PRECESSING FERROMAGNETIC NEEDLE MAGNETOMETER

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Prologue…

- ✧ CASPEr for the electron sector?
- ✧ Peter and Surjeet say:

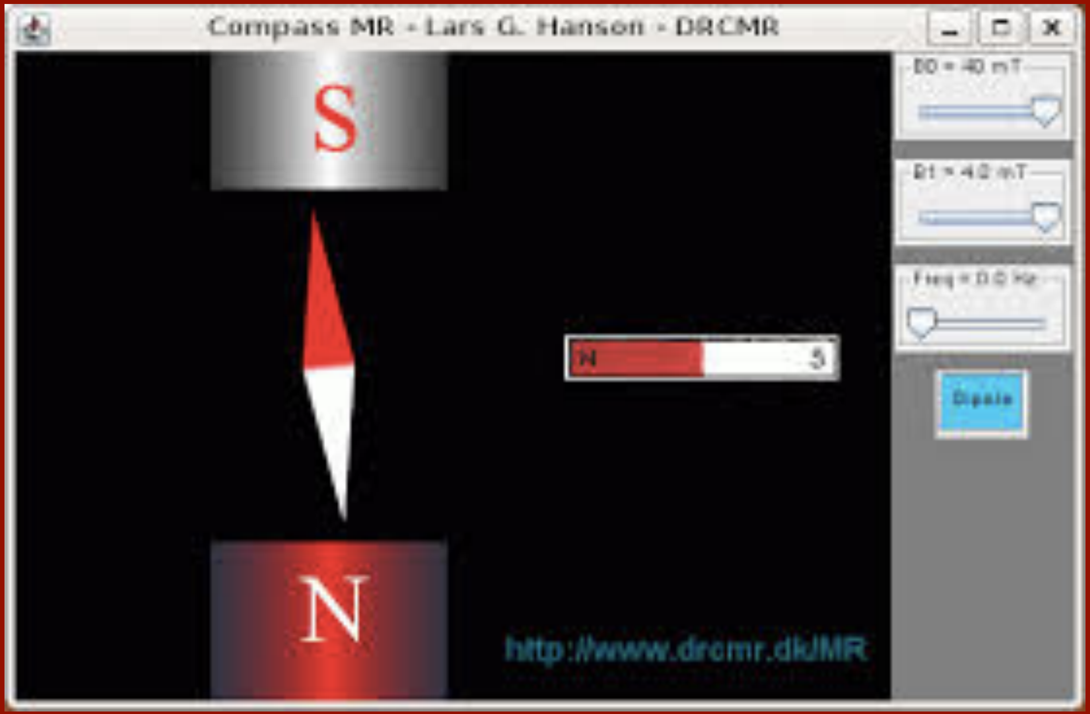
- ➢ Need high density samples with slow relaxation

(Eq. 1)

- ✧ Ferromagnetic solids !
- ✧ Magnetic-Needle Magnetometry?

✧ Magnetic-Needle Magnetometry

- How is a needle different from an atom?



Needle vs. Atom

- ✧ Needle oscillates; atom precesses
  - Why?

Atom

$$\vec{\mu} = \gamma \vec{F}$$

Magnetic moment

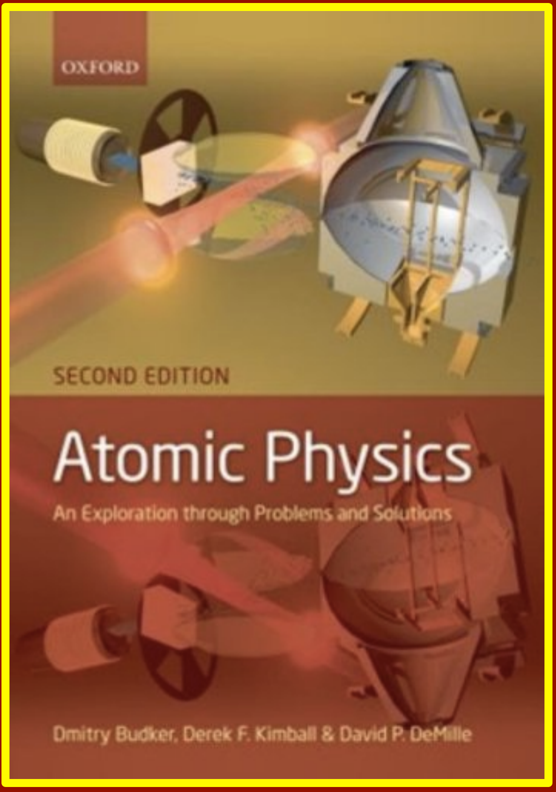
$$\frac{d\vec{F}}{dt} = \vec{\mu} \times \vec{B} = \gamma \vec{F} \times \vec{B}$$

Torque

Torque ⊥ ***F***

$$\vec{\Omega}_L = -\gamma \vec{B}$$

Precession around magnetic field



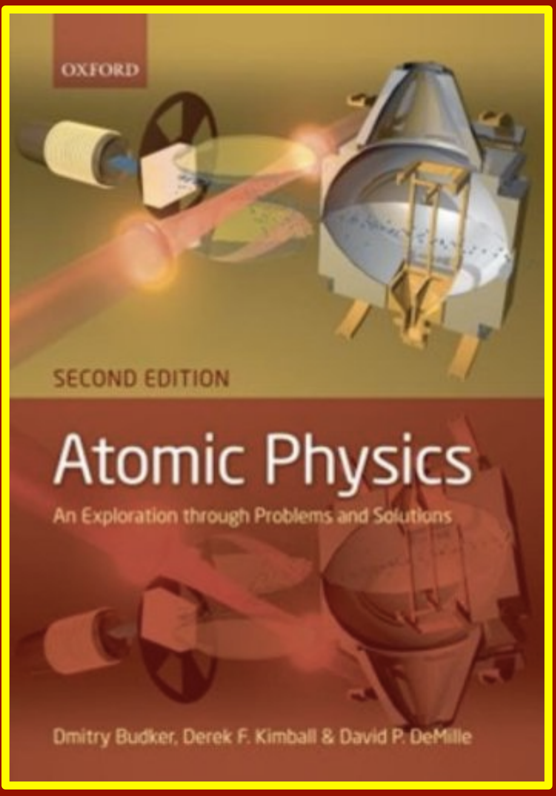
Needle vs. Atom

✧ Needle oscillates; atom precesses

- Why?

Needle

- ~ ħ per atom
- ~ 2 Bohr magneton per atom
- Same gyromagnetic ratio!
- But: nuclei move !
- Two regimes predicted !
- Analogous to bicycle-wheel gyro



Quantum Regime: precession of needle

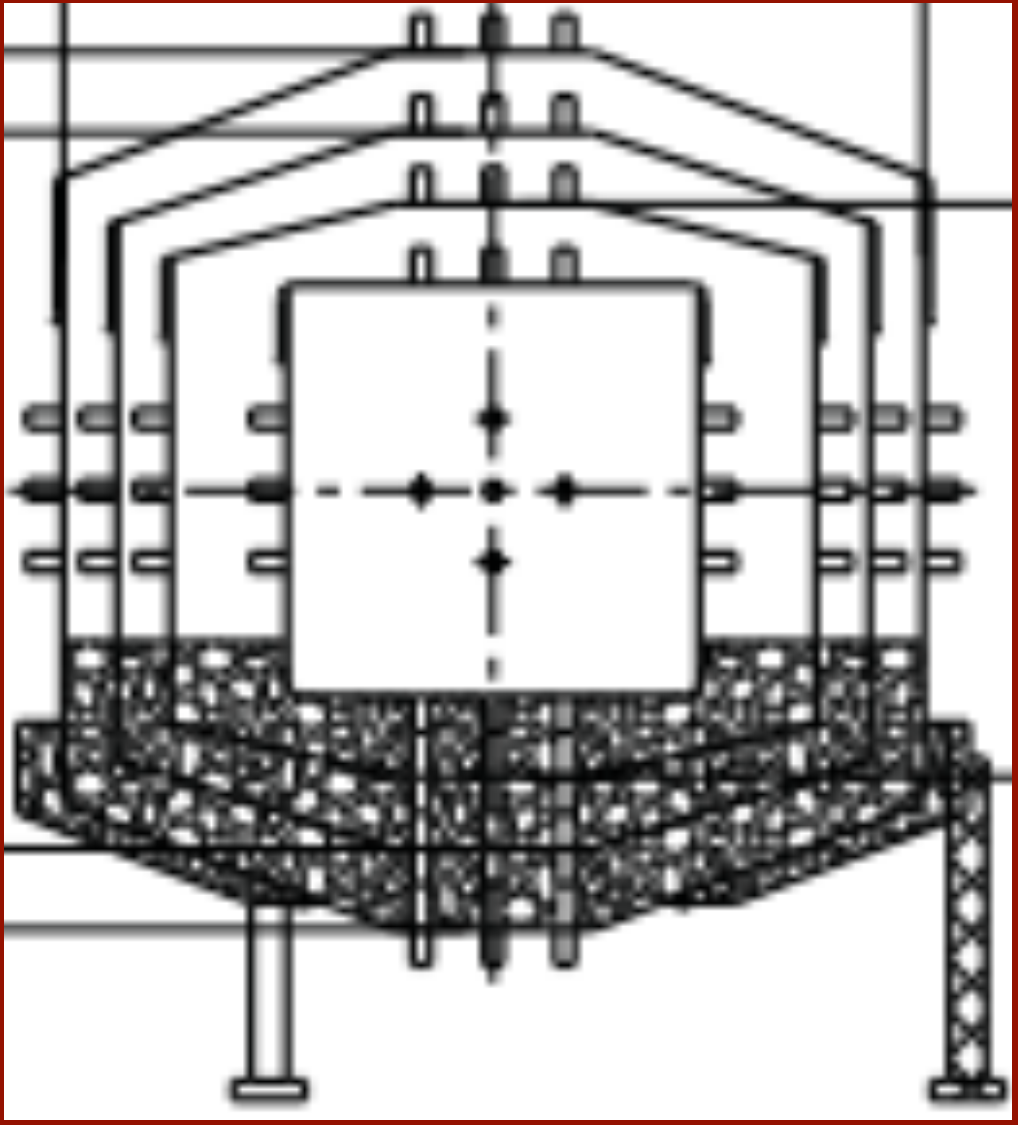
$$I \cdot \Omega_L \ll N\hbar$$

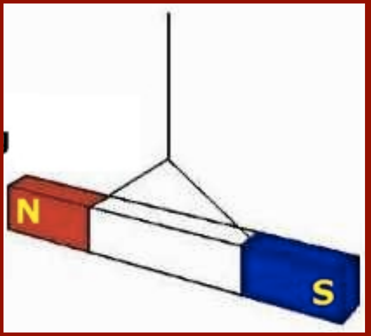
$$\frac{ml^2}{12} \cdot \mu_B B \ll N\hbar$$

$$l = 10\,\mu m \Rightarrow B \ll 10^{-5}\,G$$

Needle Magnetometer

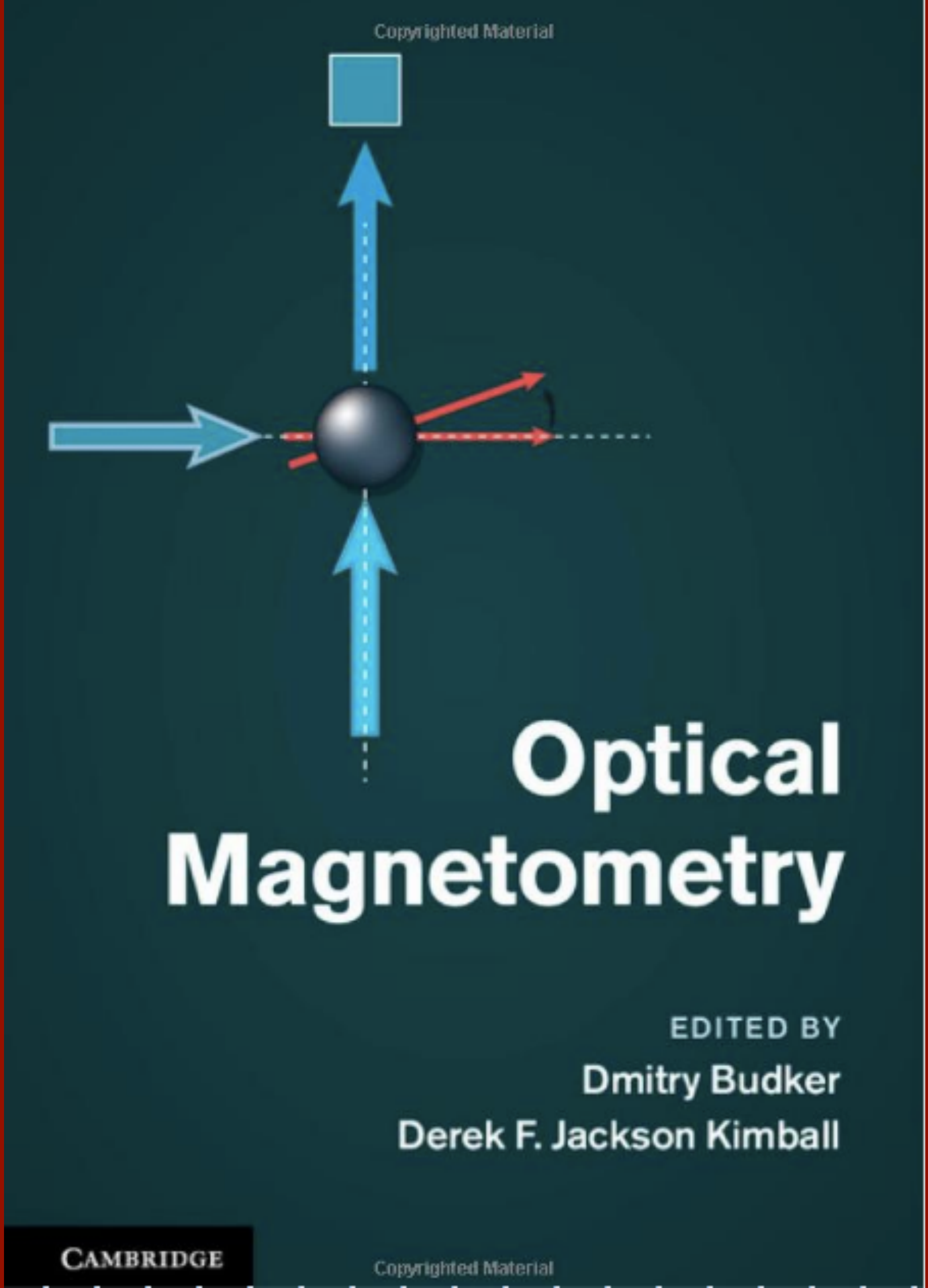
Carl Friedrich Gauss, 1832





- Sensitivity ?

- Pump
- “Precession”
- Probe



Standard quantum sensitivity limit

$$\delta B \simeq \frac{1}{g\mu} \frac{\hbar}{\sqrt{N\tau T}}$$

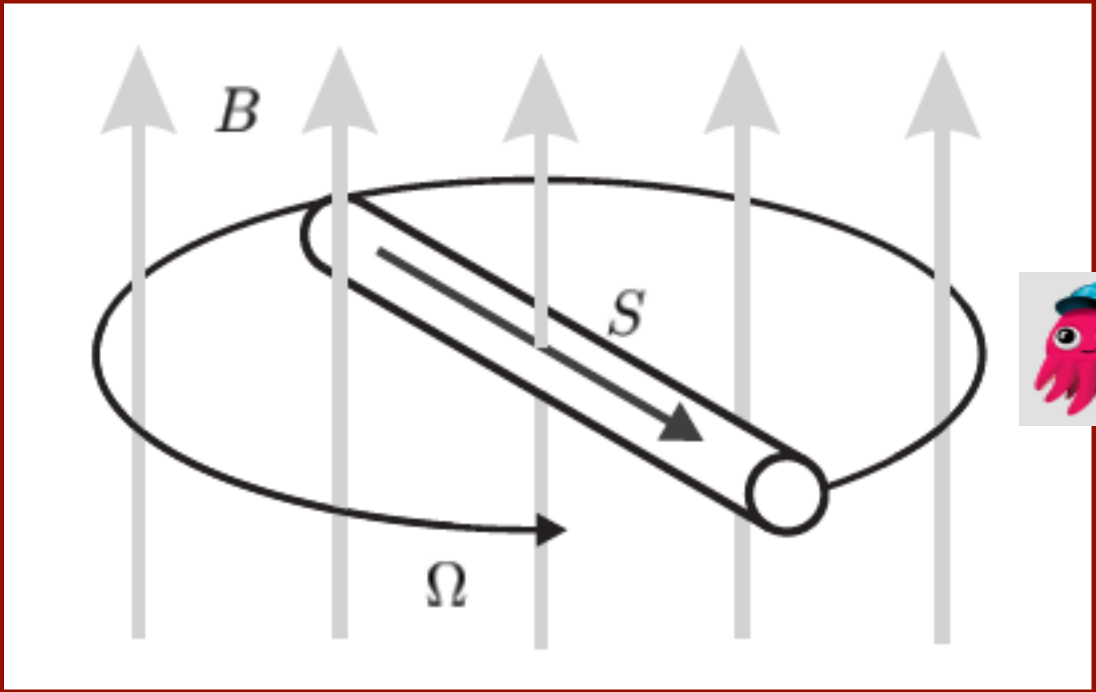
Ground-state gyromagnetic ratio

Number of atoms

Spin-relaxation time

Measurement time

Assume T=0 K, all spins locked to each other and to lattice



- SQUID: 1 μm diam loop; $\delta\Phi \approx 2 \times 10^{-14}\ \mathrm{G \cdot cm^2/\sqrt{Hz}}$

$$\Phi \approx 2 \times 10^{-4}\ \mathrm{G \cdot cm^2}$$

$$\delta B \sim 10^{-17}\ \frac{\mathrm{G}}{\sqrt{\mathrm{Hz}}}$$

Assume T=0 K, all spins locked to each other and to lattice

$$\delta B \approx \frac{1}{g\mu_B} \cdot \frac{1}{\sqrt{NT}}$$

Ground-state gyromagnetic

Numb

Measuren

~10^{-13} G in 1 s
&
1/T scaling

Assume T=0 K

$$\Delta S_b \Delta S_z \geq \frac{\hbar}{2} |\langle S_a \rangle| \approx \frac{\hbar^2 N}{2}$$

$$\Delta\theta \approx \frac{\Delta S_b}{\langle S_a \rangle} \approx \frac{1}{\sqrt{N}}$$

Features of the needle

- Spins oriented along axis indefinitely
- Gyroscopic stability
- Sensitivity apparently beyond Eq. (1); QND ?
- Finite temperature: thermal noise (phonons, magnons)
- Need to be decoupled from environment:
    - Frictionless suspension: how ?
    - Cryogenic vacuum
- Space needles?

"Vintage" Magnetometer

- Novel quantum **mechanical** regime for a macroscopic object?
- "Heisenberg" sensitivity scaling (?)
- Huge *N*, no spin relaxation (?)
- Still thinking about it…

$$\delta B \propto \frac{1}{N}$$

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Many thanks to many people:











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