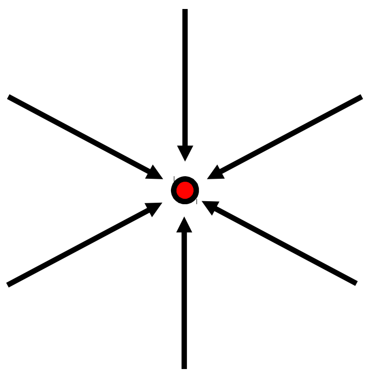
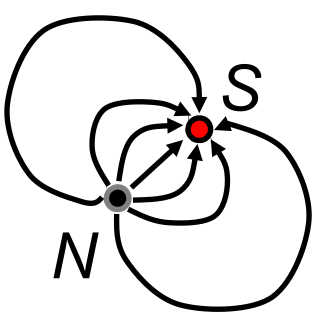
Magnetics

- Like gravity, a potential field method governed by **Poisson's** ***equation:*** $\nabla^2\psi = \boldsymbol{F}$ (sources)
- Unlike gravity, ***source term*** is a vector rather than a scalar



Gravity: $\vec{g} = \hat{r}\dfrac{Gm}{r^2}$

Monopole source ⇒ field is always directed radially toward a “sink” location



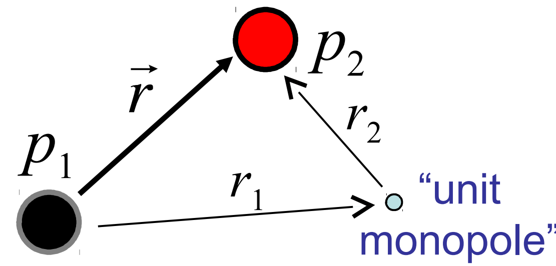
Magnetics:

Dipole source ⇒ field direction & strength depend on one “source”, one “sink”

Coulomb's Law: ***Classical (1700s) definition not used in Physics anymore!***

Also, There are NO MAGNETIC MONO-POLES!!!

Force of attraction between two magnetic poles:



$$\vec{F} = \hat{r}\,\frac{p_1 p_2}{\mu r^2}$$

where $\vec{r}$ is the distance & direction between two poles, p_1 & p_2 are pole strengths

μ is magnetic permeability, a property of the medium (usually ~1)

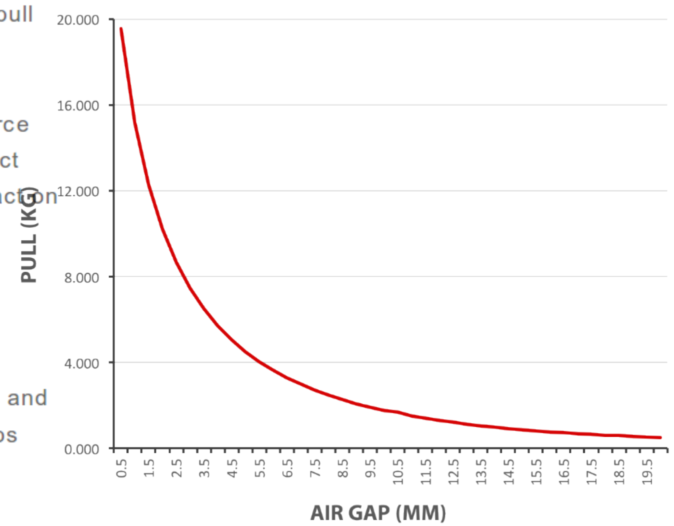
PULL STRENGTH

As neodymium magnets have become more widely used, most manufacturers and suppliers provide a pull strength for each of their magnets to show how much weight a magnet can hold.

The pull strength is the highest possible holding power of a magnet, measured in kilograms. It is the force required to prise a magnet away from a flat steel surface when the magnet and metal have full and direct surface-to-surface contact. The grade of the metal, surface condition and angle of pull all have an impact on the pull strength.

PULL GAP CURVE

A pull-gap curve plots the pulling power of a magnet in direct contact with a thick and flat piece of steel and then through a steadily increasing range of air gaps. All magnets can be tested over a variety of air gaps using a pull-gap testing machine.



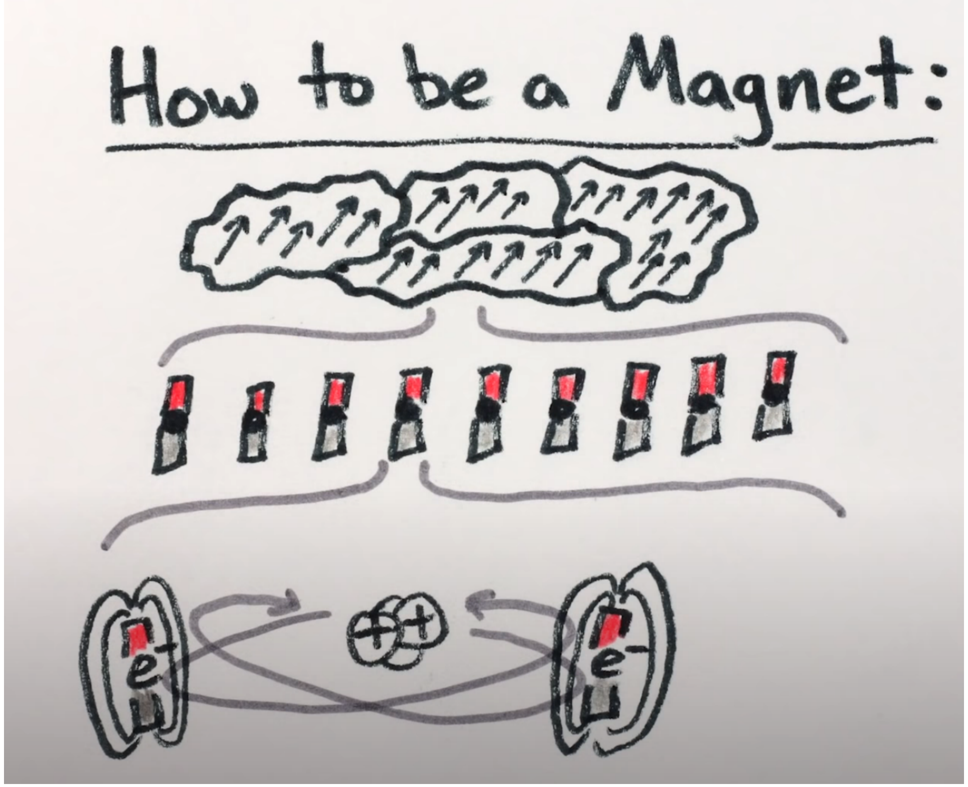
https://www.first4magnets.com/tech-centre-i61/information-and-articles-i70/how-is-the-strength-of-a-magnet-measured-i81

Causes of Magnetism: ***Magnetic (even static) fields do not exist without time varying electric fields and/or motion of charges (i.e., currents!) for magnetized materials, magnetism is primarily associated with the latter:***

Magnetism is a macroscopic manifestation of ***quantum mechanics*** – the result of a **simultaneously** occurring physical processes at at least ***FOUR*** spatial scales (!):

- ***Electronic:*** Spin magnetic moment – fundamental property of electrons
- ***Atomic:*** Electron spin alignment leads to largest moments in "remote" half filled shells (*e.g., 3d-shell of Fe, Ni, Co*)
- ***Crystal Domain:*** Crystallographic clustering of atoms with similar net magnetic moment (***minimizes energy!***).
- **Domain Orientation:** Domains in the direction of an external field grow at the expense of others (in ferromagnetic materials).

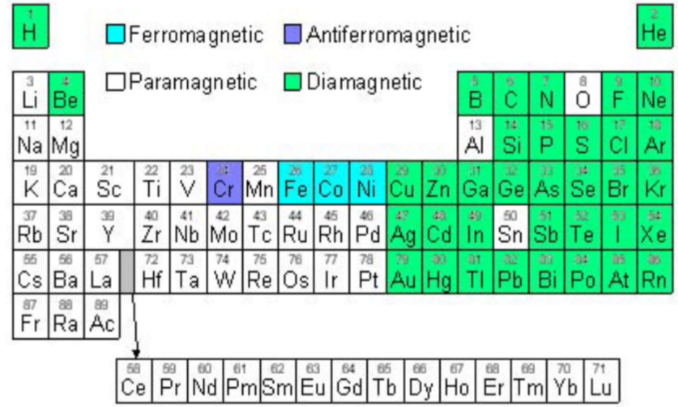
The rarity of all four occurring together is why there are so few ferromagnetic elements!



For an entertaining video explanation, see "Magnets: How do they work?" (Veritasium):

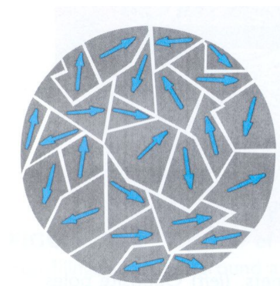
https://www.youtube.com/watch?v=hFAOXdXZ5TM

Material	Initial Relative Permeability
Magnetite, powdered	1.5
Steel	50
Cobalt	70
Nickel	110
Iron (99.8%) annealed	150
78 Permalloy	8,000
Mu-metal	20,000
Ferrites (various)	100 – 20,000



Most Earth materials are ***diamagnetic***:

– very small negative (e.g., quartz) → $k \sim -10^{-5}$

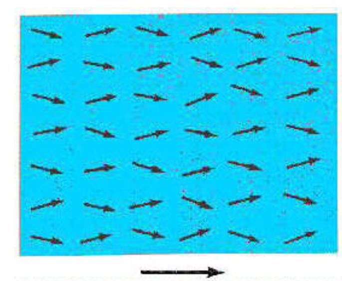


Fe-Mg silicates (pyroxene, amphibole, olivine) are ***paramagnetic*** (moments can align within small ***magnetic domains***) → $k \sim 0.02$ to 0.2

Hematite (“rust” in aeolian soils) is ***antiferromagnetic***: domains align, ~equal amounts parallel & antiparallel positive and non-negligible, but still small → $k \sim 0.05$

Magnetite, titanomagnetite, ilmenite, pyrrhotite are ***ferrimagnetic***: domains align parallel & antiparallel but one dominates: → $k \sim 0.5$ to 10!

Crystalline iron, nickel, cobalt are ***ferromagnetic***: domains align parallel (not common in crust, but common in the core!) See above: → $k \sim 50+$!!!



Magnetization of Earth materials

Intensity of Magnetization ($\vec{I}$ or $\vec{M}$): $\vec{I} = \frac{\vec{m}}{V}$

where V is volume, is a material property of the source.

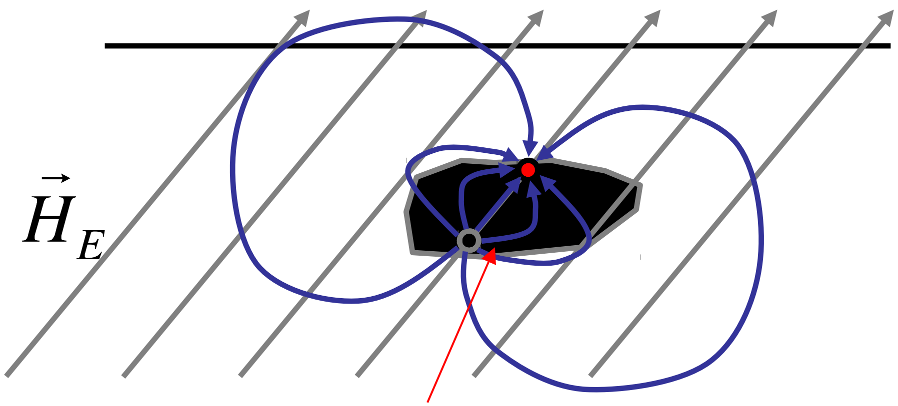
If a material that can be magnetized ($\mu > 1$) is placed within an external magnetic field $\vec{H}_E$, then intensity of the ***induced magnetization*** is:

$$\vec{I} = k\vec{H}_E$$

where k $(= \mu - 1)$ is the ***magnetic susceptibility*** of the material.

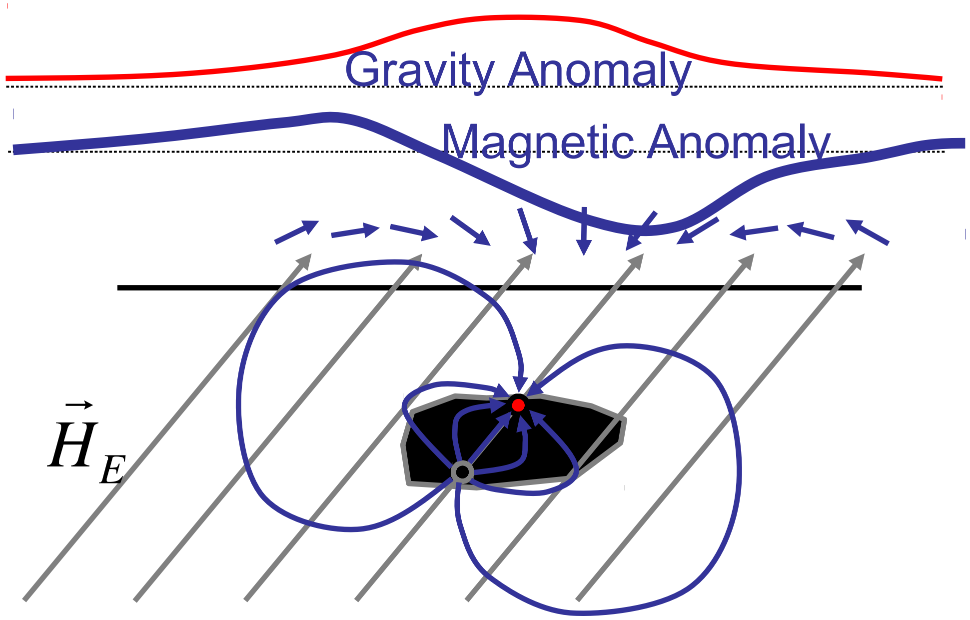
Induced magnetization is always in the direction of the ambient field.

$\Rightarrow$ Must know strength & direction of the Earth's ambient field $\vec{H}_E$ to determine location and susceptibility, k, of an anomalous source body!



(e.g., magnetite-rich body)

Magnetization of Earth materials

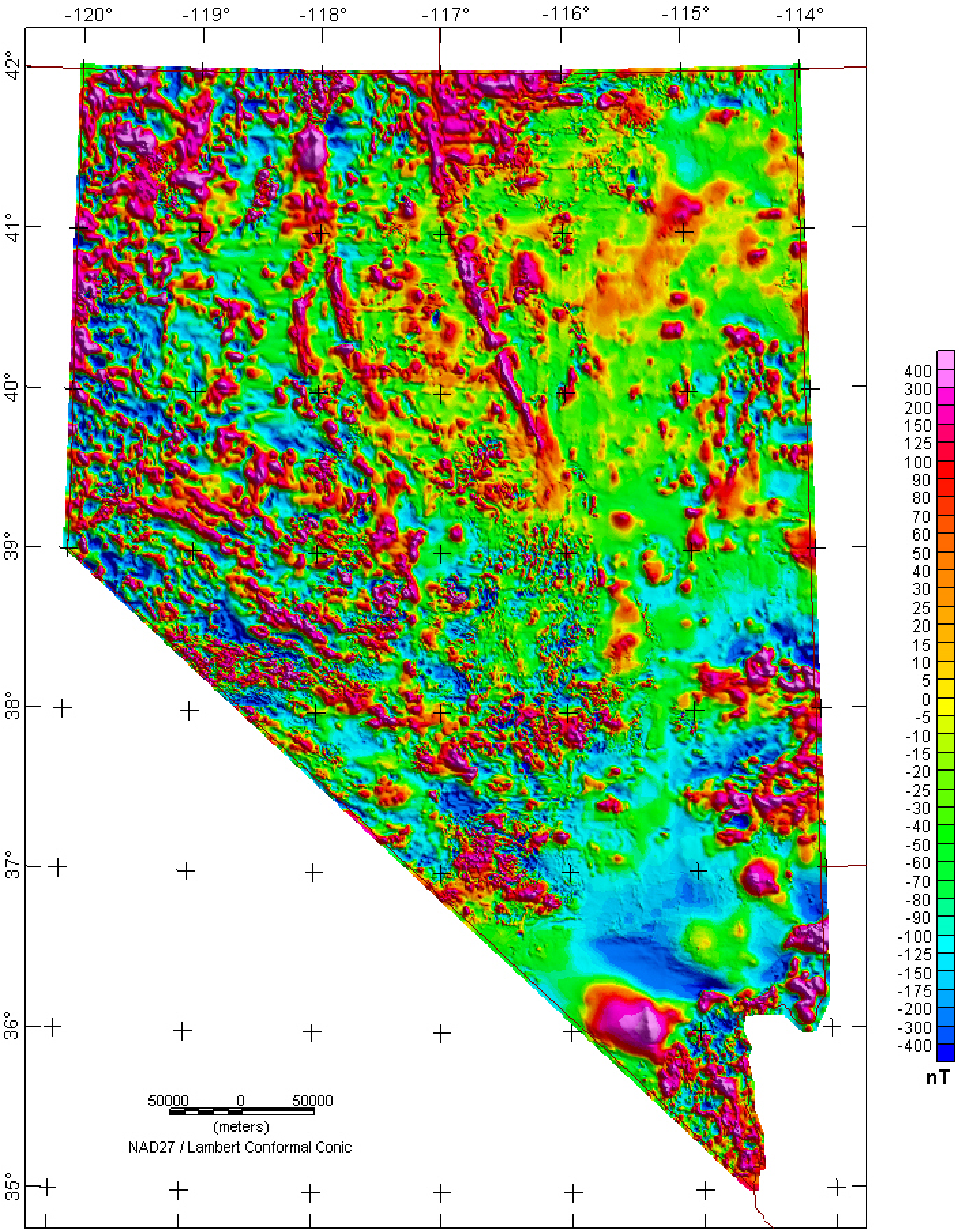


Magnetic field strength falls off proportional to $1/r^3$. Total intensity of magnetization

$$\vec{I}_T = k\vec{H}_E + \vec{I}_R$$

where ***remanent magnetization*** I_R is in the direction of H_E at the time of magnetization…

Magnetic Prospecting: Measure magnitude H of the total field, subtract out magnitude H_E of the Earth's (core dynamo-derived) ***main field*** to get a ***magnetic anomaly***



Despite the complexities of modeling, magnetic anomalies are heavily used (particularly by the mining industry and for investigations of basement structure)