

Magnetism in material



Agenda today

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

Paramagnetism

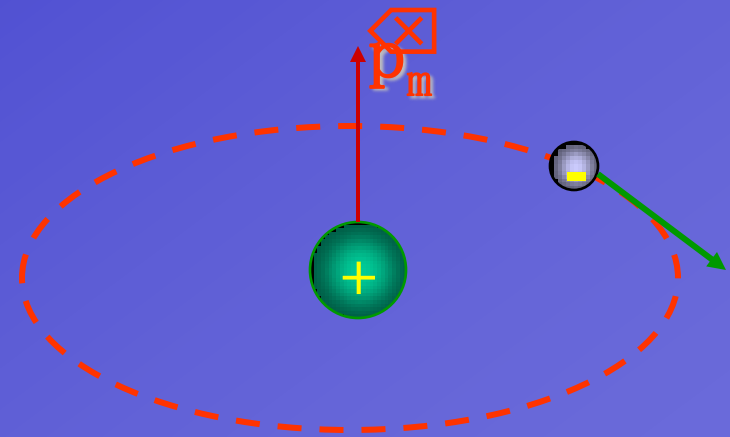
(顺磁性)

Atom magnetic moment

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

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

$$m = IS = \frac{1}{2} qv\pi r^2 = \frac{e}{2m} I$$

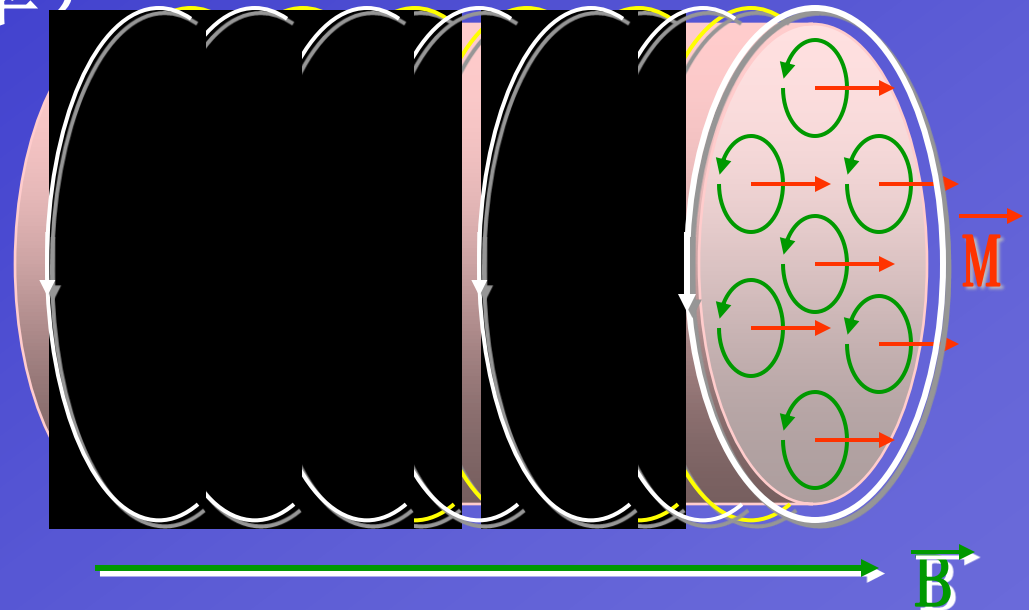


Magnetization and Magnetic Susceptibility

(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

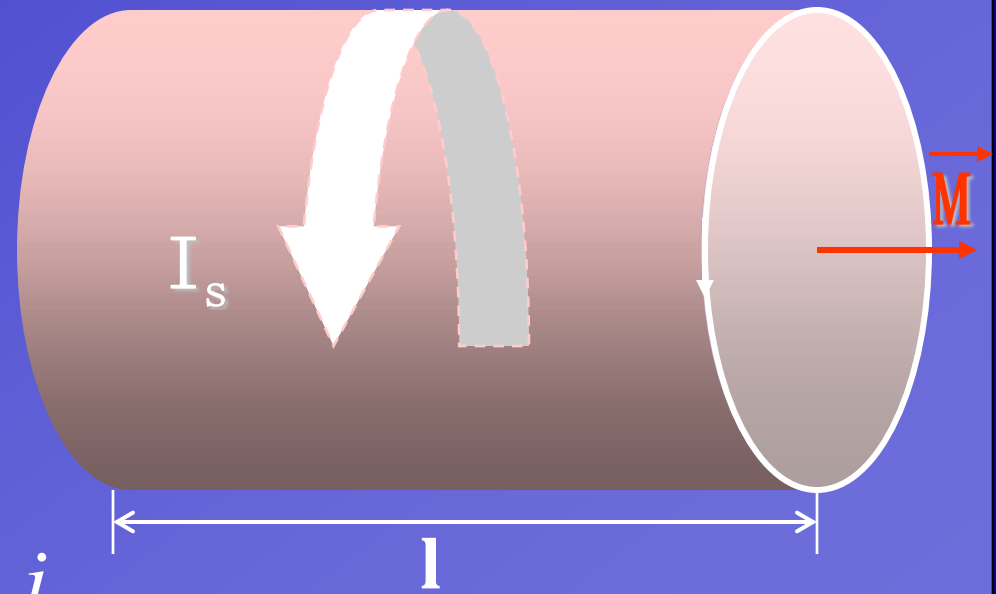


$$\vec{M} = \frac{\sum \vec{p}_m}{\Delta V}$$

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



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

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

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

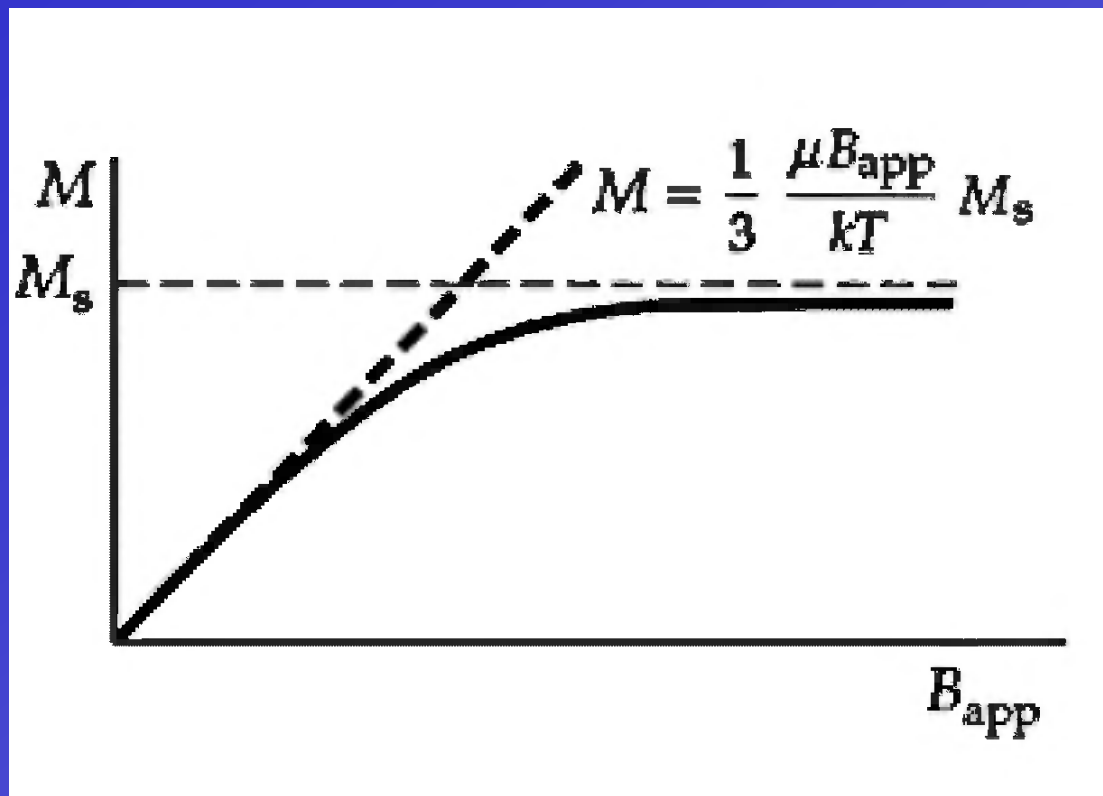
The magnetization is proportional to the applied field

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

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: $B > B_{\text{app}} \quad \chi > 0$

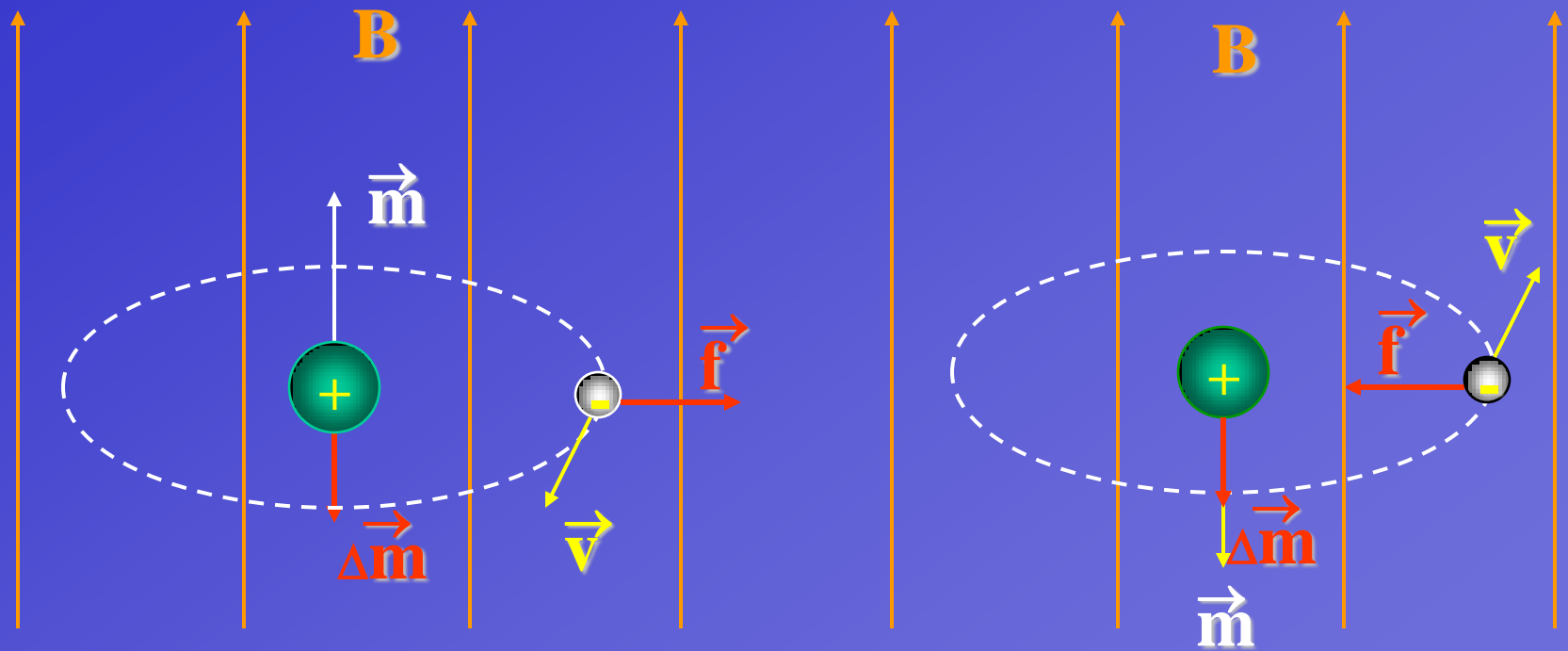
For diamagnetic material: $B < B_{\text{app}} \quad \chi < 0$

Ampere's law for magnetic material

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

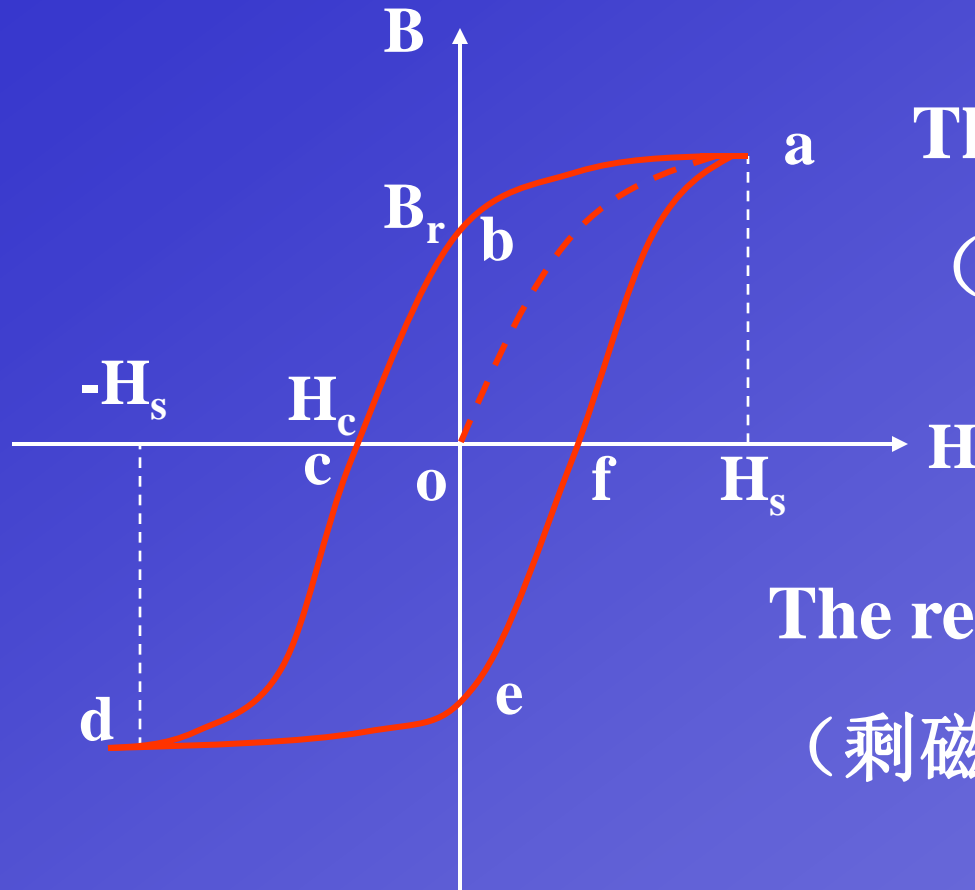
Where I is the conducting current through the loop

Diamagnetic material 抗磁性



For atoms have no net magnetic moment

Ferromagnetic material



The hysteresis loop

(磁滞回线)

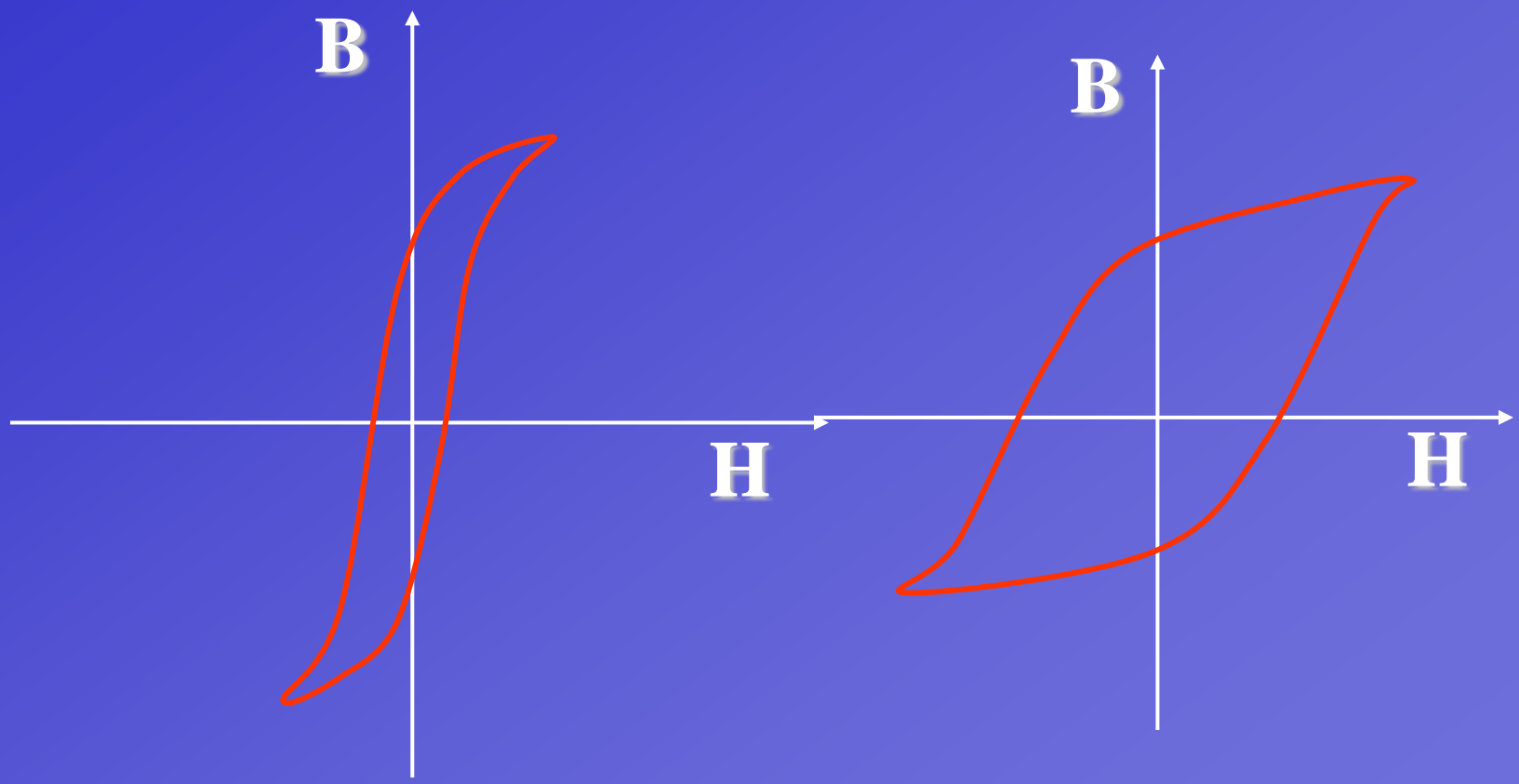
The remnant induction

(剩磁)

Coercive force (矫顽力)

Soft magnetic material

hard magnetic material

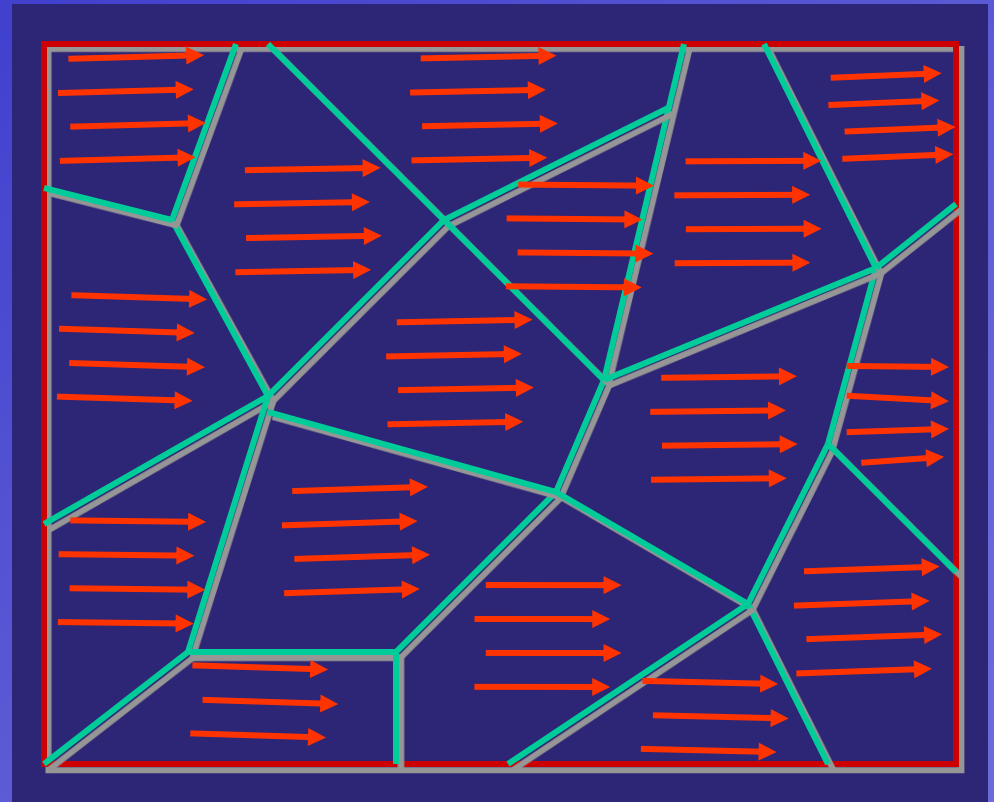


Magnetic domain

(磁畴)

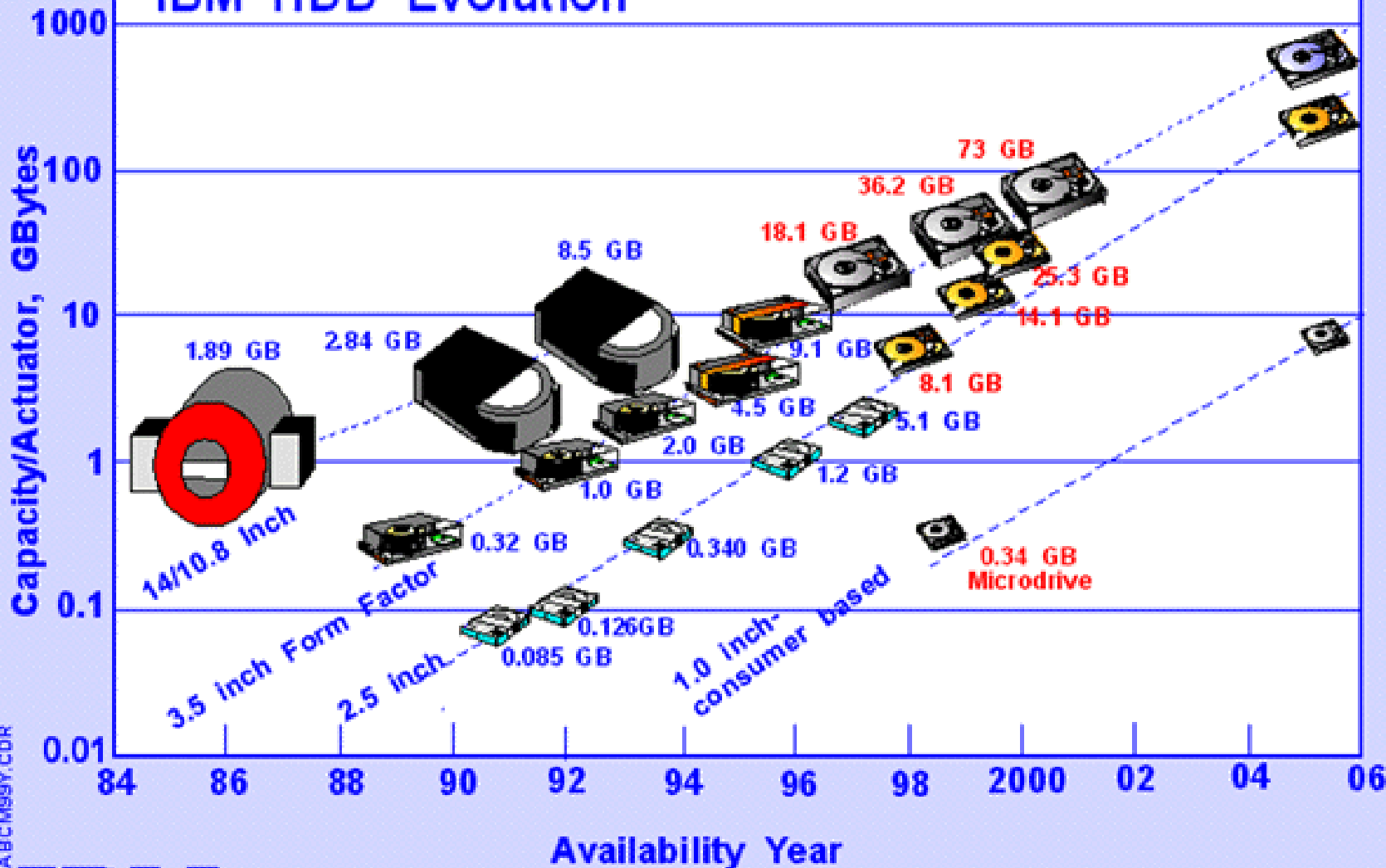
Curie temperature

(居里温度)



Iron : $T=1040\text{K}$, nickel : $T=631\text{K}$ 。

IBM HDD Evolution



RA:BCM99Y.CDR



Ed Grochowski at Almaden

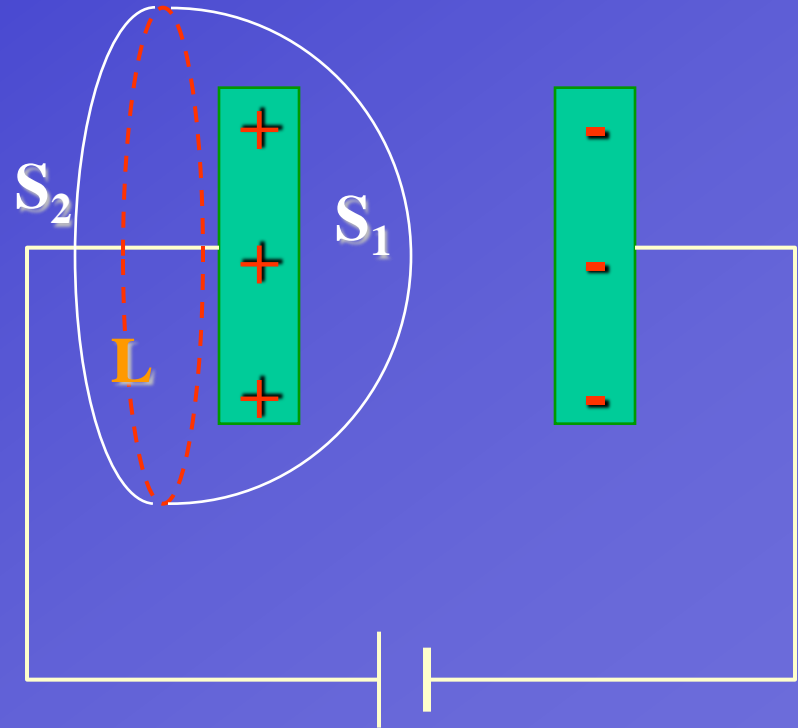
Displacement current(位移电流)

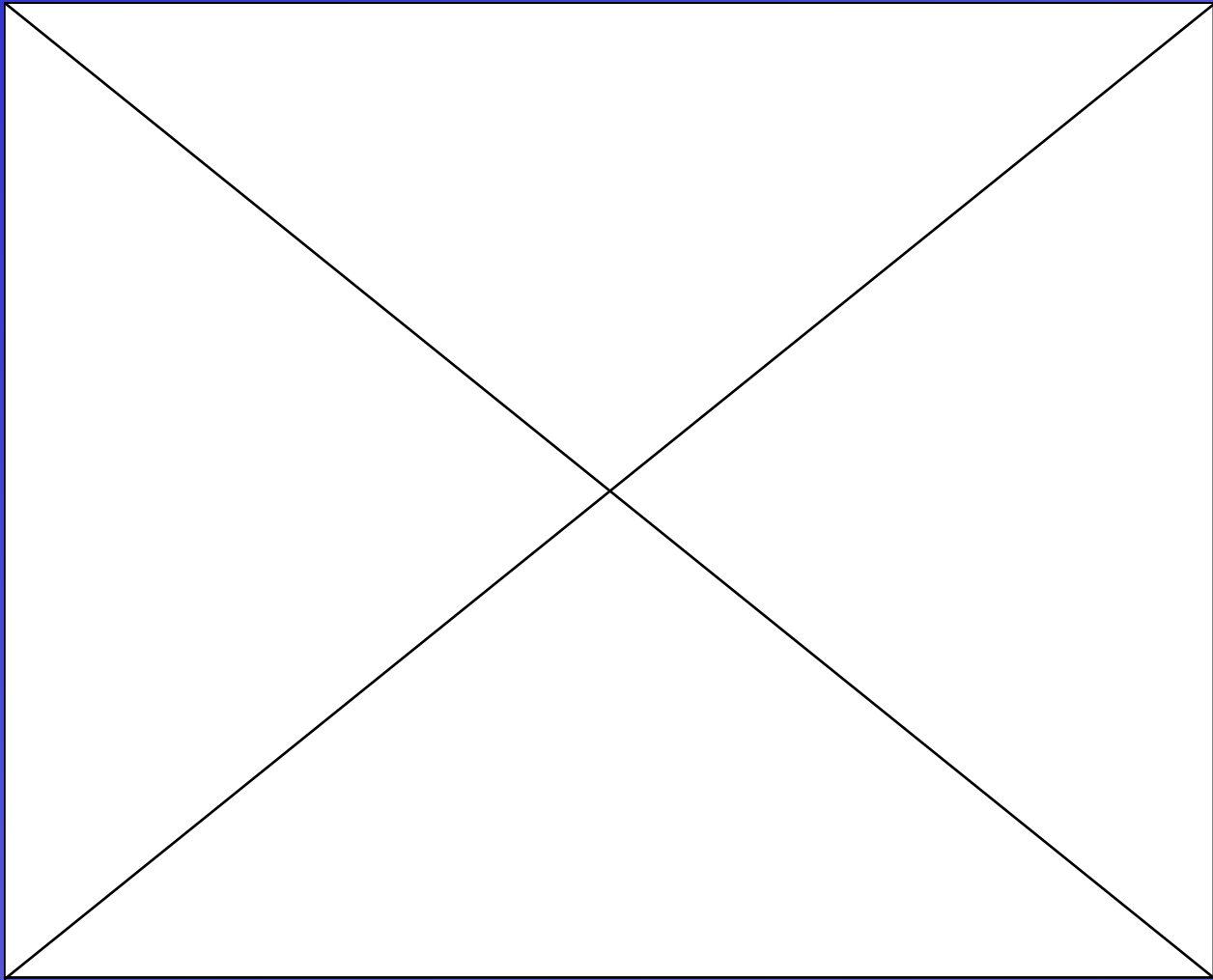
No matter what surface we choose, Ampere's Law still holds true.

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

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

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





Total current (全电流)

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

Generalized ampere's law

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

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

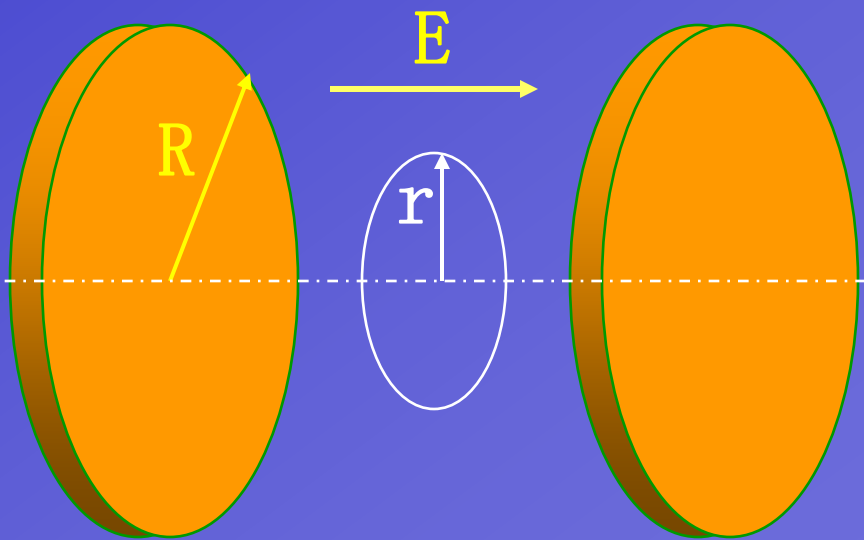
solution :

$$\Phi_D = SD = \pi R^2 \cdot \epsilon_0 E$$

$$I_d = \frac{d\Phi_D}{dt} = \pi \epsilon_0 R^2 \frac{dE}{dt}$$

$$= 2.8(\text{A})$$

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



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

$$\therefore H = \frac{B}{\mu_0} \quad , \quad D = \epsilon_0 E$$

$$\therefore \frac{B}{\mu_0} \cdot 2\pi r = \epsilon_0 \int_S \frac{\partial \vec{E}}{\partial t} \cdot d\vec{S} = \epsilon_0 \frac{dE}{dt} \pi r^2$$

$$B_r = \frac{\mu_0 \epsilon_0}{2} r \frac{dE}{dt}$$

$$B_R = \frac{\mu_0 \epsilon_0}{2} R \frac{dE}{dt} = 5.6 \times 10^{-6} (T)$$

Maxwell's equations

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

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

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

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

divergence

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

curl

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

Maxwell's equations in differential form

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

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

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

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



- 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.