Method for Measuring Electrical Resistivity of Anisotropic Materials

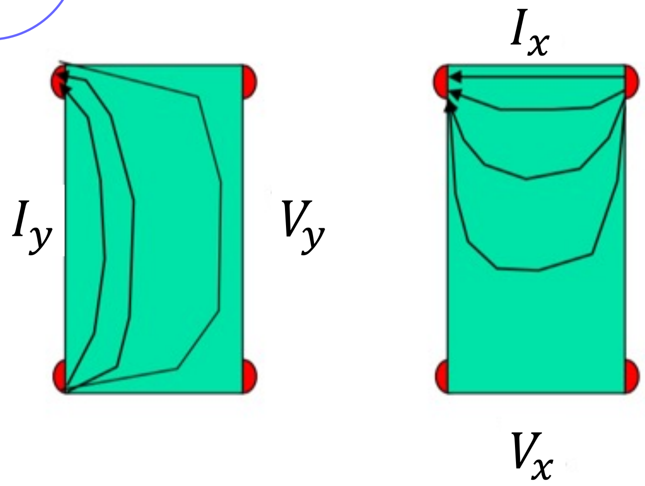
H. C. MONTGOMERY
Bell Telephone Laboratories, Incorporated, Murray Hill, New Jersey 07974
(Received 30 November 1970)

A rectangular prism with edges in principal crystal directions is prepared with electrodes on the corners of one face. Voltage–current ratios for opposite pairs of electrodes permit calculation of components of the resistivity tensor. The method can use small samples, and is best suited to materials describable by two or three tensor components. Examples are given of measurements of V_2O_3–Cr and oriented amorphous graphite.

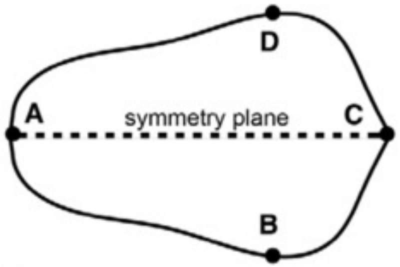
Montgomery technique

Electrical Transport

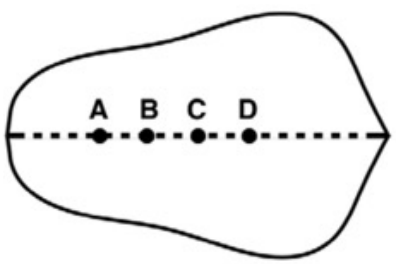
Experimental Methods



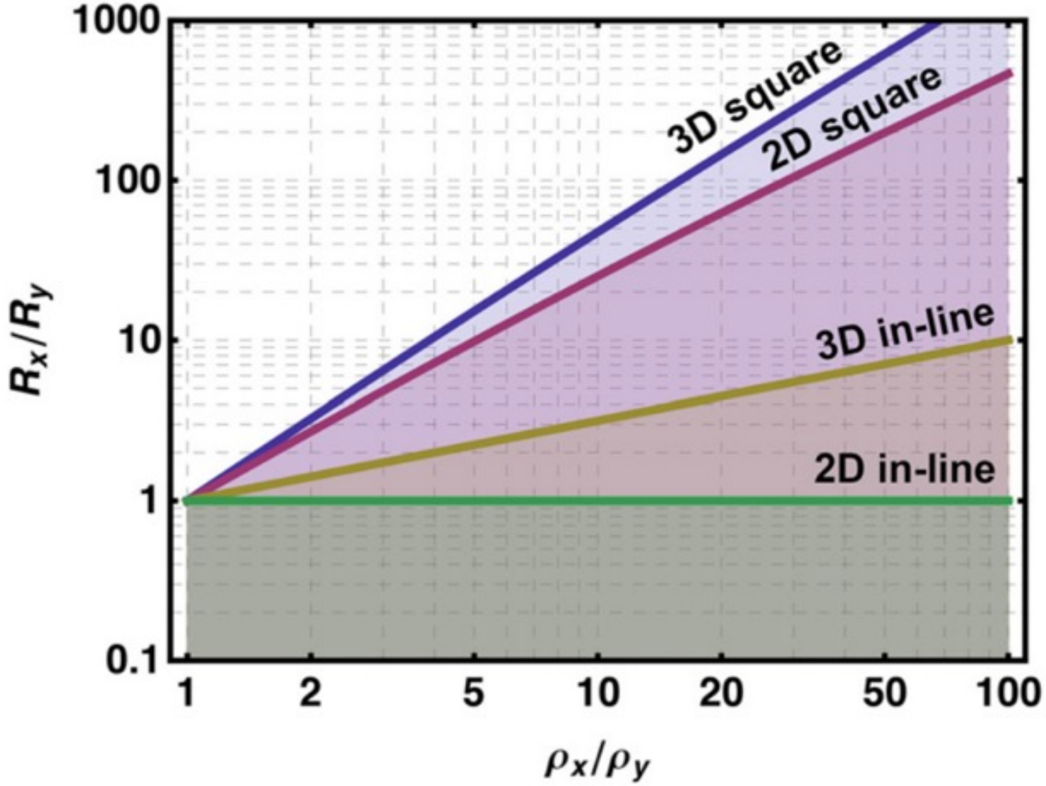
$R_y = V_y/I_y$ $R_x = V_x/I_x$



(b)



(c)



Montgomery technique

Electrical Transport

Experimental Methods

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Topical Review

The 100th anniversary of the four-point probe technique: the role of probe geometries in isotropic and anisotropic systems

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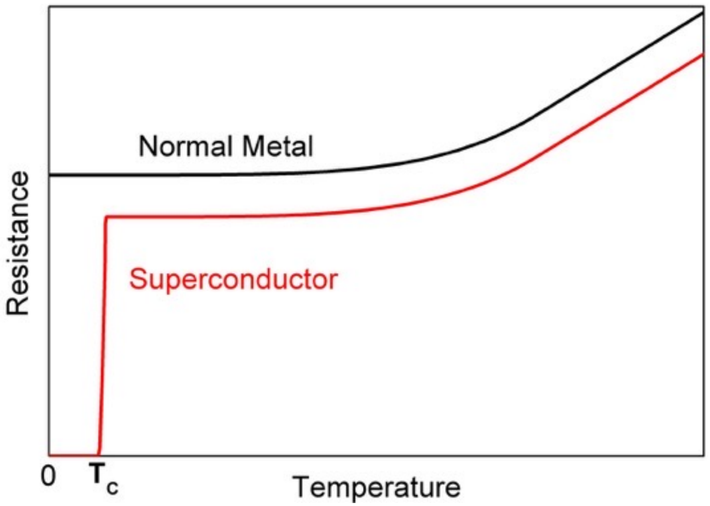
CrossMark

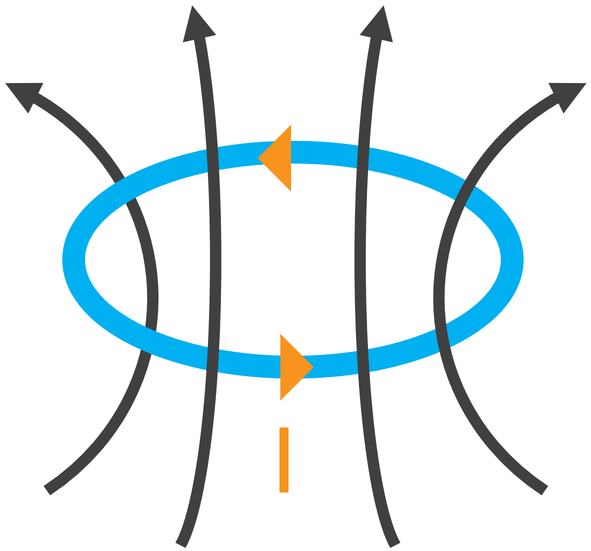
Electrical Transport

Summary

H. Kamerlingh Onnes

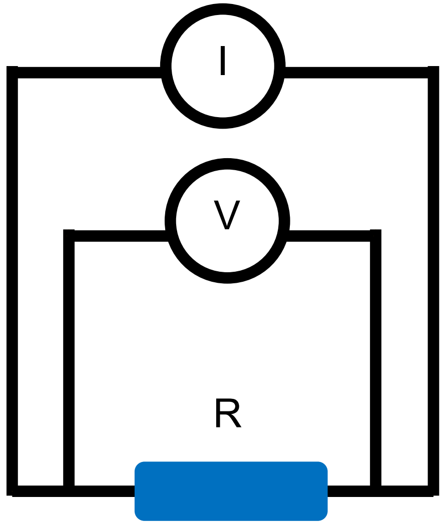


Discovered in1911



Persistent Current

Application in superconducting magnet



Kelvin four-probe method

Chapter 1 Zero Resistance