Physics II: 1702
Gravity, Electricity, & Magnetism

Professor Jasper Halekas
Van Allen 70 [Clicker Channel #18]
MWF 11:30-12:30 Lecture, Th 12:30-1:30 Discussion

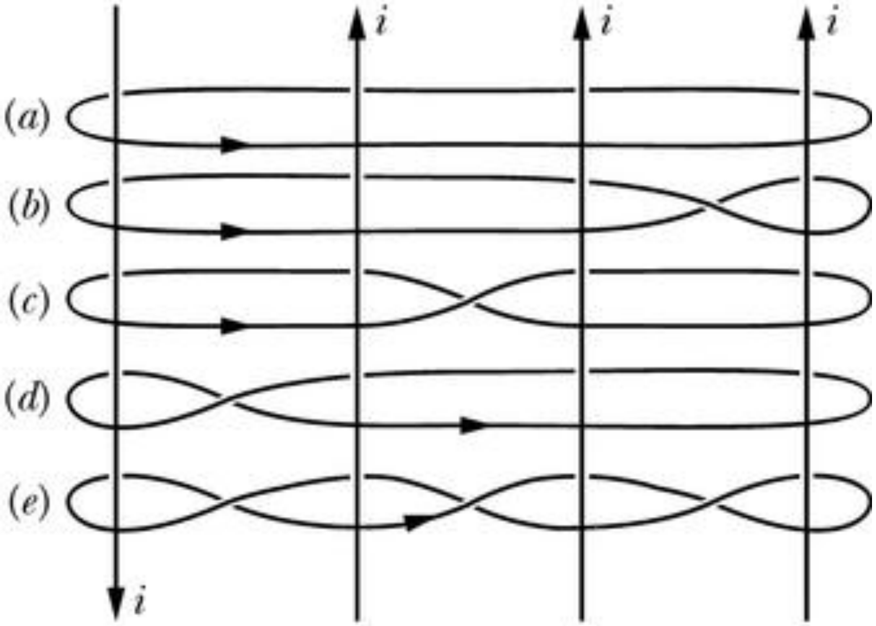
Announcements

- Van Allen and Wert Summer Research Grants
  - These programs provide funding to work on undergraduate research with faculty members
  - Short proposals (with endorsement of faculty member) due to Heather in the main office by May 2

Concept Check

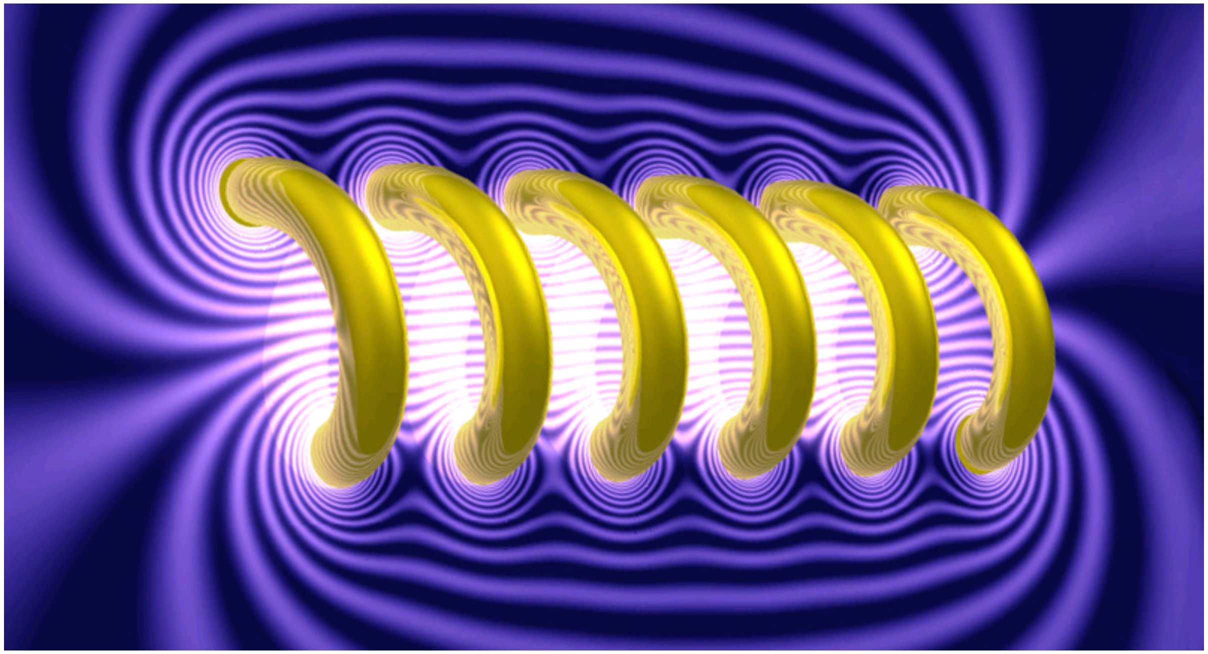
- The figure below shows four identical currents i and five Amperian paths encircling them. Rank the paths according to the line integral of B taken in the directions shown, most positive first and most negative last.

- 1) all tie
- 2) a, b = d, c, e
- 3) d, a = c = e, b
- 4) d, a = e, b, c
- 5) c, b, a = e, d



Solenoids

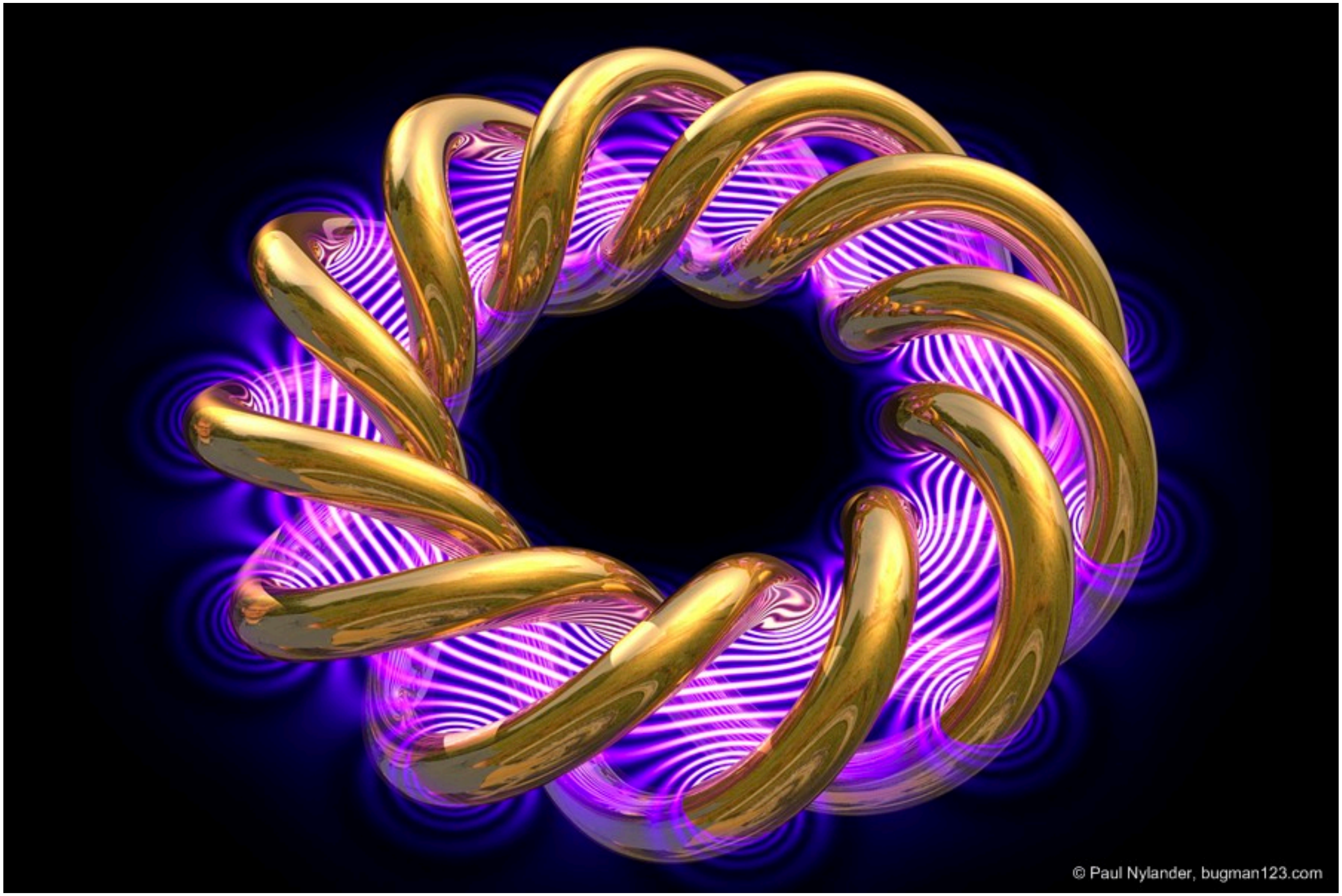
Solenoid



A single wire tightly coiled up into loops.

Since it is a single wire, the current magnitude is the same in all parts of the coil.

Toroids



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Toroid

$$\oint \vec{B} \cdot d\vec{l}$$

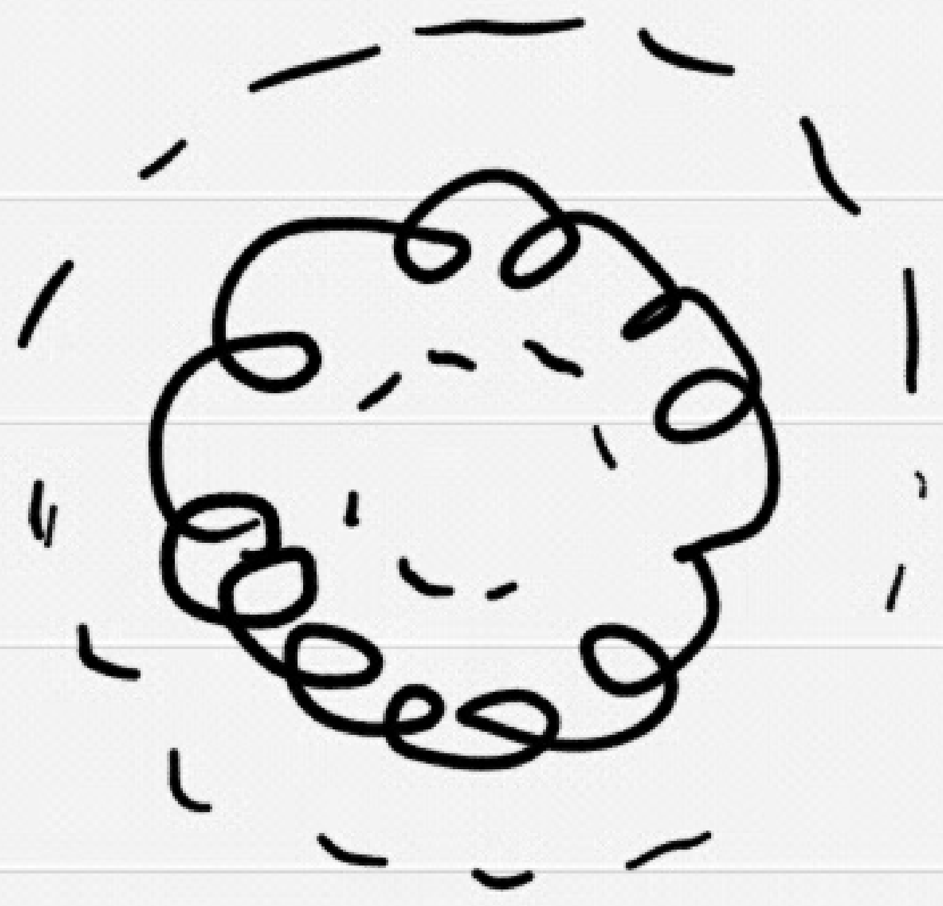
$$= B \cdot 2\pi r$$

$$= \mu_0 I_{enc}$$

$$= \frac{\mu_0 N I}{2\pi r}$$ (Not constant!)

w/ N = # loops

– what about outside?



$I_{enc} = 0$

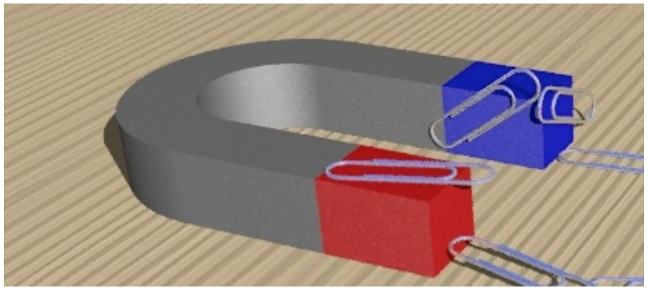
$\Rightarrow B = 0$

in plane of toroid

Currents Vs. Magnets

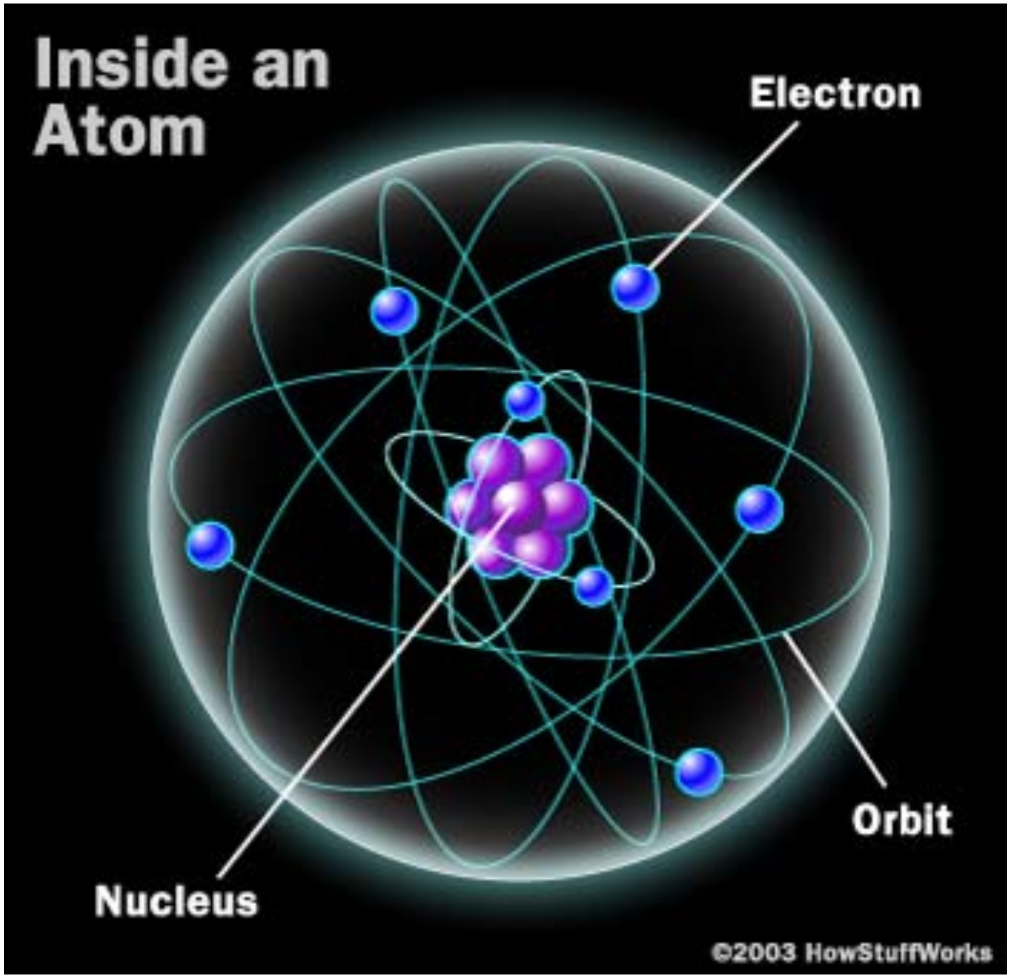
$$\boxed{d\vec{B} = \frac{\mu_0 i}{4\pi}\frac{d\vec{L}\times\hat{r}}{r^2}}$$

Moving charges (currents) create B-fields.



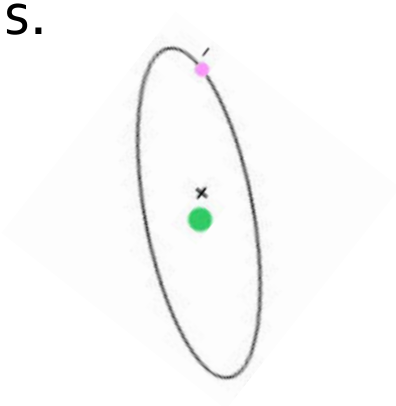
Where are the moving charges?

Orbital Magnetic Moment



Spin Magnetic Moment

Atoms have Magnetic Dipole Moments from the orbit of the electrons.



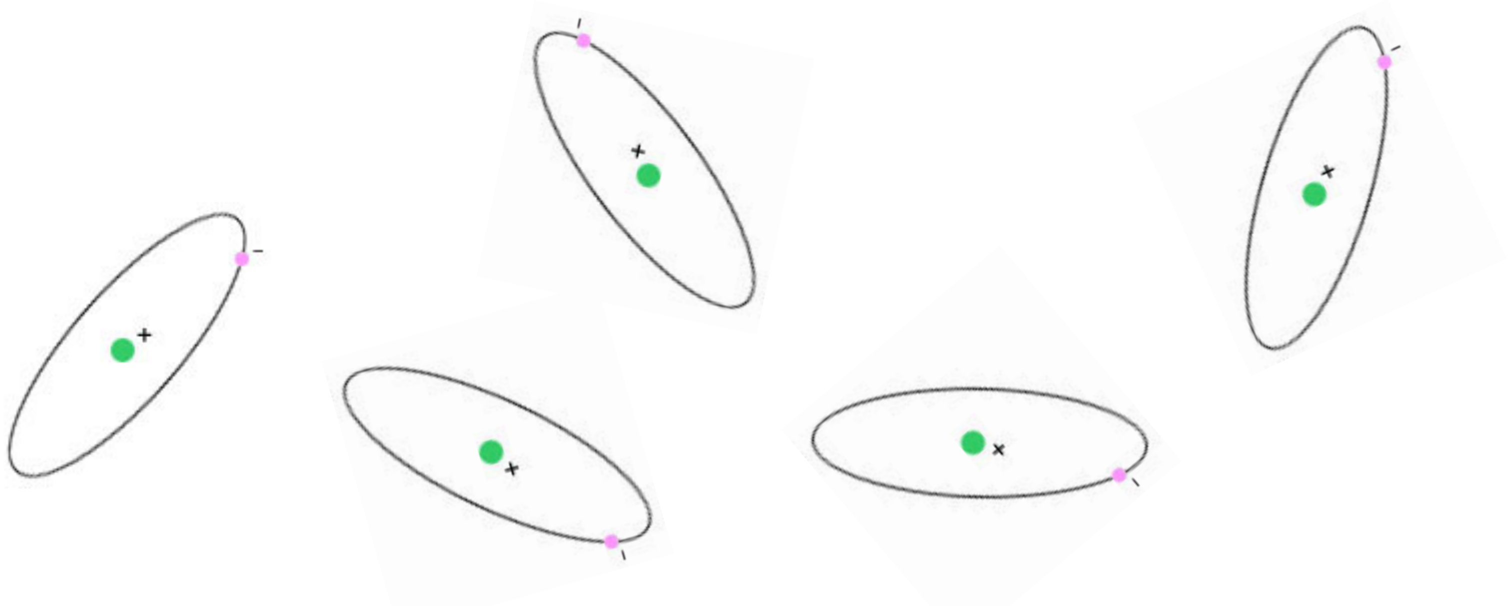
$$\boxed{\vec{\mu}(\text{orbit}) = i\vec{A}}$$

Electrons themselves also have a Magnetic Dipole Moment.

$$\boxed{\vec{\mu}(\text{electron or spin})}$$

Net Magnetic Moment

In most materials all the magnetic moments have random and/or canceling orientations.



Superposition of B-field vectors over many atoms gives B=0

Quantization of Magnetic Moment

Orbital Magnetic Moment:

$$\mu = \frac{-e}{2\,m_e} L = \frac{-e}{2\,m_e} \sqrt{l(l+1)}\,\hbar = \sqrt{l(l+1)}\,\mu_B$$

Spin Magnetic Moment:

$$\mu_z = \pm\frac{1}{2} g\mu_B$$

$$\mu_B = \frac{e\hbar}{2m_e} = 9.2740154x10^{-24} J/T = 5.7883826x10^{-5} eV/T$$

$$\text{Bohr magneton}$$

Magnetic Properties of Solids

$M = \mu_{total}/V$ = magnetic moment per volume = magnetization

$B = B_o + \mu_o M = (\mu/\mu_o)B_o = K_m B_o$= total magnetic field in material
[B_o = externally applied field]

$\mu = K_m \mu_o = \mu_o B/B_o$= magnetic permeability
[K_m = relative permeability]
[Analogous to dielectric permittivity & dielectric constant]

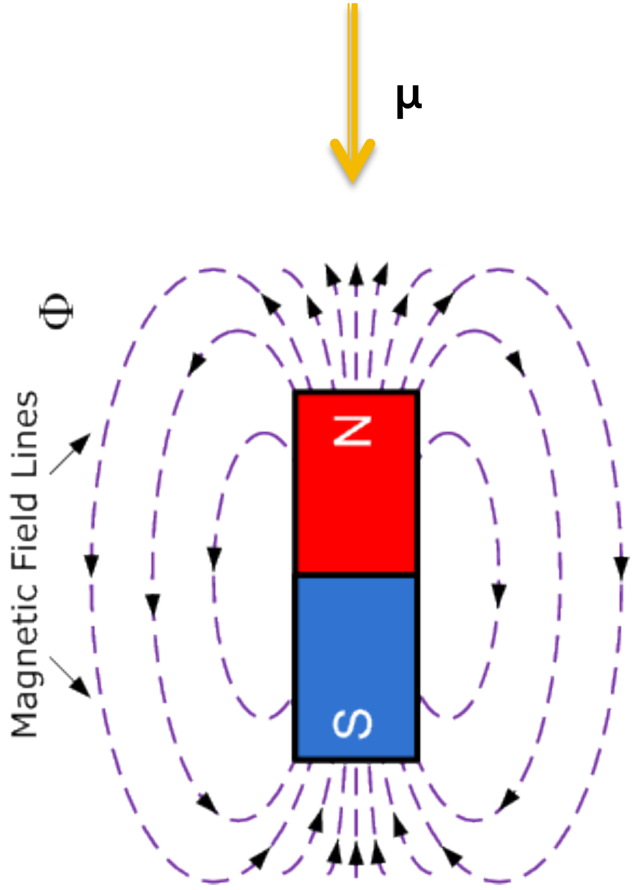
Magnetic susceptibility $\chi_m = K_m - 1 = \mu_o M/B_o$

Diamagnetism

- Intrinsic magnetic moments line up opposite to applied field
    - Negative susceptibility
- No simple electrostatic equivalent
- Diamagnetism is very weak

Force on Diamagnetic Material

- F = Gradient (**B•μ**)



https://www.youtube.com/watch?v=A1vyB-O5i6E

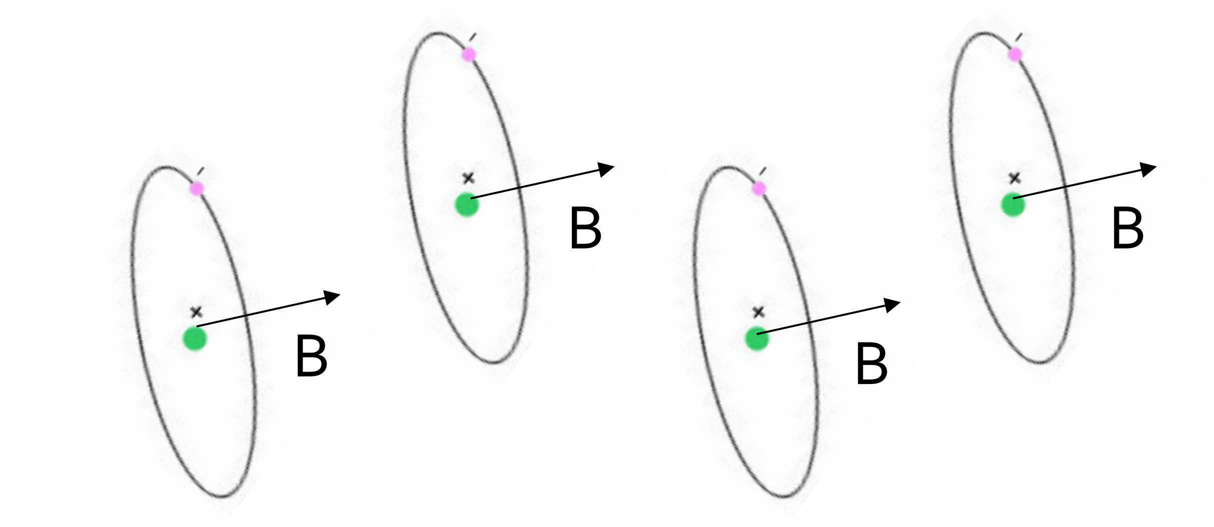
Paramagnetism

- Intrinsic magnetic moments of atoms line up parallel to external magnetic field
    - Positive susceptibility (usually weak)
    - Somewhat equivalent to polarization of insulator

- $M = C\,B_{ext}/T$
    - C = Curie constant
    - T = temperature

Ferromagnetism

In **Ferromagnetic materials** (Fe, Ni, Cr, some alloys containing these metals too), the atomic magnetic moments can all orient the same way (**domains**), making a net B-field.



Ferromagnetic materials can have very large magnetic susceptibility

Domain Structure

Sometimes the material is fragmented into many domains (top) and is thus unmagnetized. If the domains align (bottom) there is a net magnetic field (magnetized). This magnetization can remain after the magnetizing field is removed (unlike diamagnetism or paramagnetism)