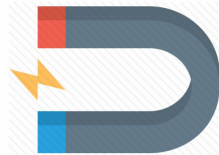
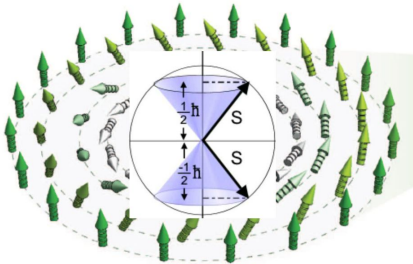


Introduction

Alexander Tsirlin

Division of Quantum Magnetism and Superconductivity

Felix Bloch Institute for Solid-State Physics



UNIVERSITÄT
LEIPZIG

Fundamentals of Magnetism, WS 24/25

J. W. von Goethe

Magnetes Geheimnis, erkläre mir das!
Kein größer Geheimnis
als Liebe und Haß

Gott, Gemüt und Welt (1813)



*monument in Meersburg,
south of Germany*



Image credit: Andreas Praefcke (CC-BY-SA)

monument in Meersburg,
south of Germany



Franz Mesmer (1734–1815)

German doctor working
in Vienna and later in Paris

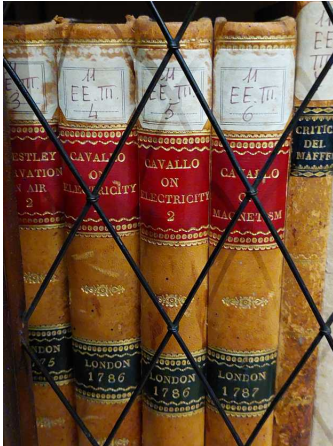
treated his patients with magnets

His methods were not approved
by the "official" medicine,
but were later understood
as the first successful
examples of hypnosis
(hence the verb *mesmerize*)



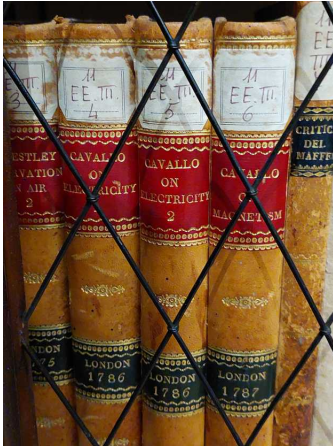
Quote by Chester Gould
from his *Dick Tracy* comic series
re-used by the Helix journal (1968)

History of (early) magnetism research



Magnetism textbook
already in 1787!

History of (early) magnetism research



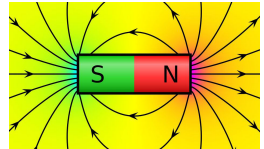
Magnetism textbook
already in 1787!

- ▶ Electric current generates magnetic field (Ørsted, 1820)
- ▶ Magnetic induction (Faraday and Henri, 1831)
- ▶ Magnetic field of Earth (Gauss, end of 1830's)
- ▶ Theory of electrodynamics (Maxwell, 1861)

Image credit (next slide): Geek3 (CC-BY-SA)

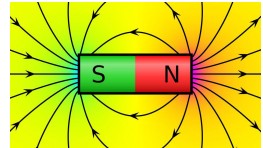
1. Individual magnetic moments

- diamagnets and paramagnets
- atomic magnetism
- magnetism of metals



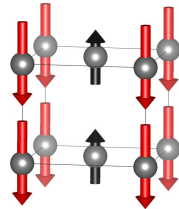
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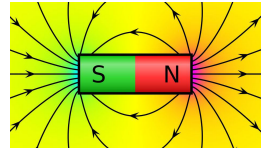
2. Cooperative effects: magnetic order

- magnetic interactions
- magnetic structures
- magnetic excitations: spin waves
- domains and anisotropies



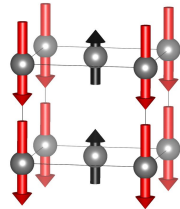
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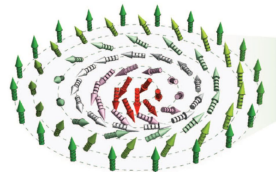
2. Cooperative effects: magnetic order

- magnetic interactions
- magnetic structures
- magnetic excitations: spin waves
- domains and anisotropies



3. Complex magnetic states

- spin glass
- spin ice and spin liquid
- skyrmions





Concepts / Theory



Concepts / Theory



Experiment



Concepts / Theory



Experiment



Technology / Material



Concepts / Theory



Experiment



Technology / Material



Person

Where and when?

Mo 13:15, SR218 (lecture)

Tu 15:15, SR225 (exercise class)

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Tu 15:15, SR225 (exercise class)

Information:

<https://research.uni-leipzig.de/sum/magnetism.html>

- *lecture slides*
- *lecture notes (alpha-version)*
- *supplemental material & reading suggestions*
- details about exercise classes



Where and when?

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- *supplemental material & reading suggestions*
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Contact: ask your questions after the lecture
or via e-mail, alexander.tsirlin@uni-leipzig.de

- **6 problem sheets** will be available on the web page
- solutions are due 2 weeks later
- merge everything into a single PDF-file
- submit via Moodle

Exercise classes

Tu 15:15, SR 225 (exercise class):

will typically end around 16:20, before the Physics Colloquium

- *solutions* to the problem sheets
- *additional content* to the lectures (relevant at the exam)

(schedule available on the web page)

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- *solutions* to the problem sheets
 - *additional content* to the lectures (relevant at the exam)
- (schedule available on the web page)

**50% points for the solutions
is a pre-requisite for taking the exam**

- **Oral exam** (30 minutes)
- Appointments: second half of February 2025
last class will be on 4.02.2025
- List of questions will be available
- **Pre-requisites:**
 - know and understand the main concepts
 - able to explain solutions to the exercises
 - know key experimental methods and applications

- S. Blundell, Magnetism in Condensed Matter
simple and comprehensive; paper copies only
- J.M.D. Coey, Magnetism and Magnetic Materials
much longer book, but still simple reading; e-book available
- R.M. White, Quantum Theory of Magnetism
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have extensive chapters on magnetism
Ashcroft&Mermin, Kittel, Hunklinger, Gross&Marx...
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All about magnetization



magnetic moment, magnetization,
susceptibility



magnetization measurements



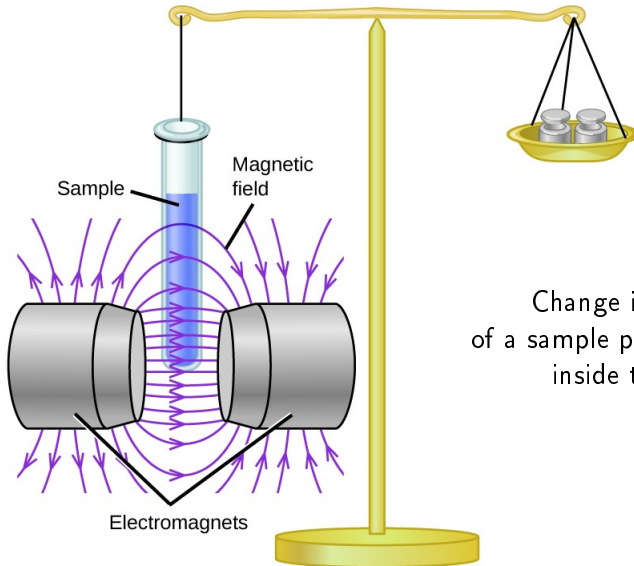
magnetite



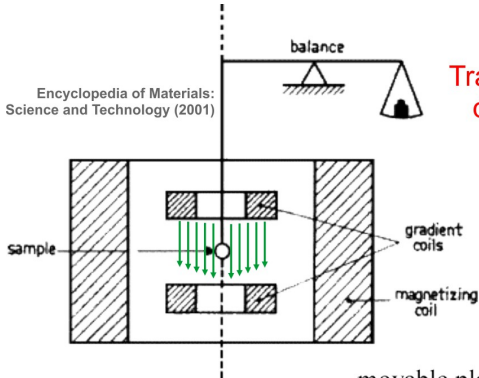


Experiment

magnetization measurements

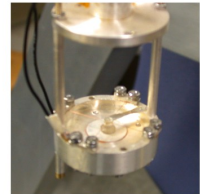
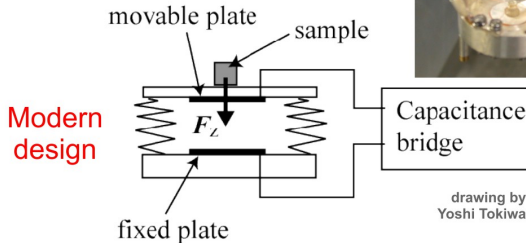


Change in the weight
of a sample partially
suspended
inside the magnet



**Traditional
design**

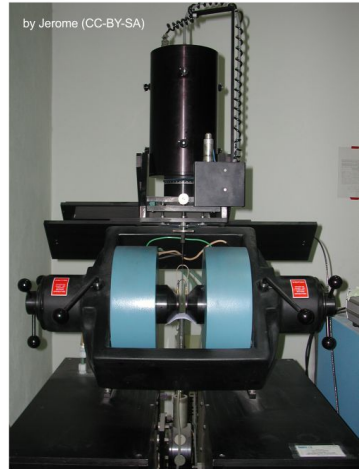
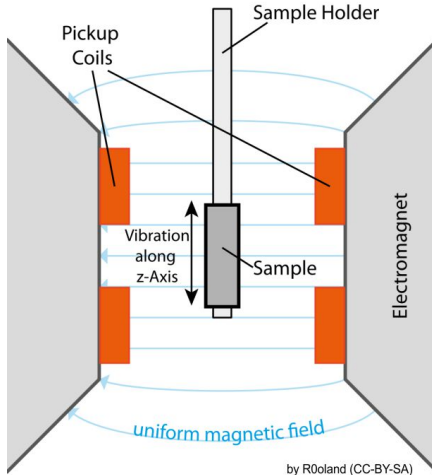
**Force acting
on the sample
in a field gradient**



$$\frac{dB}{dz}$$

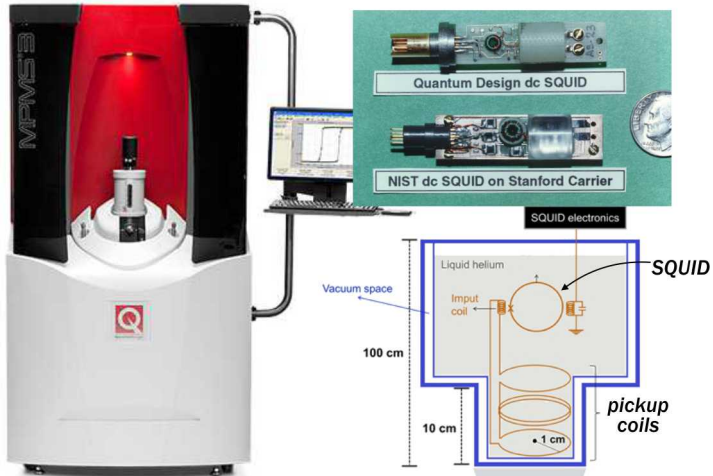
drawing by
Yoshi Tokiwa

Vibrating sample magnetometer



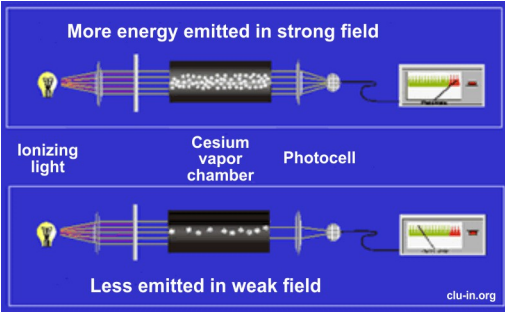
Sensitivity not better than 10^{-4} emu
with SQUID pick-up coil – down to 10^{-8} emu

Modern lab magnetometer

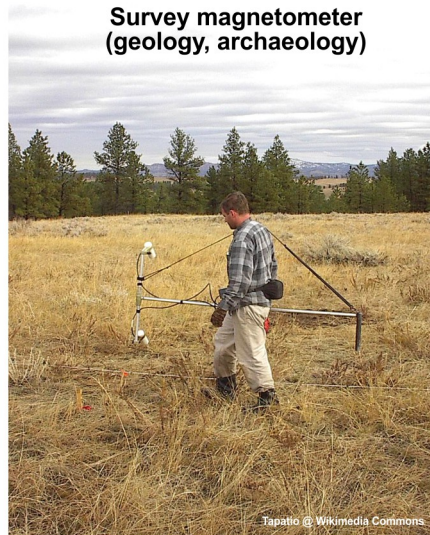


SQUID = Superconducting Quantum Interference Device

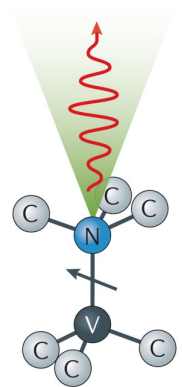
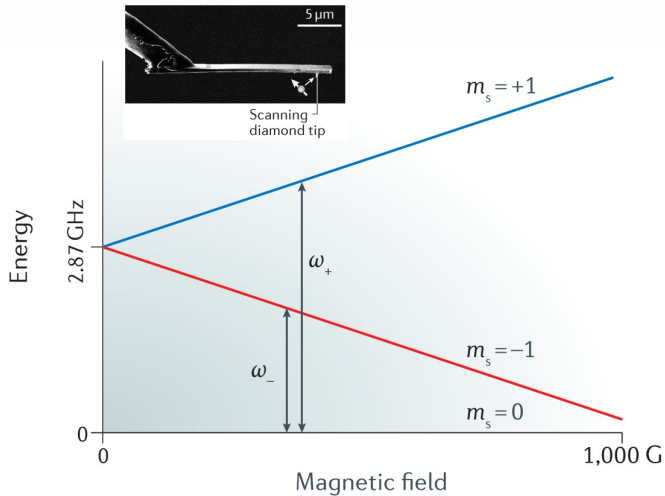
Image credits: Slicky (public domain) and Quantum Design (fair use)



Survey magnetometer (geology, archaeology)



Optical detection of electronic transitions triggered by the magnetic field





Material / Technology

magnetite

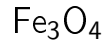
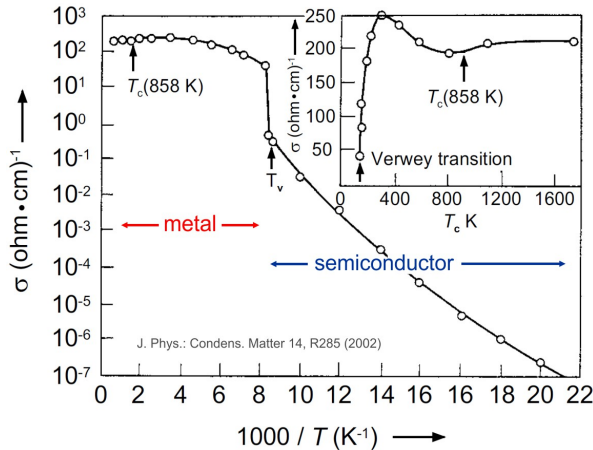


- **Around 600 BC:**
Thales of Miletus described attraction of iron by *lodestone* (magnetite, Fe_3O_4)
- **Since 200 BC:**
lodestones used as pointers in ancient China
- **Since 11th century AD:**
practical compasses in navigation



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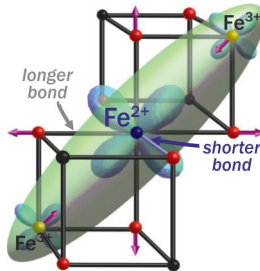
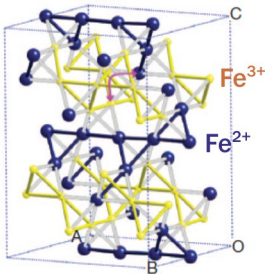




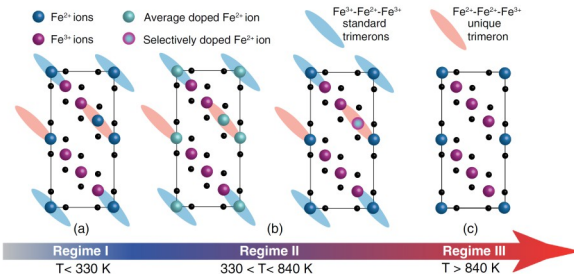
Ferrimagnetic below $T_C = 858 \text{ K}$

Changes from metallic to semiconducting around 125 K (Verwey transition), with no significant effect on the magnetism

Puzzle of magnetite



Nature 481, 173 (2012)



Phys. Rev. Lett.
127, 186402 (2021)

