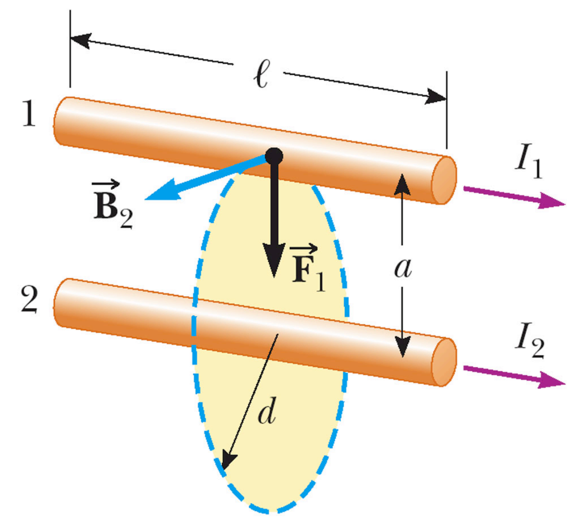
# 19.8: Magnetic force between two parallel conductors

Assume $I_1$ and $I_2$ are in the same direction.

Wire 2 produces a B-field $\vec{B}_2$; at r=d, $|\vec{B}_2|$ is $\mu_0 I_2/2\pi d$

Wire 1 experiences a magnetic force $F_1$ in the presence of $\vec{B}_2$.
(Notation: $F_1$ = force experienced BY wire 1)

$F_1 = B_2 I_1 \ell = (\mu_0 I_2/2\pi d) I_1 \ell$






Rewrite in terms of force per unit length:

$$\frac{F}{\ell} = \frac{\mu_o I_1 I_2}{2 \pi d}$$

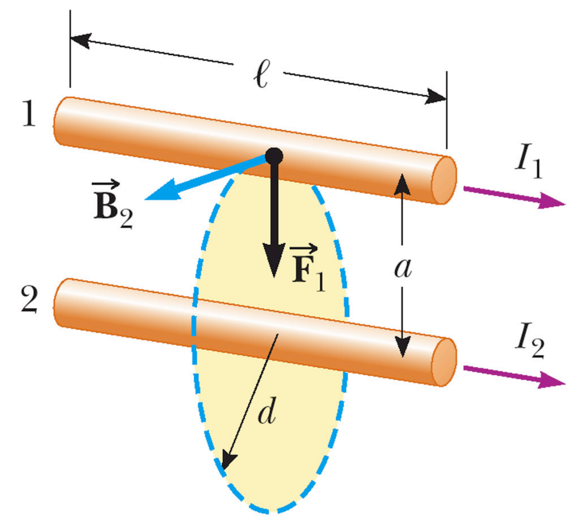
# 19.8: Magnetic force between two parallel conductors

Note that $\vec{F}_1$ is downward (attractive).

$\vec{F}_2$ on wire 2 is equal to and opposite to $\vec{F}_1$.

Parallel wires carrying currents in the same direction ATTRACT each other.

Parallel wires carrying currents in opposite directions REPEL each other.

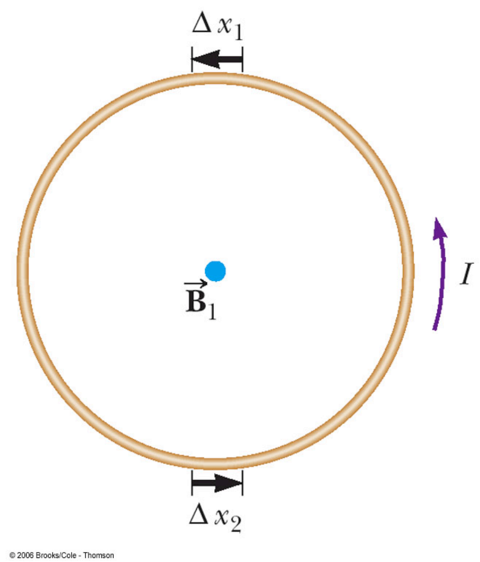




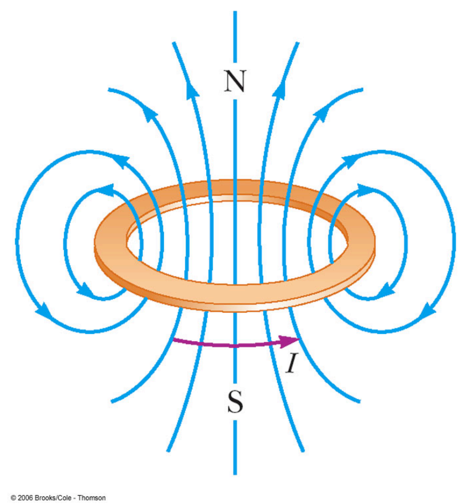

$$\frac{F}{\ell} = \frac{\mu_o I_1 I_2}{2 \pi d}$$

# 19.9: Magnetic fields of current loops and solenoids

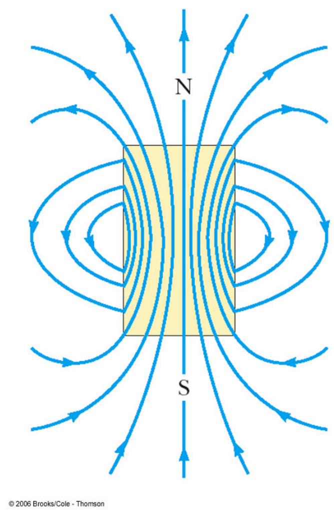
Consider a loop of current: What is the net $\vec{B}$ like at the center of the loop?




Net effect:

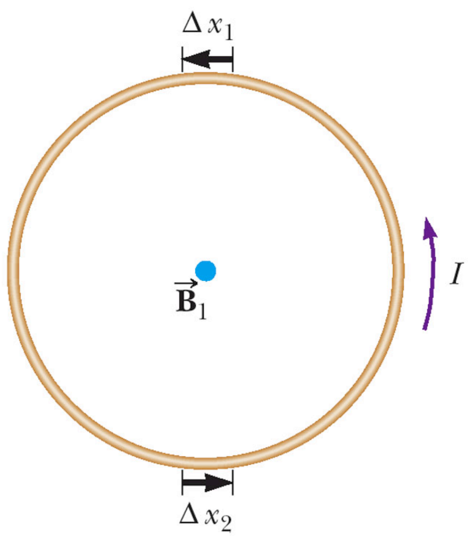



Similar to a magnetic dipole



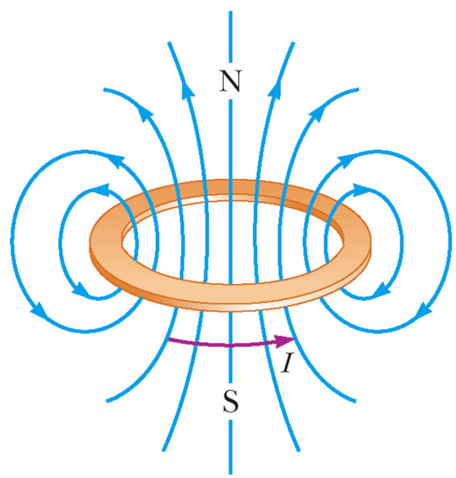
# 19.9: Magnetic fields of current loops and solenoids

Consider a loop of current: What is the net $\vec{B}$ like at the center of the loop?






Net effect:





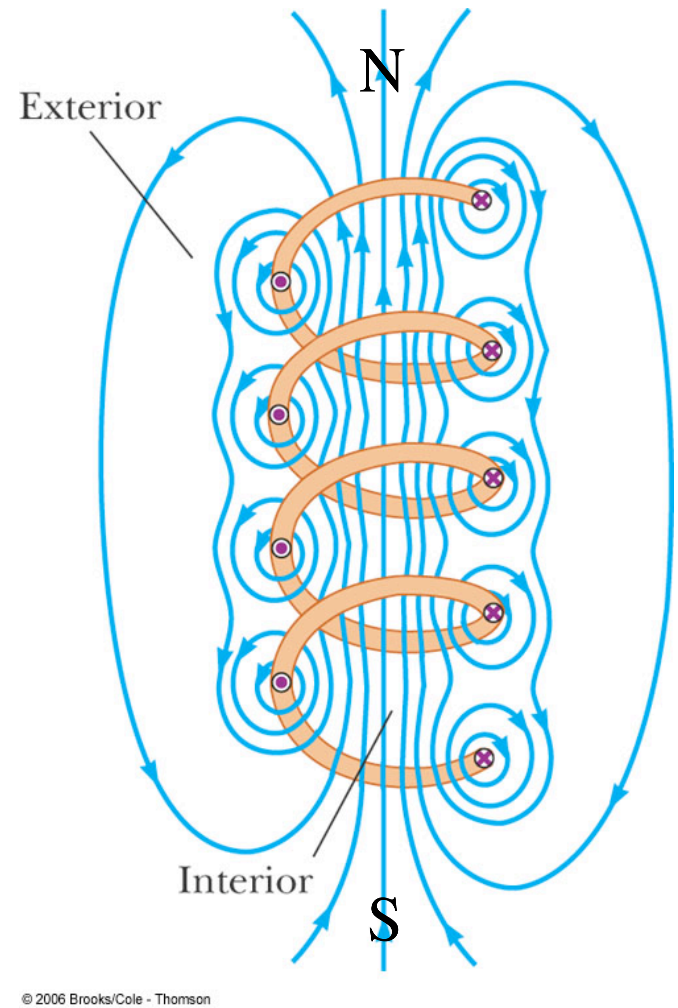

B at center of loop of radius R can be derived using calculus, and is

$B = \mu_0 I / 2R$

# Stack of current loops = solenoid

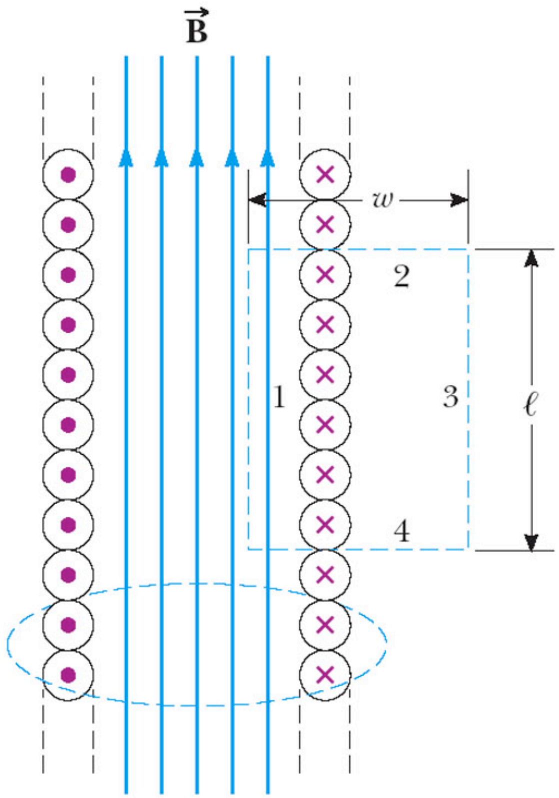
When the loop are spaced together tightly enough, the B-field inside is strong and rather uniform, and B-field outside is essentially negligible.

Commonly used in electromagnets, devices used to convert electrical current to magnetic field.



# B-field in the center of a solenoid

Use Ampere's Law; choose a closed loop as follows:






Only segment 1 contributes:
$B_{||}\Delta\ell = 0$ for other segments.

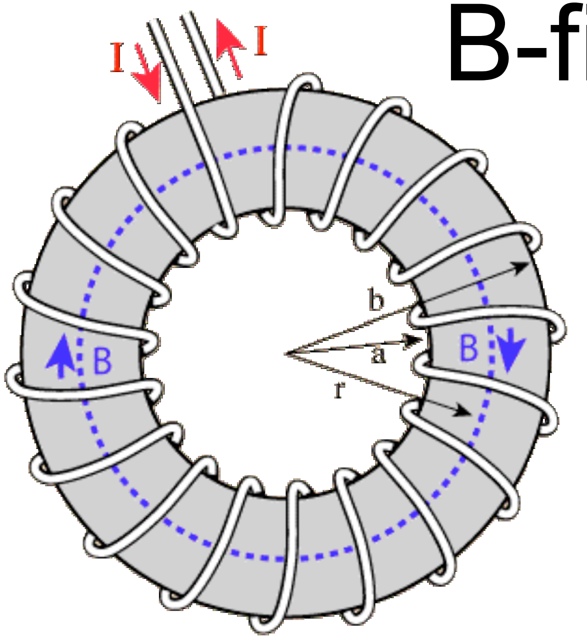
$BL = \mu_0(NI)$

$B = \mu_0 I\,(N/L) = \mu_0 In \quad (n=N/L)$

Example: An electromagnet consists of 100 turns of wire, and the length is 3.0 cm. The wire carries 20 Amps of current. What's the B-field at the center of the magnet?

$B = \mu_0 I\ (N/L) = 4\pi \times 10^{-7}\ T\ m / A\ *\ 20\ A\ (100/0.03m) = 0.084\ A$

# B-field of a toroid

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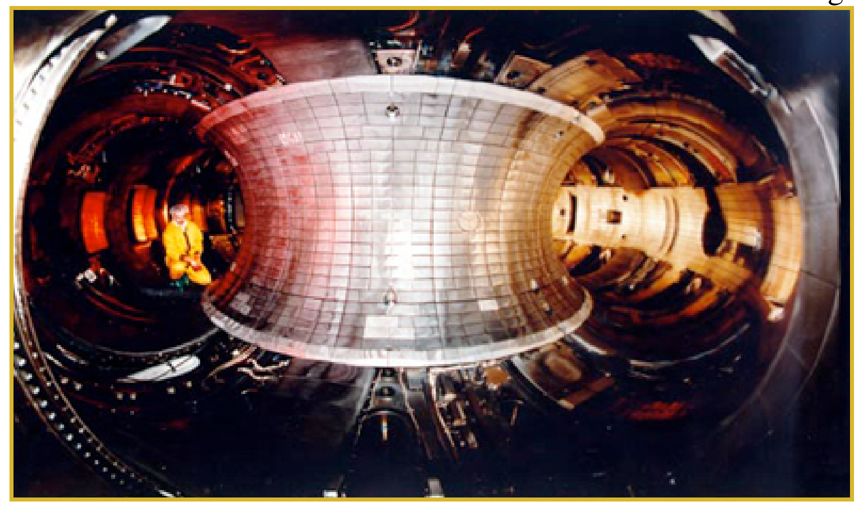


Tokamak: used for fusion energy research

$\Sigma B_{||} \Delta \ell = B \, 2\pi r$

enclosed current on blue line = $\mu_0$ N I

**$B = \mu_0 N I / 2\pi r$**

B-field higher towards inner radius (not perfectly uniform), but uniform along each radius

# 19.10 Magnetic Domains

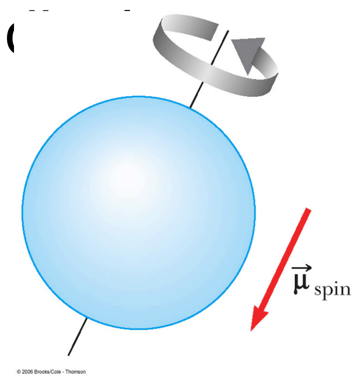
Magnetic materials owe their properties to magnetic dipole moments of electrons in atoms

Classical model for electrons in atoms:

1.Orbital motion of electron: like a loop current (but B-field produced by 1 electron can be cancelled out by an oppositely revolving electron in the same atom)

2. “spin” of individual electrons produces much stronger B-field: each electron itself acts like a magnetic

Ferromagnetic materials: B-field from spins do not cancel out completely….

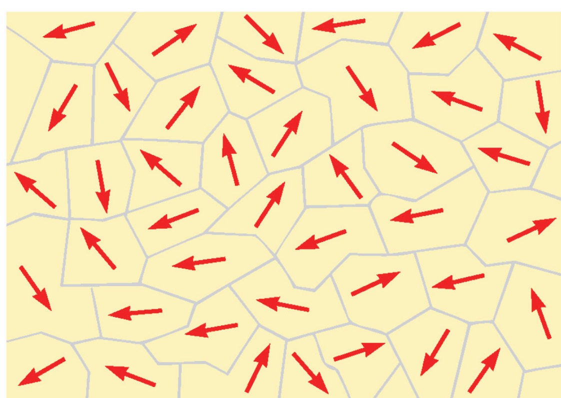


# Magnetic Domains

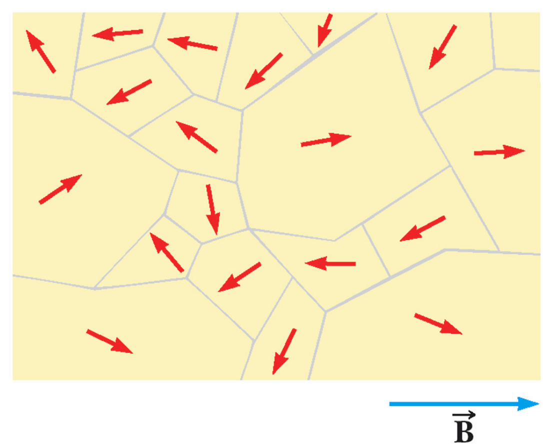
Magnetic domains ($10^{-4}$ - $10^{-1}$ cm): Each domain has a substantial fraction of atoms with magnetic moments coupled. They're separated by domain boundaries.

Ferromagnetic materials (Fe, Co, Ni) have these domains

Randomly oriented, but when an external $\vec{B}$ is applied, domains tend to align with magnetic field; domain boundaries adjust accordingly.







Result: material produces its own **internal** $\vec{B}$

($\vec{B}_{net} = \vec{B}_{external} + \vec{B}_{internal}$)

Re-cap:

Soft magnetic materials (e.g. Fe): Easily magnetized in presence of external B, but doesn't retain magnetization for long. Used as cores for electromagnets.

When external B is turned off, thermal agitation returns dipoles to random orientations

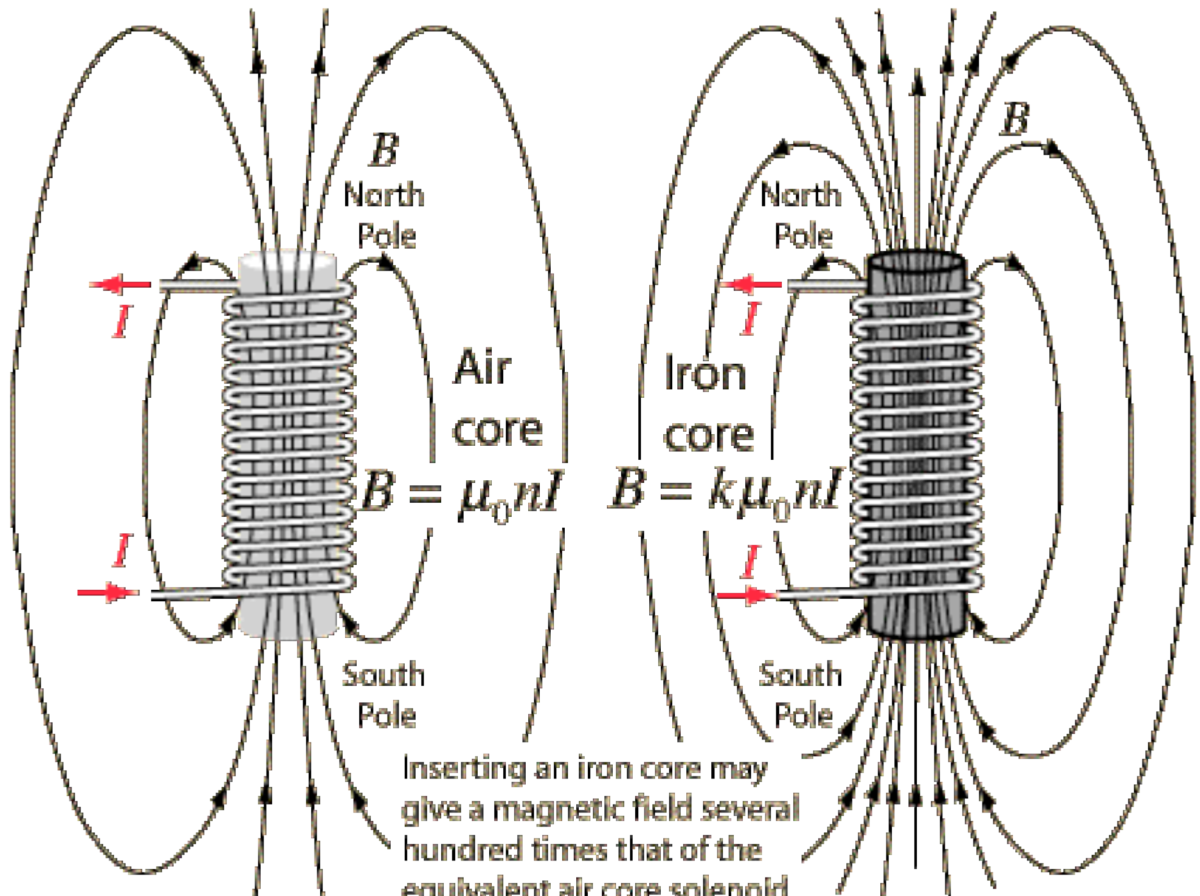
Hard magnetic materials (e.g. metal alloys: Alnico (Aluminum, Nickel, Cobalt)): Harder to magnetize (requires higher $\vec{B}_{external}$) but retains the magnetization for a long time. Used as permanent magnets.

# Air-core vs Fe-core solenoid electromagnets

Total B-field is much larger with an Fe-core

$B = \mu \, I \, n$

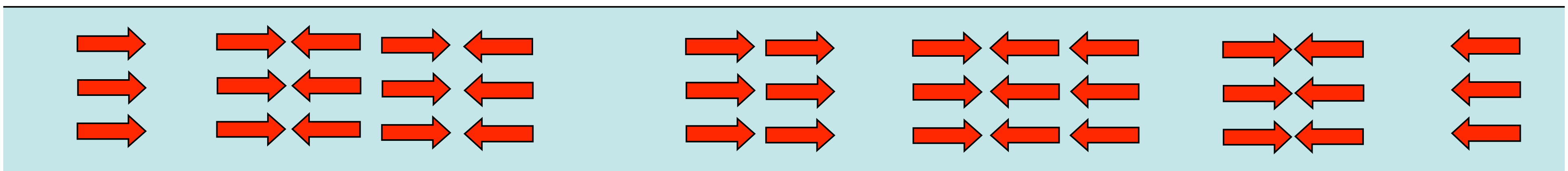
$\mu / \mu_0 \sim 1000$



# Magnetic recording

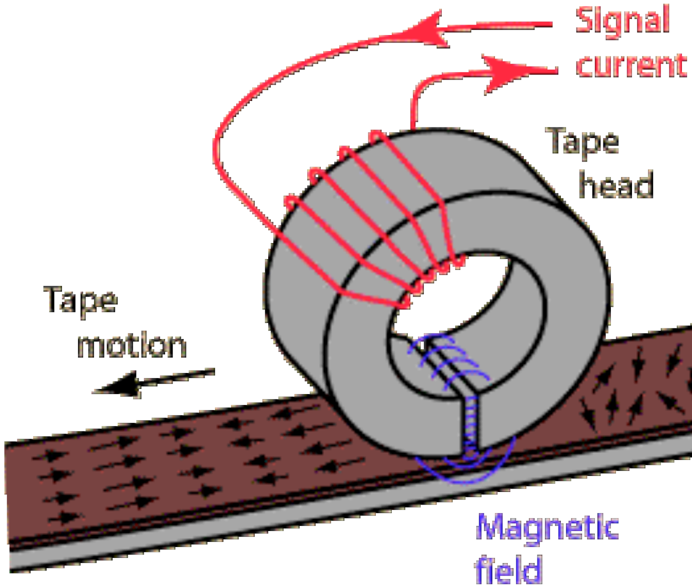
computer drives; cassette/VCR tapes; credit card strips

Information coded in the orientation of magnetic domains



Magnetization can be read on playback to generate a voltage signal

Info can be erased by applying VERY STRONG B-field to re-align all domains.



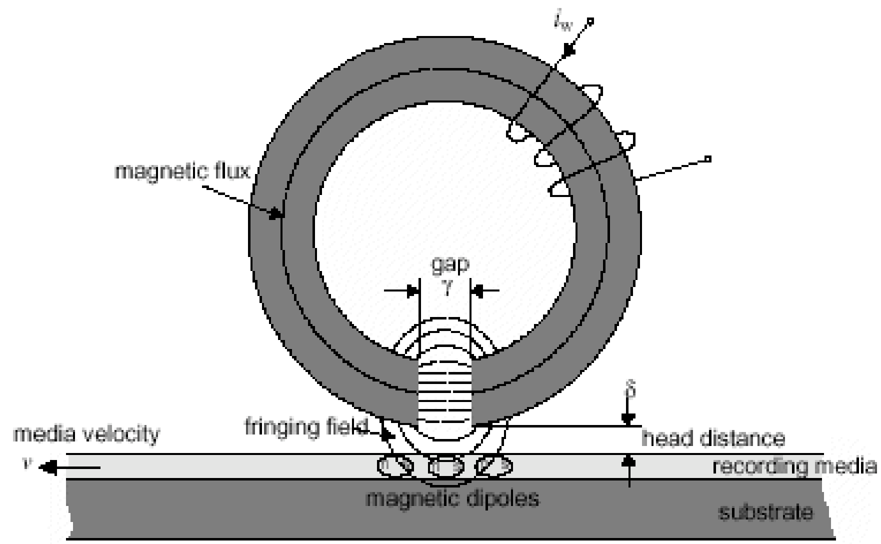

Iron oxide

$Fe_2O_3$ $Fe_3O_4$

Chromium dioxide

$CrO_2$

Metal powder




**Basic Ring read/write head.**