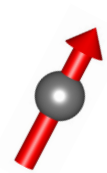
Diamagnets and paramagnets

Curie law, Langevin and Brillouin function

adiabatic demagnetization refrigeration

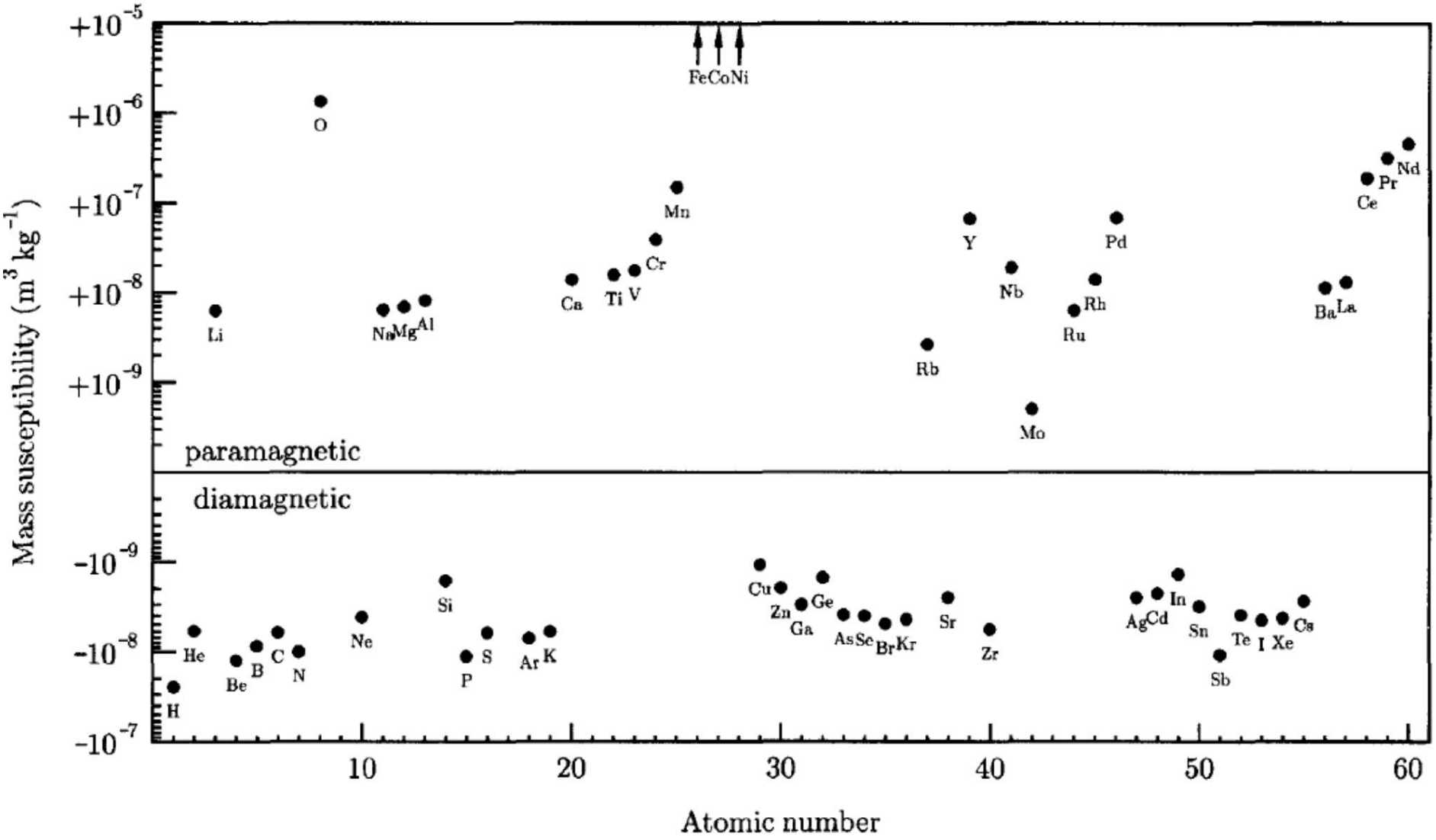
Pierre Curie and Paul Langevin



by Alexander Tsirlin, Leipzig University

Lecture 2: October 28, 2024

Elemental solids



S. Blundell, Magnetism in Condensed Matter

List of samples that showed diamagnetic response

Rock crystal.	Nitric acid.
Sulphate of lime.	Sulphuric acid.
Sulphate of baryta.	Muriatic acid.
Sulphate of soda.	Solutions of various alkaline and earthy salts.
Sulphate of potassa.	Glass.
Sulphate of magnesia.	Litharge.
Alum.	

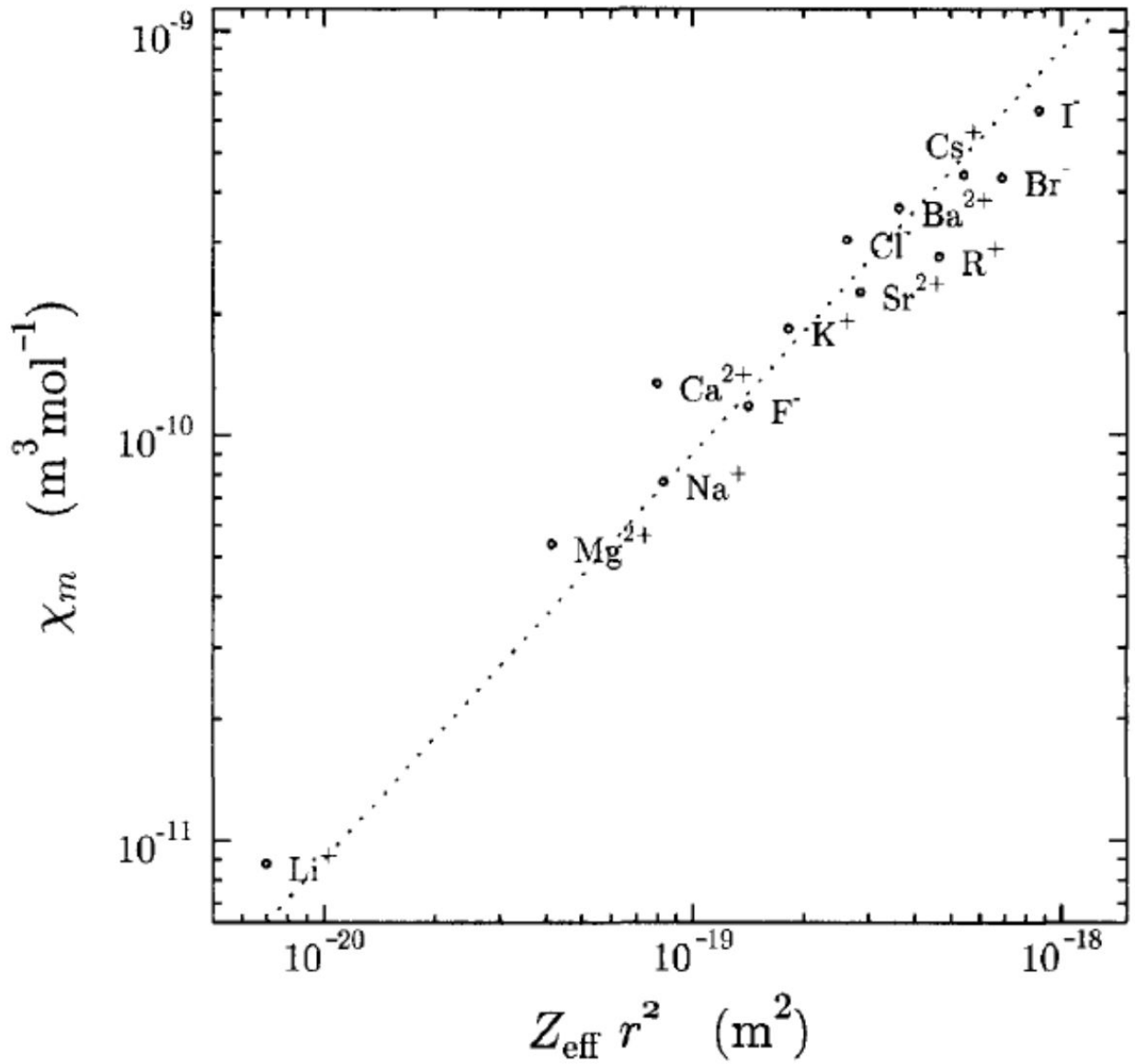
M. Faraday, Phil. Trans. Royal Soc. London 136, 21 (1846)

List of samples that showed diamagnetic response

Rock crystal.	Nitric acid.
Sulphate of lime.	Sulphuric acid.
Sulphate of baryta.	Muriatic acid.
Sulphate of soda.	Solutions of various alkaline and earthy salts.
Sulphate of potassa.	Glass.
Sulphate of magnesia.	Litharge.
Alum.	

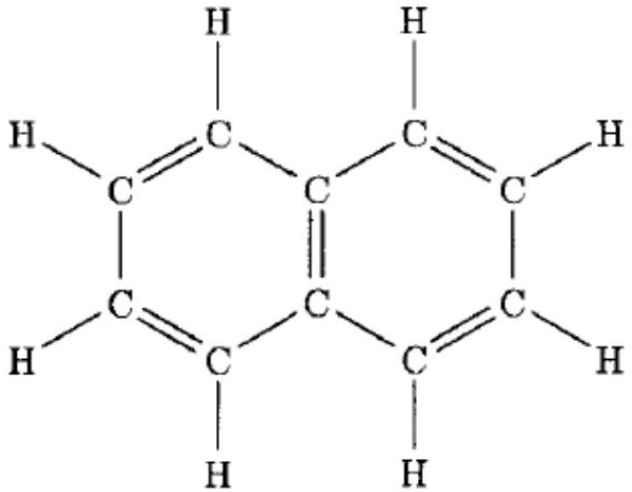
Sugar.	Beef, dried.
Starch.	Blood, fresh.
Gum-arabic.	Blood, dried.
Wood.	Leather.
Ivory.	Apple.
Mutton, dried.	Bread.
Beef, fresh.	

M. Faraday, Phil. Trans. Royal Soc. London 136, 21 (1846)



$$\chi_{\mathrm{dia}} \sim \langle r^2 \rangle$$

S. Blundell, Magnetism in Condensed Matter

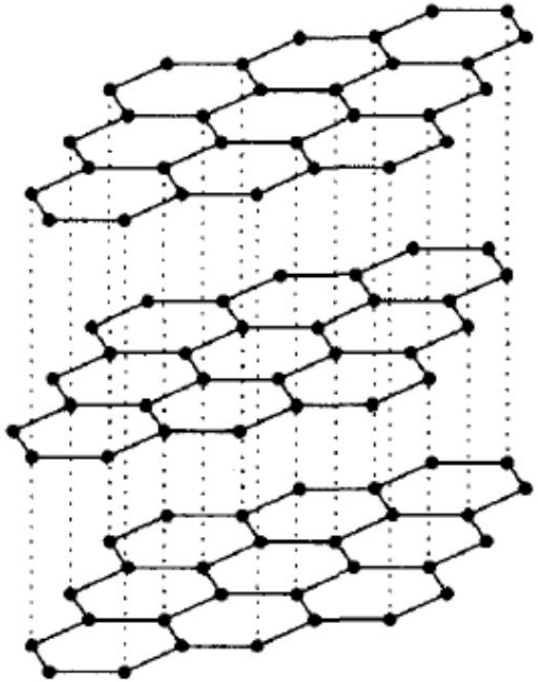


Naphtalene

$\chi_\perp \simeq -40 \times 10^{-6}\,\mathrm{emu/g}$

$\chi_\parallel \simeq -187 \times 10^{-6}\,\mathrm{emu/g}$

$\chi_\parallel/\chi_\perp \simeq 4.5$



Graphite

$\chi_\perp \simeq -0.5 \times 10^{-6}\,\mathrm{emu/g}$

$\chi_\parallel \simeq -22 \times 10^{-6}\,\mathrm{emu/g}$

$\chi_\parallel/\chi_\perp \simeq 44$

Pascal constants

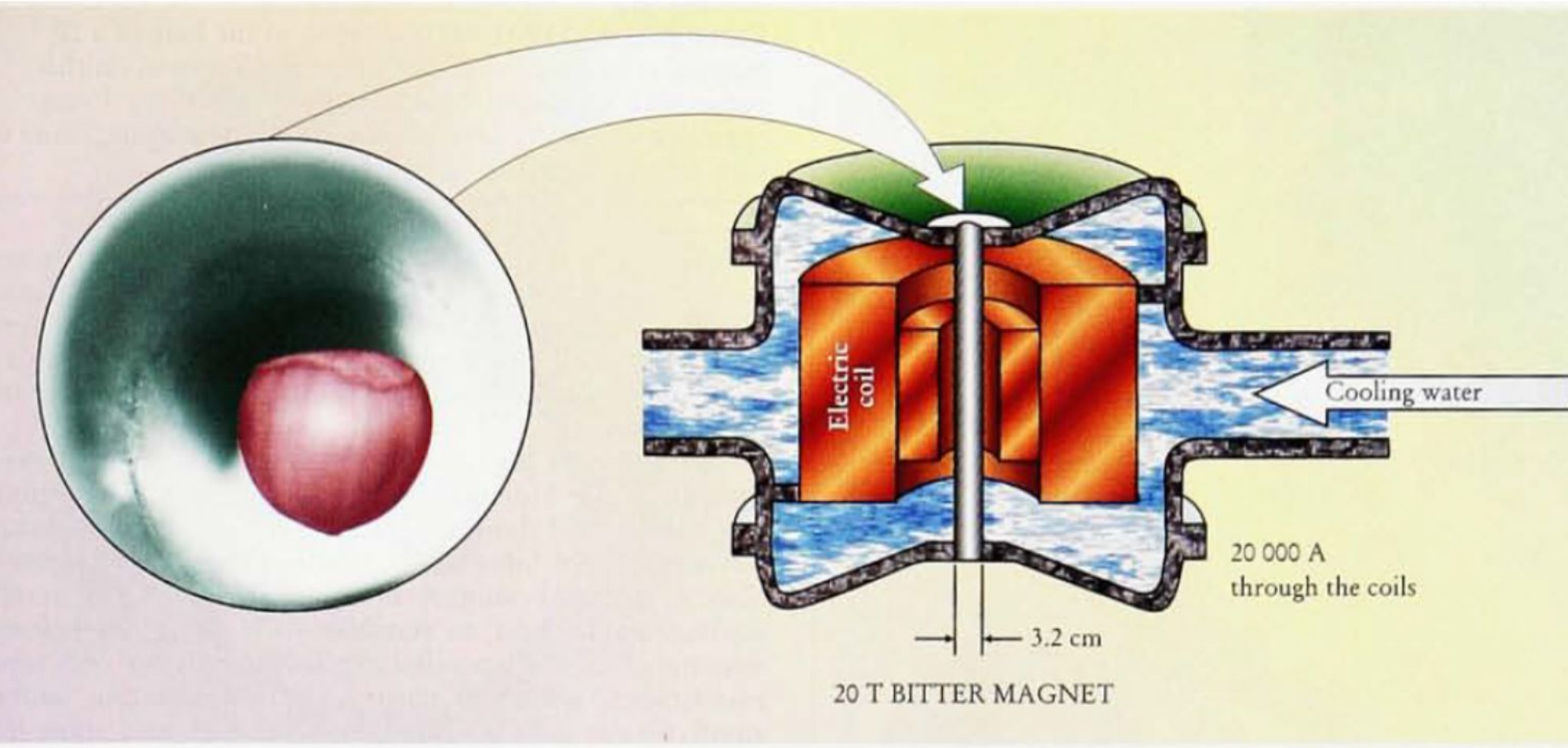
Atom	χ_{Di}/(1 x 10^{-6} emu mol^{-1})	Atom	χ_{Di}/(1 x 10^{-6} emu mol^{-1})
Ag	–31.0	C (ring)	–6.24
Al	–13.0	Ca	–15.9
As(III)	–20.9	Cl	– 20.1
As(V)	–43.0	F	–6.3
B	–7.0	H	–2.93
Bi	–192.0	Hg(II)	–33.0
Br	– 30.6	I	–44.6
C	– 6.00	K	–18.5

χ_{D_i} (core)

λ_i

C=C	+5.5	$Cl–CR_2CR_2–Cl$	+4.3
C≡C	+0.8	R_2CCl_2	+1.44
C=C–C=C	+10.6	$RCHCl_2$	+6.43
Ar–C≡C–Ar[b]	+3.85	C–Br	+4.1
CH_2=CH–CH_2–(allyl)	+4.5	$Br–CR_2CR_2–Br$	+6.24
C=O	+6.3	C–I	+4.1

J. Chem. Education 85, 532 (2008)



Levitating nuts

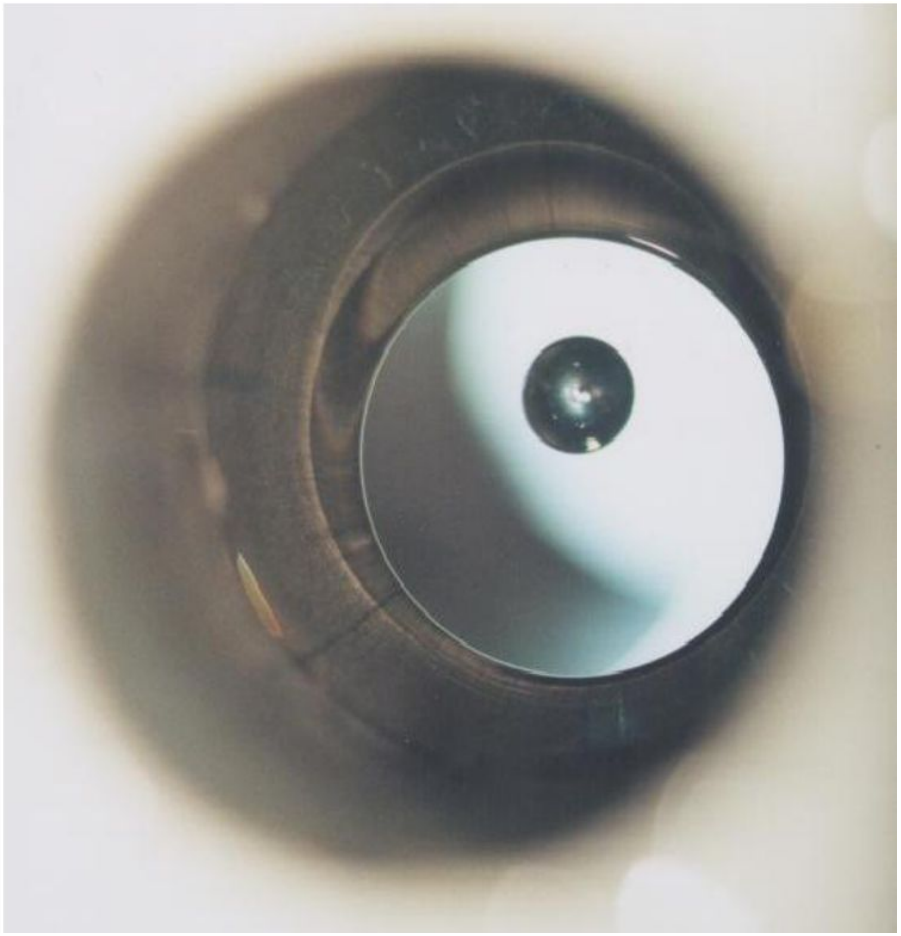
Applied field of 16 T generates the field of -1 G inside the nut

Physics Today 51(9), 36 (1998)

Diamagnetic levitation

Live frog

Water drop

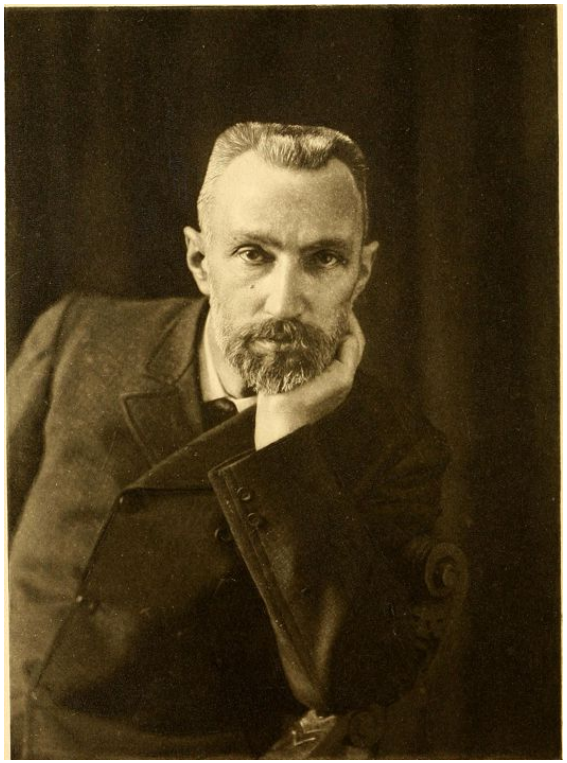


Effects of microgravity can be studied in the lab

Image credit: HFML, Nijmegen

Person

Pierre Curie and Paul Langevin

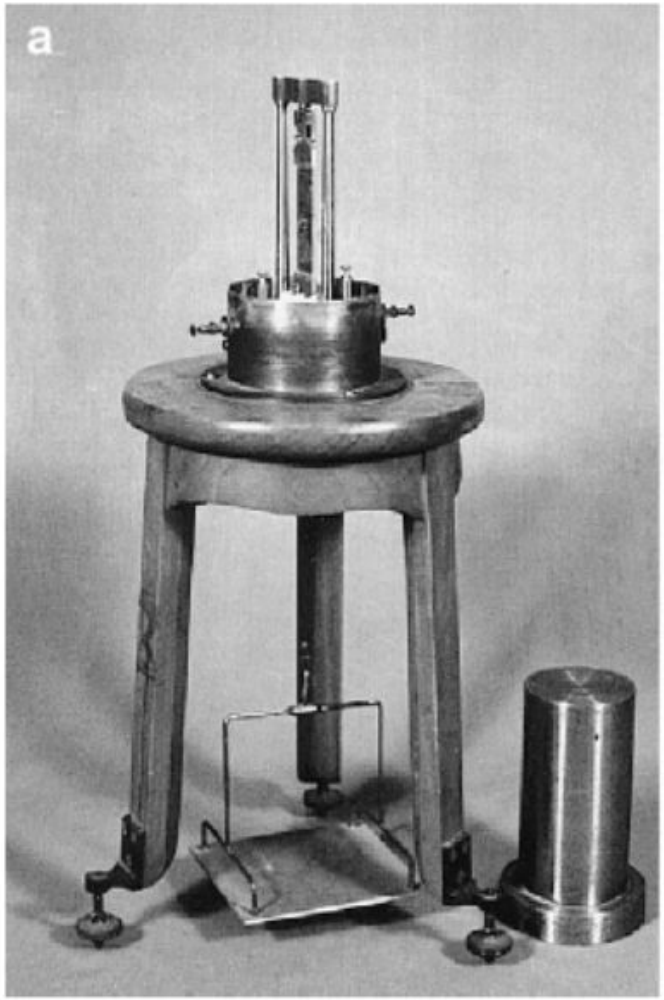


Pierre Curie
1859–1906

discovery of piezoelectricity

experimental studies
of T-dependent magnetic behavior

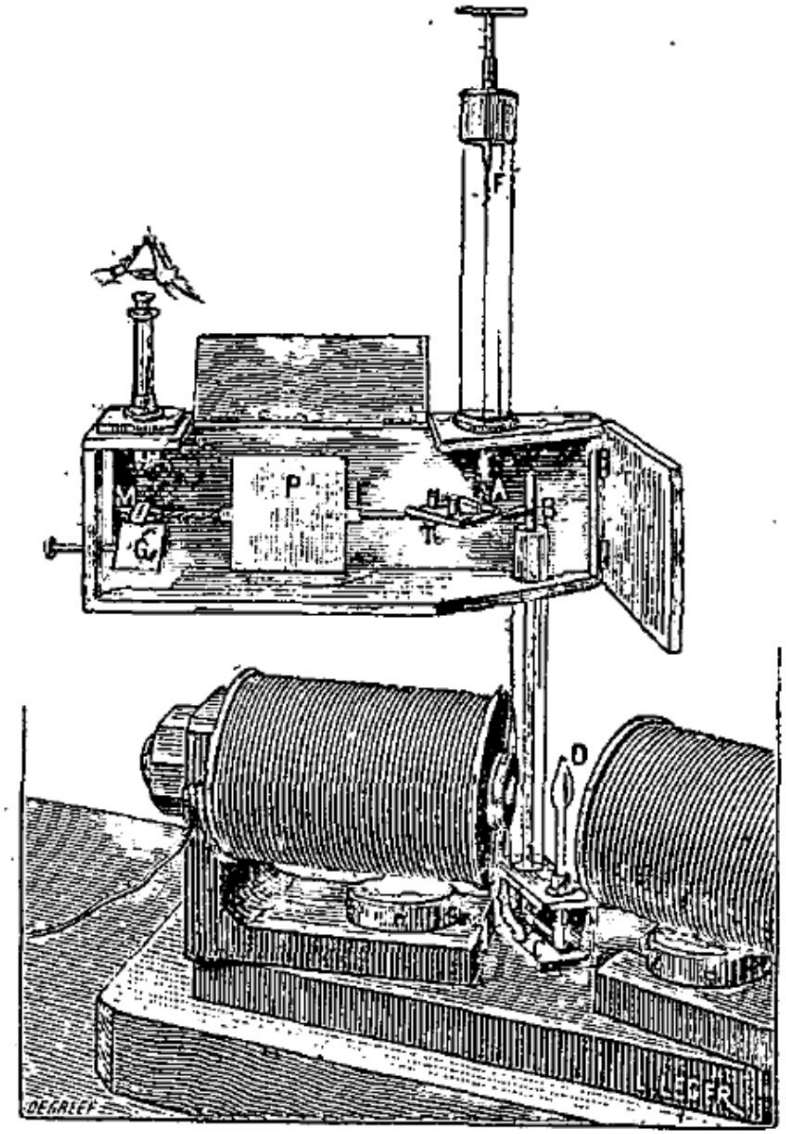
Curie compensator

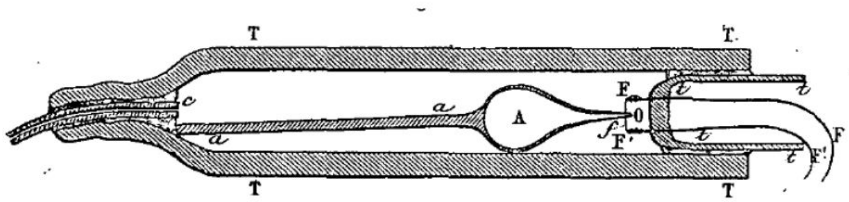


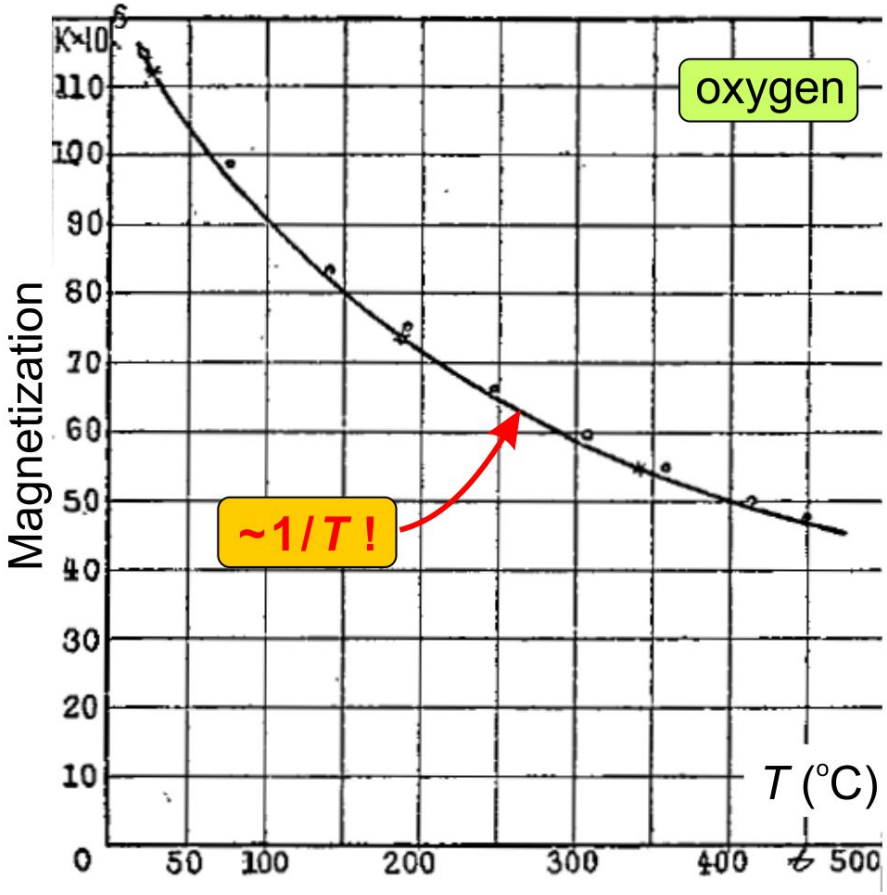
Strained quartz crystal used to measure currents on the pA scale

J. Electrostatics 67, 524 (2009)

Curie's apparatus

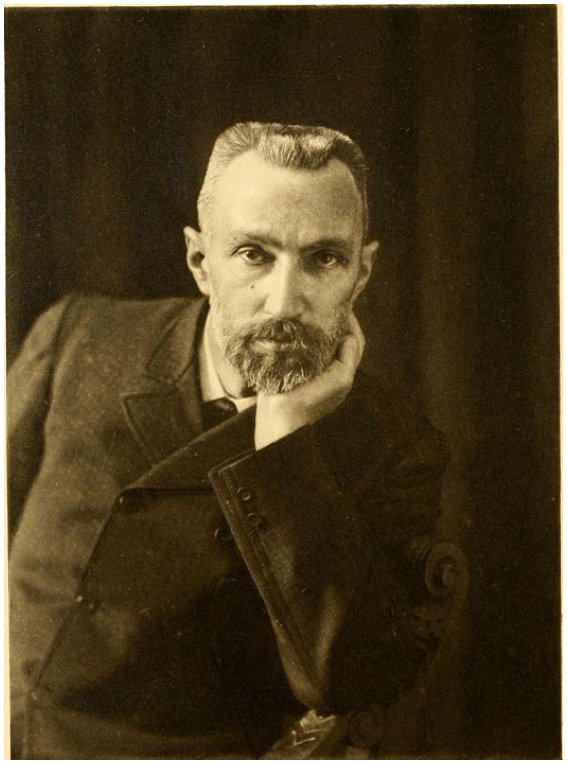






P. Curie, Ann. Chim. Phys. (5), 295 (1895)

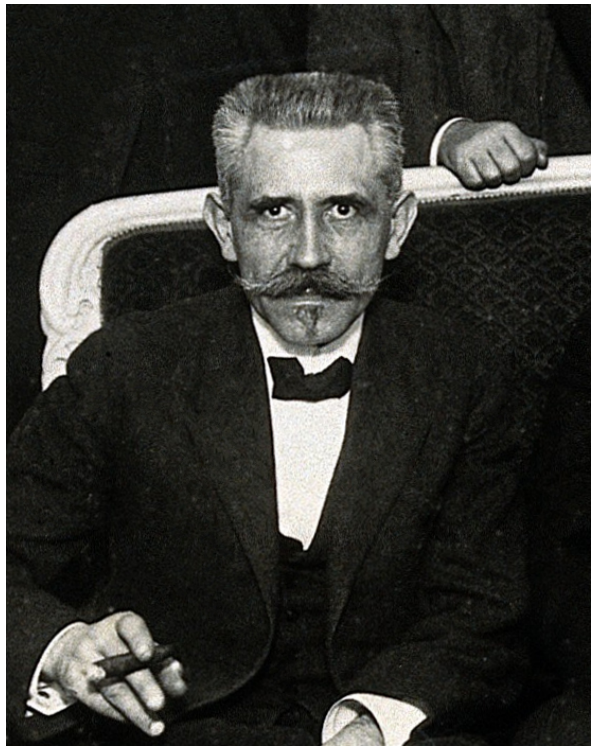
Curie vs. Langevin



Pierre Curie
1859–1906

discovery of piezoelectricity

experimental studies
of T-dependent magnetic behavior



Paul Langevin
1872–1946

use of piezoelectric sensors
for submarine detection

first theory of dia- and paramagnetism

Curie's greatest discovery

Pierre Curie (1859–1906)
Marie Skłodowska-Curie (1867–1934)

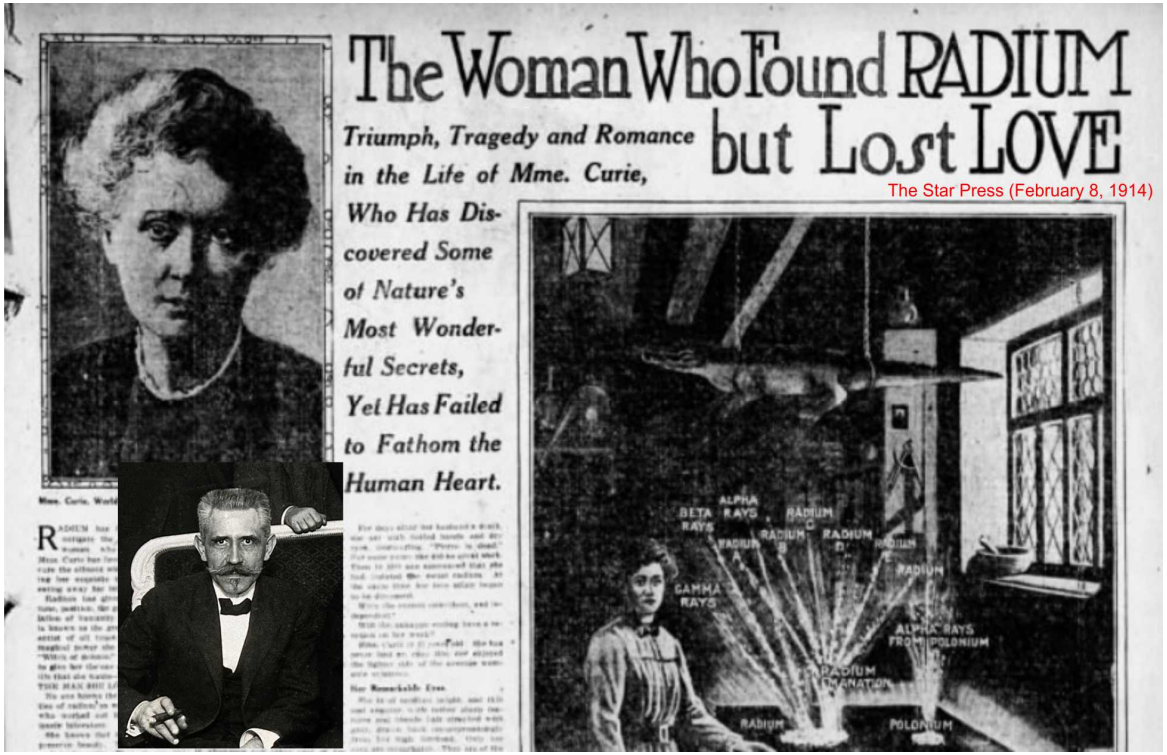
1903: Nobel prize in physics for radioactivity

1911: Nobel prize in chemistry for the discovery of new chemical elements, especially radium (Marie only)

Pierre Curie (1859–1906)
Marie Skłodowska-Curie (1867–1934)

1903: Nobel prize in physics for radioactivity

1911: Nobel prize in chemistry for the discovery of new chemical elements, especially radium (Marie only)

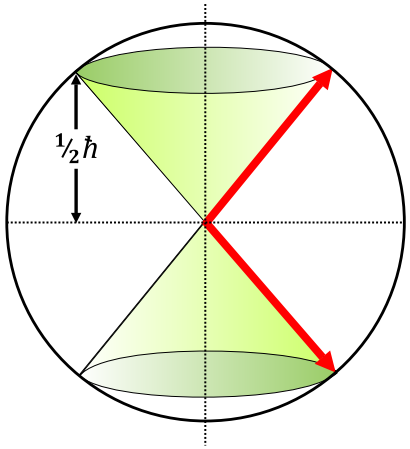


Langevin affair

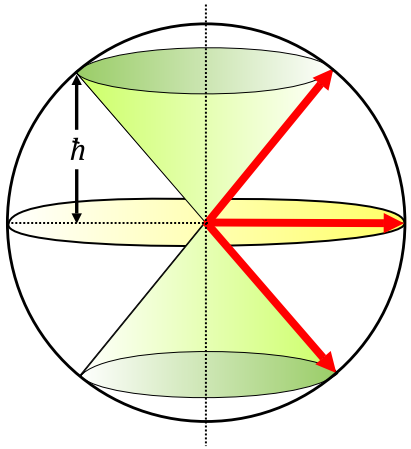
Léon Brillouin
1889–1968

PhD student of Langevin

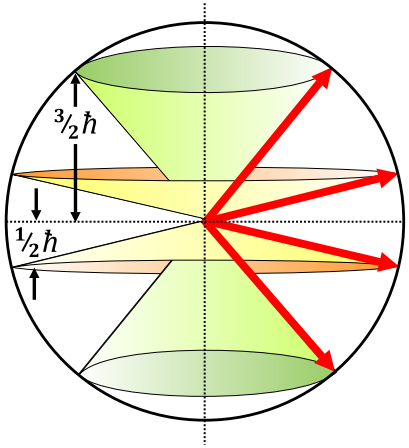
better known for the Brillouin zone,
WKB approximation...



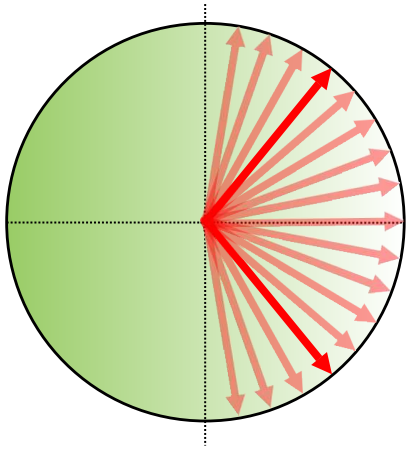
$J = 1/2$



$J = 1$

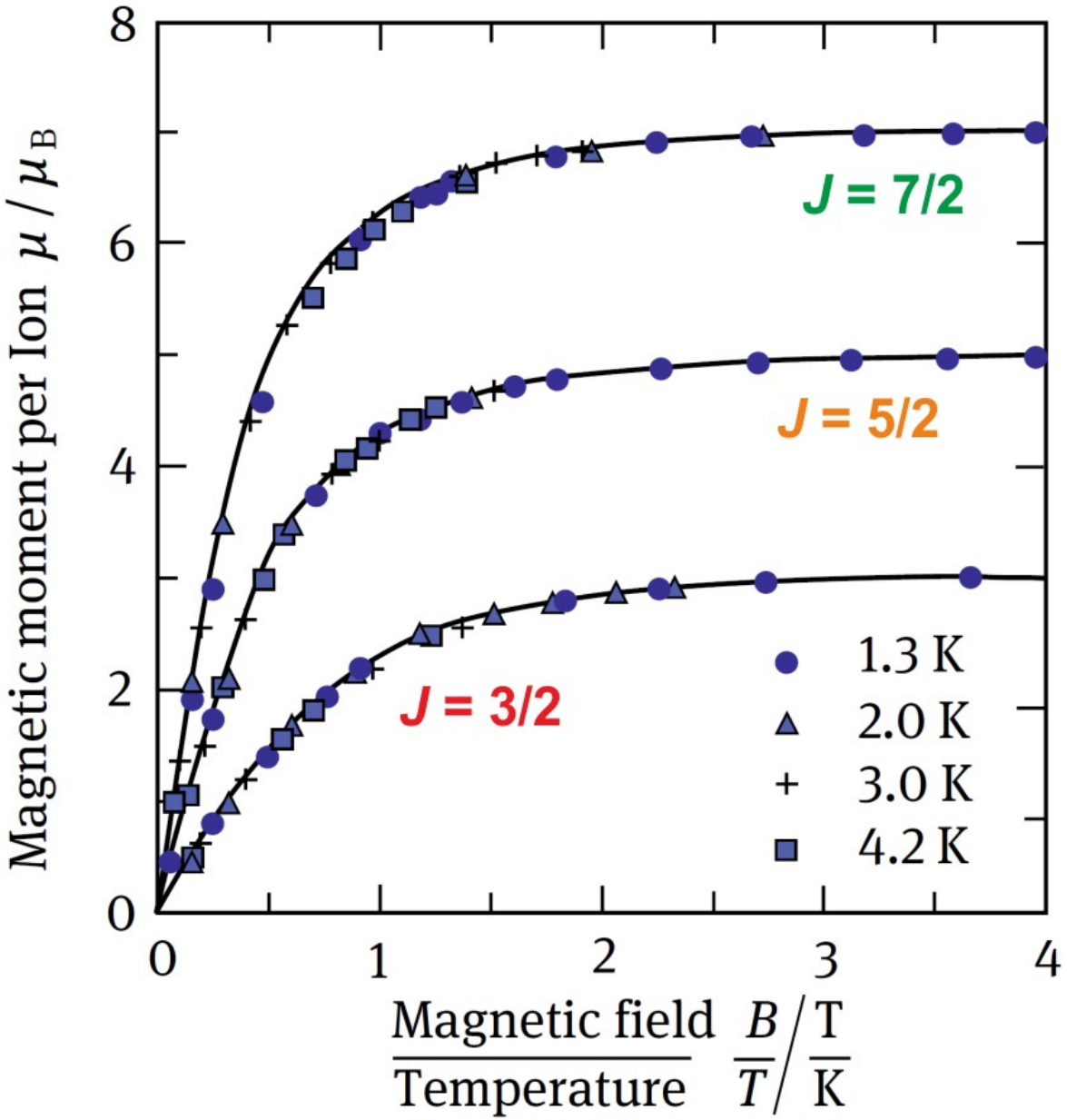


$J = 3/2$



$J = \infty$

Brillouin function



Universal behavior as a function of B/T

S. Hunklinger, Festkörperphysik

Material / Technology

adiabatic demagnetization refrigeration

Operation principle

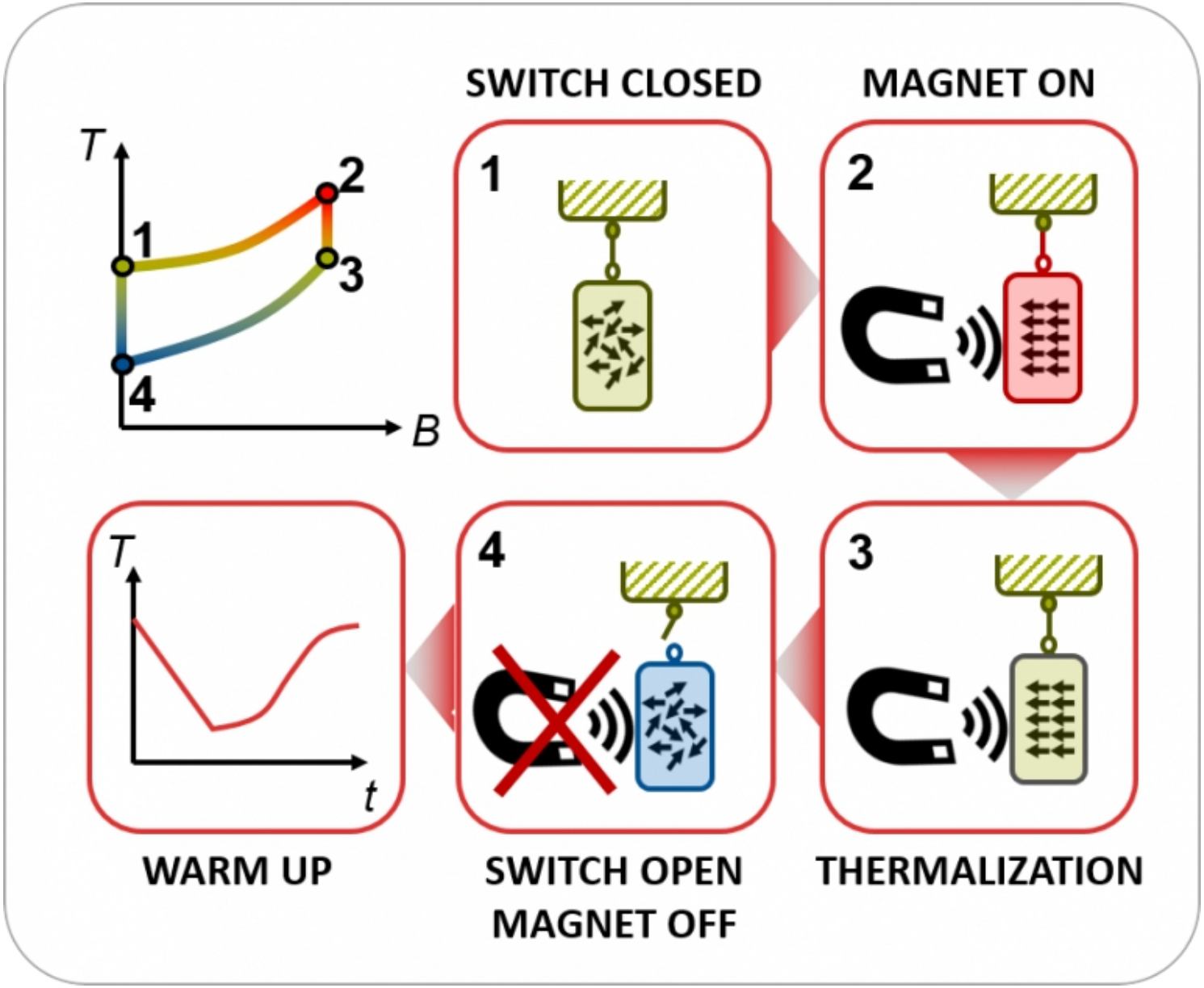


Image credit: cryodynamics.de

16. *Einige Bemerkungen zur Magnetisierung bei tiefer Temperatur;*
von P. Debye

Ann. Phys. 386, 1154 (1926)

A THERMODYNAMIC TREATMENT OF CERTAIN MAGNETIC EFFECTS. A PROPOSED METHOD OF PRODUCING TEMPERATURES CONSIDERABLY BELOW 1° ABSOLUTE

By W. F. Giauque

JACS 49 1864 (1927)

Received December 14, 1926 Published August 5, 1927

Attainment of Temperatures Below 1° Absolute by Demagnetization of $Gd_2(SO_4)_3 \cdot 8H_2O$

Phys. Rev. 43, 768 (1933)

Department of Chemistry,
University of California,
Berkeley, California,
April 12, 1933.

W. F. Giauque
D. P. MacDougall

Current lab appliance

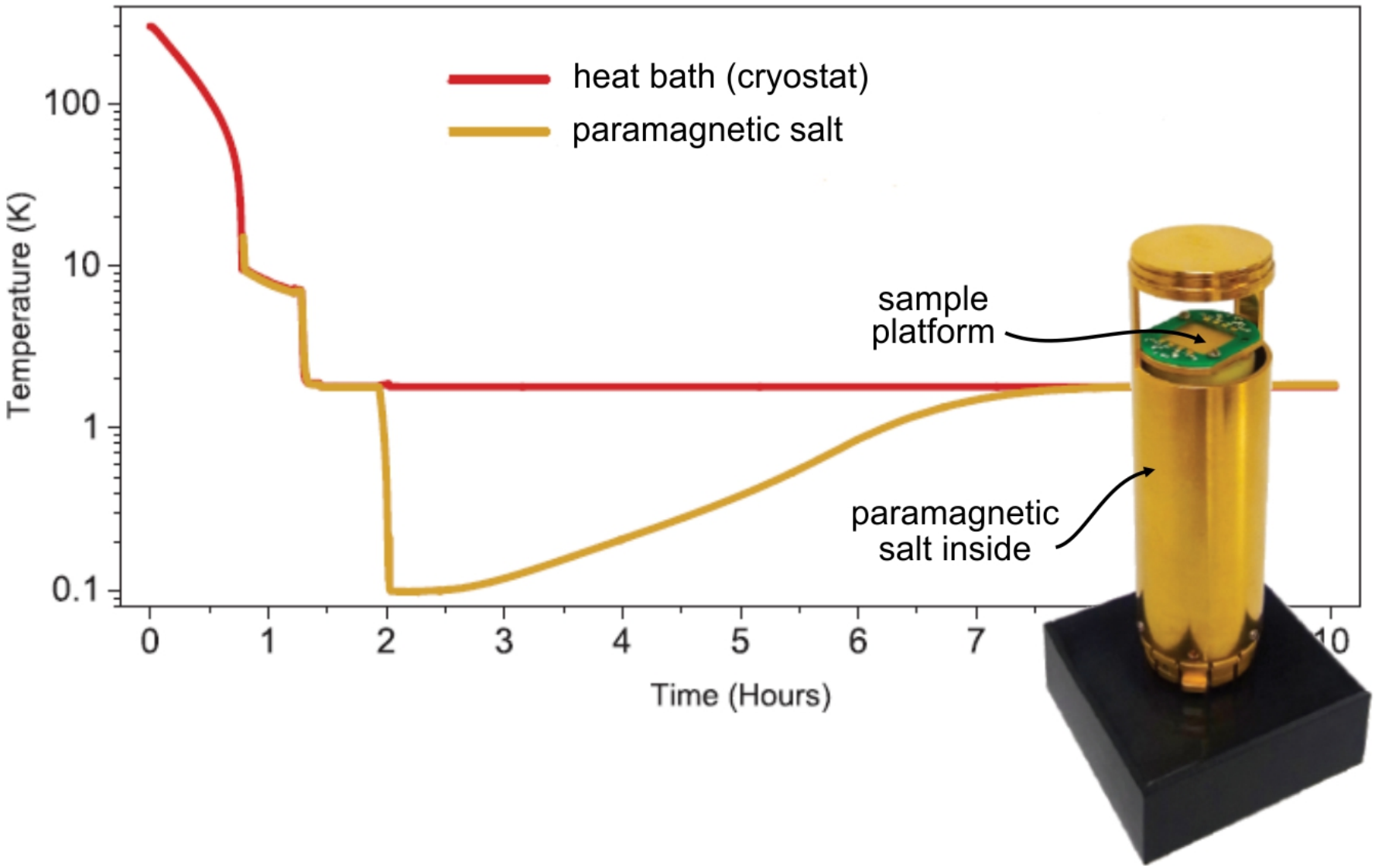
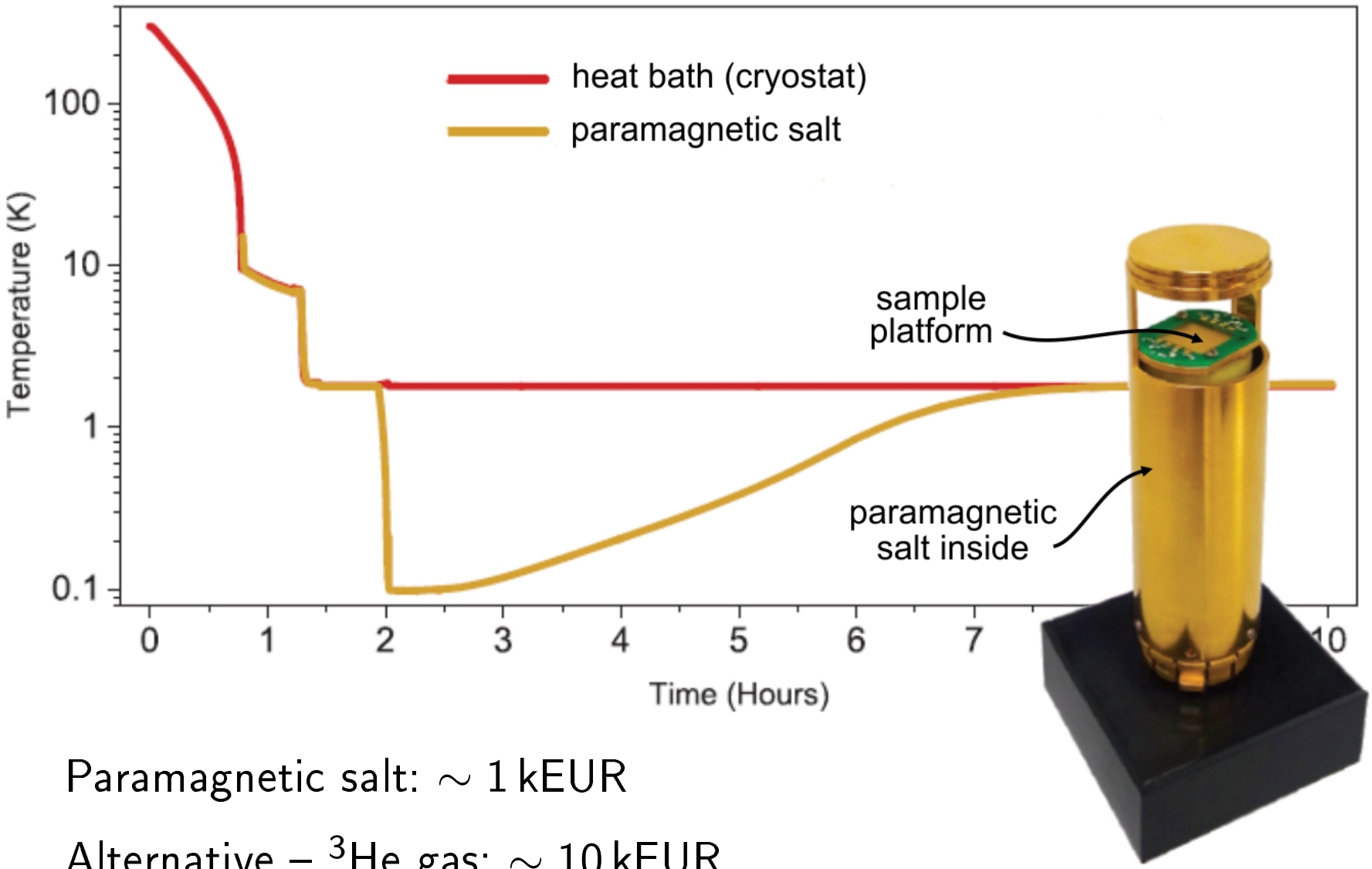


Image credit: Quantum Design (fair use)

Current lab appliance



Paramagnetic salt: $\sim 1\,\mathrm{kEUR}$

Alternative – ^{3}He gas: $\sim 10\,\mathrm{kEUR}$

Image credit: Quantum Design (fair use)