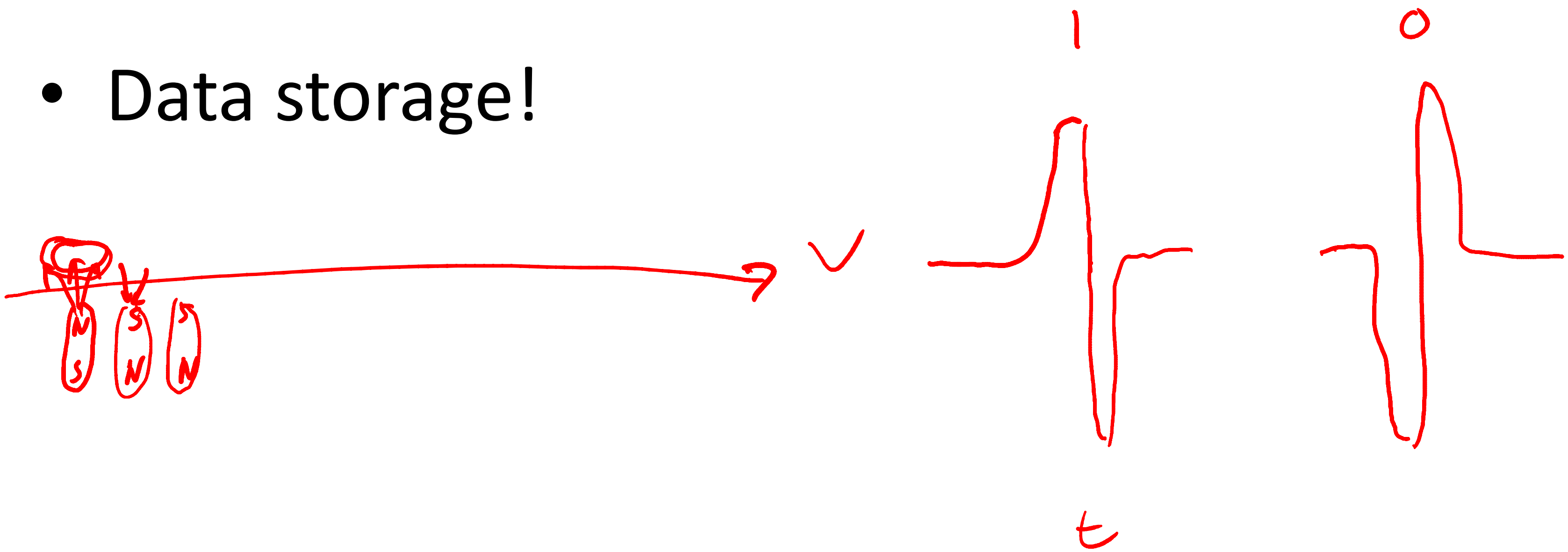
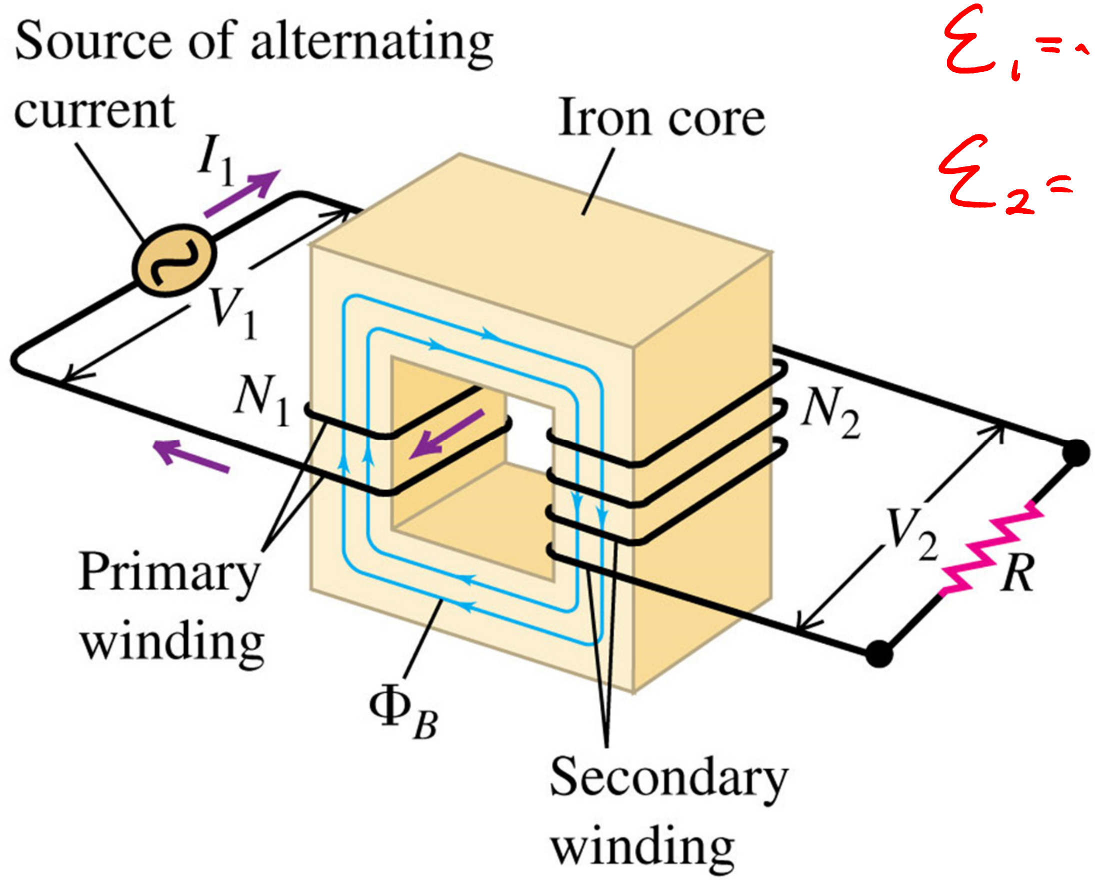
One More use for Induction

- Data storage!





$$\mathcal{E}_1 = -N_1 \frac{d\Phi_B}{dt}$$

$$\mathcal{E}_2 = -N_2 \frac{d\Phi_B}{dt}$$

combine

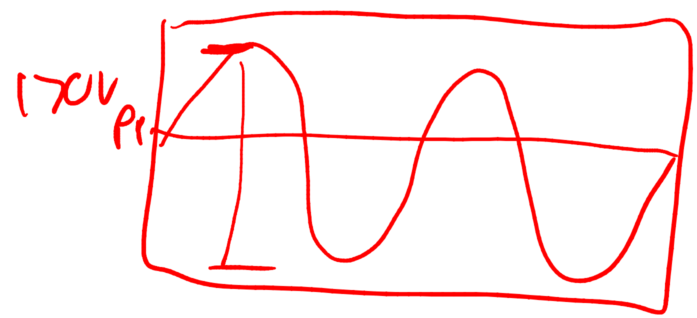
$$\frac{\mathcal{E}_2}{\mathcal{E}_1} = \frac{N_2}{N_1}$$

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

Power? $P = VI$

$$P_1 = P_2$$

$$V_1 I_1 = V_2 I_2$$



High Voltage Transmission line pic from Wikipedia

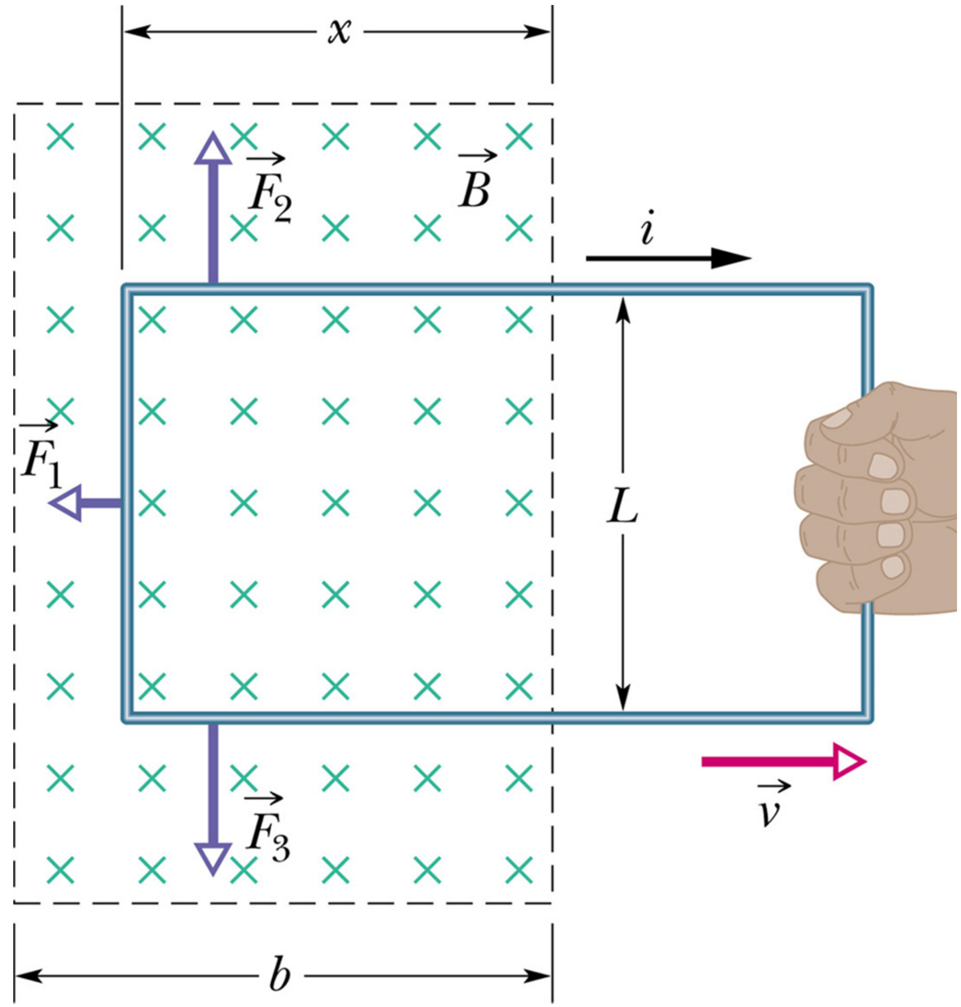
Do “Transformers” worksheet

Pull loop out of $\vec{B}$

Φ_B is changing, so

you get a $\mathcal{E}$.

How?



Do “Motional EMF” worksheet

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

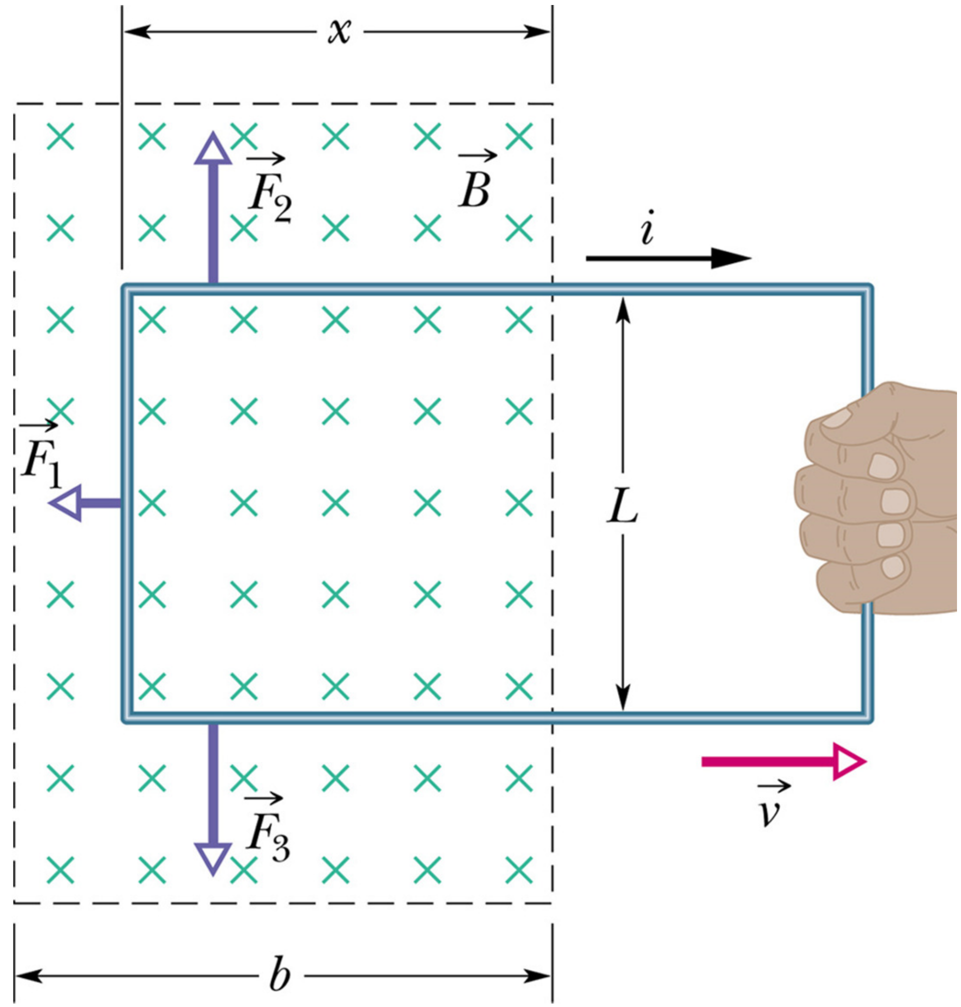
$$\Phi_B = \int \vec{B} \cdot d\vec{A} = BA \cancel{\cos\theta}$$

$A = L \cdot x$ so $\Phi_B = BLx$

$$\frac{d\Phi_B}{dt} = \frac{d}{dt}(BLx)$$

x is only thing that is changing, so

$$\mathcal{E} = -BL\frac{dx}{dt} = -BLv$$

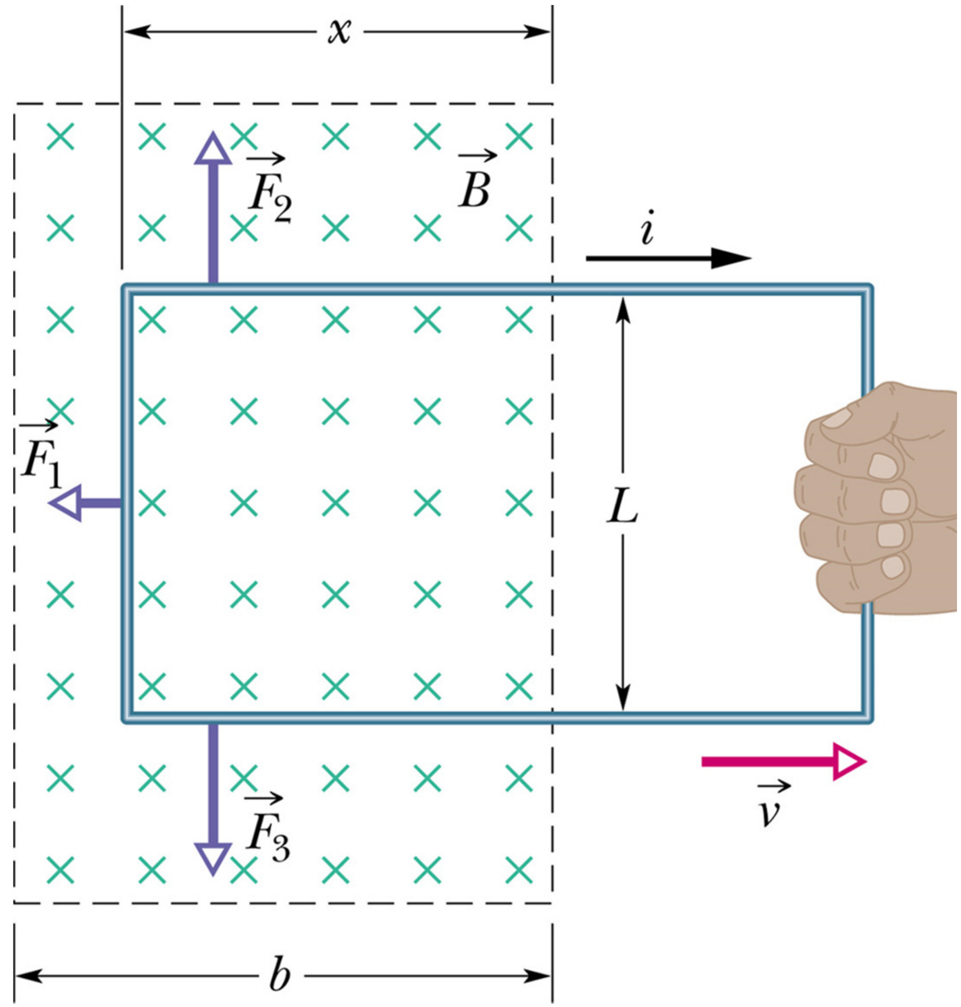


So, if $\mathcal{E} = -BLv$

and R is resistance,

$V = IR$ so $I = V/R$

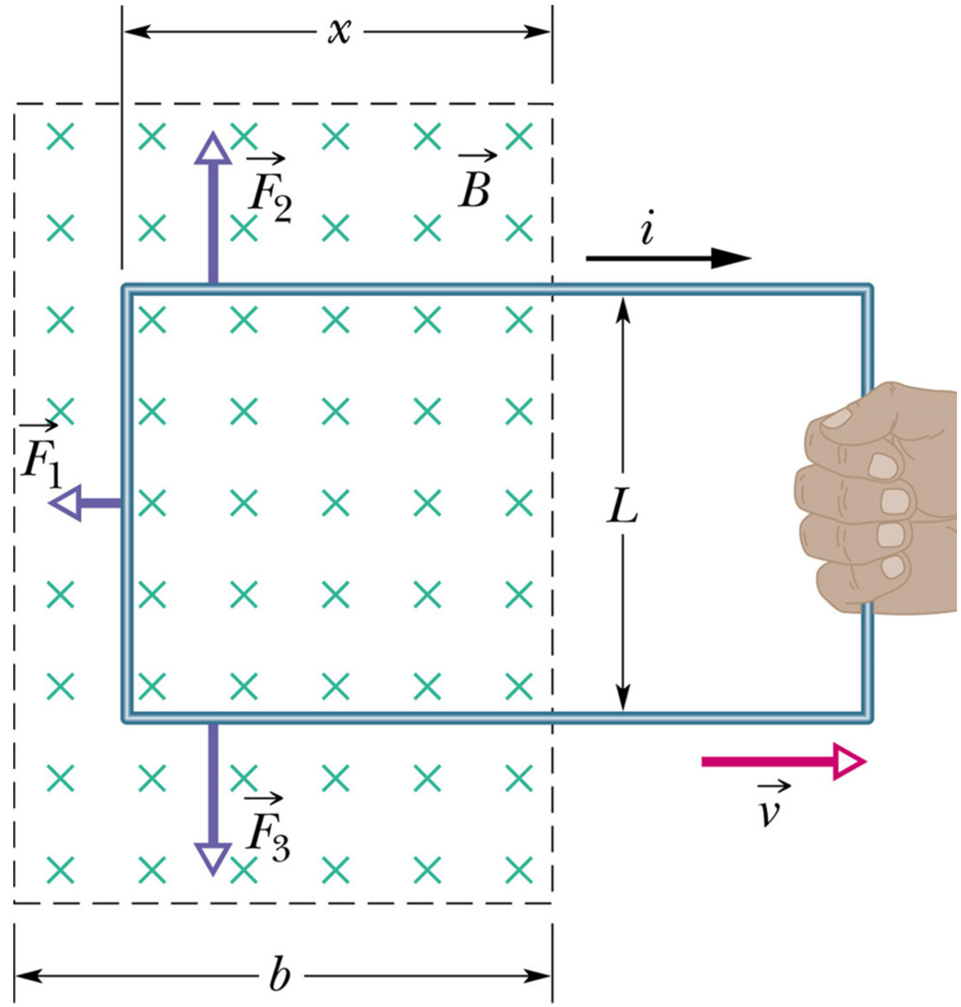
$$I = \frac{-BLv}{R}$$



$$\text{Power} = VI = I^2 R$$

$$\text{so } \left(\frac{-BLv}{R}\right)^2 \cdot R$$

$$P = \frac{B^2 L^2 v^2}{R}$$



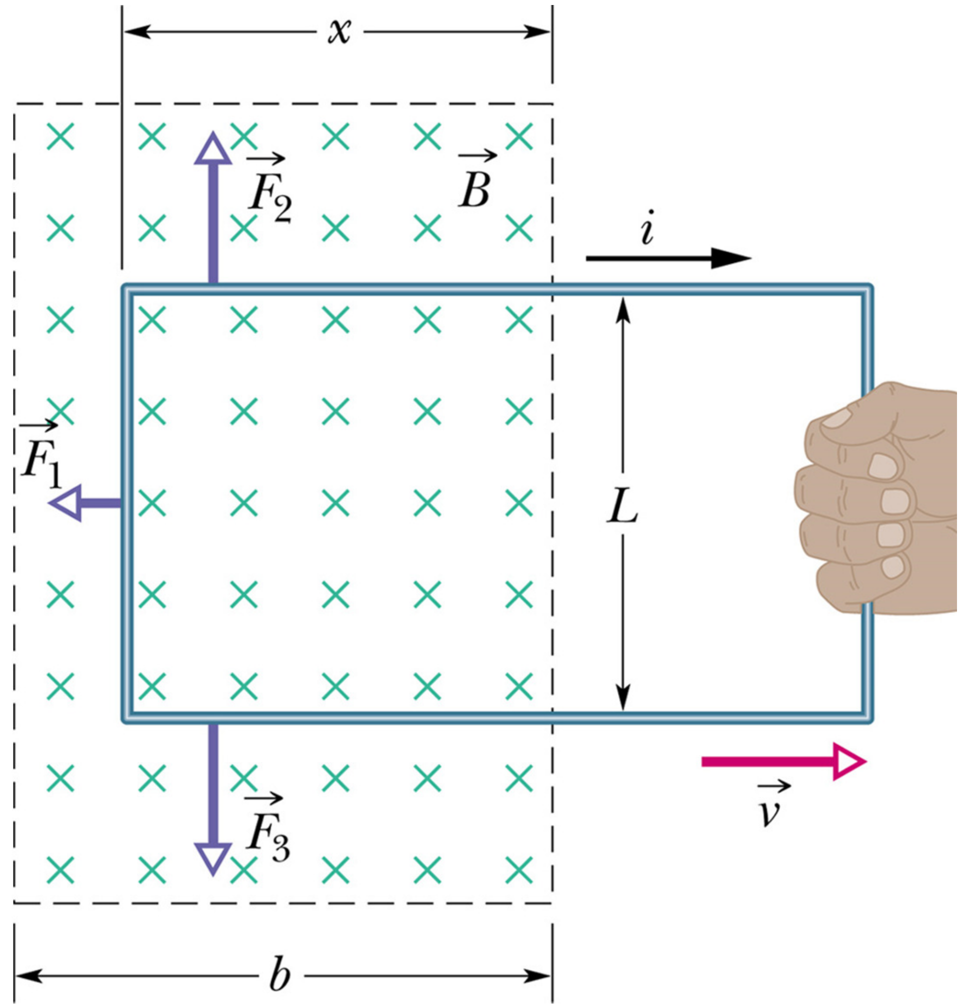
$\vec{F} = I\vec{L} \times \vec{B}$

Hey look those are the

F's already on the

drawing!

$\vec{F} = I|L||B|\cancel{\sin}\, 90^\circ = ILB$



$$W = -\int \vec{F} \cdot \vec{dl}$$

$$P = \frac{\text{work}}{\text{time}} = \frac{d}{dt}\left(\vec{F} \cdot \vec{dl}\right)$$

$$\frac{dl}{dt} = v \quad \therefore \quad P = \vec{F} \cdot \vec{v}$$

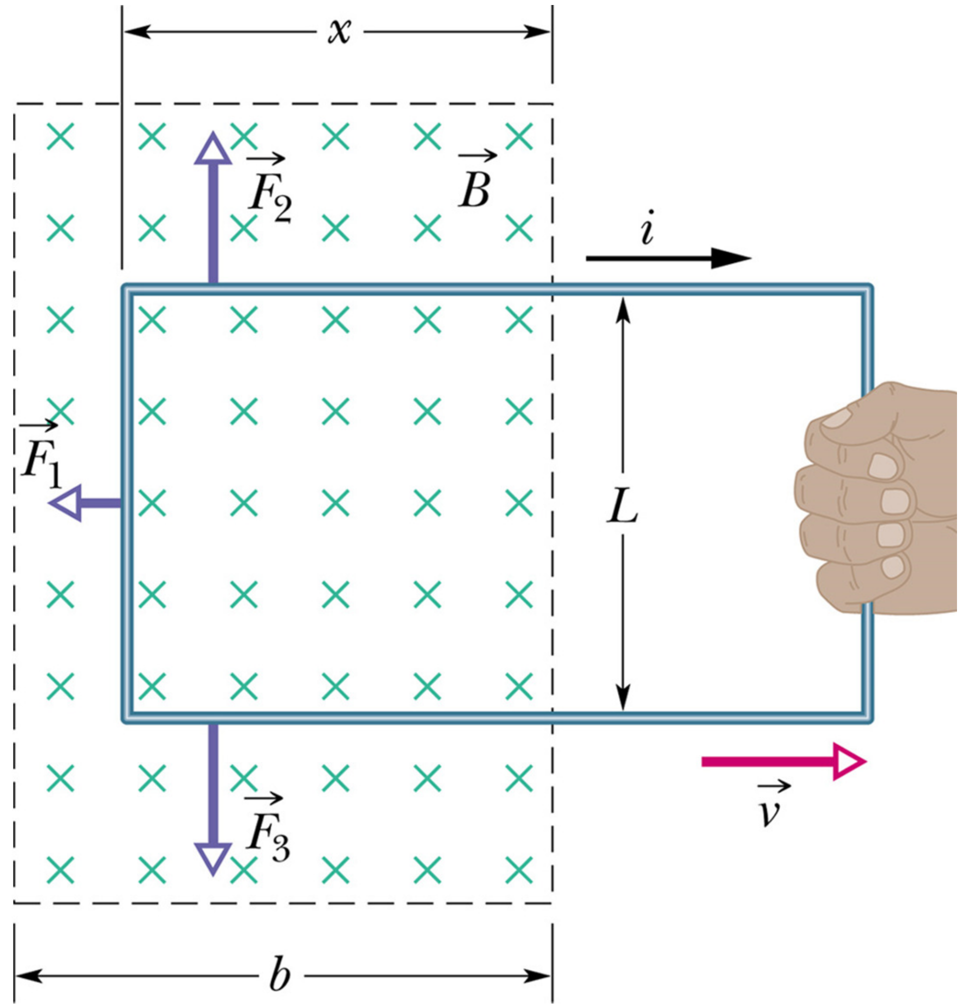
F was IBL

Subst in for I

$$F = -\left(\frac{BL}{R} v\right) BL$$

$$P = F \cdot v = +\frac{B^2 L^2 v^2}{R}$$ = work done over time

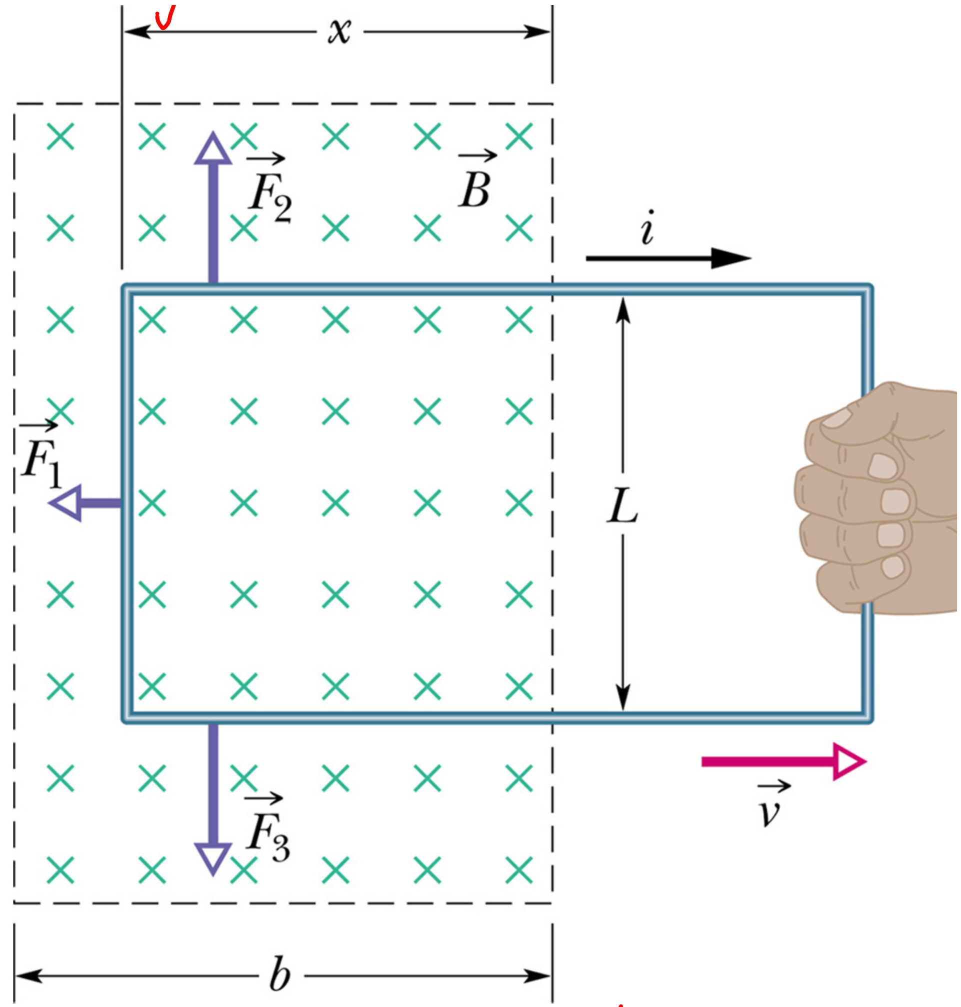
= same as $I^2 R$ Power!



Get it going with v_0, stop pulling, let it coast to a stop.

$$F = -\frac{B^2L^2v}{R} = ma$$

or $$-\frac{B^2L^2}{R}v - m\frac{dv}{dt} = 0$$



Could solve for $v(t)$ with initial condition $v(0) = v_0$

final condition $v(t_f) = 0$

but we won't (hint - it'll be another exponential)

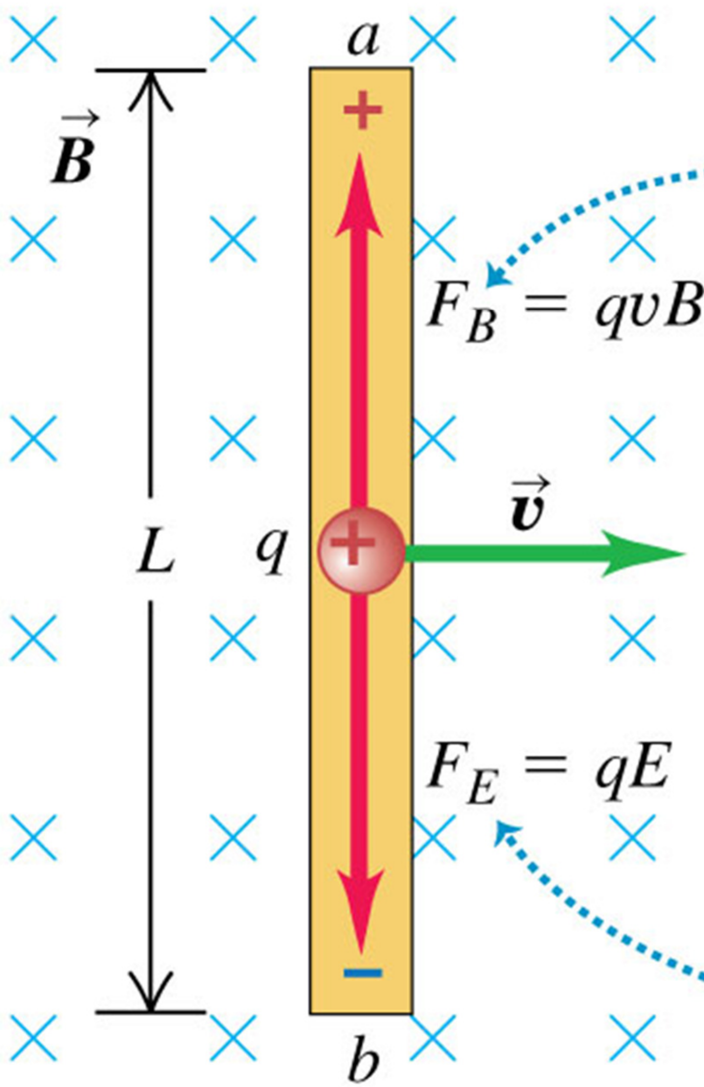
HW question is easier, since terminal velocity means $a=0$

$\vec{F}_B = q\vec{v} \times \vec{B}$

$|F_B| = qvB$

$F_E = qE$

(a) Isolated moving rod



Charges in the moving rod are acted upon by a magnetic force $\vec{F}_B$ ...

$F_B = F_E = qvB = qE$

... and the resulting charge separation creates a canceling electric force $\vec{F}_E$.

$E = vB$

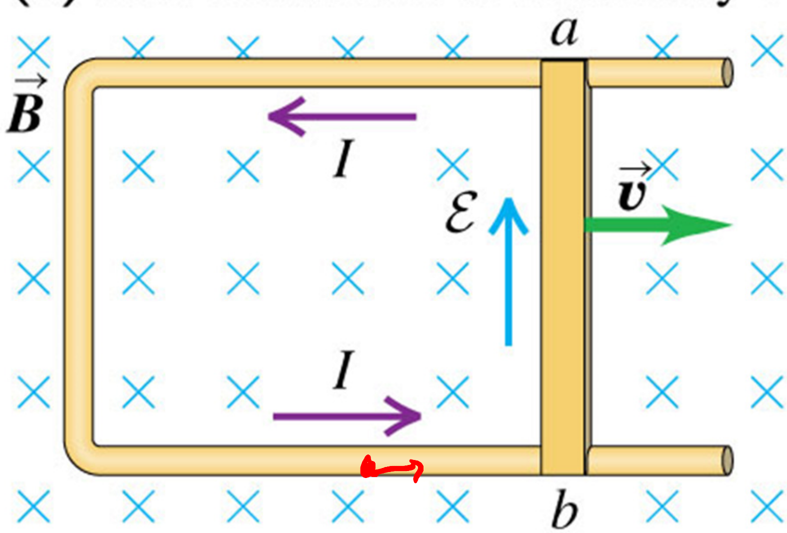
$\Delta V_{ab} = \int \vec{E} \cdot d\vec{l}$

$= EL$

$\Delta V_{ab} = vBL$

Voyager uses this effect to find where the edge of the Heliosphere is (and thus, when it actually leaves the solar system)

(b) Rod connected to stationary conductor



The motional emf $\mathcal{E}$ in the moving rod creates an electric field in the stationary conductor.

$V_{ab} = BvL$

$I = V/R = \dfrac{BvL}{R}$

OR $\Phi_B \uparrow$ into screen $\otimes$

more $\Phi_B \otimes$ makes I CCW to oppose this

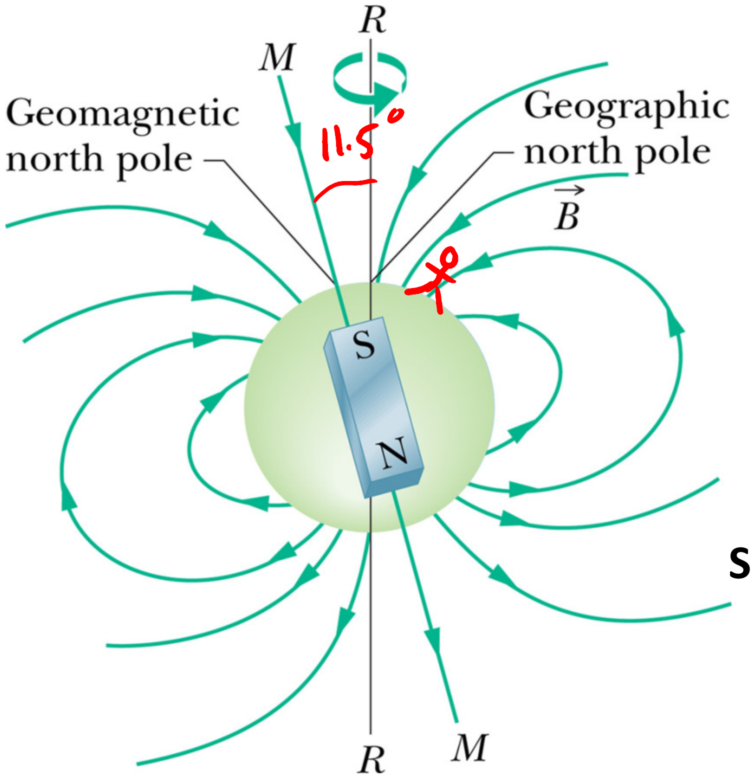
$d\mathcal{E} = (\vec{v} \times \vec{B}) \cdot d\vec{l}$

$\mathcal{E} = \oint (\vec{v} \times \vec{B}) \cdot d\vec{l}$

More general form

What follows are cool magnetic things we don't have time to go through in detail

No, this stuff won't be on the test: not enough time to work out problems.



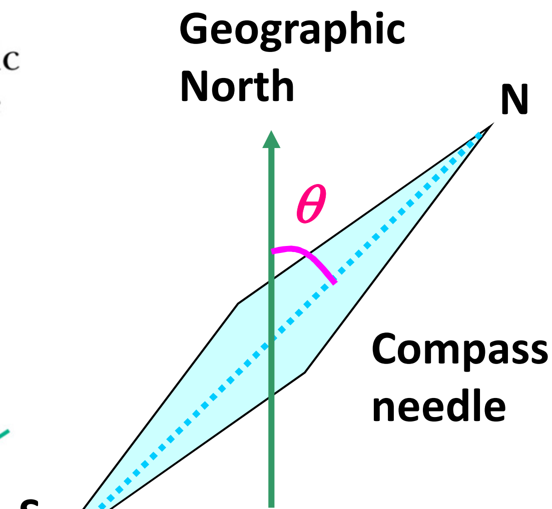


Fig. *a* : Top view

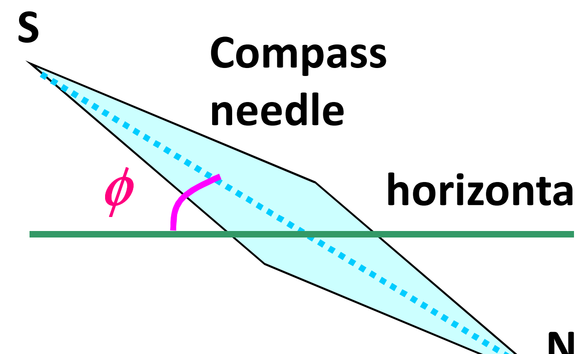
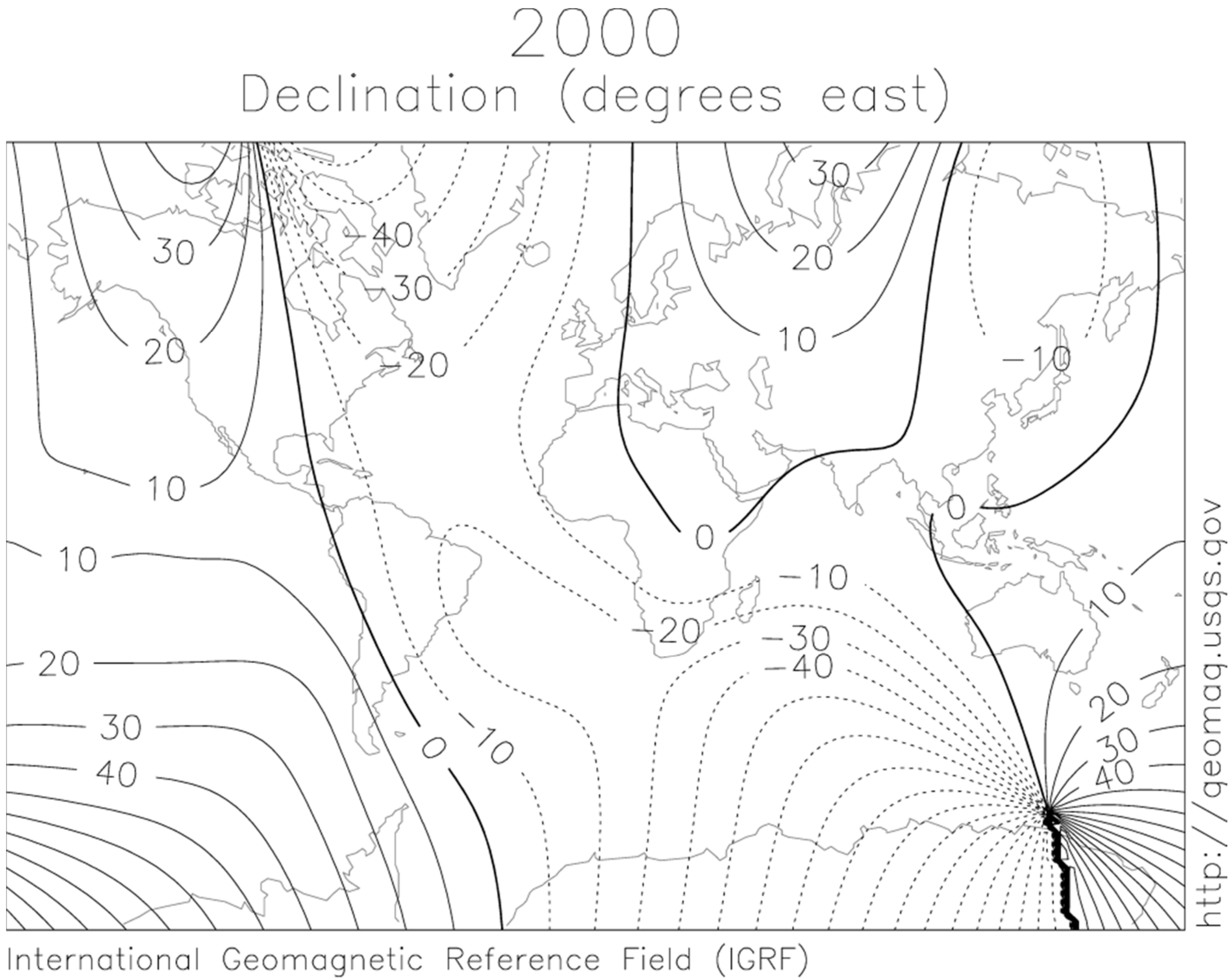


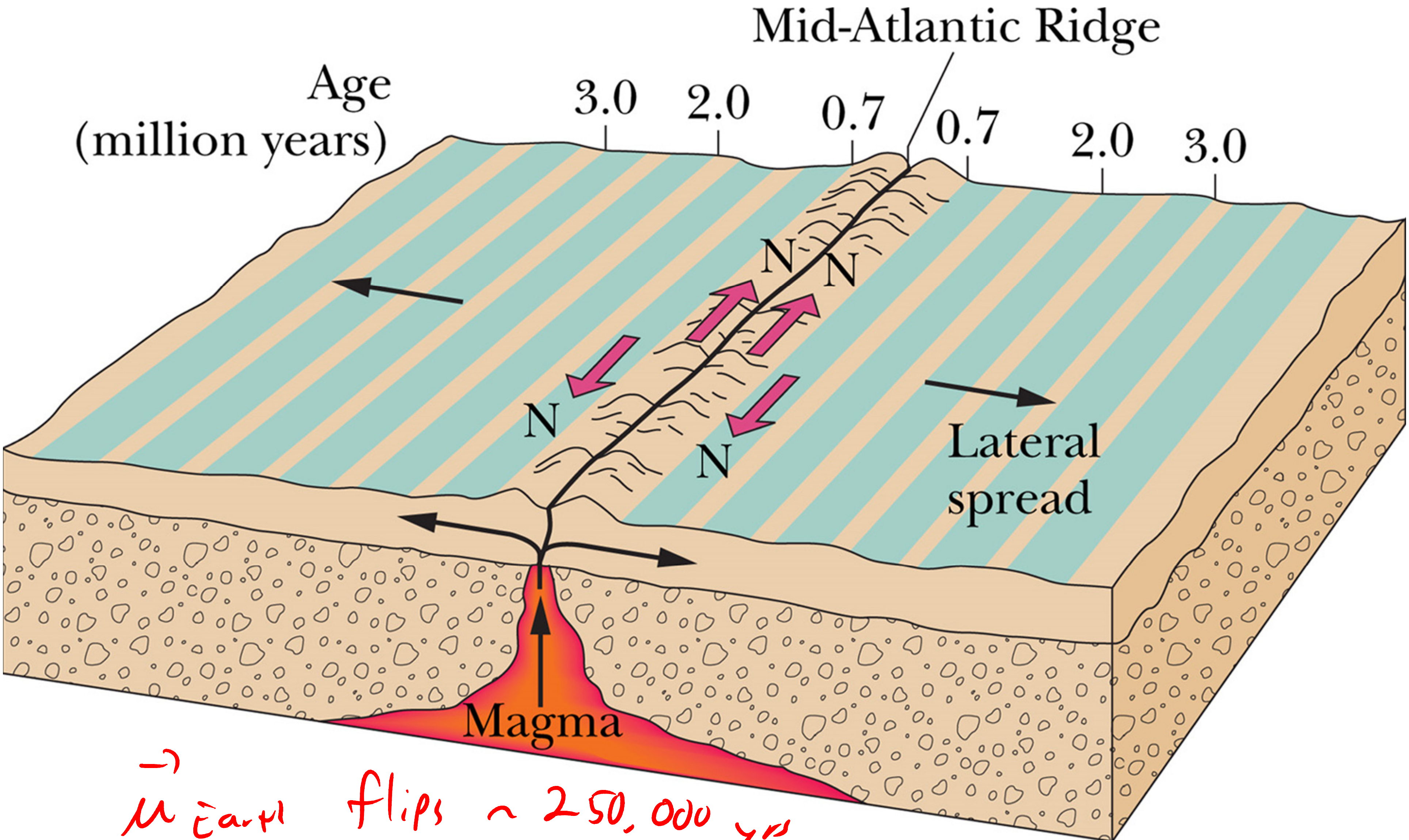
Fig. *b* : Side view

Earth $\vec{\mu} = 8.0 \times 10^{22}$ J/T

θ = declination $\quad\quad$ ϕ = inclination

Duluth: Declination = 0° 32' W changing by 0° 6' W/year



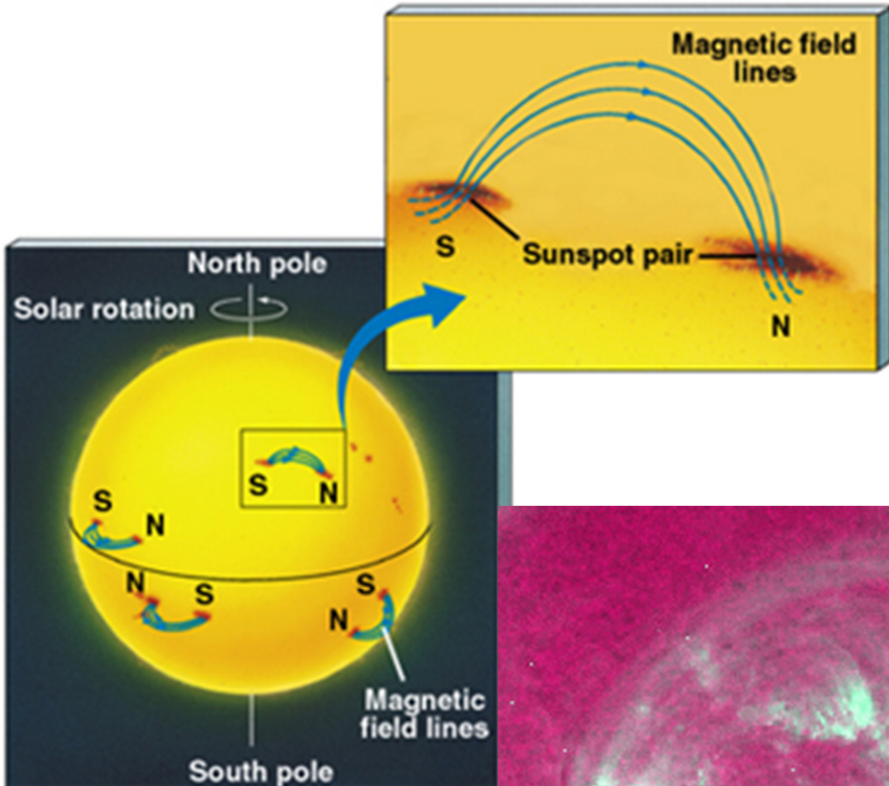


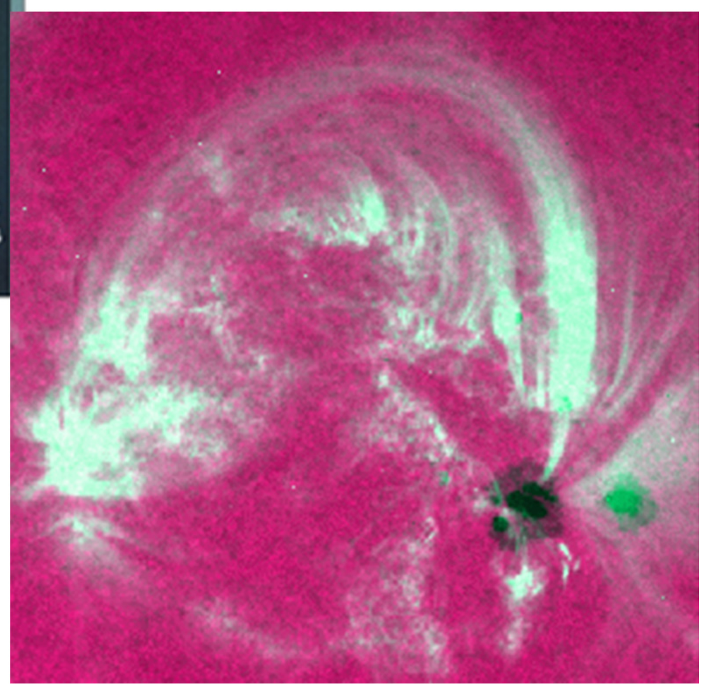
$\vec{\mu}_{Earth}$ flips ~ 250,000 yrs

Last Time: ~780,000 yrs ago

O (1000 yrs) to flip

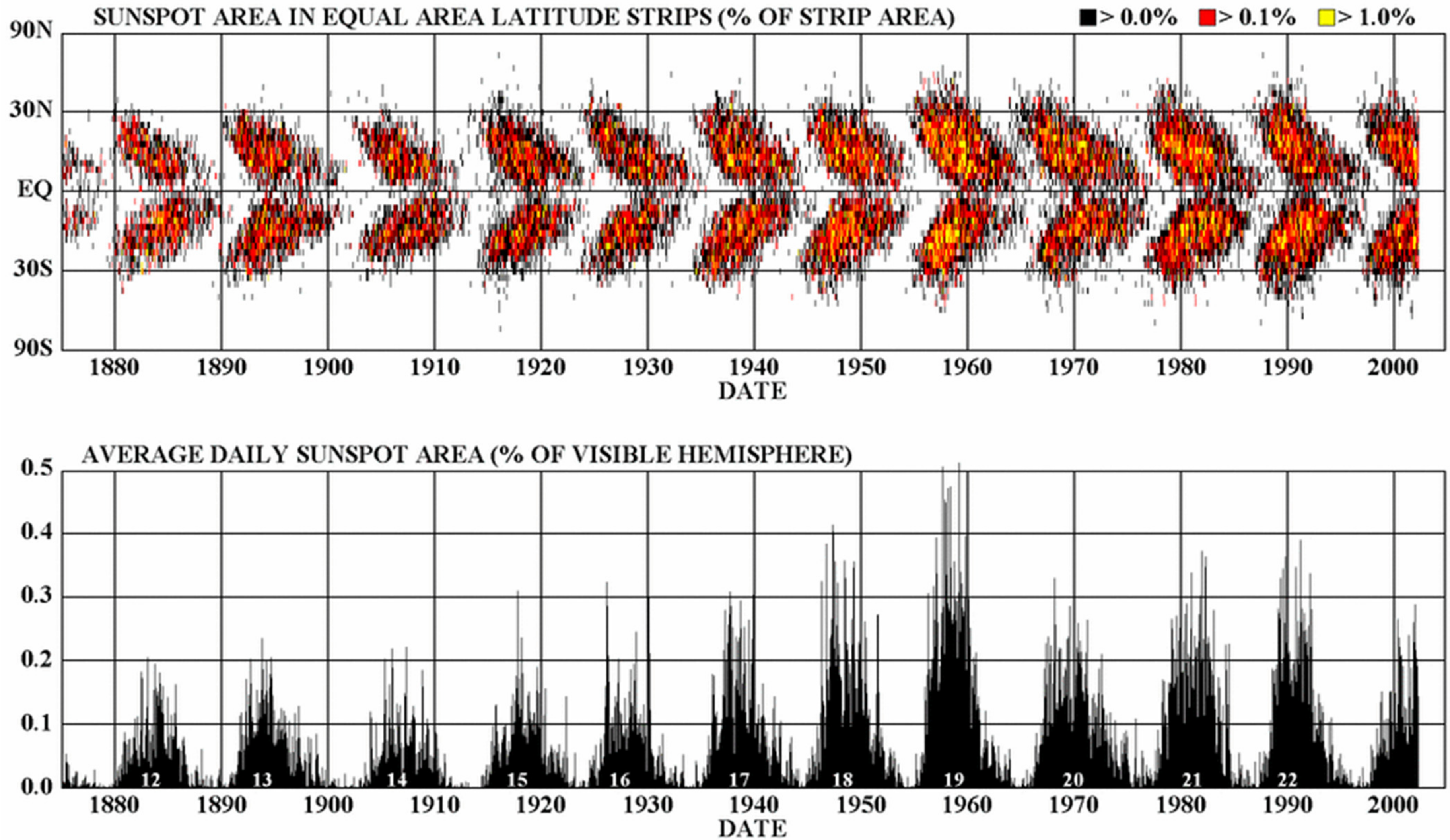
Solar Magnetism





- The Sun rotates, has a conductive core
  - Ionized gas
  - Has a strong magnetic field
- Sunspots have intense magnetic fields, often paired
  - Where field lines pop out of surface of sun
  - Intense field cools the photosphere where it passes through

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS



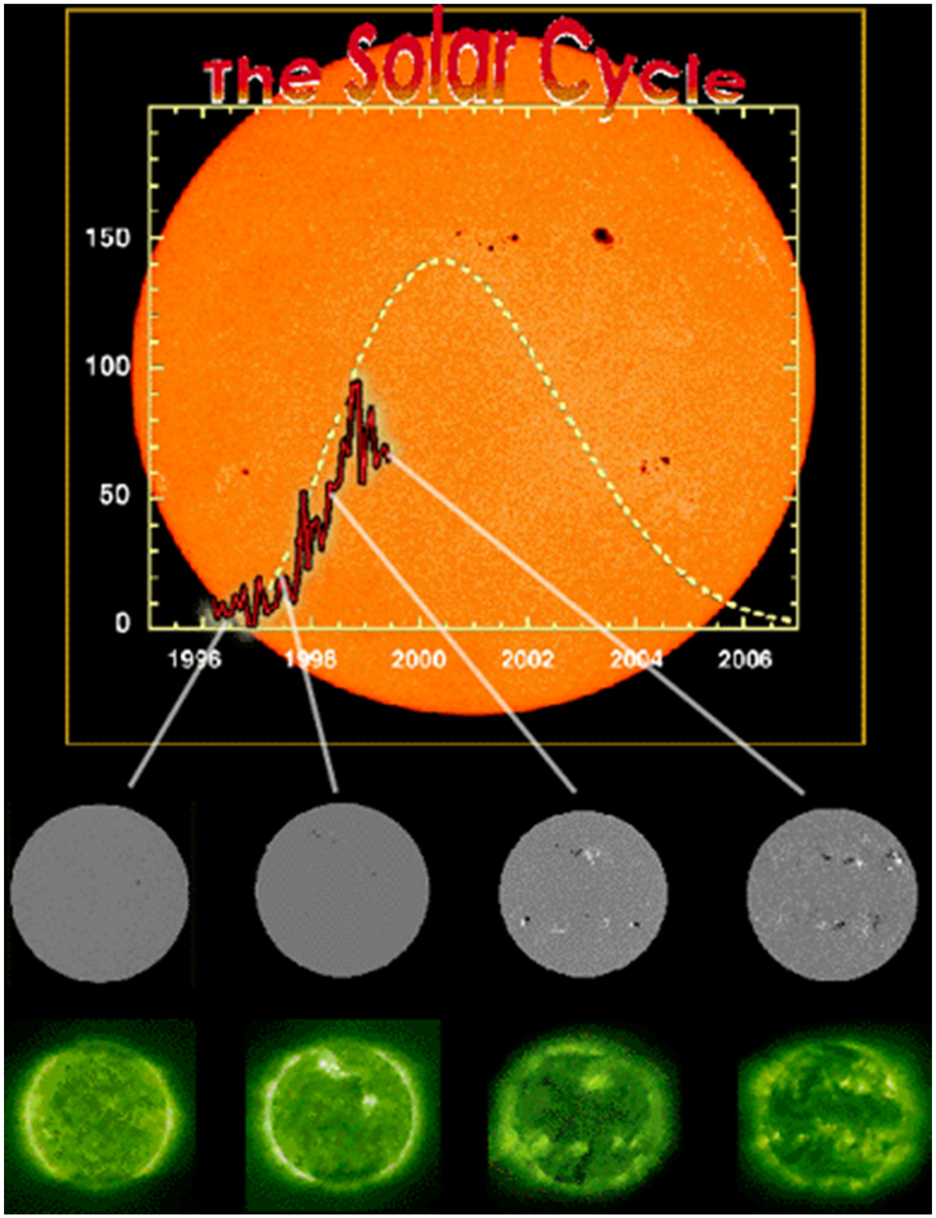
http://science.msfc.nasa.gov/ssl/pad/solar/images/bfly.gif

NASA/NSSTC/HATHAWAY 03/2002

Sunspot Cycle

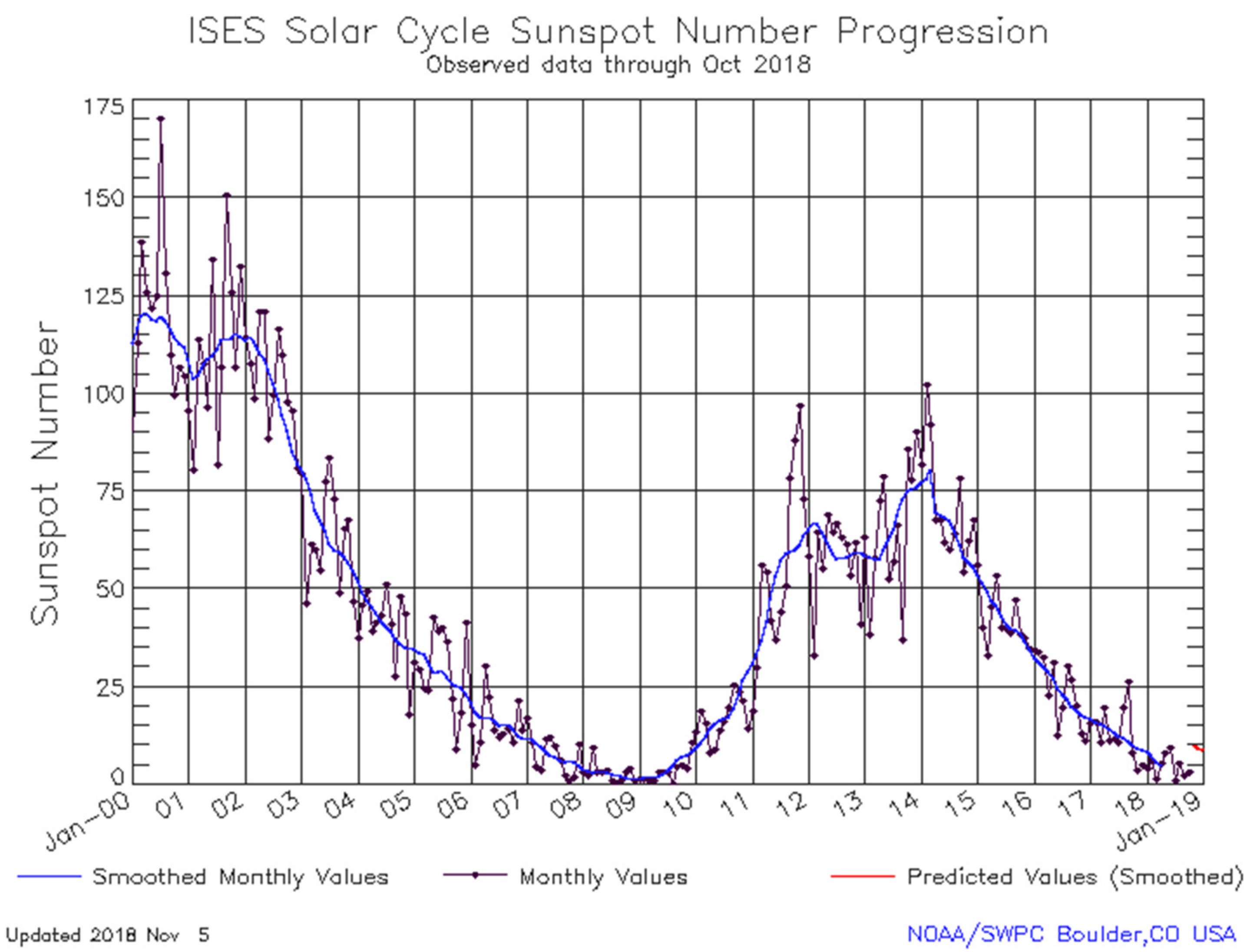
- Note 11-year cycle
  - Sunspots increase in number to a “Solar Maximum” then virtually disappear every 11 years
- “Butterfly Diagram”
  - Sunspot location and number
  - At beginning of cycle, they are near the poles
  - Move towards equator as cycle progresses

Last Cycle



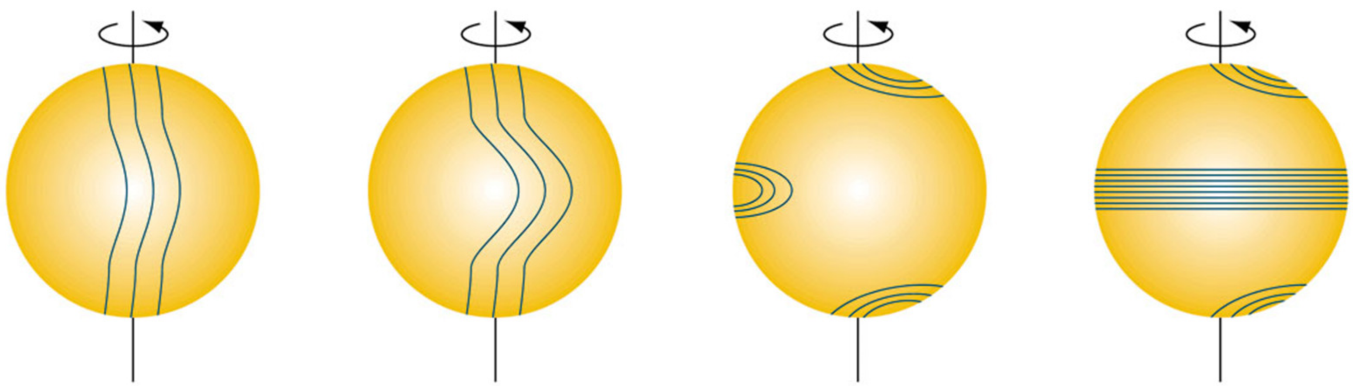
- Last Solar Max was in 2001 (we’re somewhere just past the next one now)
- Useful figure showing sunspot number plot combined with pictures
- Note activity in outer atmosphere changes too!

Current Solar Cycle



Why?

- The Sun rotates differentially
- Faster at equator (25 days)
- Slower at poles (36 days)
- Magnetic field gets would up like rubber band



(a) (b) (c) (d)

Field Reversal

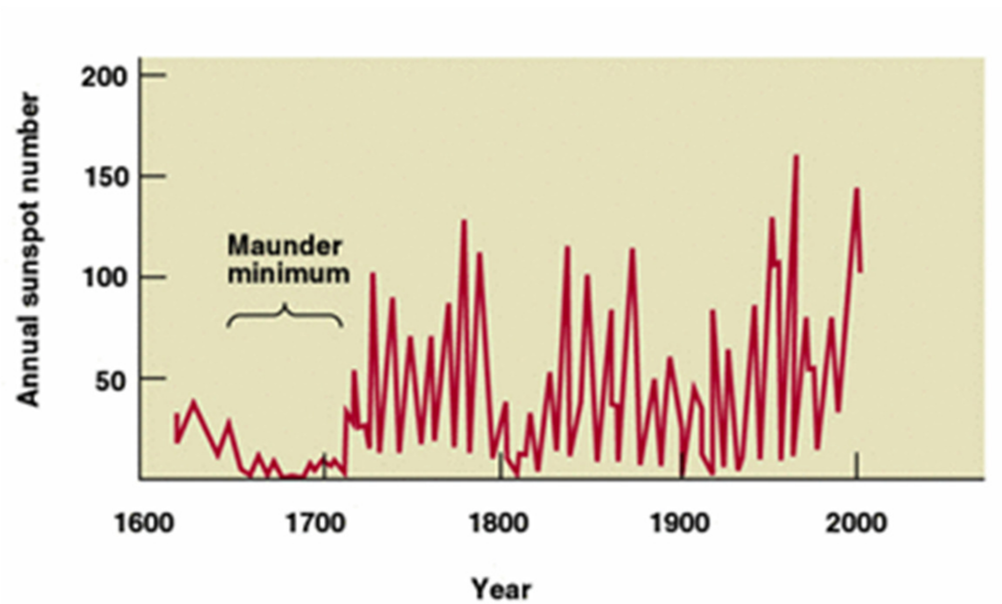
- A twisted field pops through the surface, makes activity
- Twist it too much, it snaps
- Reforms with poles reversed!
- Wash, rinse, repeat each 11 years

[Animation](#) from the SOHO satellite team

Solar Cycle

- So, an 11-year Sunspot Cycle is ½ of the 22-year Solar Cycle
- Each 22 years, the Sun's magnetic field is back to the same state it was 22 years ago

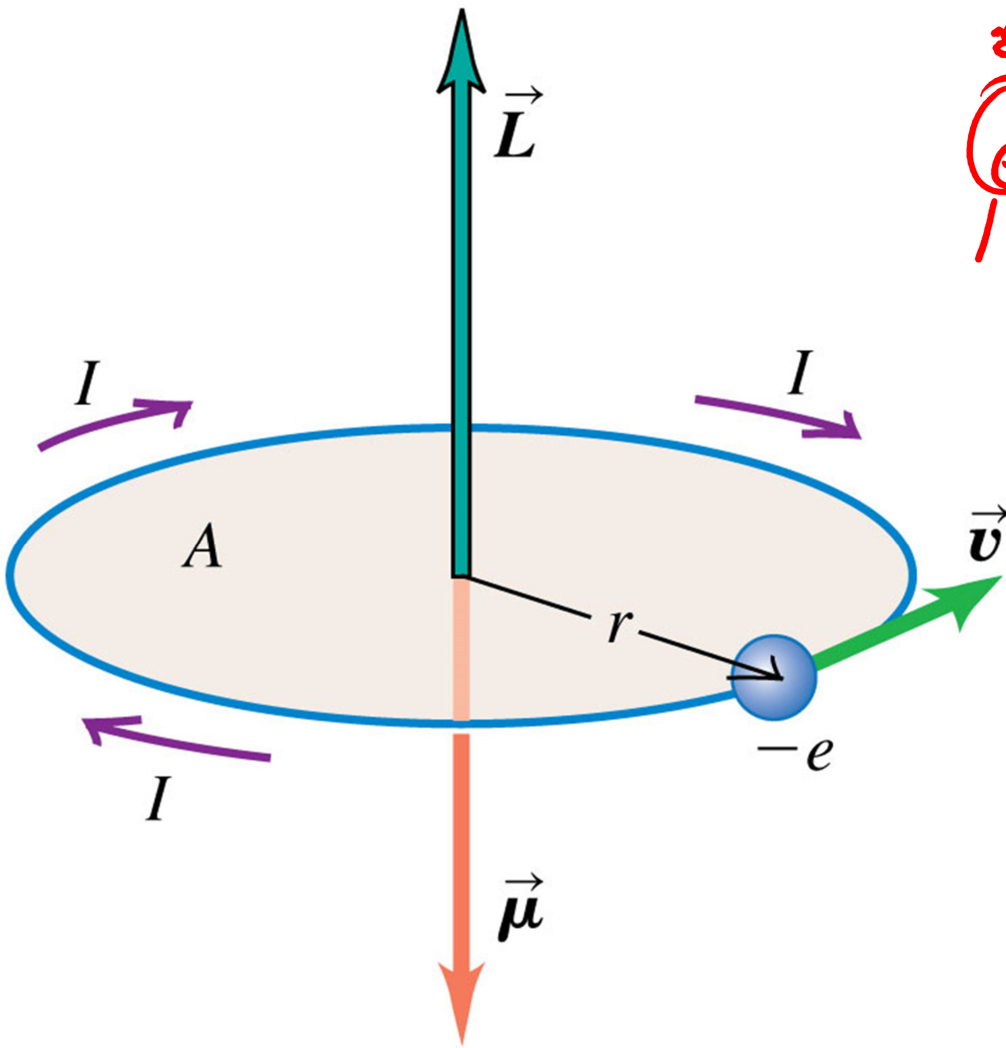
Effects on Earth



"Maunder Minimum" corresponds with the "Little Ice Age"

- Solar Wind causes Aurora
- Solar Flares, CME's can disrupt satellites, communications
  - Look at www.spaceweather.com
- Sunspot activity seems to be correlated with solar energy output
- The Sun is a Very Important Thing to understand
  - We must learn more!

So what's going on with permanent magnets?



$\vec{\mu}_s = -\frac{e}{m}\vec{S}$

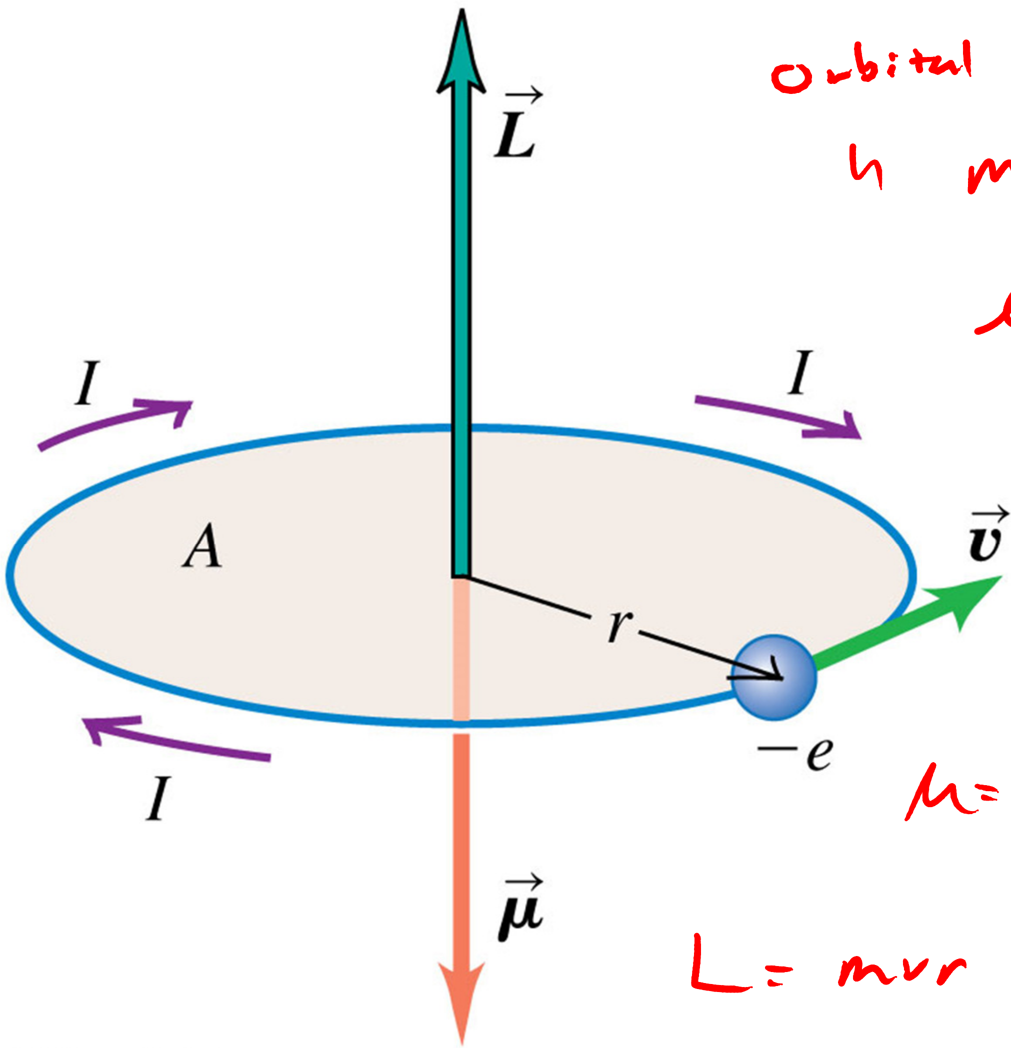
$S_z = m_s \frac{h}{2\pi}$

$m_s = \pm \frac{1}{2}$

$\mu_{s,z} = -\frac{e}{m} S_z = \pm \frac{eh}{4\pi m_e}$

$\vec{\mu}_B = 9.27\times10^{-24}$ J/T

Bohr



orbital ang. momentum $\vec{L}$

& magnetic moment

$$\vec{\mu} = IA = I\pi r^2$$

$$T = \frac{2\pi r}{v}$$

$$\frac{e}{T} = \frac{ev}{2\pi r} = I$$

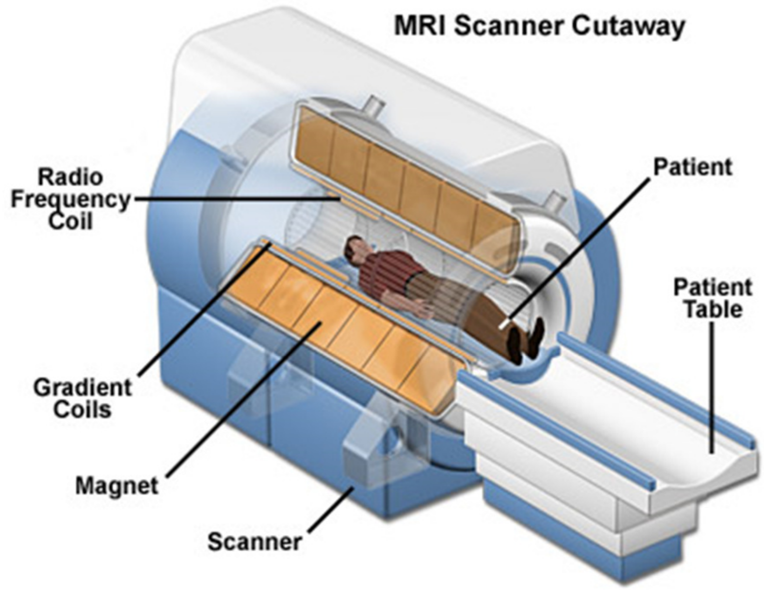
$$\mu = IA = \frac{ev}{2\pi r}(\pi r^2) = \frac{evr}{2}$$

$L = mvr$ $\qquad \mu = \frac{e}{2m} L \qquad (L = n\hbar)$

$$\hbar = \frac{h}{2\pi}$$

$$\mu = \frac{e}{2m}\frac{h}{2\pi} = \frac{eh}{4\pi m} = \vec{\mu}_B$$

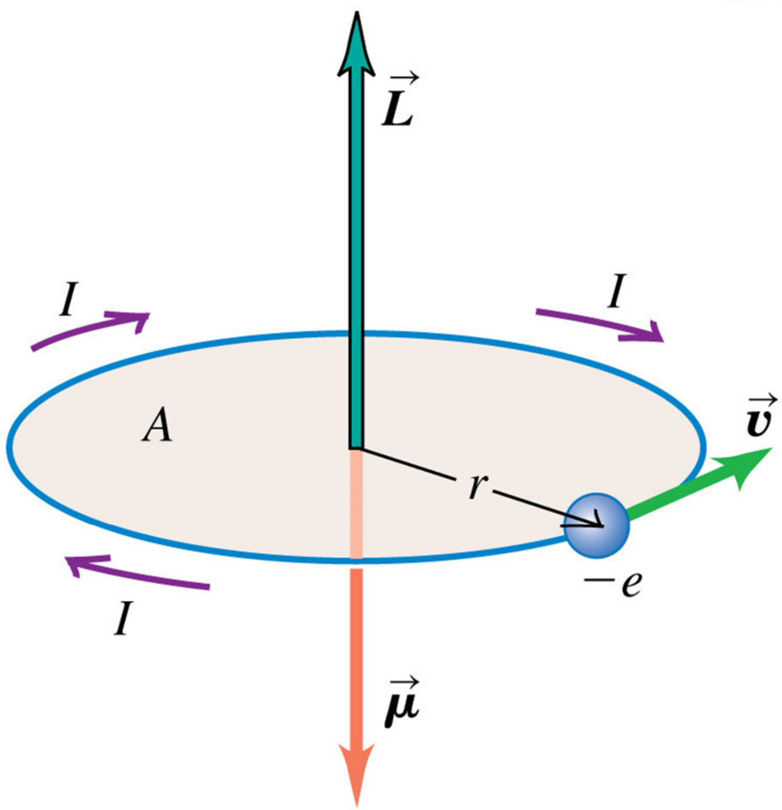
$U = \vec{\mu} \cdot \vec{B}$

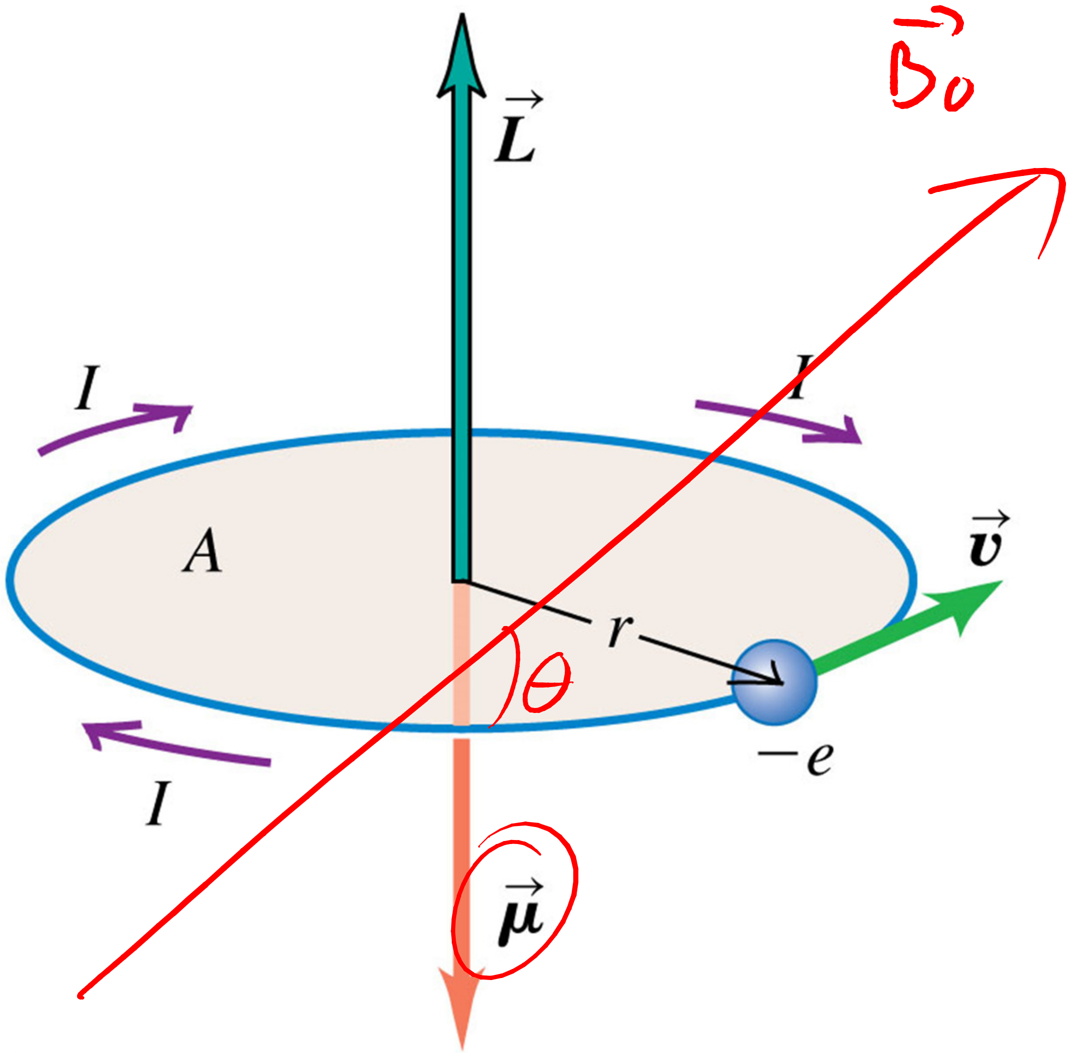


$B \quad \mu_0 \vec{I}$

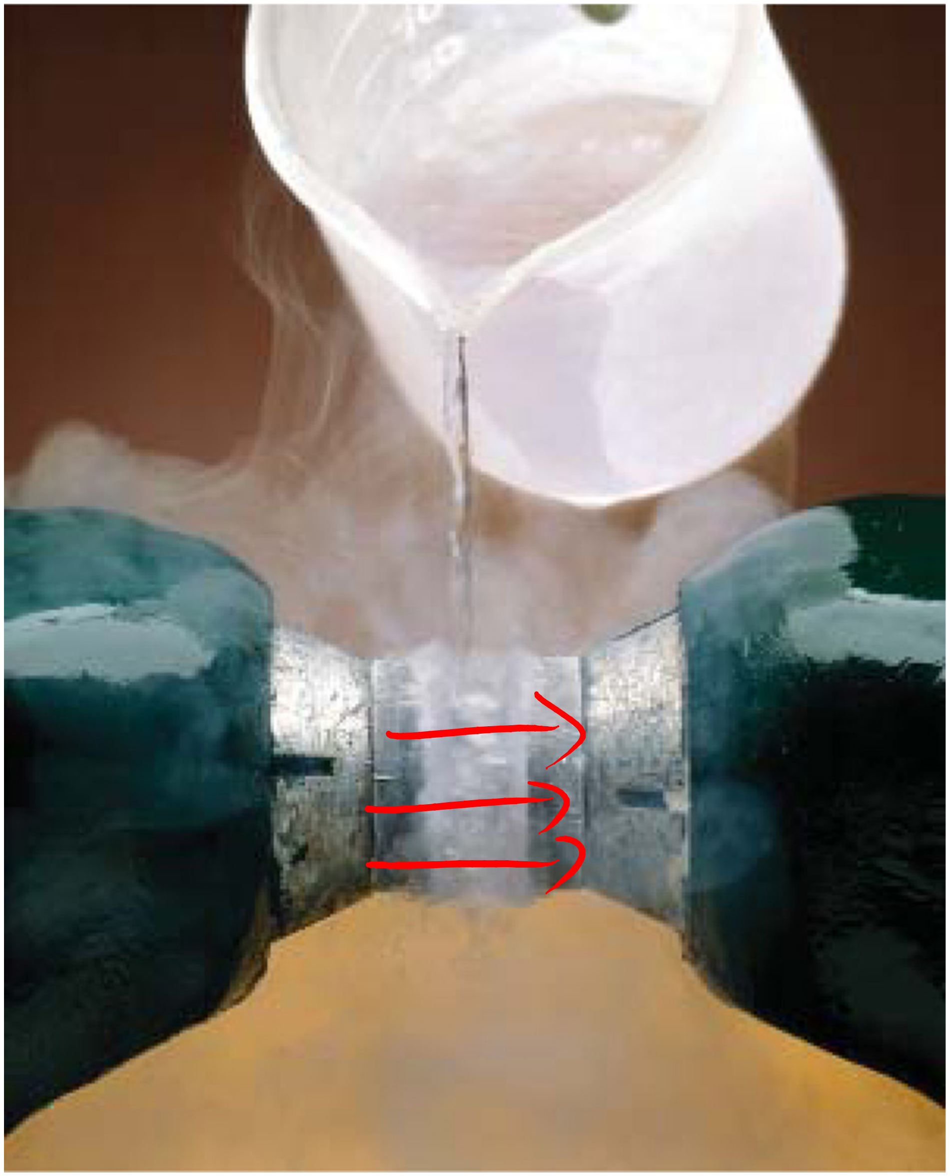
$U = -\vec{\mu}_s B_{ext}$

$= \mu_{s,z} B_{ext}$

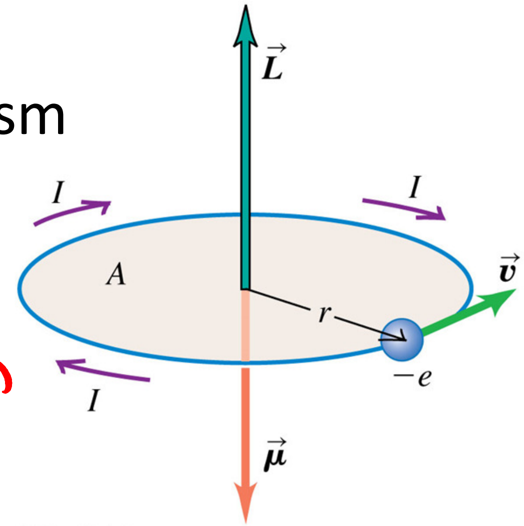




$\vec{B}_0$
$\vec{L}$
I
I
A
$\vec{v}$
r
θ
$-e$
I
$\vec{\mu}$



Paramagnetism



Get induced $\vec{\mu}$

$$\vec{M} = \frac{\mu}{\text{volume}}$$

$$= N\frac{\mu}{\text{vol}}$$

$$\vec{B}_{TOT} = \vec{B}_0 + \mu_0 \vec{M}$$

$\mu = K_m \mu_0$

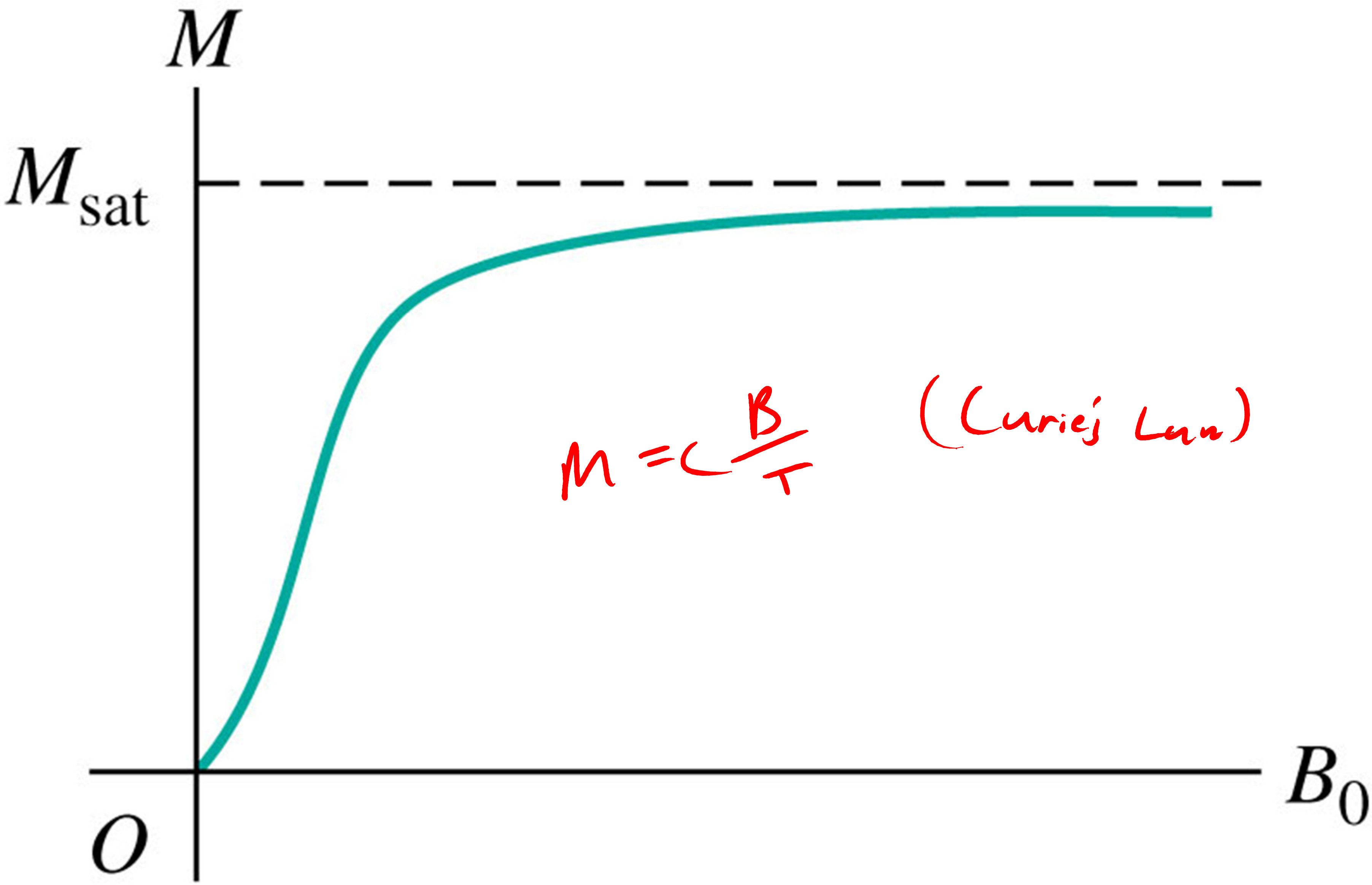
B_{TOT} bigger by K_m relative Permeability

Magnetic Susceptability

$$\chi_m = K_m - 1$$

χ positive

Fig. 28.28

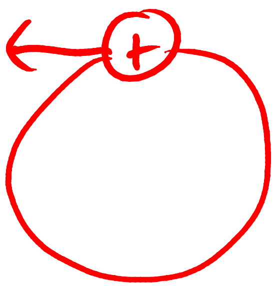


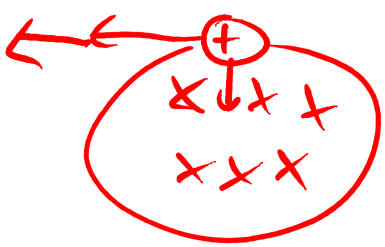
Diamagnetism

Apply a $\vec{B}_{ext}$, induces a weak $\vec{B}$ in opposite direction

$\vec{\mu}$ 0

express as $-\chi$





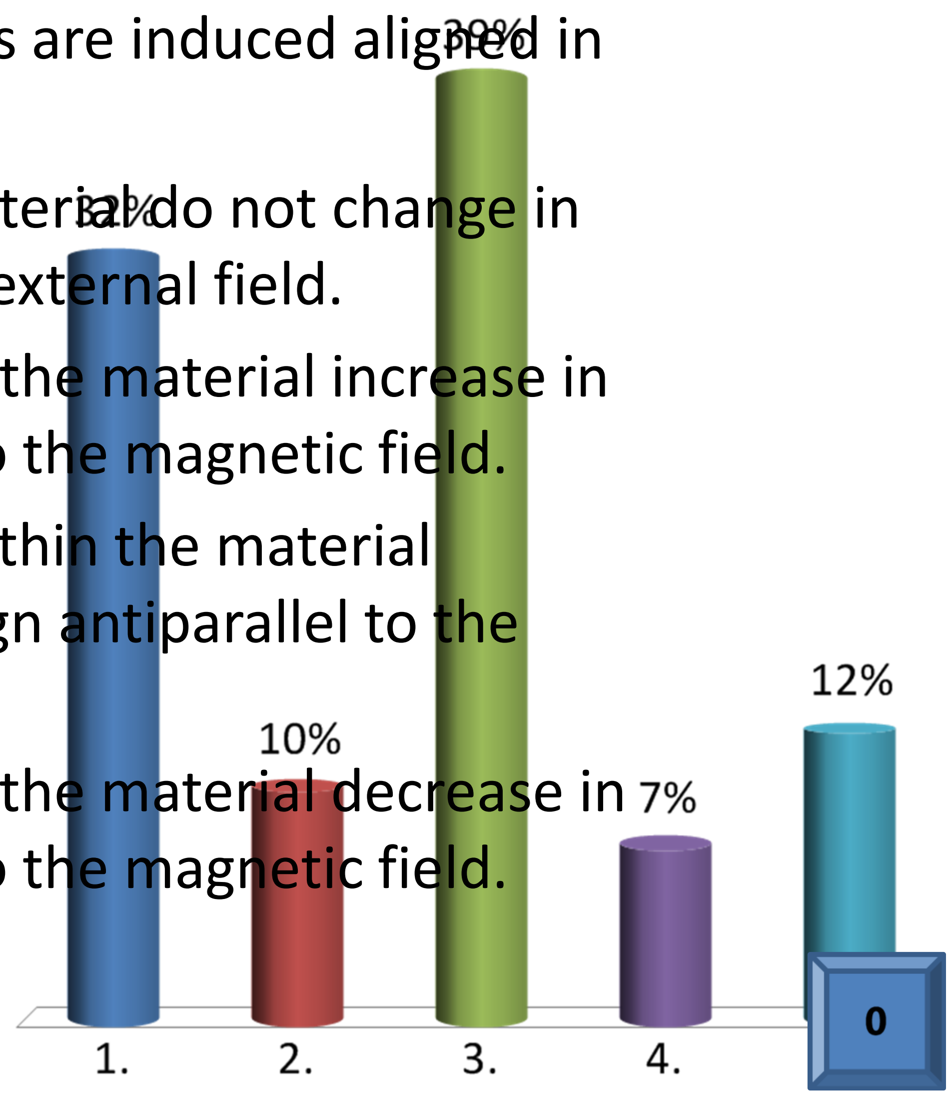
Get more μ up

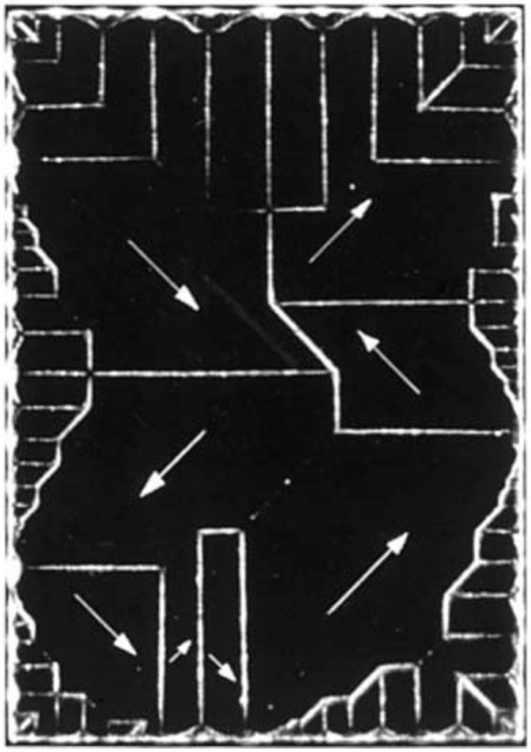
Table 28.1 Magnetic Susceptibilities of Paramagnetic and Diamagnetic Materials at $T = 20°C$

Material	$\chi_m = K_m - 1\ (\times 10^{-5})$
Paramagnetic	
Iron ammonium alum	66
Uranium	40
Platinum	26
Aluminum	2.2
Sodium	0.72
Oxygen gas	0.19
Diamagnetic	
Bismuth	−16.6
Mercury	−2.9
Silver	−2.6
Carbon (diamond)	−2.1
Lead	−1.8
Sodium chloride	−1.4
Copper	−1.0

Which of the following will occur when a diamagnetic material is placed in an external magnetic field?

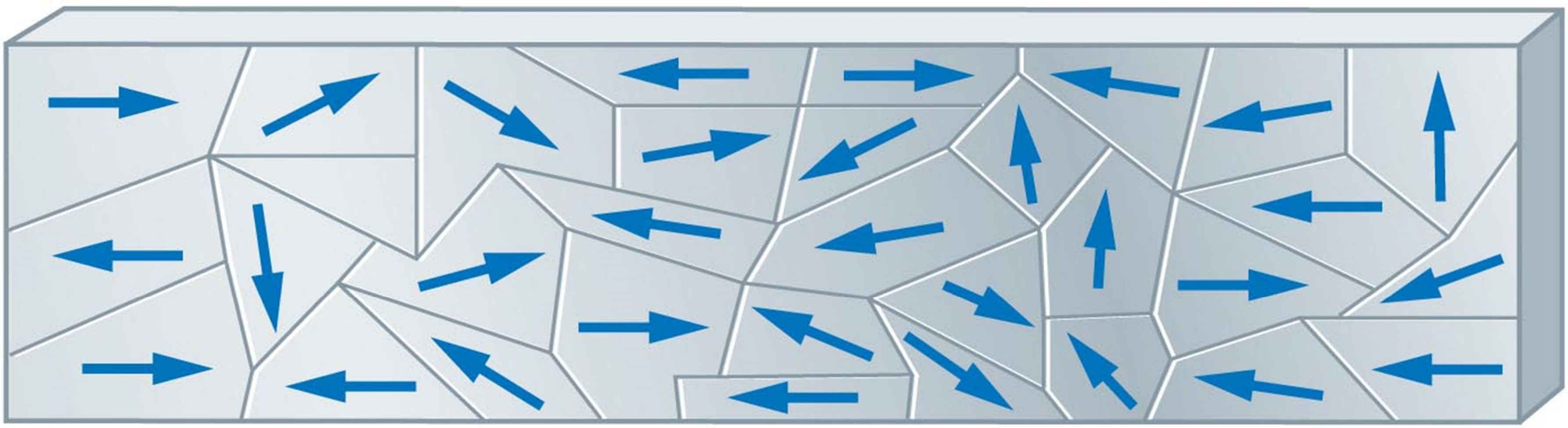
1. Weak magnetic dipole moments are induced aligned in opposition to the applied field.
2. Magnetic dipoles within the material do not change in strength or alignment with the external field.
3. Permanent magnetic dipoles in the material increase in strength as they align parallel to the magnetic field.
4. Permanent magnetic dipoles within the material decrease in strength as they align antiparallel to the external magnetic field.
5. Permanent magnetic dipoles in the material decrease in strength as they align parallel to the magnetic field.





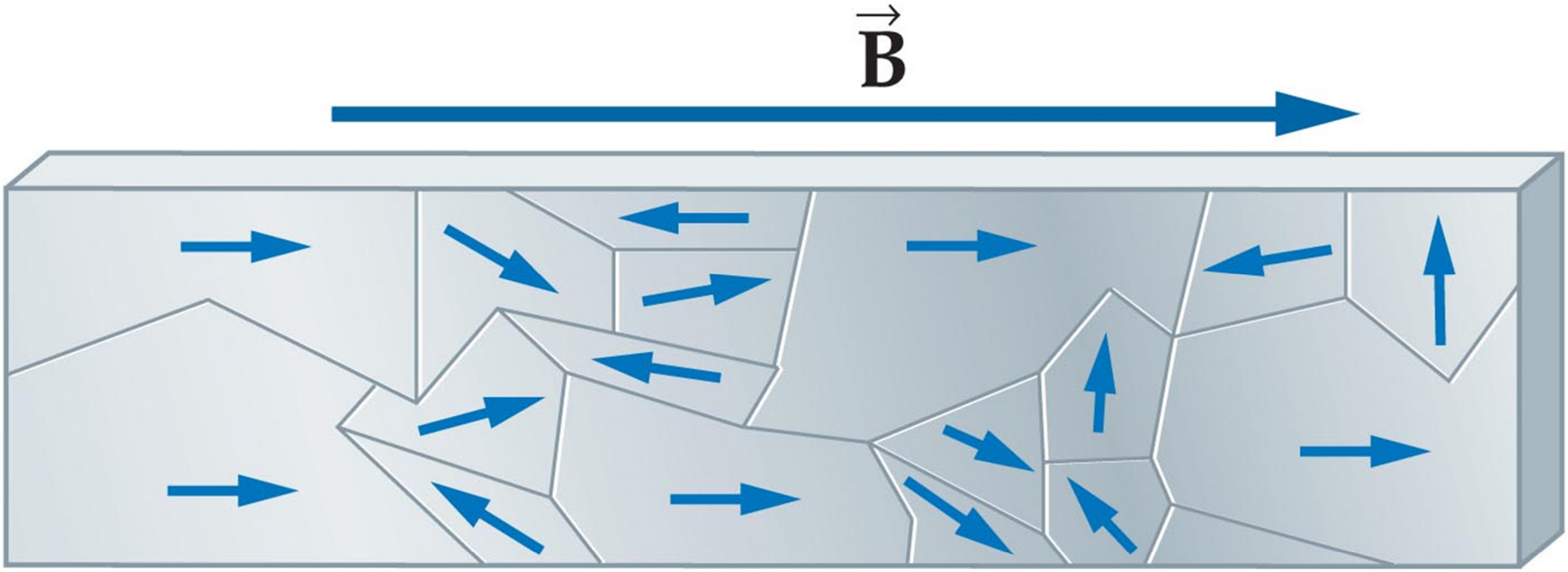
Ferromagnetism

Many regions of $\vec{m}$



(a) Magnetic domains in zero external field

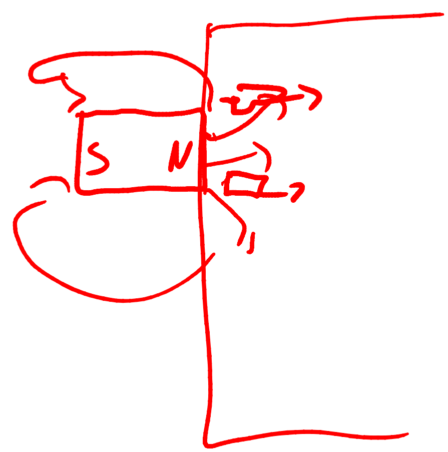
Curie Temp. $T_c = 1043\ K$

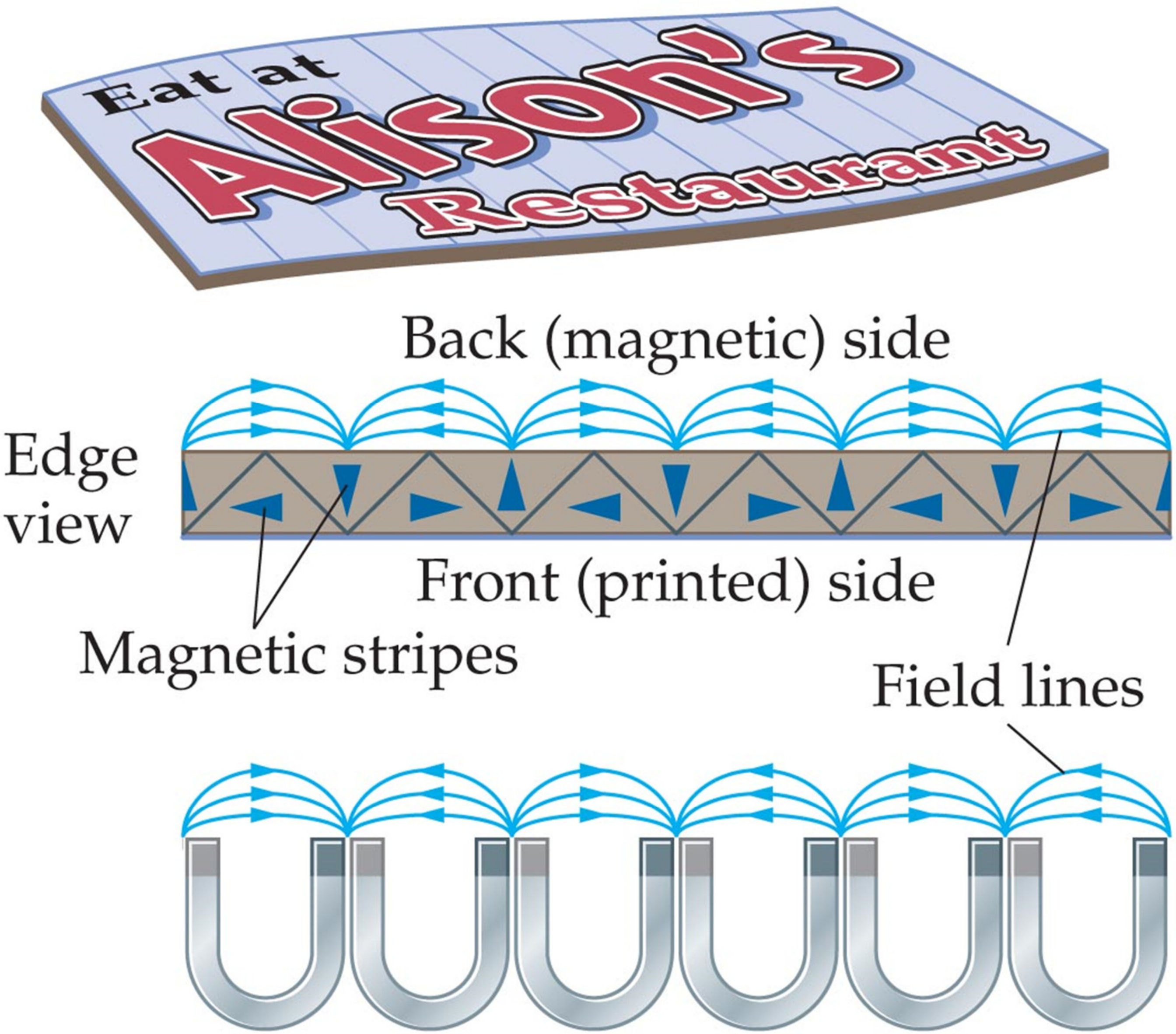


(b) Domains in direction of external magnetic field grow in size

$\vec{M}$ $\longrightarrow$

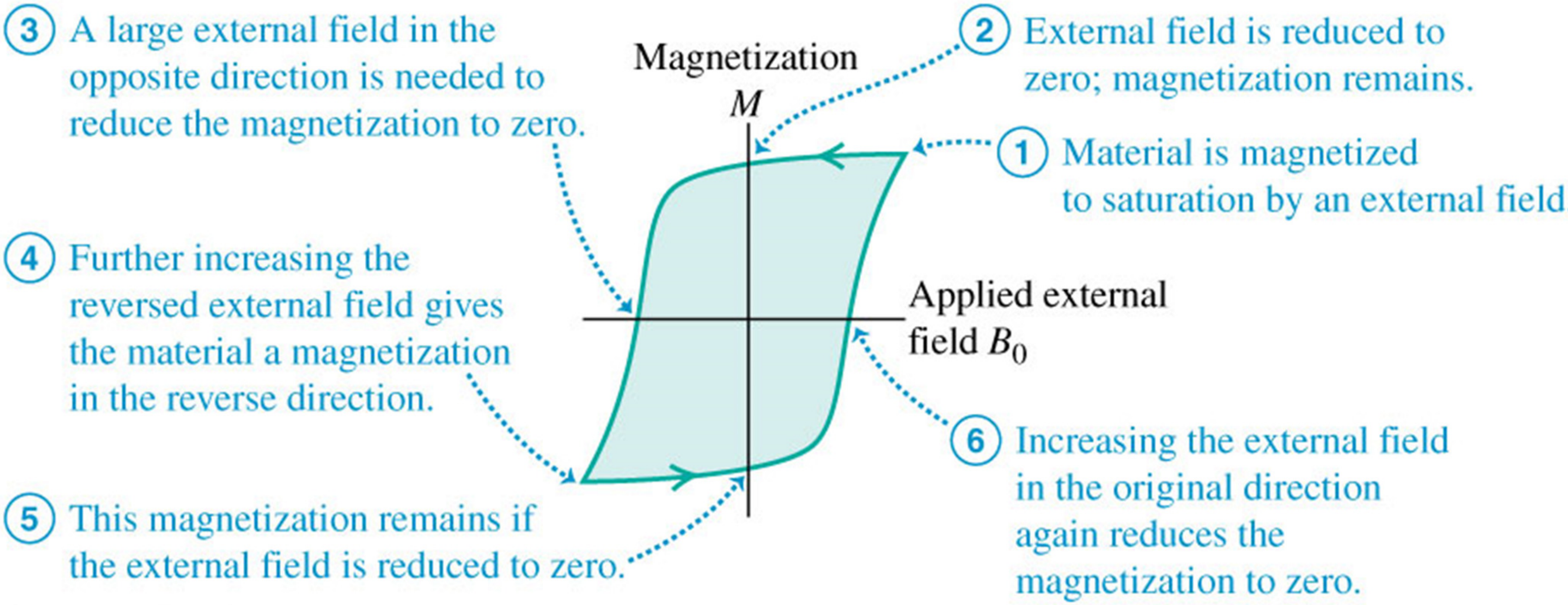
Why do magnets stick to iron?





Magnetic field lines more intense on one side than the other

(a)



3 A large external field in the opposite direction is needed to reduce the magnetization to zero.
Magnetization
M
2 External field is reduced to zero; magnetization remains.
1 Material is magnetized to saturation by an external field.
4 Further increasing the reversed external field gives the material a magnetization in the reverse direction.
Applied external field B_0
6 Increasing the external field in the original direction again reduces the magnetization to zero.
5 This magnetization remains if the external field is reduced to zero.

Right Hand Rule

- Cross Products
  - *e.g.* (**F** = q **v** x **B**), (**F** = I **L** x **B**)

- Magnetic field around a bit of current
  - From Biot-Savart (or maybe a whole wire)

- Magnetic Field from a loop of current
  - Or, vice-versa if using Faraday's Law