Introduction to Geophysics

R. Drews

Magnetics

Houskeeping

- Ask and take picture from Plenum.
- Geophysics at seminar 20.05.2022
- Should we do linearly varying density from Ex?

Learning Goals

Learning goals today:

- Understand the shape of the magnetic anomalies
- Understand the measurement principle and sensors
- Understand different types of magnetism and its temperature dependency

Remember: Differentiation between $\vec{H}$ and $\vec{B}$

The total (physically relevant) magnetic induction $\vec{B}$ is the superposition of external ($\vec{H}$) and local ($\chi \vec{M}$):

$$\begin{aligned}\vec{B} &= \mu_0 \left(\vec{H} + \vec{M}\right) \\ &= \mu_0 (1 + \chi) \vec{H} \\ &= \mu_0 \mu \vec{H}\end{aligned}$$

μ magnetic permeability

χ magnetic susceptibility (dimensionless)

$[B]$: Tesla

Remember: Differentiation between $\vec{H}$ and $\vec{B}$

In geomagnetics, the magnetic susceptibility is the parameter that we are after.

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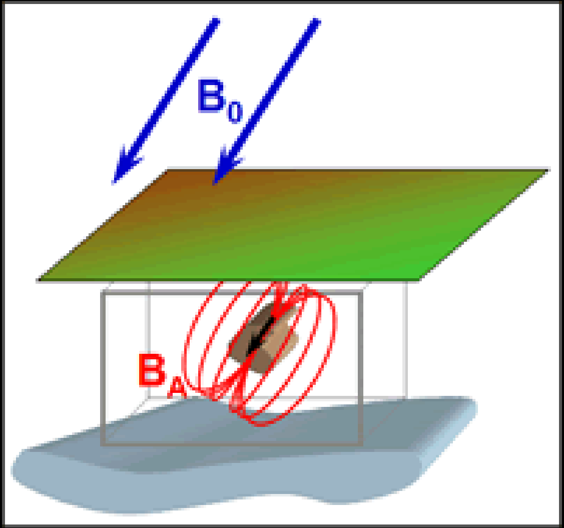
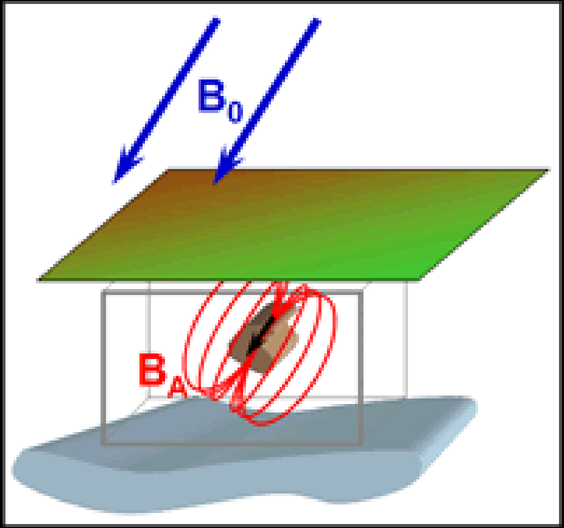
Principals of magnetic surveys



[2017, GeoSci Developers.]

Principals of magnetic surveys



[2017, GeoSci Developers.]

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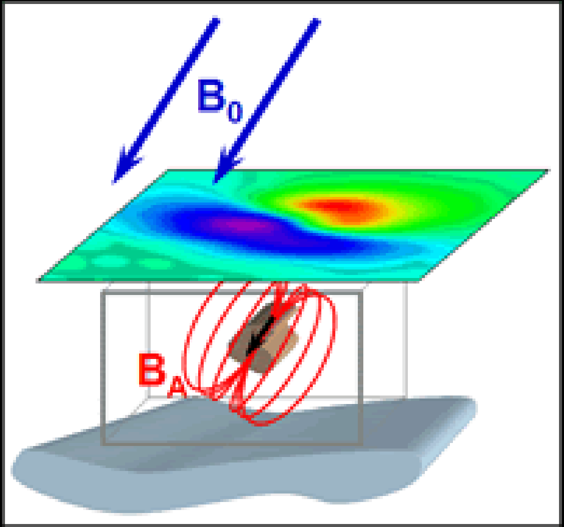

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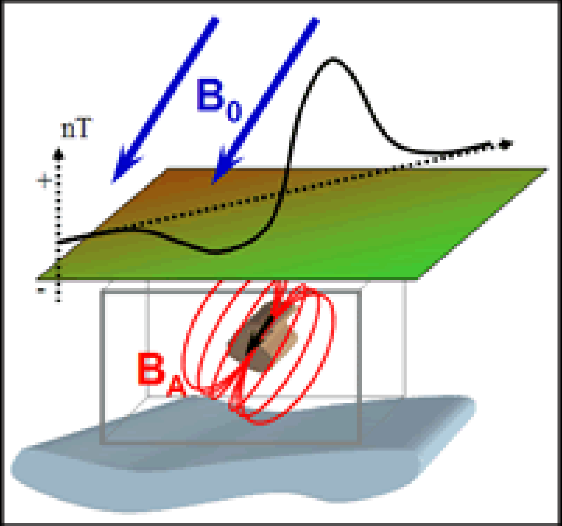
Principals of magnetic surveys



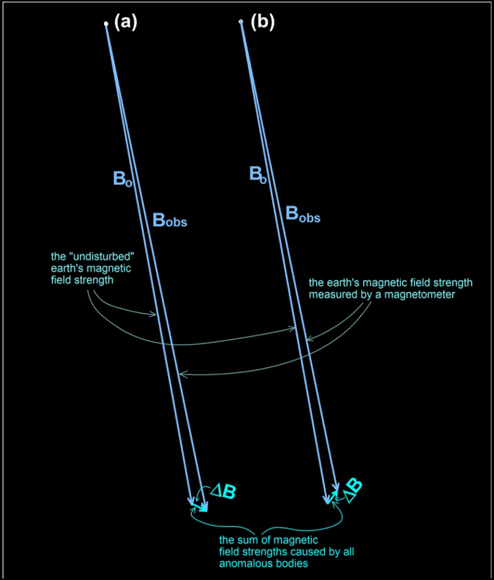
[2017, GeoSci Developers.]

Strategy for expectations of induced magentic dipoles

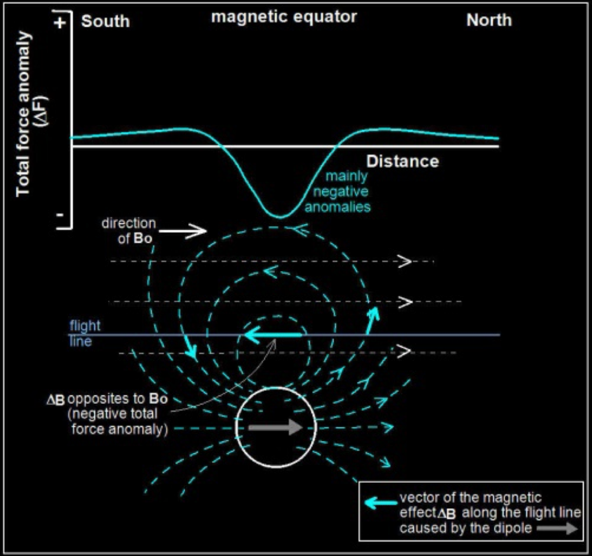
Induced magnetic dipole:=Direction of $\vec{m} \parallel \vec{B}_0$

- Draw S-End, N-End and inclination of planned profile
- Draw $\vec{m}$ and corresponding dipole field at depth
- Analyse superposition of B_0 and dipolfield.
- (Assume that the anomaly is essentially parallel to B_0)

Induced magnetization examples

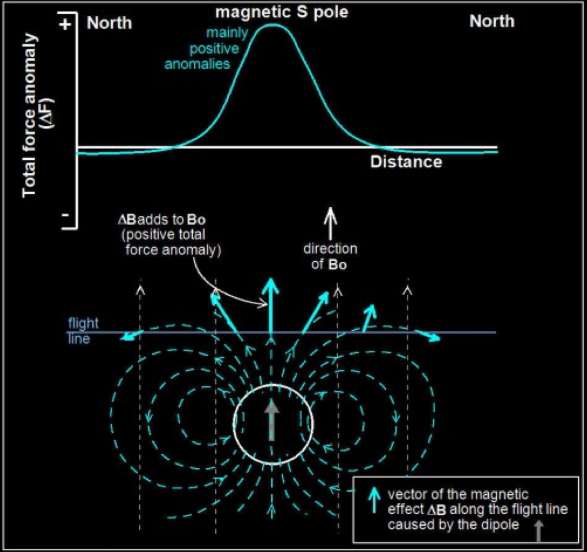


Induced magnetization examples



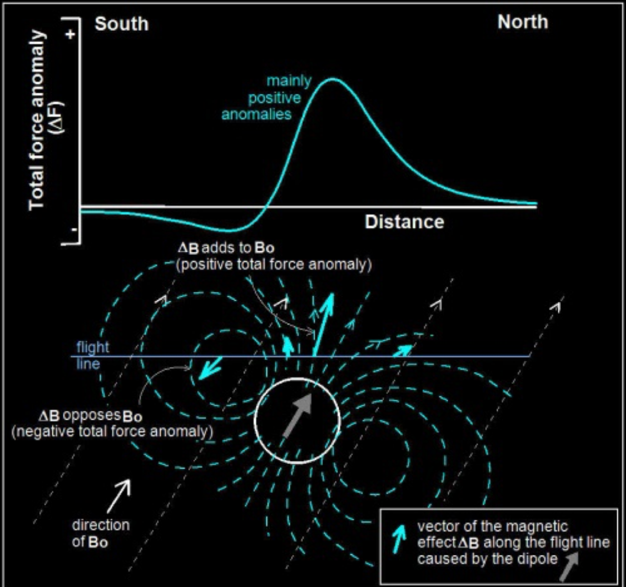
(d) Magnetic equator

Induced magnetization examples

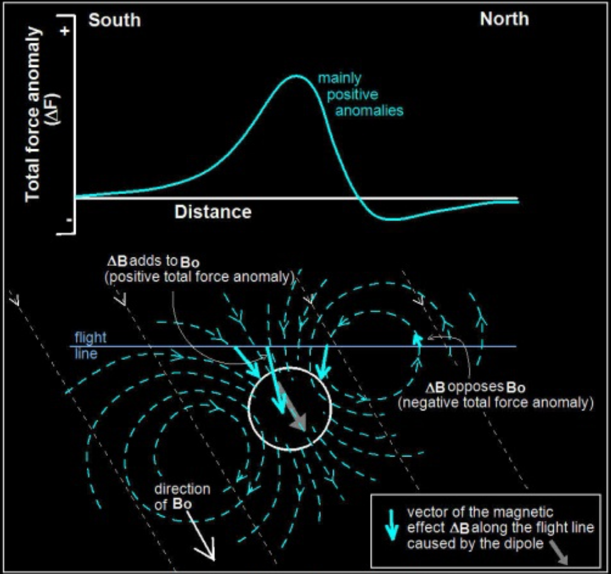


(c) Magnetic south pole

Induced magnetization examples



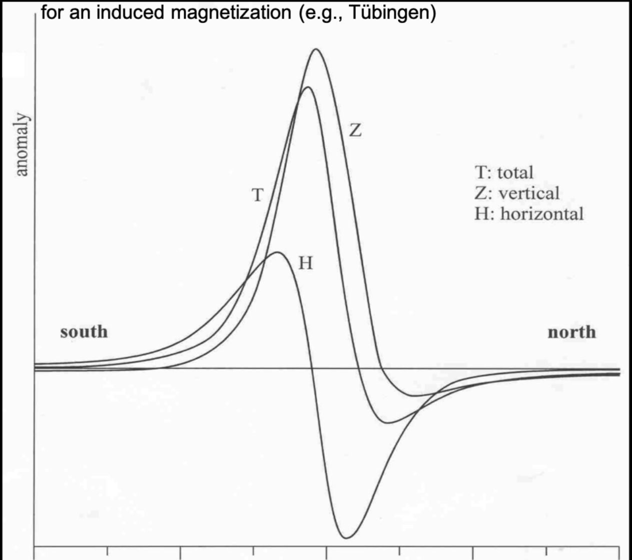
Induced magnetization examples



Interpreting magnetic anomalies:

- Unlike in gravity, magnetic can be measured in 3D
- Interpretation of ΔT, ΔH, ΔZ, ...
- Commonly also the vertical gradient of ΔZ (cf. exercises)

Demonstration of foreward model



Demonstration of foreward model

Locally

To run them locally, you will need to have python installed, preferably through anaconda.

You can then clone this reposiroty. From a command line, run

```
git clone https://github.com/geoscixyz/gpgLabs.git
```

Then `cd` into `gpgLabs`

```
cd gpgLabs
```

To setup your software environment, we recommend you use the provided conda environment

```
conda env create -f environment.yml
conda activate geosci-labs
```

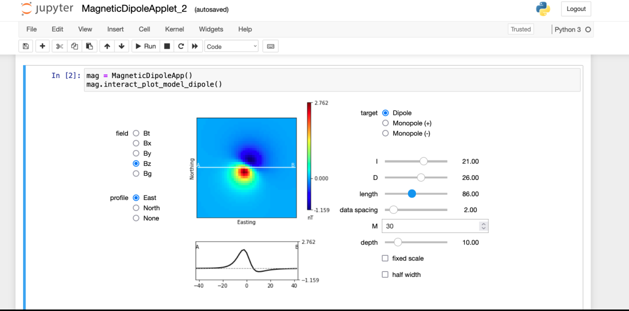
alternatively, you can install dependencies through pypi

```
pip install -r requirements.txt
```

You can then launch Jupyter

```
jupyter notebook
```

Demonstration of foreward model



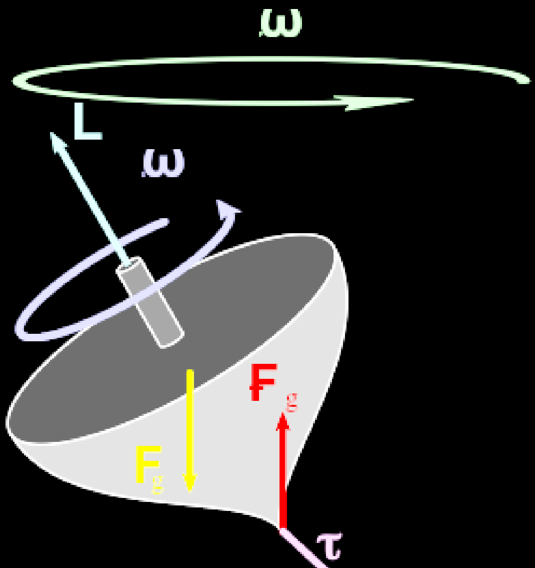
Half-width rules

Similar to the anomaly in gravity surveys, we can also apply a half-width rule in magnetics to estimate the depth of the object.

$$d \sim HW$$

Check this with the forward model.

Types of Magnetometers: Proton Precession



Types of Magnetometers: Proton Precession

- Hydrogen atoms have angular momentum (spin) and magnetic moment (moved charge). Both are vectors which are parallel to each other and linked by the gyromagnetic ratio (γ_p).

Types of Magnetometers: Proton Precession

- Protons have angular momentum and magnetic moment.
- External magnetic field induces torque, so that mini magnetic moment tends to aligns parallel to the external field.

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- Because of internal spin, this torque induces precession (analogy to spinning top).

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- Idea: Measure ω and infer $|B|$

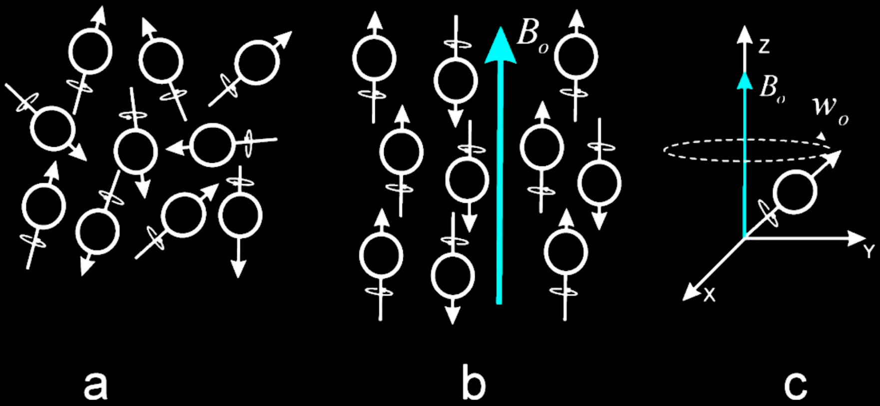
$$\omega = \gamma_p |B|$$

Types of Magnetometers: Proton Precession

Practical implementation:

- Use liquid with many hydrogen atoms (e.g. water or kerosene).
- Align their magnetic moments with strong, external magnetic field.

Types of Magnetometers: Fluxgate



[F. Ordonez 2014]

At room temperatures spins are not aligned as Earth's magnetic field is too weak to do so.

Types of Magnetometers: Proton Precession

Practical implementation:

- Use liquid with many hydrogen atoms (e.g. water or kerosene).
- Align their magnetic moments with strong, external magnetic field.
- Measure the precession frequency (how?)

Induction: Time variable B field induce currents

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$$\varepsilon = \frac{d\phi_B}{dt}$$

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$$\varepsilon = \frac{d\phi_B}{dt}$$

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- ϕ_B intercepted magnetic flux
- Faraday's law of induction

$$\nabla \times \vec{E} = -\frac{\partial}{\partial t}\vec{B}$$

Types of Magnetometers: Proton Precession

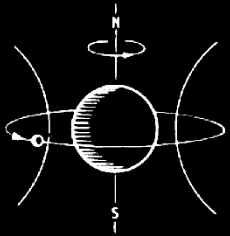


Fig. 1. Magnetic field around hydrogen proton produced by orbiting electron

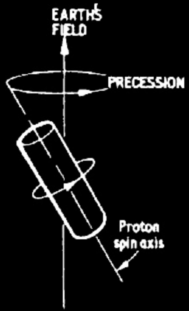


Fig. 2 Precession of proton relative to earth's field when acted upon by external magnetic influence

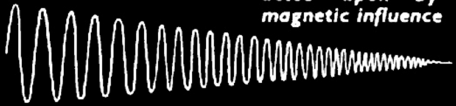


Fig. 3. Diminishing alternating voltage set up by precession frequencies from the detector coils

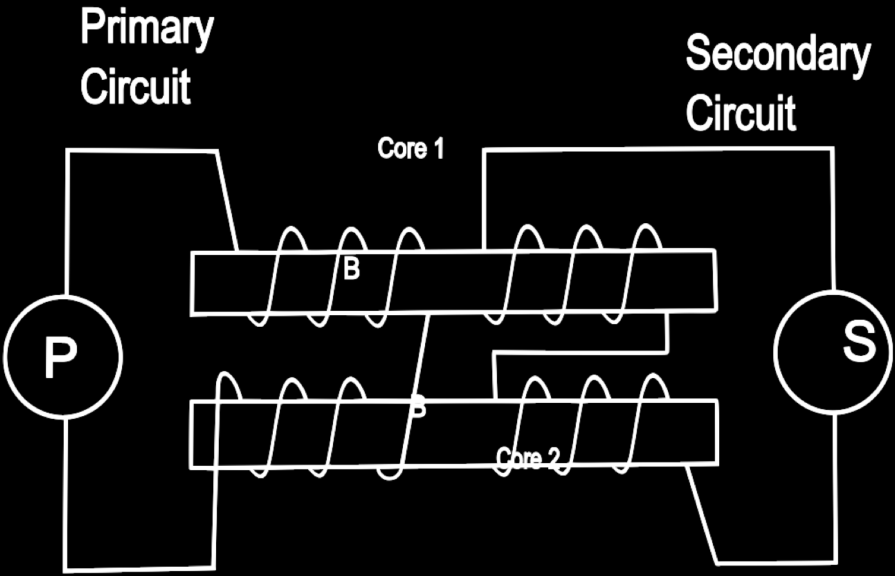
[Huggard 1970]

Types of Magnetometers: Proton Precession

Types of Magnetometers: Proton Precession

- Measures total field (alignment of sensor less important).
- Based on magnetic moment of hydrogen atom and larmor precession.
- Alignment in artificial external B field.
- Measure relaxation and larmor precession via induction in surrounding coils.
- Sensitivity $\sim 0.1nT$.
- Principals are similar to MRI

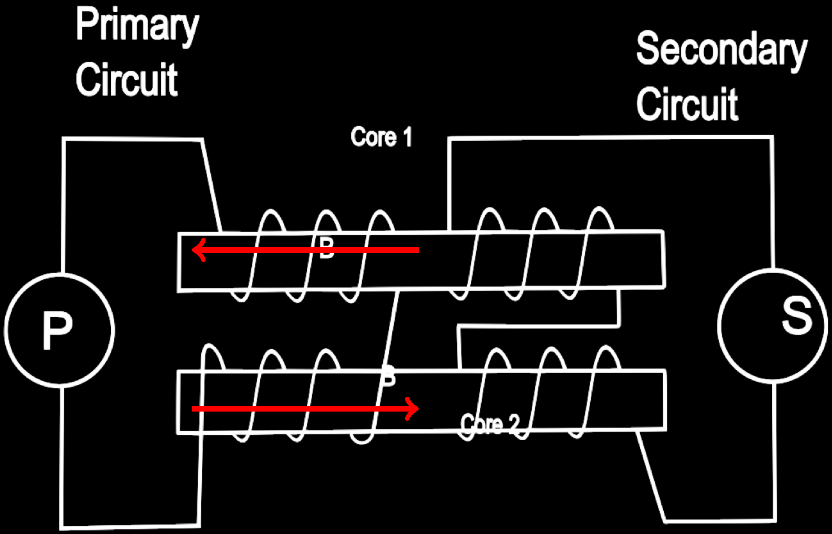
Types of Magnetometers: Fluxgate



Fluxgate magnetometer

- Induce low-frequencey (kHz) current in primary circuit.
- The magnetic fields in secondary coil will be balanced in absence of external field.
- External field causes imbalance between primary and secondary coils that can be used to measure B_x, B_y, B_z depending on coil orientation.

Types of Magnetometers: Fluxgate



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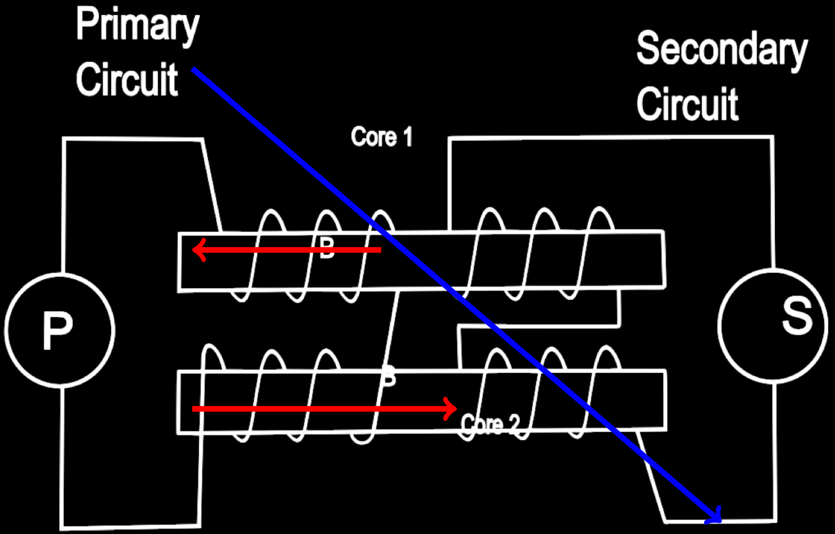
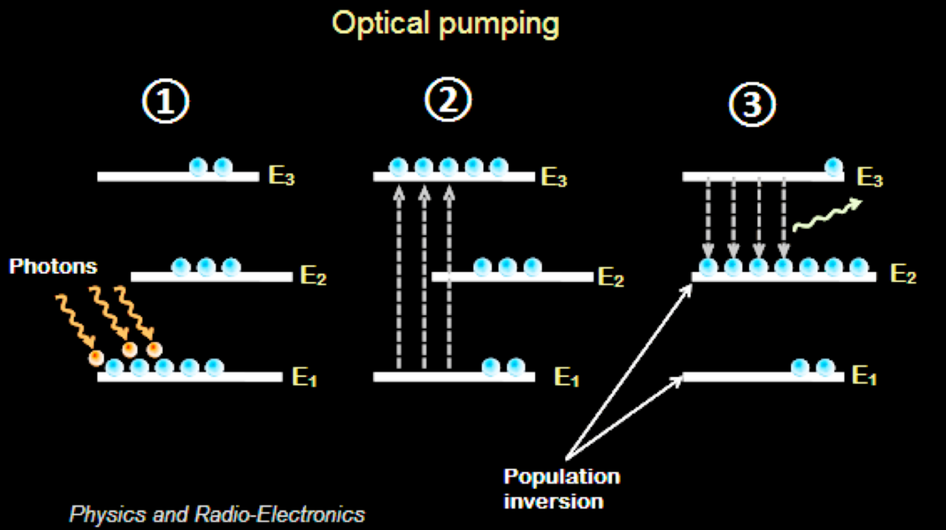
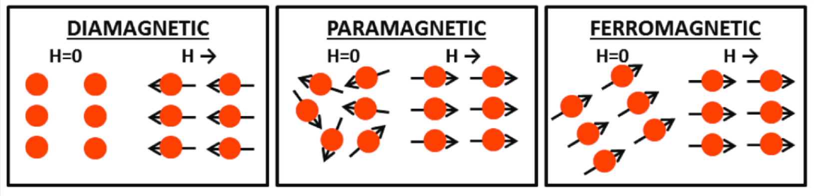


Types of Magnetometers: Optically pumped



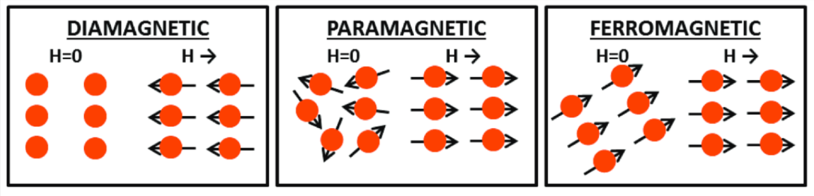
Gradiometry: Measure the vertical gradient

- Install two sensors at different heights (e.g., 0.5 m apart).
- Consider only the vertical gradient.
- Insensitive to the total field and temporal variability thereof.
- Sensitive to near-surface structures (why?).
- Sensitive to horizontal boundaries.
- Relevant for applied exercises.



[Lacovacci2016]

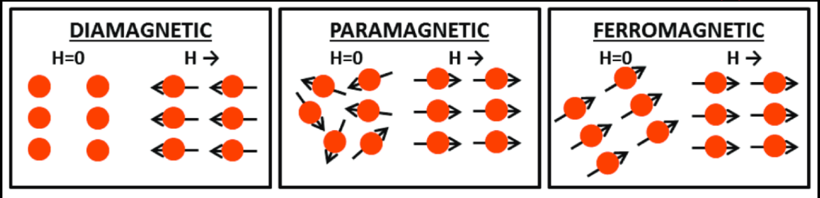
How do materials react to application of an external magnetic field?



[Lacovacci2016]

Diamagnetism

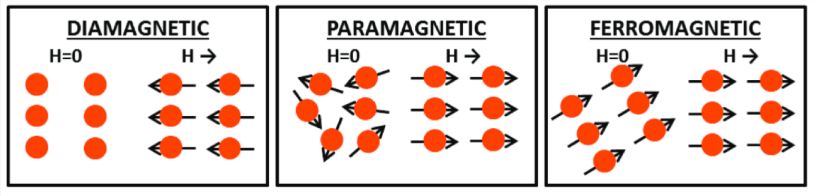
- Weak mini-dipoles induced, opposing external field ($\chi < 0$).
- Diappears if external field is removed.
- Occurs essentially in all materials, but is not noted everywhere, due to other effects.
- Examples: Quarzite, Calcite, ...



[Lacovacci2016]

Paramagnetism

- Material exhibits pre-existing dipoles which orient themselves in external field (unpaired electrons).
- Reinforce external field ($\chi > 0$).
- Effect dissipates due to thermal fluctuations once external field is removed.
- Examples: gold, copper,...



[Lacovacci2016]

Ferromagnetism

- Material exhibits pre-existing dipoles which are oriented in domains with strong coupling.
- Domains align and strongly reinforce external field ($\chi >> 0$).
- Effect can be maintained if external field is removed.
- Examples: iron, nickel, ...

Temperature dependency

$$\chi = \frac{M}{H} = \frac{C}{T}$$

- C is the Curie Constant.
- Overall, magnetic susceptibility decreases with increasing temperature.

Temperature dependency

$$\chi \sim \frac{1}{T - T_c}$$

- At the Curie Temperature materials loose their permanent magnetic properties.

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