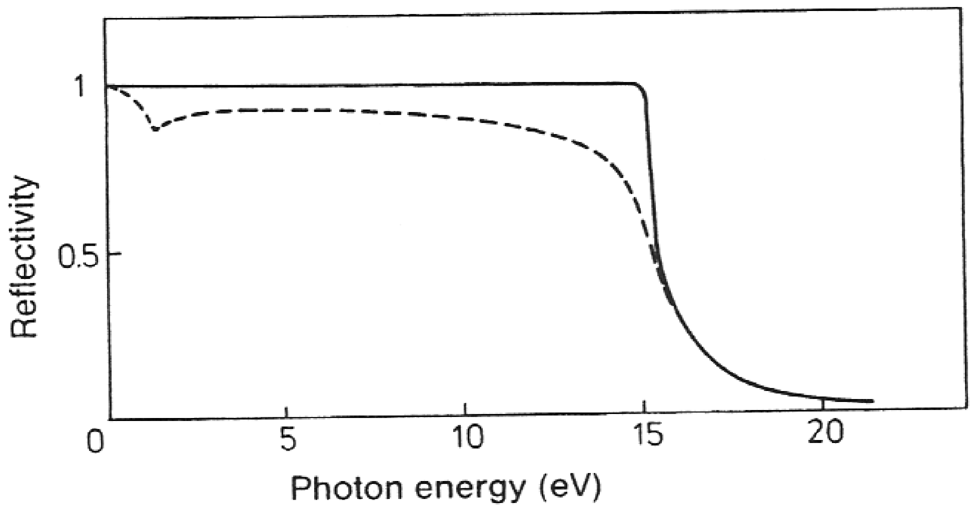
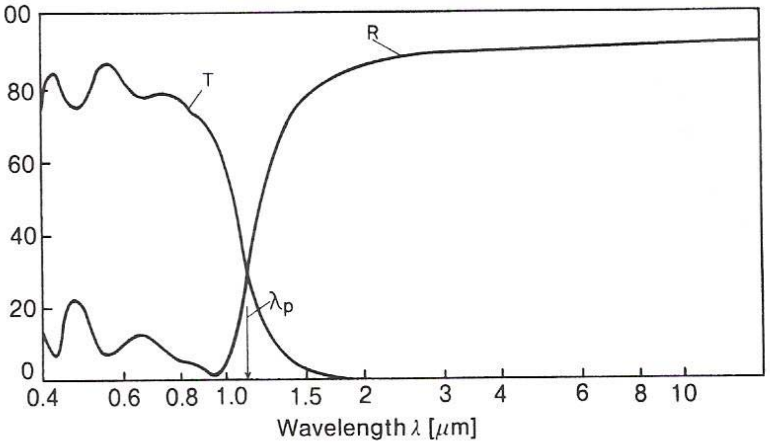
Magnetism

low frequency metal / high frequency insulator

Ibach & Lueth



Aluminum



ITO

Conducting transparent contacts for LEDs and Solar cells

$$\omega_p^2 \approx \frac{ne^2}{\varepsilon_0 m}$$

Windows that reflect infrared

Reflection of radio waves from ionosphere

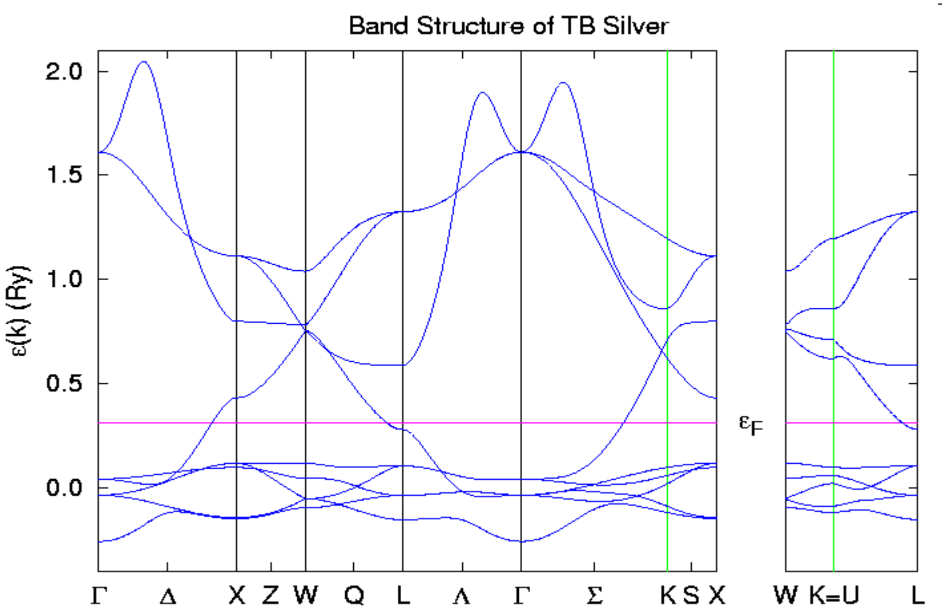
Intraband transitions

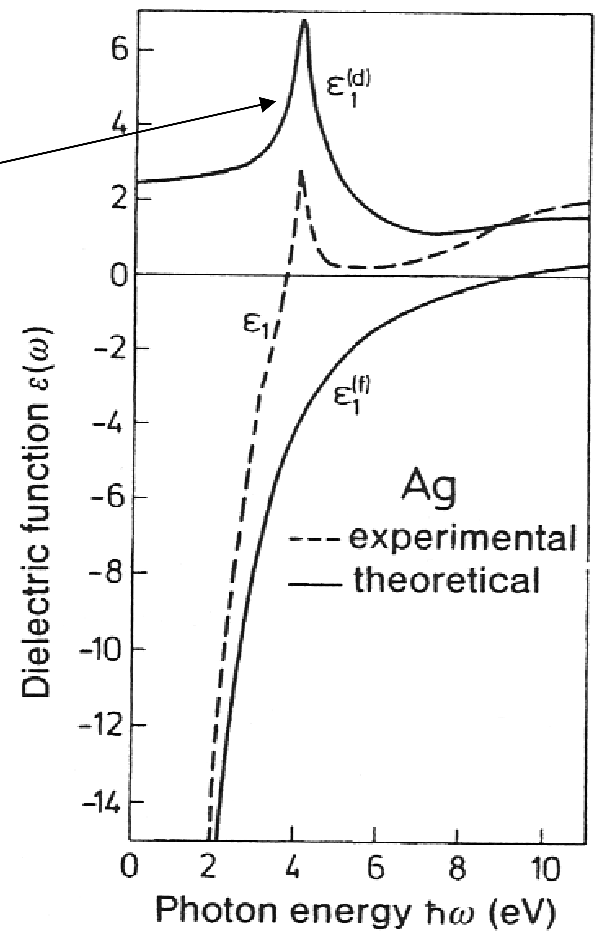
When the bands are parallel, there is a peak in the absorption (ε")

$$\hbar\omega = E_c(\vec{k}) - E_v(\vec{k})$$

Intraband (d-band) absorption

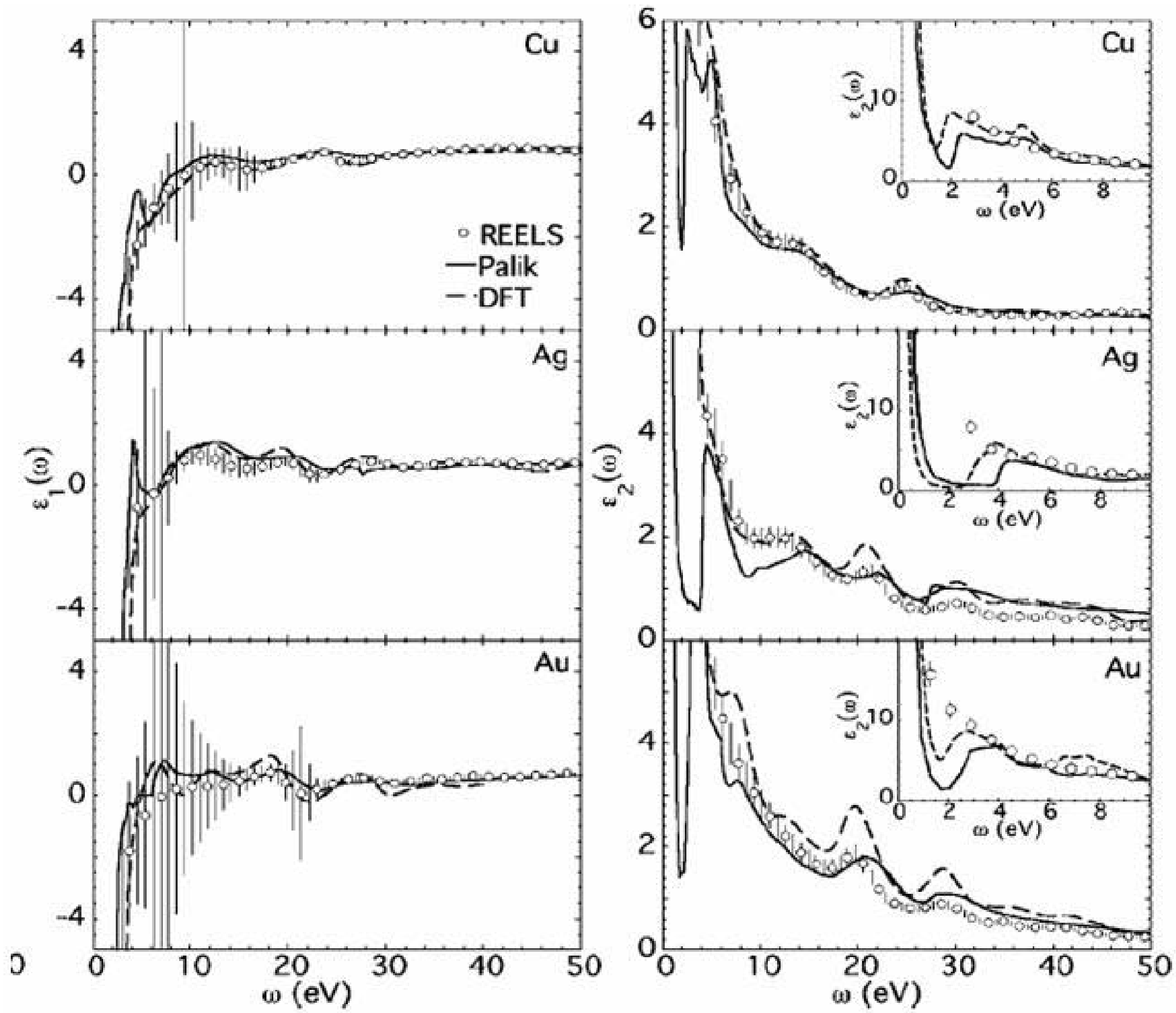
1 Ry = 13.6 ev





Ibach &Lueth

Dielectric function of Cu, Ag, and Au obtained from reflection electron energy loss spectra, optical measurements, and density functional theory



Werner (TU Vienna) APL 89 213106 (2006)

Magnetism

diamagnetism
paramagnetism
ferromagnetism (Fe, Ni, Co)
ferrimagnetism (Magneteisenstein)
antiferromagnetism
helimagnetism
superparamagnetism
spin glass

$$H = -\sum_i \frac{\hbar^2}{2m_e}\nabla_i^2 - \sum_A \frac{\hbar^2}{2m_A}\nabla_A^2 - \sum_{i,A} \frac{Z_A e^2}{4\pi\varepsilon_0 r_{iA}} + \sum_{i<j} \frac{e^2}{4\pi\varepsilon_0 r_{ij}} + \sum_{A<B} \frac{Z_A Z_B e^2}{4\pi\varepsilon_0 r_{AB}}$$

Coulomb interactions cause ferromagnetism not magnetic interactions.

Magnetism

magnetic intensity

$$\vec{B} = \mu_0 \left(\vec{H} + \vec{M} \right)$$

magnetic induction field

magnetization

$$\vec{M} = \chi \vec{H}$$

χ is the magnetic susceptibility

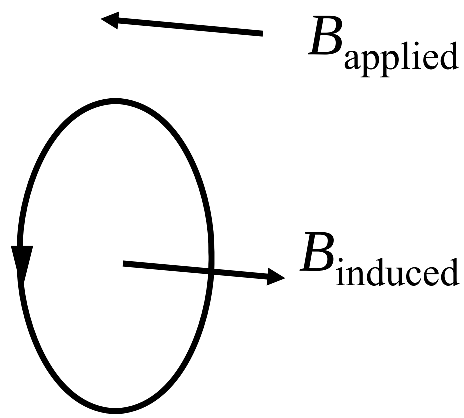
$\chi < 0$ diamagnetic

$\chi > 0$ paramagnetic

χ is typically small (10^{-5}) so $B \approx \mu_0 H$

Diamagnetism

A free electron in a magnetic field will travel in a circle



The magnetic created by the current loop is opposite the applied field.

Diamagnetism

Dissipationless currents are induced in a diamagnet that generate a field that opposes an applied magnetic field.

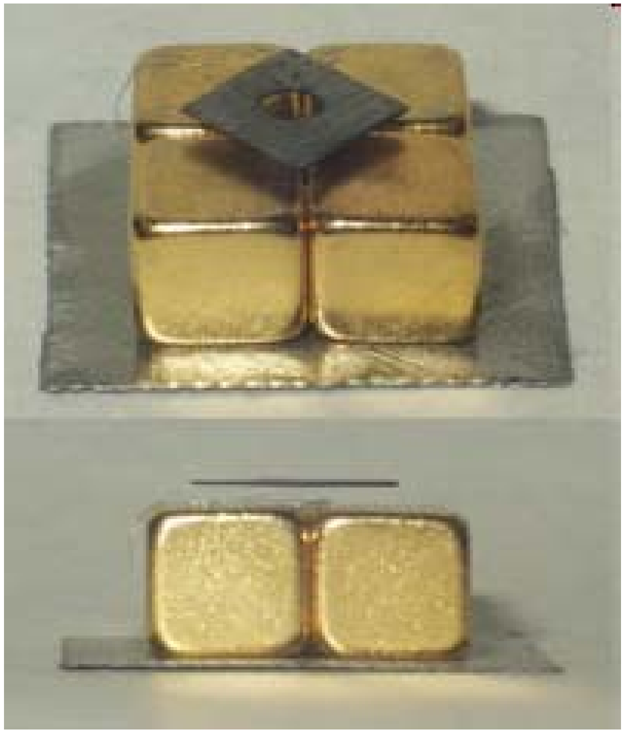
Current flow without dissipation is a quantum effect. There are no lower lying states to scatter into. This creates a current that generates a field that opposes the applied field.

$\chi = -1$ superconductor (perfect diamagnet)

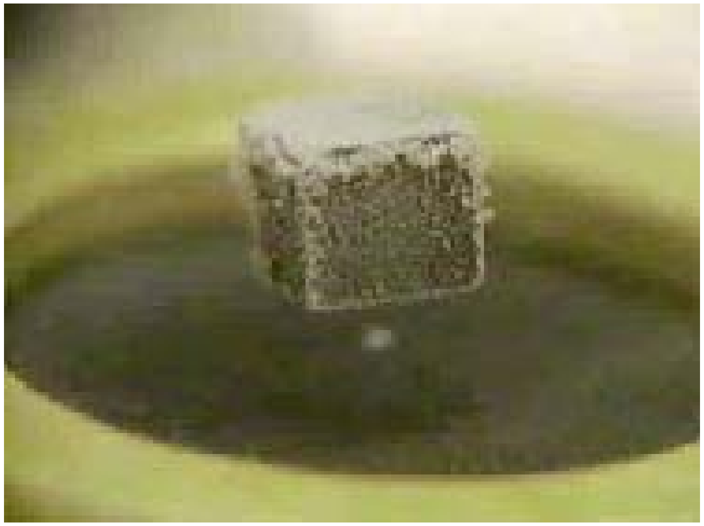
$\chi \sim -10^{-6} - 10^{-5}$ normal materials

Diamagnetism is always present but is often overshadowed by some other magnetic effect.

Levitating diamagnets



Levitating pyrolytic carbon



NOT: Lenz's law

$$V = -\frac{d\Phi}{dt}$$

Levitating frogs

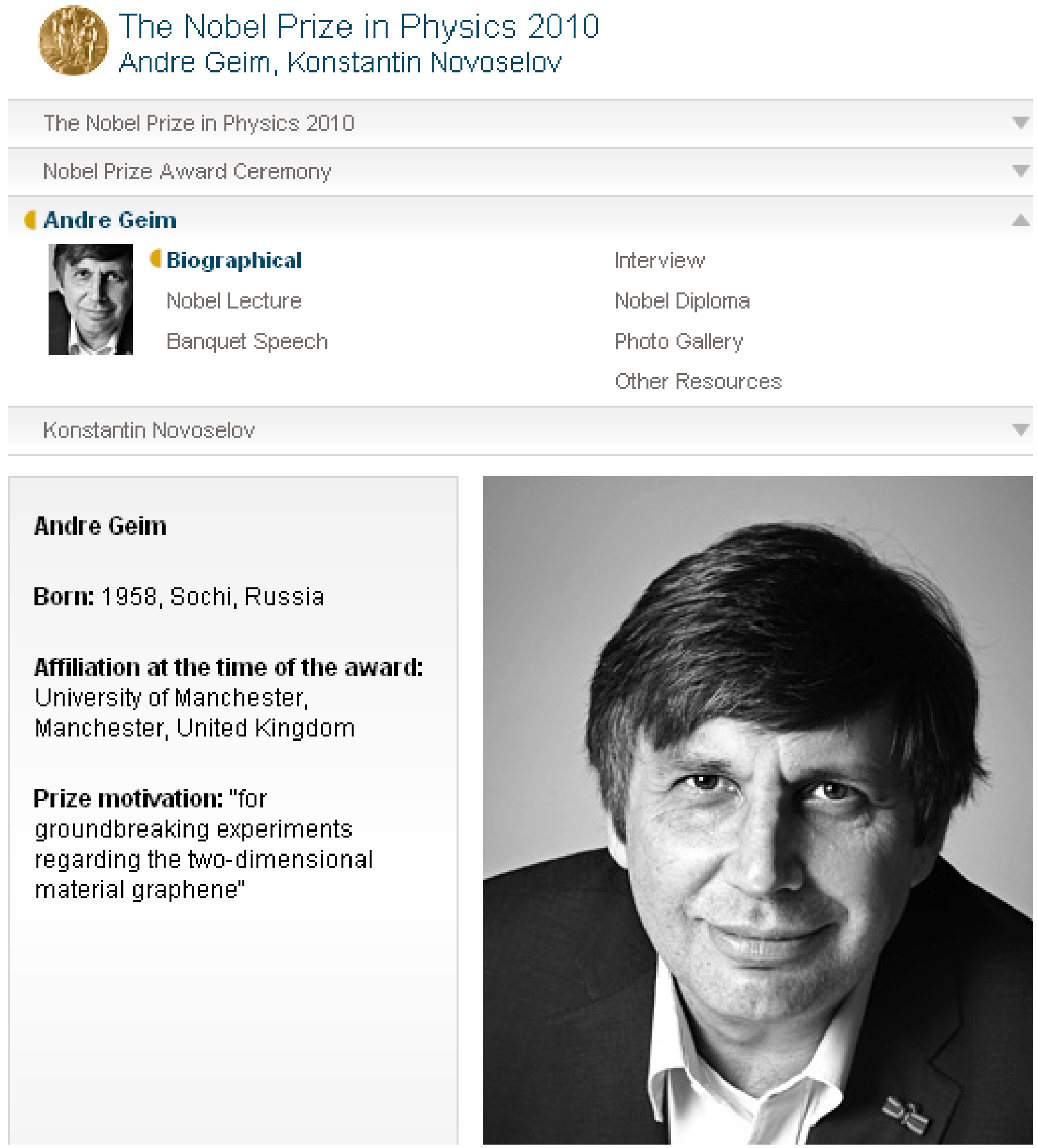
χ for water is -9.05×10^{-6}

16 Tesla magnet at the Nijmegen High Field Magnet Laboratory

http://www.hfml.ru.nl/froglev.html

Andre Geim

2000 Ig Nobel Prize for levitating a frog with a magnet


The Nobel Prize in Physics 2010
Andre Geim, Konstantin Novoselov

The Nobel Prize in Physics 2010
Nobel Prize Award Ceremony
Andre Geim
- **Biographical**
- Nobel Lecture
- Banquet Speech
- Interview
- Nobel Diploma
- Photo Gallery
- Other Resources

Konstantin Novoselov

Andre Geim

Born: 1958, Sochi, Russia

Affiliation at the time of the award: University of Manchester, Manchester, United Kingdom

Prize motivation: "for groundbreaking experiments regarding the two-dimensional material graphene"

Diamagnetism

A dissipationless current is induced by a magnetic field that opposes the applied field.

$$\vec{M} = \chi \vec{H}$$

Diamagnetic susceptibility	
Copper	-9.8×10^{-6}
Diamond	-2.2×10^{-5}
Gold	-3.6×10^{-5}
Lead	-1.7×10^{-5}
Nitrogen	-5.0×10^{-9}
Silicon	-4.2×10^{-6}
water	-9.0×10^{-6}
bismuth	-1.6×10^{-4}

Most stable molecules have a closed shell configuration and are diamagnetic.

Paramagnetism

Materials that have a magnetic moment are paramagnetic.

An applied field aligns the magnetic moments in the material making the field in the material larger than the applied field.

The internal field is zero at zero applied field (random magnetic moments).

$$\vec{M} = \chi \vec{H}$$

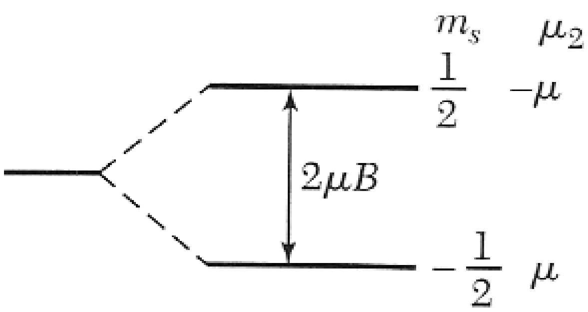
Paramagnetic	**susceptibility**
Aluminum	2.3×10^{-5}
Calcium	1.9×10^{-5}
Magnesium	1.2×10^{-5}
Oxygen	2.1×10^{-6}
Platinum	2.9×10^{-4}
Tungsten	6.8×10^{-5}

Boltzmann factors

To take the average value of quantity A

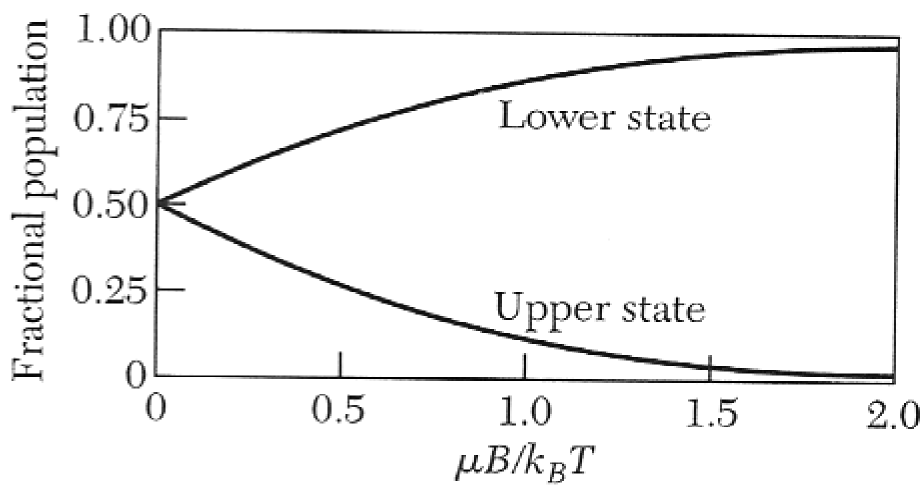
$$\langle A \rangle = \frac{\sum_i A_i e^{-E_i / k_B T}}{\sum_i e^{-E_i / k_B T}}$$

Spin populations



$$\frac{N_1}{N} = \frac{\exp(\mu B / k_B T)}{\exp(\mu B / k_B T) + \exp(-\mu B / k_B T)}$$

$$\frac{N_2}{N} = \frac{\exp(-\mu B / k_B T)}{\exp(\mu B / k_B T) + \exp(-\mu B / k_B T)}$$

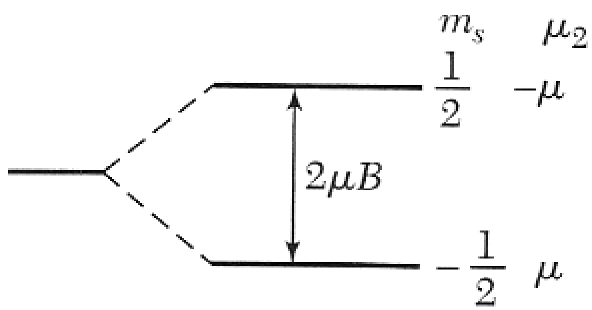


$$M = (N_1 - N_2)\mu$$

$$= N\mu \frac{\exp(\mu B / k_B T) - \exp(-\mu B / k_B T)}{\exp(\mu B / k_B T) + \exp(-\mu B / k_B T)}$$

$$= N\mu \tanh\left(\frac{\mu B}{k_B T}\right)$$

Paramagnetism, spin 1/2



$$M = N\mu \tanh\left(\frac{\mu B}{k_B T}\right) \approx \frac{N\mu^2 B}{k_B T} = \frac{CB}{T}$$

for $\mu B << k_B T$

Curie law