# Magnetism in  material

## Agenda today

1. Paramagnetism and dimagnetism
2. Magnetization and Magnetic susceptibility
3. Ferromagnetism
4. Displacement current

## Paramagnetism

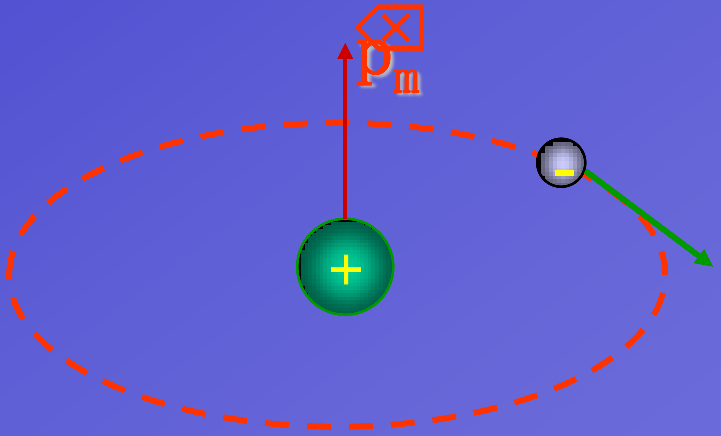
## (顺磁性）

## Atom magnetic moment

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

$$I = \frac{q}{T} = \frac{qv}{2\pi r}$$

$$m = IS = \frac{1}{2}qvr = \frac{e}{2m_e}\mathrm{I}$$

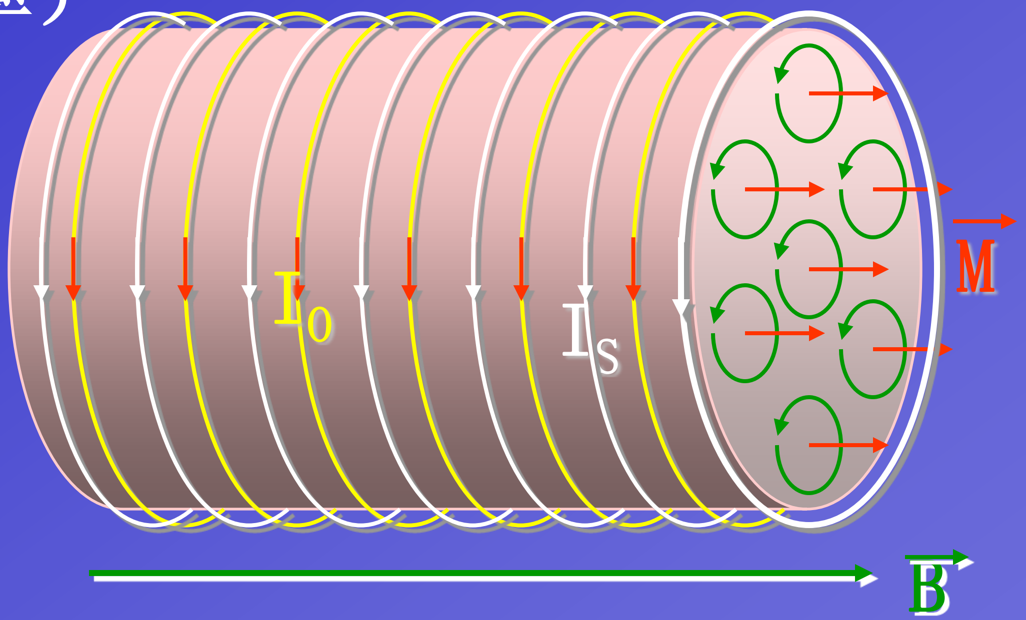


# Magnetization and Magnetic Susceptibility

（磁化强度与磁导率）

In magnetic field, the direction of magnetic dipoles

have the tendency to align to applied field



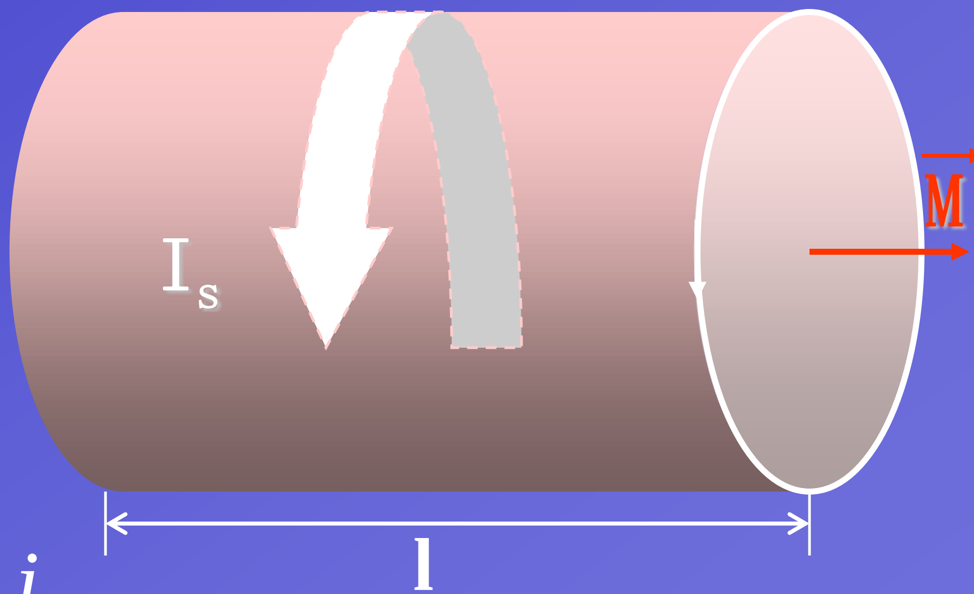

Magnetization

$$\vec{M} = \frac{\sum \vec{p}_m}{\Delta V}$$

The result of magnetization is equivalent to a current on the surface of the material, called an amperian current（表面电流）

**Density of Amperian current**

Amperian current per unit length




$$\left|\vec{M}\right| = \frac{\left|\sum \vec{p}_m\right|}{\Delta V} = \frac{j_s l S}{l S} = j_s$$

By ampere’s law

The magnetic field produced by amperian current is:

$$B_m = \mu_0 j = \mu_0 M$$

The magnetic field in the material is

$$B = B_{app} + B_m = B_{app} + \mu_0 M$$

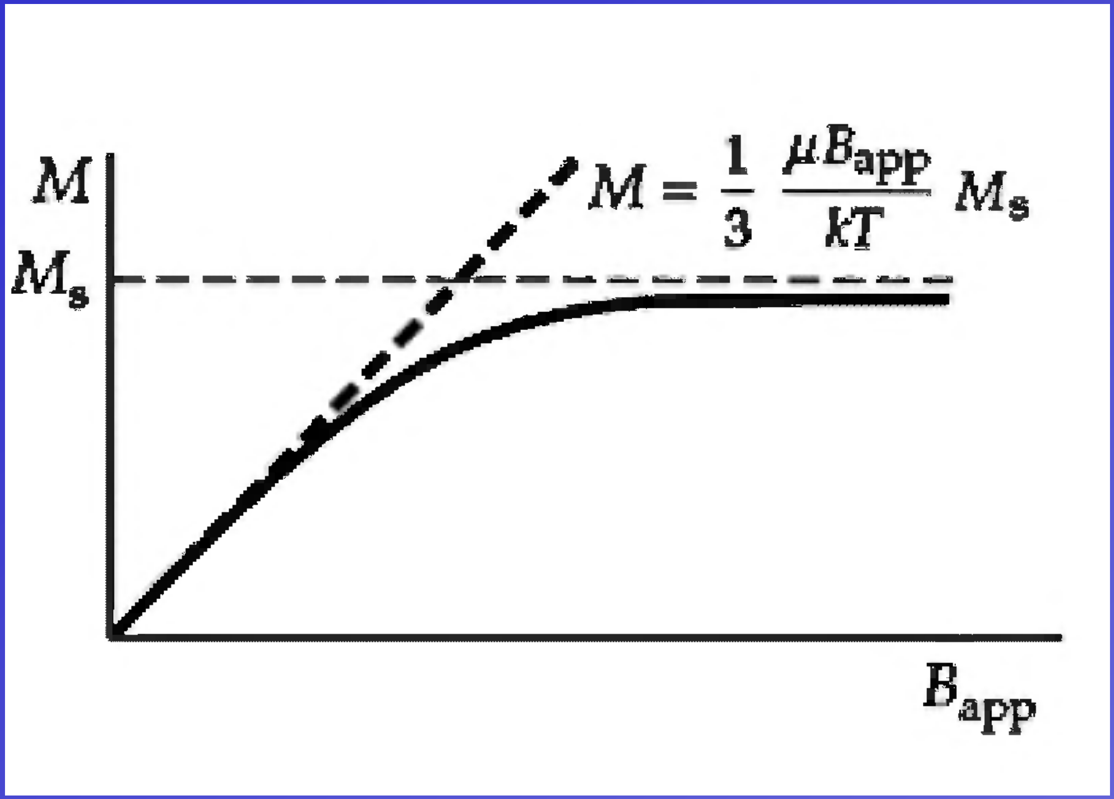
The magnetization is proportional to the applied field

$$M=\chi\frac{B_{app}}{\mu_0}=\chi H_{app}$$

**Where** χ is called the susceptibility of the material （磁化率）and H is called the magnetic field intensity of the applied field.（磁场强度）

$$B=(1+\chi)\mu_0 H=\mu H$$

**Where μ  is called the permeability of the material**




$$M = C\frac{B_{app}}{T}$$

居里定律

For paramagnetic material: $B>B_{app}$ $\chi>0$

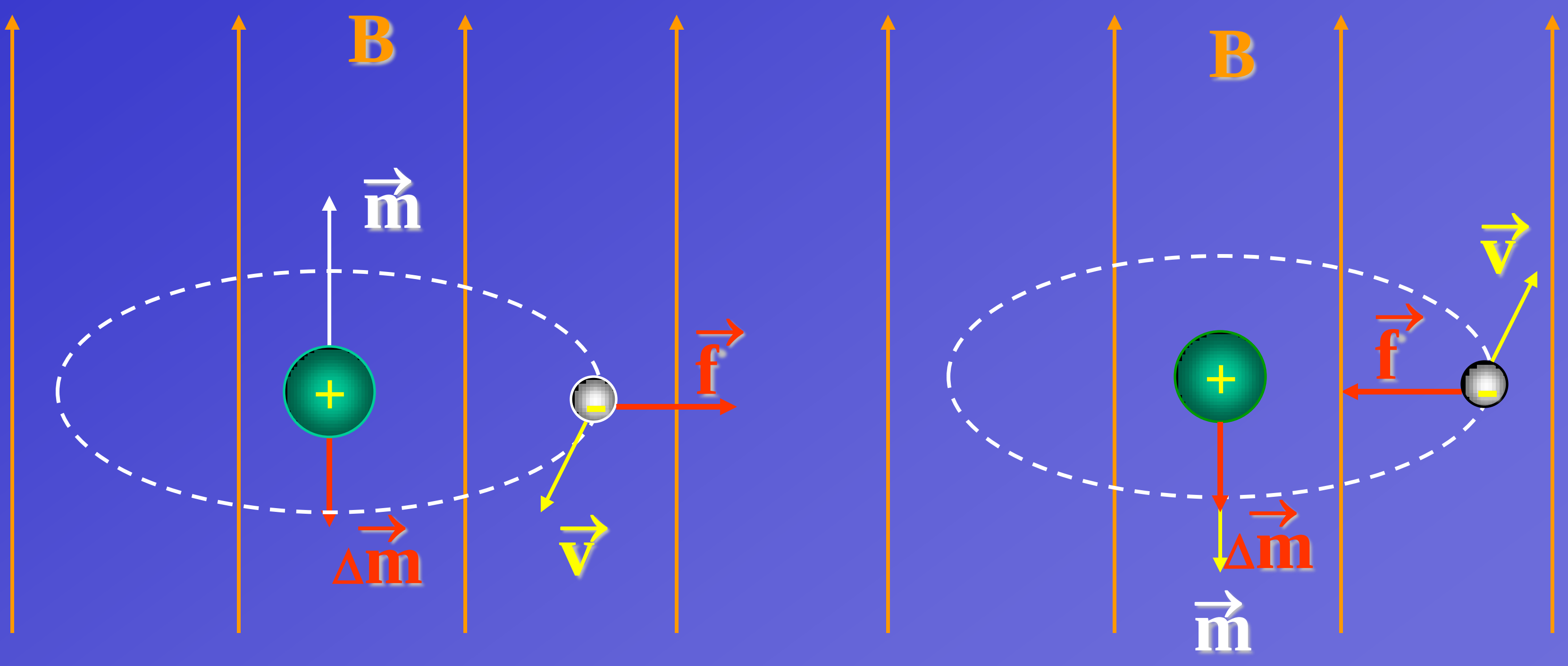
For diamagnetic material: $B<B_{app}$ $\chi<0$

Ampere's law for magnetic material

$$\boxed{\oint_L \vec{H}\cdot d\vec{l} = \sum I}$$

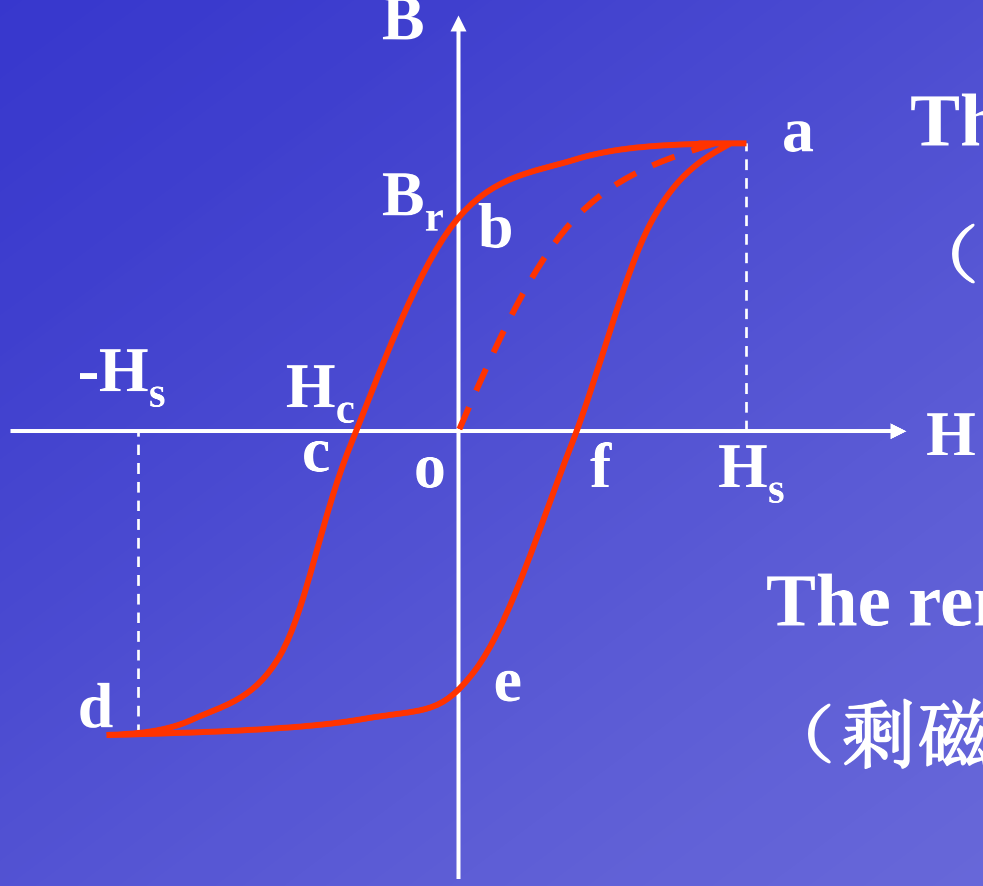
Where I is the conducting current through the loop

# Diamagnetic material 抗磁性




For atoms have no net magnetic moment

# Ferromagnetic material




The hysteresis loop

（磁滞回线）

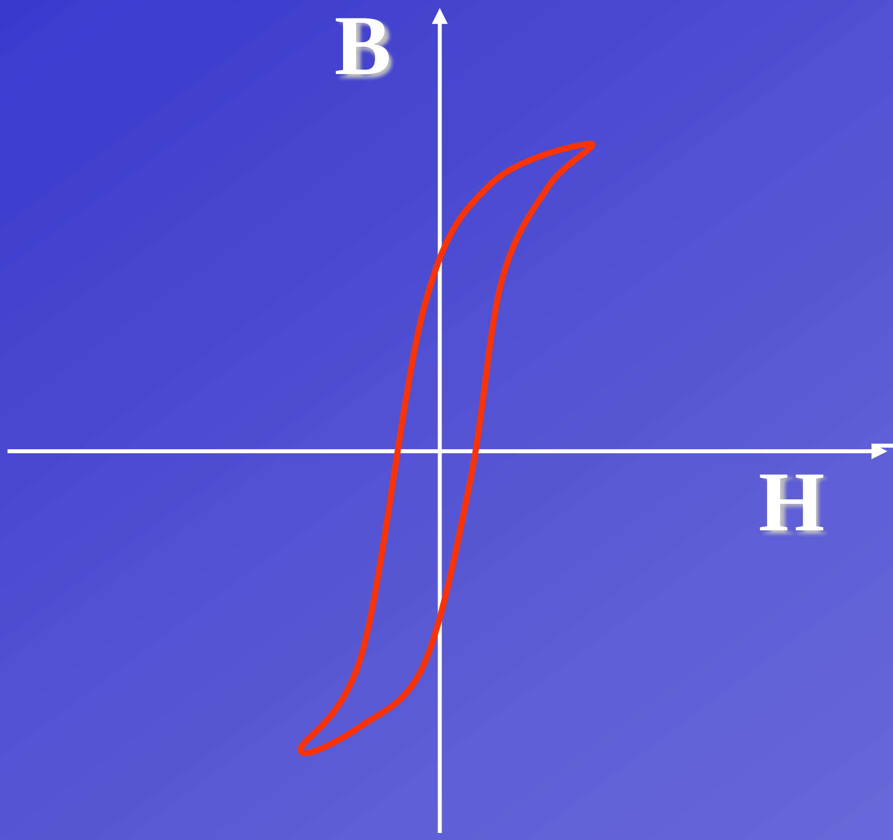
The remnant induction

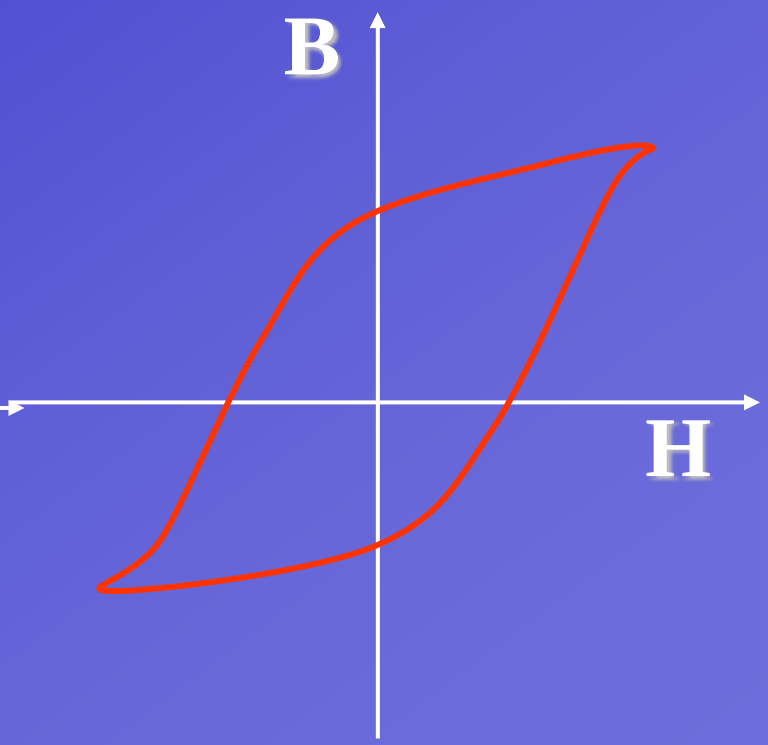
（剩磁）

Coercive force（矫顽力）

Soft magnetic material

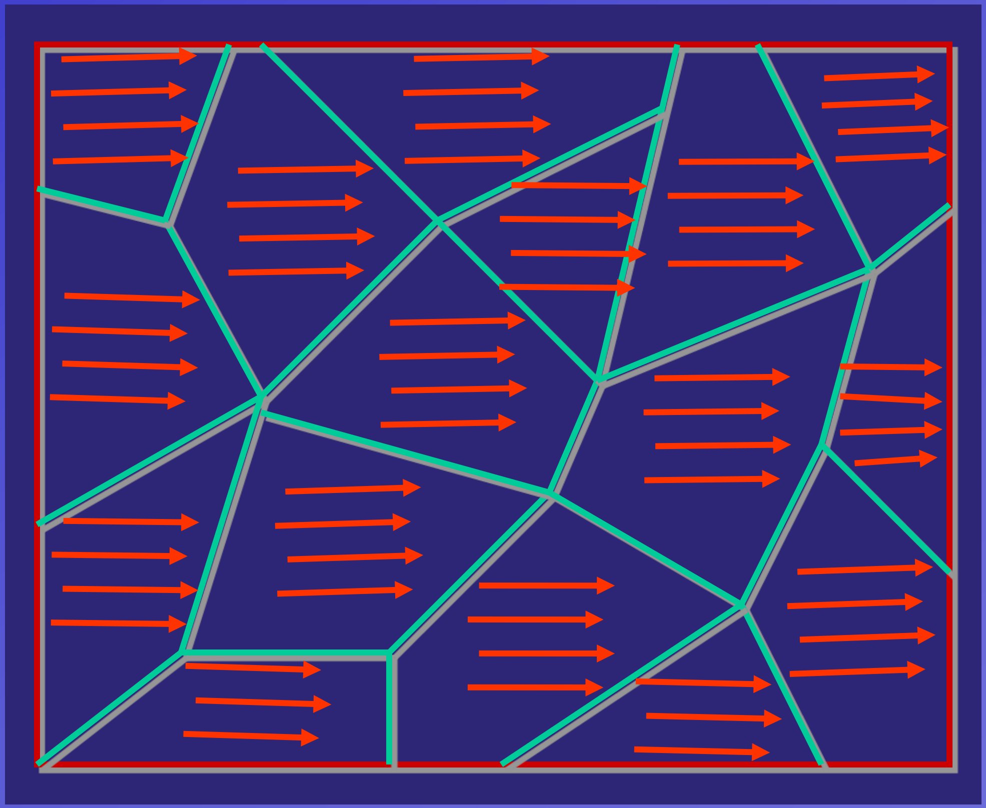
hard magnetic material



Magnetic domain

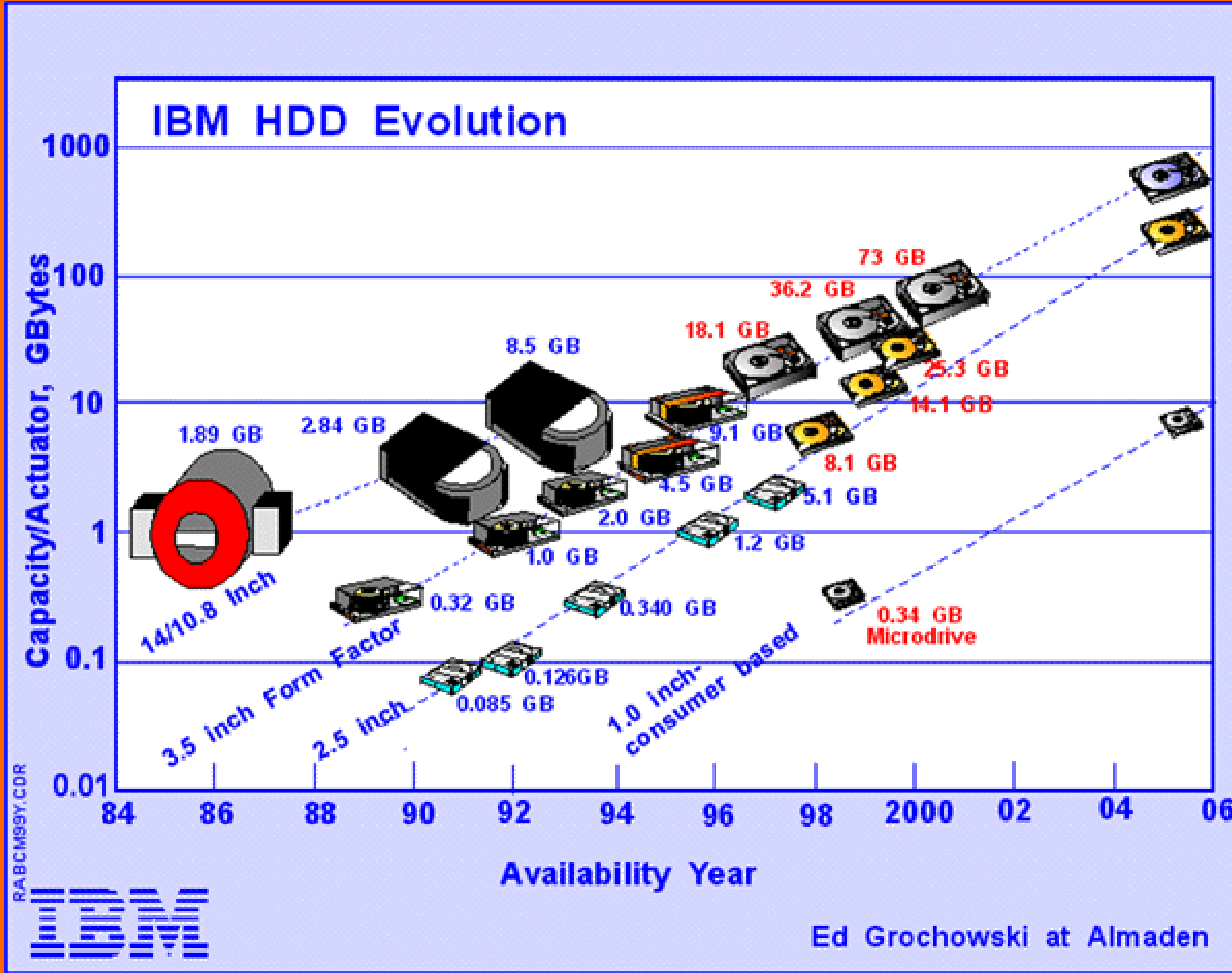
（磁畴）



Curie temperature

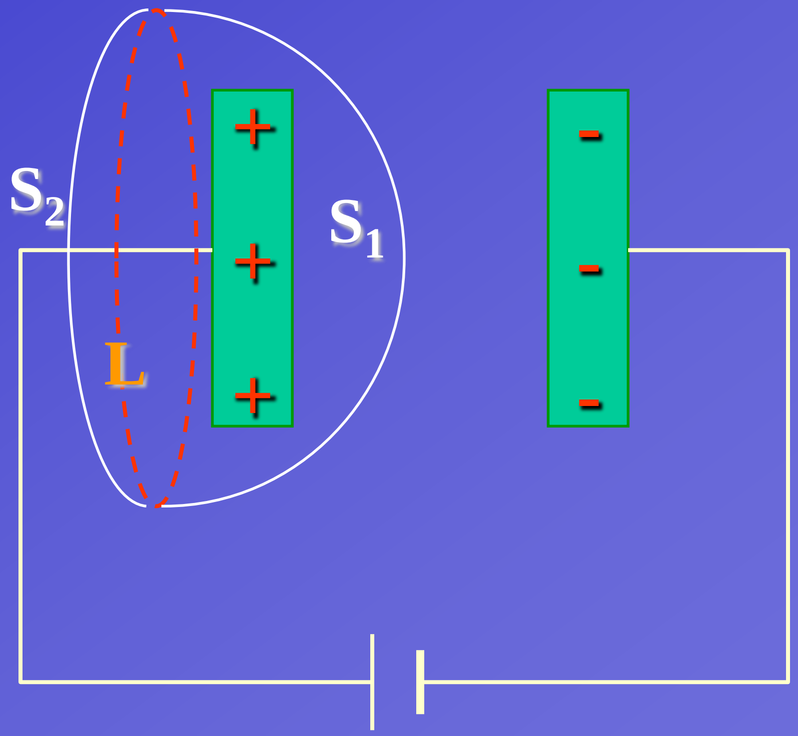
（居里温度）


Iron ： T=1040K ， nickel ： T=631K。


IBM HDD Evolution
1000
100
10
1
0.1
0.01
Capacity/Actuator, GBytes
84
86
88
90
92
94
96
98
2000
02
04
06
Availability Year
1.89 GB
2.84 GB
8.5 GB
18.1 GB
36.2 GB
73 GB
25.3 GB
14.1 GB
9.1 GB
8.1 GB
4.5 GB
5.1 GB
2.0 GB
1.2 GB
1.0 GB
0.32 GB
0.340 GB
0.34 GB
Microdrive
0.126GB
0.085 GB
14/10.8 Inch
3.5 Inch Form Factor
2.5 inch
1.0 inch-
consumer based
RABCM99Y.CDR
IBM
Ed Grochowski at Almaden

# Displacement current(位移电流）

No matter what surface we choose, Ampere’s Law still holds true.




$$\Phi_D = \oint_S \vec{D} \cdot d\vec{S} = q$$

$$I_o = \frac{dq}{dt}$$

$$I_o = \frac{dq}{dt} = \frac{d\Phi_D}{dt} = \int_{S_2} \frac{\partial \vec{D}}{\partial t} \cdot d\vec{S}$$

Total current（全电流）

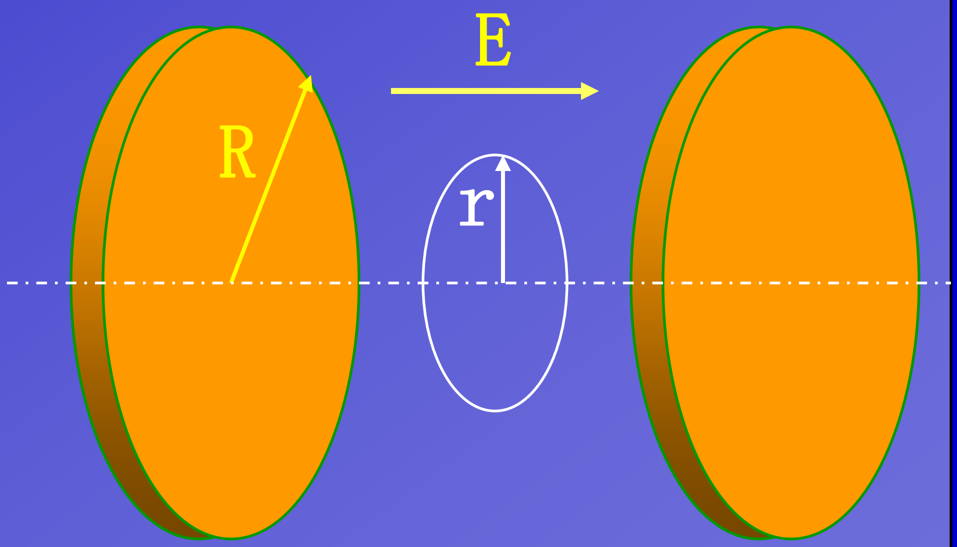
$$I = I_c + I_d = I_c + \int \frac{dD}{dt} dS$$

Generalized  ampere’s law

$$\oint H \cdot dl = \sum I_e + \frac{d\Phi_e}{dt}$$

The parallel circular plates with radius R=0.1m make up the capacitor below, the changing rate of electric field is $10^{13}$V/ms。Find the displacement current and magnetic field

**solution：**




$$\Phi_D = SD = \pi R^2 \cdot \varepsilon_o E$$

$$I_d = \frac{d\Phi_D}{dt} = \pi\varepsilon_o R^2 \frac{dE}{dt}$$

$$= 2.8(A)$$

$$\oint_L \vec{H} \cdot d\vec{l} = \frac{d\Phi_D}{dt}$$

$$H \cdot 2\pi r = \int_S \frac{\partial \vec{D}}{\partial t} \cdot d\vec{S}$$

$$\because \quad H = \frac{B}{\mu_o} \quad , \quad D = \varepsilon_o E$$

$$\therefore \quad \frac{B}{\mu_o} \cdot 2\pi r = \varepsilon_o \int_S \frac{\partial \vec{E}}{\partial t} \cdot d\vec{S} = \varepsilon_o \frac{dE}{dt} \pi r^2$$

$$B_r = \frac{\mu_o \varepsilon_o}{2} r \frac{dE}{dt}$$

$$B_R = \frac{\mu_o \varepsilon_o}{2} R \frac{dE}{dt} = 5.6 \times 10^{-6} (T)$$

Maxwell's equations

$$\oint_S \vec{D}\cdot d\vec{S} = \sum q = \int_V \rho\, dV$$

$$\oint_S \vec{B}\cdot d\vec{S} = 0$$

$$\oint_L \vec{E}\cdot d\vec{l} = -\frac{d\Phi}{dt} = -\int_S \frac{\partial \vec{B}}{\partial t}\cdot d\vec{S}$$

$$\oint_L \vec{H}\cdot d\vec{l} = I_o + I_d = \int_S \vec{\delta}\cdot d\vec{S} + \int_S \frac{\partial \vec{D}}{\partial t}\cdot d\vec{S}$$

divergence

$$\nabla \cdot \vec{D} = \frac{\partial D_x}{\partial x} + \frac{\partial D_y}{\partial y} + \frac{\partial D_z}{\partial z}$$

curl

$$\nabla \times \vec{H} = \begin{vmatrix} i & j & k \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ H_x & H_y & H_z \end{vmatrix}$$

# Maxwell's equations in differential form

$$\nabla \cdot \overrightarrow{D} = \rho$$

$$\nabla \times \overrightarrow{E} = -\frac{\partial B}{\partial t}$$

$$\nabla \cdot \overrightarrow{B} = 0$$

$$\nabla \times \overrightarrow{H} = j_c + \frac{\partial D}{\partial t}$$

- In the grate the flickering embers
  Served to show how dull November’s
  Fogs had stamped my torpid members,
  Like a plucked and skinny goose.
  And as I prepared for bed, I
  Asked myself with voice unsteady,
  If of all the stuff I read, I
  Ever made the slightest use.