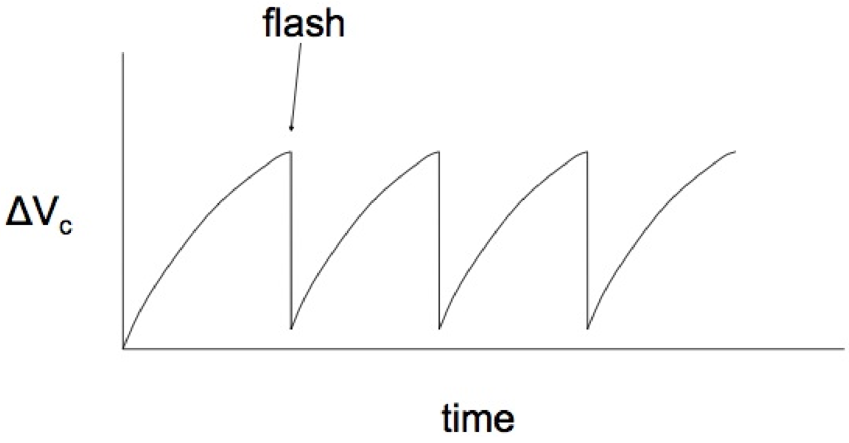
You want to make a flashing circuit that charges a capacitor through a resistor up to a voltage at which a neon bulb discharges once every 5.0 sec. If you have a 10 microfarad capacitor what resistor do you need?

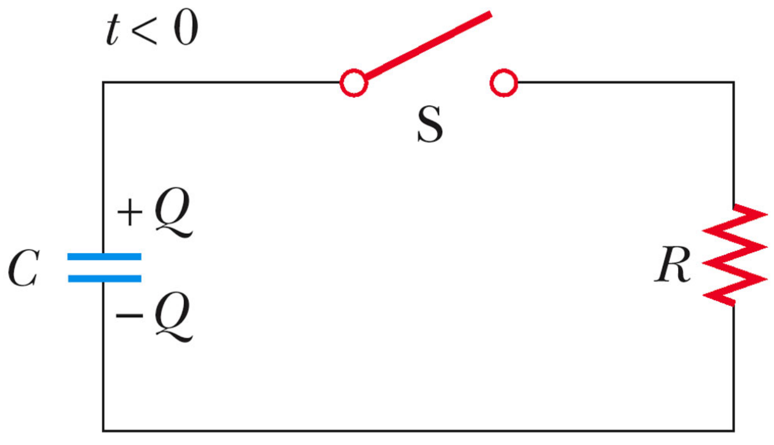


Solution: Have the flash point be equal to 0.63 $\Delta V_{C,max}$

$\tau = RC \rightarrow R = \tau/C = 5s/10^{-5}F = 5 \times 10^5$ Ohms

This is a very big resistance, but 5 seconds is pretty long in "circuit" time

Discharging an RC circuit:

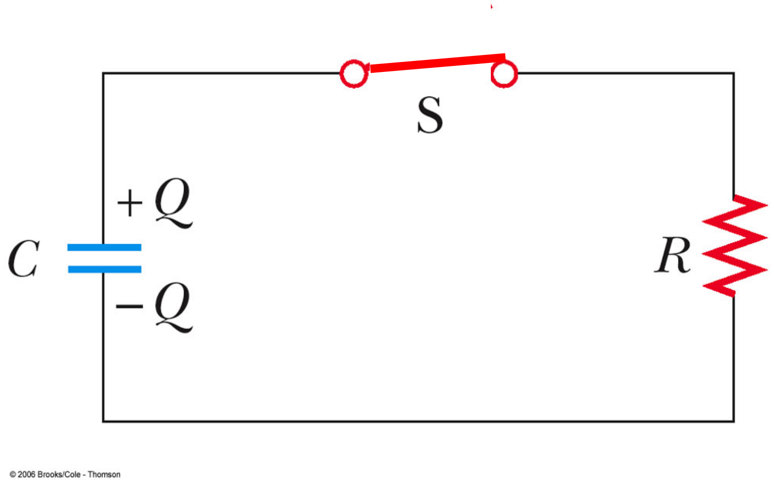


First, disconnect from EMF source.

Q is at maximum value, $Q_{max} = C\varepsilon$

ΔV_C is at maximum value of $\Delta V_{C,max} = \varepsilon$

Discharging an RC circuit:



Then close switch at time t=0.

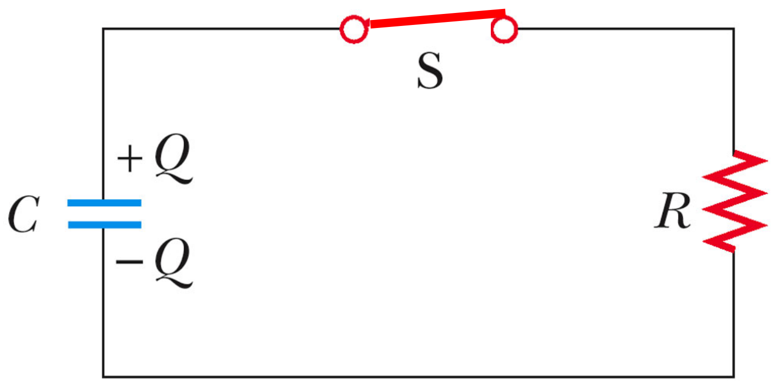
Circuit now has only R and C.

Current will flow from the capacitor, clockwise.

From loop rule: $+\Delta V_C - \Delta V_R = 0$

Note: I made a mistake in lecture: ΔV_C should be positive for travel in clockwise direction, with current

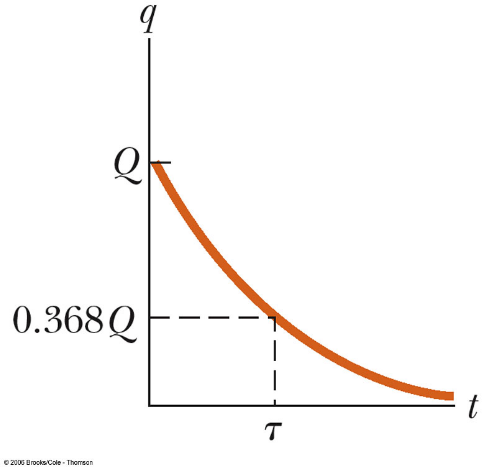
Discharging an RC circuit:

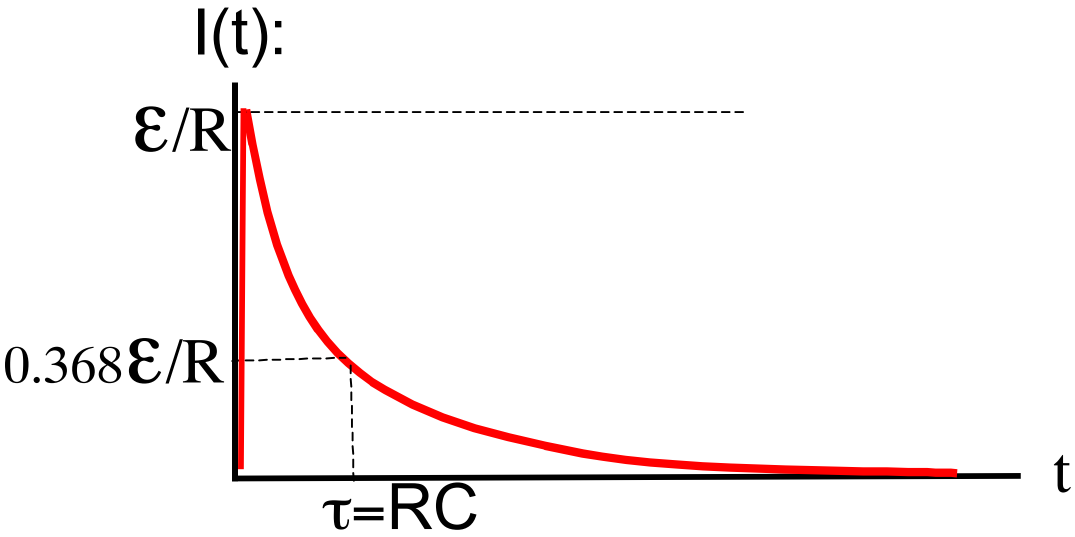


As capacitor discharges, Q and ΔV_C decrease with time.

ΔV_R will track ΔV_C

So I = $\Delta V_R/R$ will jump from 0 to ε/R at t=0, then exponentially decay





	t=0		t → ∞
ΔV_C	ε	$\varepsilon(e^{-(t/\tau)})$	0
Q	$Q_{max}=C\varepsilon$	$C\varepsilon(e^{-(t/\tau)})$	0
ΔV_R	ε	$\varepsilon(e^{-(t/\tau)})$	0
I	ε/R	$\varepsilon/R(e^{-(t/\tau)})$	0

Think about why increasing R and/or C would increase the time to discharge the capacitor:

τ will increase with C because there is more stored charge in the capacitor to unload. τ increases with R because the flow of current is lower.

Given a 12 μF capacitor being discharged through a 2000 Ω resistor. How long does it take for the voltage drop across the resistor (V) to reach 5% of the initial voltage (V_{max})?

Solution: First, calculate τ: $\tau = 2000\Omega * 12\text{x}10^{-6}$ F = 24 ms

Then: $V = V_{max} \exp(-t/\tau)$

$V / V_{max} = \exp(-t/\tau)$

Take natural log (ln) of both sides: $\ln(V/V_0) = -t/\tau$

Solve for t: $t = -\tau * \ln(V/V_{max}) = -0.024 \text{ s } (\ln(0.05)) = 0.072$ sec

(After 1 time constant, I, ΔV_R, ΔV_C, etc. are 37% of their initial values)
(After 3 time constants, I, ΔV_R, ΔV_C, etc. are 5% of their initial values)

Ex. 21.10: Charging a defibrillator

The RC circuit in a defibrillator has $C = 32\mu F$, $R=47\ k\Omega$. The circuitry in the charging system applies 5000 V to the RC circuit to charge it.

A: Find τ, Qmax, I_{max}, q(t) and I(t).

B: Find the energy in the capacitor when it's fully charged.

Answers:

A: $\tau = RC = (47\times10^{3}\Omega)(32\times10^{-6}F\ ) = 1.50\ \text{sec}$

$Q_{max} = C\varepsilon = (32\times10^{-6}F)(5000V) = 0.160\ C$

$I_{max} = \varepsilon/R = (5000V)/(47\times10^{3}\Omega) = 0.106\ A$

$Q(t) = Q_{max}(1 - e^{-t/\tau}) = (0.160C)(1 - e^{-t/1.5\text{sec}})$

$I(t) = I_{max}(e^{-t/\tau}) = (0.106A)(e^{-t/1.5\text{sec}})$

B: $U = {}^{1}/_{2}C(\Delta V)^{2} = {}^{1}/_{2}(32\times10^{-6}F)(5000V)^{2} = 400\ J$

Energy stored in the capacitor

Discharging a capacitor:

$U = Q^2/2C = Q_{max}{}^2/2C\ e\hat{}(-2t/RC)$

In-lecture demo: Charging and discharging an RC circuit

Brightness of light bulb (tracking current) exponentially decays both when charging & discharging the capacitor bank

21.10: The atmosphere as a conductor: lightning/sparks

Noaa.gov

Air is normally a good insulator, but it’s possible for current to exist in air (lightning, sparks)

When there’s a strong electric field, the effective resistivity of the air drops….

School-for-champions.com

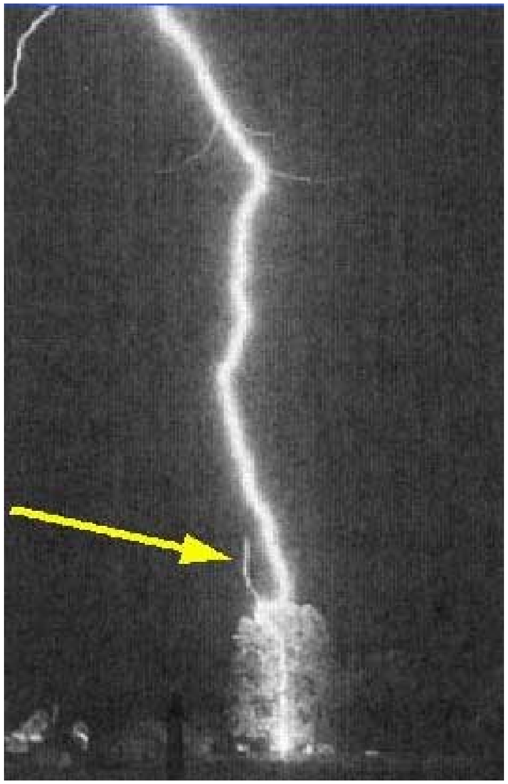
1. Molecules get ionized (e.g., by cosmic rays)
2. If a weak (strong) E-field is present, they accelerate away from each other slowly (rapidly)
3. For a WEAK E-field. The ions gently collide with other ions, recombine.
4. For a STRONG E-field: Ions collide violently. Electrons with sufficient kinetic energy can ionize other molecules.
5. More freed electrons become accelerated
6. Rapid increase in number of free electrons -- conductivity of the air is increased -- a current can be established

Lightning: Stepped leader: 200-300 A

Then, once connection between stepped leader and return stroke is made: Current rises to ~50000 A (typ. value).

Typical ΔV between cloud and ground: $\sim 10^{5-7}$ V

Typical POWER delivered in a lightning strike: many billions of Watts



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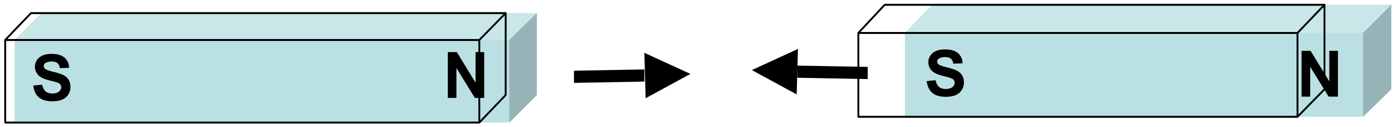
Ch. 22: Magnetism

Bar magnets.
Planetary magnetic fields.
Forces on moving charges.
Electrical motors
    (electrical energy →mechanical energy)
Generators (mechanical → electrical energy)
Magnetic data storage: magnetic tapes, computer drives
MRI (magnetic resonance imaging)

A magnet has two poles (magnetic dipole)

North–South

Opposite poles attract



Like poles repel

stable

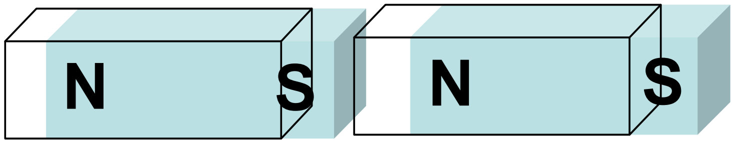
unstable

No magnetic monopoles

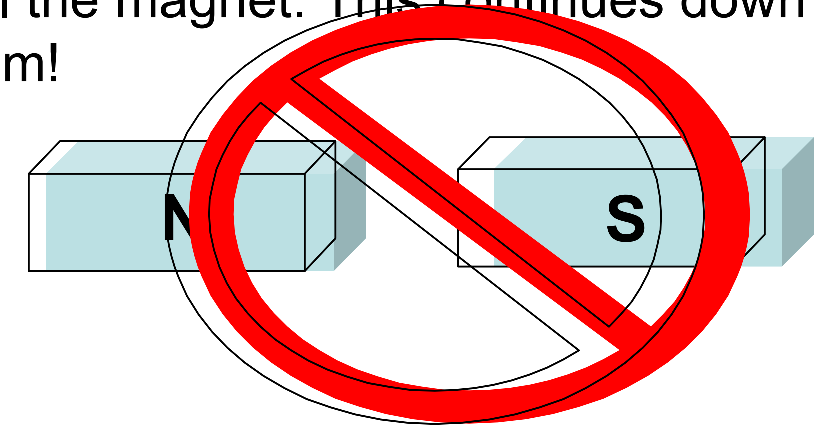
No *magnetic monopoles* are found (i.e. there is no magnetic equivalent of charge).

If you cut a magnetic bar in two….

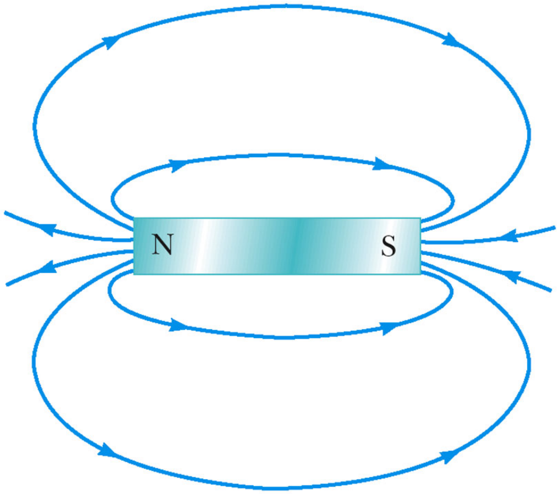
You get two smaller magnets:



You do not get separate N & S magnetic charges -- no matter how small the magnet. This continues down to the scale of a single atom!



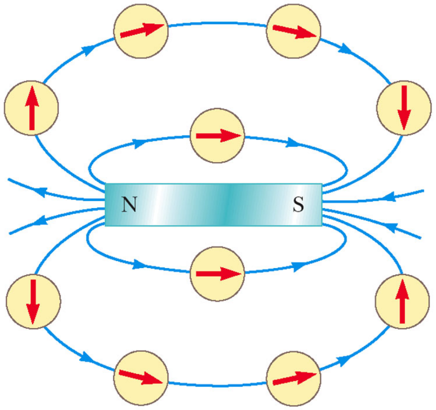
Magnetic Field Lines



B-field lines flow from N to S pole.

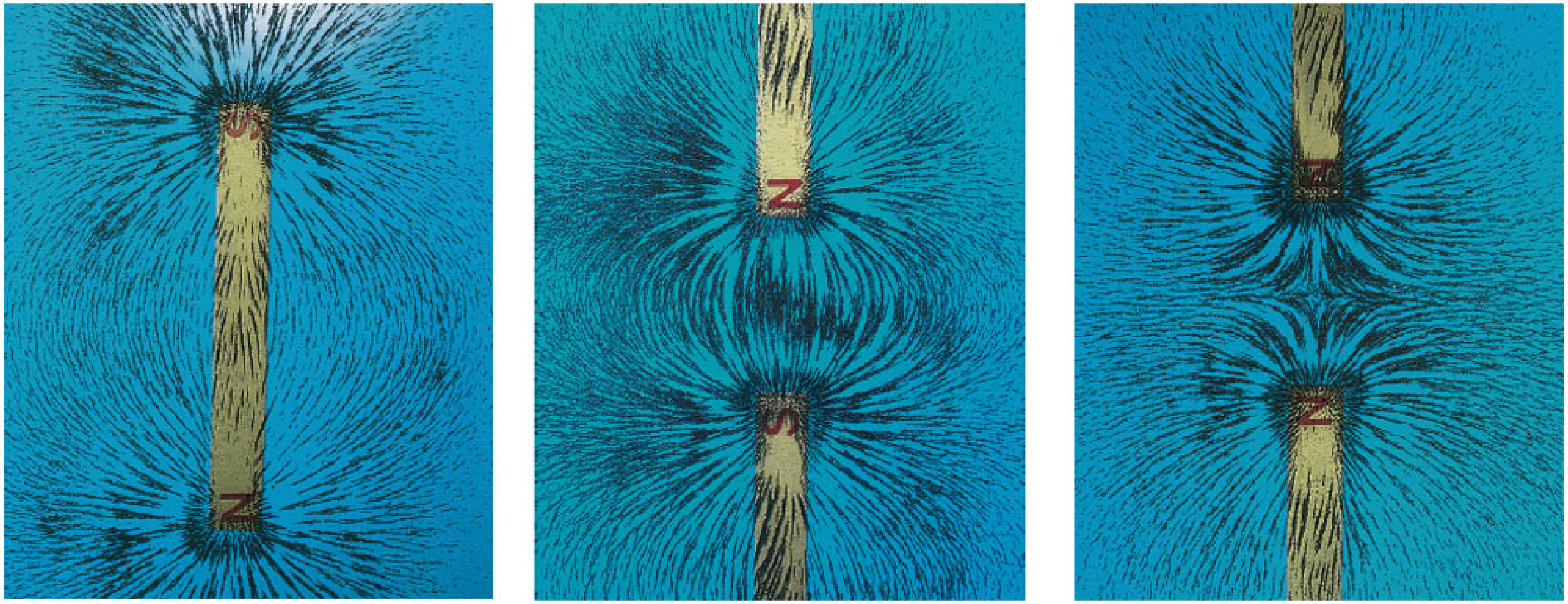
Can be traced out using a compass

When placed in external magnetic fields, magnetic dipoles (e.g., compass needle) orient themselves parallel to B-field lines.



Vector $\vec{\mathbf{B}}$ Direction is given by the direction a *north pole* of a compass needle points in that location

Magnetic Field Lines



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Can also be traced out with Fe filings

In-lecture demo: The 3-D magnetic field viewer

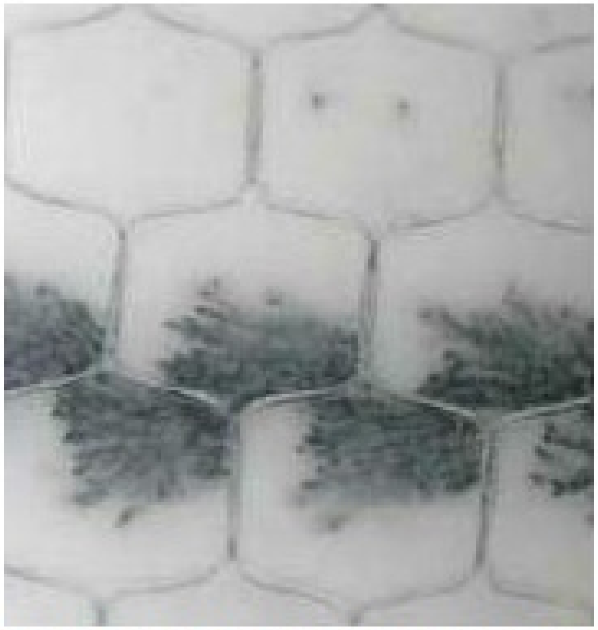
Soft/Hard Magnetic materials

Soft magnetic materials (e.g., Fe): Easily magnetized, but can lose magnetization easily

Hard materials more difficult to magnetize, but retain magnetism for a long time (“permanent magnet”)
Ex.: metal alloys such as Alnico (Aluminum, Nickel, Cobalt)

Ferromagnetic materials: materials which can become magnetized and can be attracted to other magnets

Magna-doodle



Close-up of the honeycombed structure of the display

The tip of the magnetic pen

Ferromagnetic fluids

“Leaping ferrofluid demonstration:”
http://www.youtube.com/watch?v=Rg9xSLdXKXk

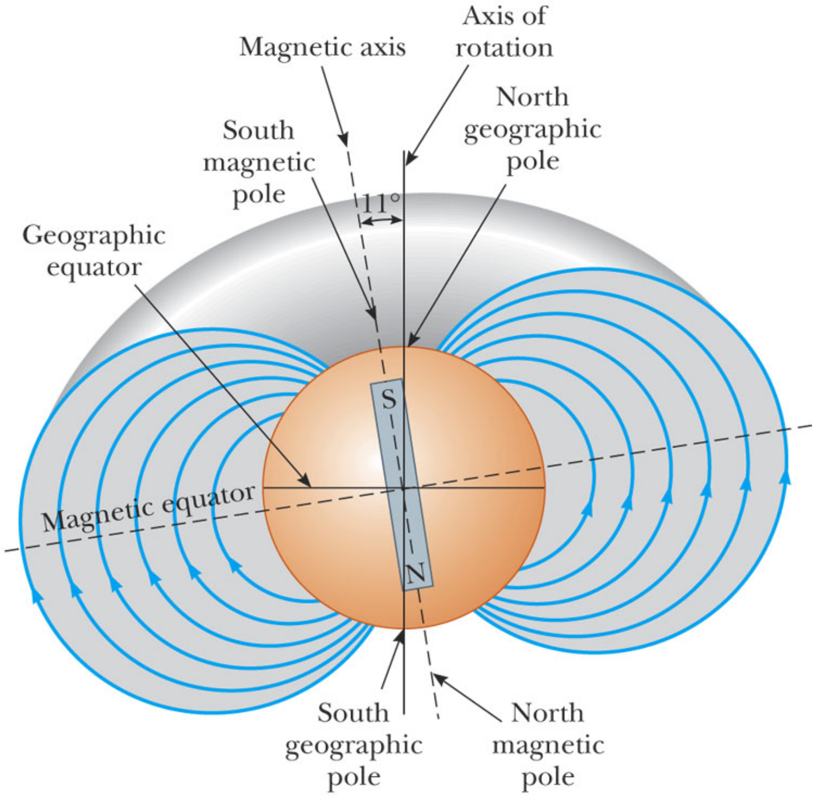
Sachiko Kodama, Yasushi Miyajima "Morpho Towers -- Two Stand”:
http://www.youtube.com/watch?v=me5Zzm2TXh4
(see also sachikokodama.com)

Ferrofluid: how it works:
http://www.youtube.com/watch?v=PvtUt02zVAs

Ferrofluid on the track of a Magnetized Meatgrinder
http://www.youtube.com/watch?v=OE2pB1pyZN0

The N pole of a magnet got its name because it points roughly towards Earth's *north* pole. It points towards NE Canada, since that's the Earth's South magnetic pole.

Earth’s B-field is actually upside down, and the dipole axis is offset slightly (~11°) from Earth's rotation axis.



Earth's magnetic field has a vertical component at the surface:
Points upwards in southern hemisphere.
Points downwards in northern hemisphere.

Parallel to surface at magnetic equator.

Source: Current/ convection in hot Fe liquid core